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Dry matter production of Tanzania grass as a function of agrometeorological variables

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Abstract – The objective of this work was to develop and validate linear regression models to estimate the production of dry matter by Tanzania grass (*Megathyrsus maximus*, cultivar Tanzania) as a function of agrometeorological variables. For this purpose, data on the growth of this forage grass from 2000 to 2005, under dry-field conditions in São Carlos, SP, Brazil, were correlated to the following climatic parameters: minimum and mean temperatures, degree-days, and potential and actual evapotranspiration. Simple linear regressions were performed between agrometeorological variables (independent) and the dry matter accumulation rate (dependent). The estimates were validated with independent data obtained in São Carlos and Piracicaba, SP, Brazil. The best statistical results in the development and validation of the models were obtained with the agrometeorological parameters that consider thermal and water availability effects together, such as actual evapotranspiration, accumulation of degree-days corrected by water availability, and the climatic growth index, based on average temperature, solar radiation, and water availability. These variables can be used in simulations and models to predict the production of Tanzania grass.

Index terms: *Panicum maximum*, climatic growth index, degree-days, evapotranspiration, modeling.

Produção de matéria seca de capim-tanzânia em função de variáveis agrometeorológicas

Resumo – O objetivo deste trabalho foi desenvolver e validar modelos de regressão linear para a estimativa de produção de matéria seca de capim-tanzânia (*Megathyrsus maximus*, cultivar Tanzania) em função de variáveis agrometeorológicas. Para tanto, dados de períodos de crescimento da forragem entre 2000 e 2005, em condições de sequeiro em São Carlos, SP, foram correlacionados aos seguintes parâmetros climáticos: temperaturas mínima e média, graus-dia, evapotranspiração potencial e atual. Foram realizadas regressões lineares simples entre as variáveis agrometeorológicas (independentes) e a taxa média de acúmulo (dependente). As estimativas foram validadas com dados independentes obtidos em São Carlos e Piracicaba, SP. Os melhores resultados estatísticos observados no desenvolvimento e na validação dos modelos foram obtidos para parâmetros agrometeorológicos que levem em consideração o efeito térmico e hídrico conjuntamente, como evapotranspiração real, acúmulo de graus-dia corrigido pela disponibilidade hídrica e índice climático de crescimento, baseado na temperatura média, na radiação solar e na disponibilidade hídrica. Essas variáveis podem ser utilizadas em simulações e modelos para prever a produção do capim-tanzânia.

Termos para indexação: *Panicum maximum*, índice climático de crescimento, graus-dia, evapotranspiração, modelagem.

Introduction

Although extensive livestock grazing is still predominant in Brazil, there is a growing pressure for more intensive grazing methods, as a result of restrictions on deforestation and the opening of new areas for grazing, as well as land use competition with farming. There is also a need to control the process of pasture and soil degradation. Tanzania grass [*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs (Syn. *Panicum maximum* Hochst. ex A. Rich.)] is a widely used grass cultivar in intensive production systems, due to its high productivity, excellent agronomic characteristics, and elevated animal intake (Barbosa et al., 2006).

In intensive grazing systems, there is a reduced capacity for pasture recovery, implying the need to use more efficient management instruments. A more accurate estimation of the production of forage plants can contribute to productivity gains, allowing for a better planning and control of forage production within a concept of forage budgeting (Barioni et al., 2005).

Forage output from pastures varies mainly in response to changes in physical variables, including solar radiation, temperature, and water availability, considered alone or in combination (Villa Nova et al., 2004; Detomini et al., 2005; Zhu et al., 2008). However, according to these authors, the estimation of patterns and the quantification of these responses for different climate conditions in Brazil are limited by the shortage of information.

Agrometeorological models have been used to predict forage yield based on meteorological parameters (minimum and average air temperatures, degree-days, and photo-thermal-units) for several tropical forages, such as *Urochloa ruziziensis* (Syn. *Brachiaria ruziziensis*) (Villa Nova et al., 2005), *Cynodon*, *Panicum* and *Urochloa* (Tonato et al., 2010), and *U. brizantha* cultivar Marandu (Cruz et al., 2011). The incorporation of soil water availability in those models has improved their performance (Detomini et al., 2005; Cruz et al., 2011).

The development of mathematical models, which consider the effect of climate parameters on the output of forage grasses, can facilitate planning and management of grazing lands (Corson et al., 2007; Pedreira et al., 2011). In addition, strategies using simple mathematical models of reality permit various simulations to estimate the repercussion of current and future agricultural scenarios, as well as the impacts that changing climate conditions can cause on farming, stock raising, and natural systems.

The objective of this work was to develop and validate linear regression models to estimate the production of dry matter by Tanzania grass as a function of agrometeorological variables.

Materials and Methods

Data on the dry matter accumulation rate (kg of dry matter per hectare per day) of Tanzania grass, during 53 forage growth periods between 2000 and 2005, under dry-field conditions in São Carlos, SP, Brazil (21°57'42"S and 47°50'28"W, at 860-m altitude), were used.

The pastures were established in areas of Latossolo Vermelho-Amarelo (Typic Hapludox), and Latossolo Vermelho distrófico (Rhodic Hapludox) soils, in 1994. These areas are used for grazing of beef cattle, in a rotational system, with 36 days of rest and three of grazing during the rainy season, and 48 days of rest followed by four days of grazing during the dry season. Based on the results of soil chemical analysis, 200 to 360 kg ha^{-1} of nitrogen fertilizer were applied annually using the formula N-P-K (20-5-20). The average stocking rate in the rainy season varied from 6 to 8.5 animals per hectare, and animal grazing was supplemented with silage during the dry season.

Parameters were estimated from simple linear regressions between the accumulation rate (AR, dependent variable) and the following agrometeorological variables (calculated as the average values of the rest period): minimum temperature (Tmin); mean temperature (Tmean); degree-days (DD); potential evapotranspiration (PET); actual evapotranspiration (AET), obtained from the sequential water balance; and the climatic growth index (CGI).

The daily degree-day values (DDi) were calculated according to the following two equations: $DD_i = (Tmax_i + Tmin_i)/2 - Tb$, for Tmin>Tb (1); and $DD_i = (Tmax_i - Tb)^2/2(Tmax_i - Tmin_i)$, for Tb>Tmin (2), in which: $Tmax_i$ is the maximum daily air temperature (ºC); $Tmin_i$ is the minimum daily air temperature (ºC); and Tb is the base temperature (ºC), using the value of 17ºC (Pedreira et al., 2009).

The PET values were estimated according to Thornthwaite (1948), and the AET values were obtained from the five-day sequential water balance and the maximum water storage capacity of 100 mm (Thornthwaite & Mather, 1955).

The CGI is an index based on mean temperature, solar radiation, and water availability, developed by Fitzpatrick & Nix (1973), which is calculated by CGI = LI x TI x WI, in which: LI is the light index; TI is the temperature index; and WI is the water index. The value of LI is calculated as a function of the incident solar radiation, the TI as a function of the relative growth of tropical grasses based on air temperature values, and the WI value is calculated by the ratio between AET and PET. The LI and TI values were obtained according to Mota et al. (1981).

To verify the effect of water availability on forage accumulation, two penalization factors were tested in energy accumulation parameters (DD): WI and the relative water storage in the soil – determined by the ratio between the actual soil water storage and the maximum storage (WS) –, to obtain the variables DD_{WI} and DD_{WS}.

The linear regression models were evaluated by the coefficient of determination (R^2) and the root mean square error (RMSE).

To ascertain the performance of the estimates, validation was performed with independent data from 29 growth periods of the forage grass, obtained in Piracicaba, SP, Brazil (22°41'S and 47°38'W, at 576-m altitude), based on the works of Penati (2002) and Maya (2003); and in the experimental fields of Embrapa Pecuária Sudeste, São Carlos, SP, Brazil (Silva et al., 2007). These validation tests involved the use of the coefficient of determination (R^2), Wilmott's index (d), Camargo's index (c, r x d correlation coefficient) (Camargo & Sentelhas, 1997), and the mean absolute error (MAE).

Results and Discussion

There was a large variation in the dry matter accumulation rates obtained from the set of data used in the present study, with minimum rates near zero and maximum ones close to 160 kg ha^{-1} per day (Figure 1). This variation in forage accumulation is coherent with the variation in water availability (obtained by the ratio of water storage in the soil/ maximum water storage, or the actual/potential evapotranspiration ratio) and in air temperature. In the months that had the lowest accumulation, with rates below 20 kg ha^{-1} of dry matter per day (between

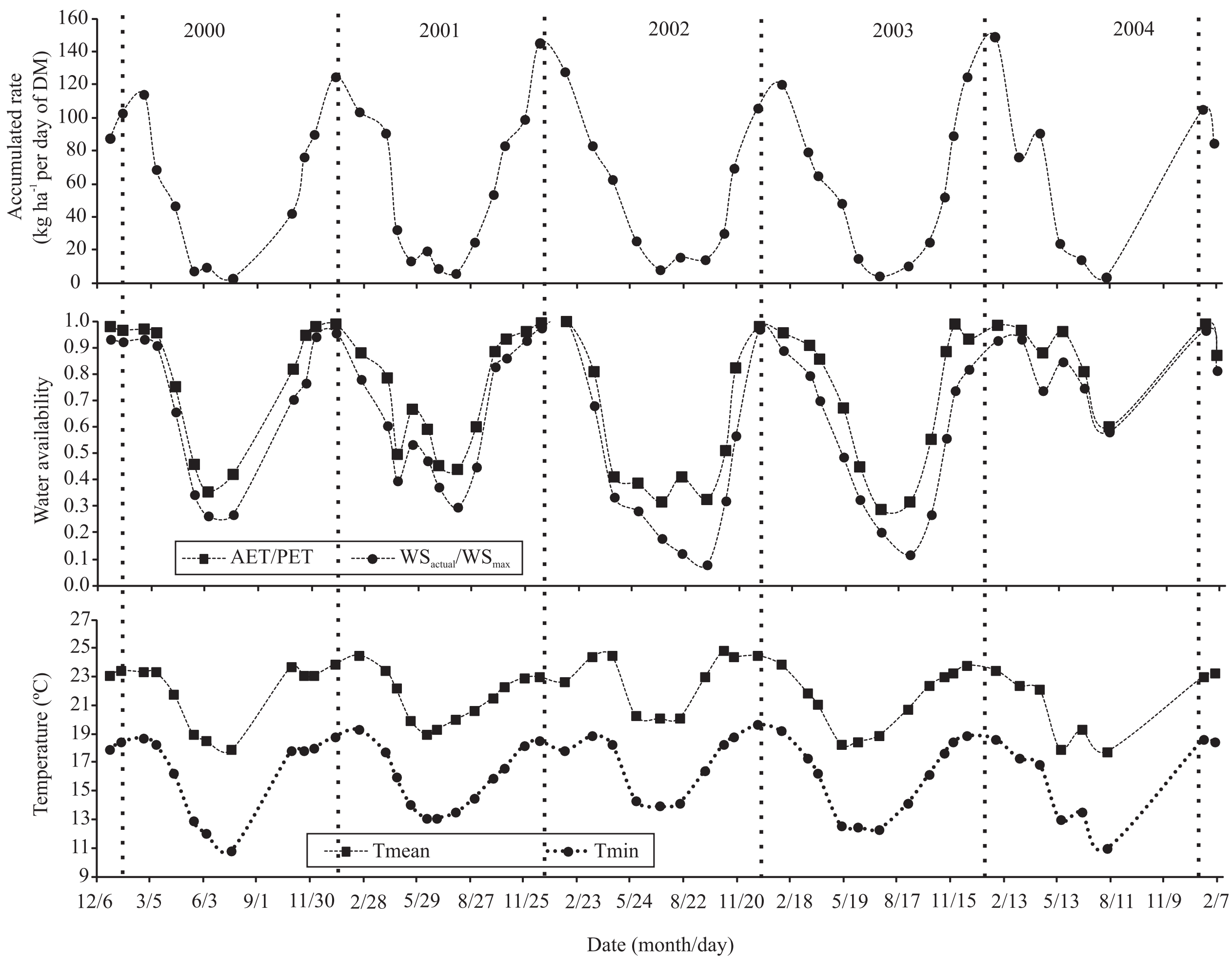

Figure 1. Tanzania grass dry matter accumulation rate, water availability, expressed by the ratio between actual soil water storage and maximum storage (WS_{actual}/WS_{max}) or by the relation between actual and potential evapotranspiration (AET/PET), and mean (Tmean) and minimum (Tmin) air temperatures, from December 2000 to February 2005.

June and September), the water availability values were lower than 0.4 and the mean temperature was between 17 and 19ºC.

Despite the presentation of a typical seasonality curve for growing conditions in Brazil (Pedreira et al., 2009), there was a variation between the years analyzed during the resumption of production (spring), as well as during the winter and summer months. This is evident from the behavior of the resumption of production in 2002, which was delayed due to a prolonged drought that year, and from the fall in the production at the start of 2004, influenced by the occurrence of an unseasonably cool February (Figure 1).

The thermal and water effects, which limited production, occurred simultaneously in most of the years, notably in autumn and winter. However, in some periods, such as from April to June 2004, only one of these factors was present, since, despite sufficient water availability, the low temperatures (average near 17ºC and minimum near 12ºC) limited the output. Rassini (2004) and Pedreira et al. (2009) considered average temperatures below 17ºC as a limiting factor for the growth of *Panicum*.

In the present study, the linear correlation among the agrometeorological variables selected to correlate dry matter production showed significant values, with positive correlations among the variables, which is in accordance with Tonato et al. (2010) (Table 1). The highest correlations were found

Table 1. Correlation coefficient among the agrometeorological variables used as production predictors of Tanzania grass dry matter(1).

Variable(2)	Tmin	Tmed	PET	AET	DD	DD_{WI}	DD_{WS}
Tmed	0.973	-	-	-	-	-	-
PET	0.978	0.984	-	-	-	-	-
AET	0.897	0.805	0.867	-	-	-	-
DD	0.950	0.992	0.977	0.776		-	-
DD_{WI}	0.931	0.863	0.907	0.990	0.842	-	-
DD_{WS}	0.869	0.777	0.832	0.977	0.752	0.973	-
CGI	0.928	0.860	0.908	0.990	0.838	0.997	0.969

(1)All correlations were significant at 1% probability. (2)Tmin, minimum temperature; Tmed, medium temperature; PET, reference evapotranspiration; AET, actual evapotranspiration; DD, degree-days; DD_{WI}, degree-days corrected by relative evapotranspiration; DD_{WS}, degree-days corrected by relative soil water storage; and CGI, climatic growth index.

among the variables temperature, degree-days, and potential evapotranspiration, as well as among actual evapotranspiration, degree-days corrected by the water availability factors – AET/PET (DD_{WI}) or (DD_{WS}) –, and the climatic growth index.

The use of the method proposed by Thornthwaite (1948) to estimate potential evapotranspiration implies, although indirectly, on relating this variable to the concept of degree-days, explaining the high correlation values between these variables and the average air temperature.

According to Tonato et al. (2010), high correlation values in modeling indicate that simple and multiple correlations would have similar explanatory power, so the inclusion of more than one variable in the model would increase its complexity, but add very little in terms of precision. In this case, when the variables have estimates with similar statistics, it is possible to choose those that are the easiest to obtain, such as the variables DD_{WI} and CGI, which showed high correlation ($r = 0.99$), or DD_{WS} and CGI ($r = 0.967$), since the variables using the corrected degree-days only depend on air temperature and water balance, whereas the CGI variable requires solar radiation values to be calculated.

Regarding the components of the linear regression between the agrometeorological variables and the dry matter accumulation rate of Tanzania grass, the best estimates were obtained with the models that considered thermal and water parameters together, as in the case of AET, the two measures of corrected degree-day (DD_{WI} and DD_{WS}), and the climatic growth index (CGI), which showed higher coefficients of determination and lower RMSE (Table 2).

In general, the inclusion of a correction factor for the water conditions improved the estimates of all the analyzed parameters, indicating that it is an important factor in estimating the production and the seasonality of forage under grazing conditions (Rassini, 2004; Medeiros et al., 2005).

Pedro Júnior et al. (1990) and Tonato et al. (2010) obtained good predictive capacity of the production of tropical forage grasses by using minimum temperature, which, in the present study, performed worse than the other agrometeorological variables. However, those authors worked with production estimates in periods without water deficiency, unlike in the present study. For cultivation conditions without irrigation, the CGI showed satisfactory statistics in the test of the estimates of tropical forage grass production in the states of São Paulo (Pedro Júnior, 1995) and Bahia (Santos et al., 2008).

When analyzing the test results of models to predict dry matter production with independent data, the variables that produced the best statistics in generating the regressions also provided the best estimates of dry matter production of Tanzania grass (Table 3).

AET was the variable that best estimated dry mater production, as shown by the higher values of R^2, Wilmott's index (d), and Camargo's index (c), producing the lowest estimation error. The variables CGI, DD_{WI}, and DD_{WS} also performed satisfactorily, being classified as "very good" (d values higher than 0.80) in the classification proposed by Camargo & Sentelhas (1997) (Table 3 and Figure 2).

The dispersion between the observed and estimated values for the four models producing the best statistical indices showed that, for high dry matter accumulation rates (above 100 kg ha^{-1} per day), the models tended to underestimate production (Figure 2). This could have been caused by the different fertilization regimes of the experiments. In this case, it is important to calibrate the models with data from plants grown with other fertilizer doses, to make the necessary adjustments in parameterization for large-scale use (Vargas et al., 2006; Fontoura Júnior et al., 2009; Tonato et al., 2010).

Variables not corrected for the water factor (Tmin, PET, and DD) were the ones that produced the farthest estimates from the observed accumulation rates, with a tendency to overestimate production in periods with low output, mainly due to the failure to consider the water factor in the prediction.

Although the variables that considered the two water correction factors (DD_{WI} and DD_{WS}) showed high correlation and similar statistics for the conditions, in the present study, it was possible to identify differences in dry matter production estimates between the two water availability indicators (WI and WS factor), especially in very dry periods and in the return of the rainy season, indicating different potentials for the use of these models, depending on the climate conditions in the region.

Table 2. Linear regression components between Tanzania grass dry matter accumulation rates and agrometeorological variables.

Statistcs[(1)]	Variable[(2)]							
	Tmin	Tmed	PET	AET	DD	DD_{WI}	DD_{WS}	CGI
a	-175.91	-276.9	-73.13	-21.58	-38.41	-17.02	-6.38	-12.88
b	14.43	15.38	44.27	34.73	18.70	18.80	18.9	330.09
R^2	0.74	0.58	0.67	0.87	0.53	0.84	0.87	0.84
RMSR	21.59	27.66	24.57	15.58	29.27	16.87	15.1	16.94
Range	12.2 to 24.9	18.0 to 24.9	1.65 to 4.05	0.62 to 4.02	2.1 to 7.9	0.9 to 7.4	0.34 to 7.3	0.04 to 0.41

[(1)]a, intercept; b, slope; R^2, coefficient of determination; RMSR, root mean square residual; and Range, range observed for the independent variable. [(2)]Tmin, minimum temperature; Tmed, medium temperature; PET, potential evapotranspiration; AET, actual evapotranspiration; DD, degree days; DD_{WI}, degree days corrected by relative evapotranspiration; DD_{WS}, degree days corrected by relative soil water storage; and CGI, climatic growth index.

Table 3. Statistical parameters related to the model test results in predicting Tanzania grass dry matter accumulation rate using agrometeorological variables.

Statistics[(1)]	Variable[(2)]							
	Tmin	Tmed	PET	AET	DD	DD_{WI}	DD_{WS}	CGI
d	0.79	0.82	0.86	0.94	0.84	0.93	0.93	0.93
R^2	0.65	0.60	0.68	0.82	0.65	0.78	0.76	0.77
c	0.64	0.64	0.71	0.85	0.67	0.82	0.81	0.82
MAE	30.7	25.3	24.1	14.1	23.6	16.0	18.0	15.8

[(1)]d, Wilmott's index; R^2, coefficient of determination; c, Camargo's index (r x d correlation coefficient); and MAE, mean absolute error. [(2)]Tmin, minimum temperature; Tmed, medium temperature; PET, potential evapotranspiration; AET, actual evapotranspiration; DD, degree days; DD_{WI}, degree days corrected by relative evapotranspiration; DD_{WS}, degree days corrected by relative soil water storage; and CGI, climatic growth index.

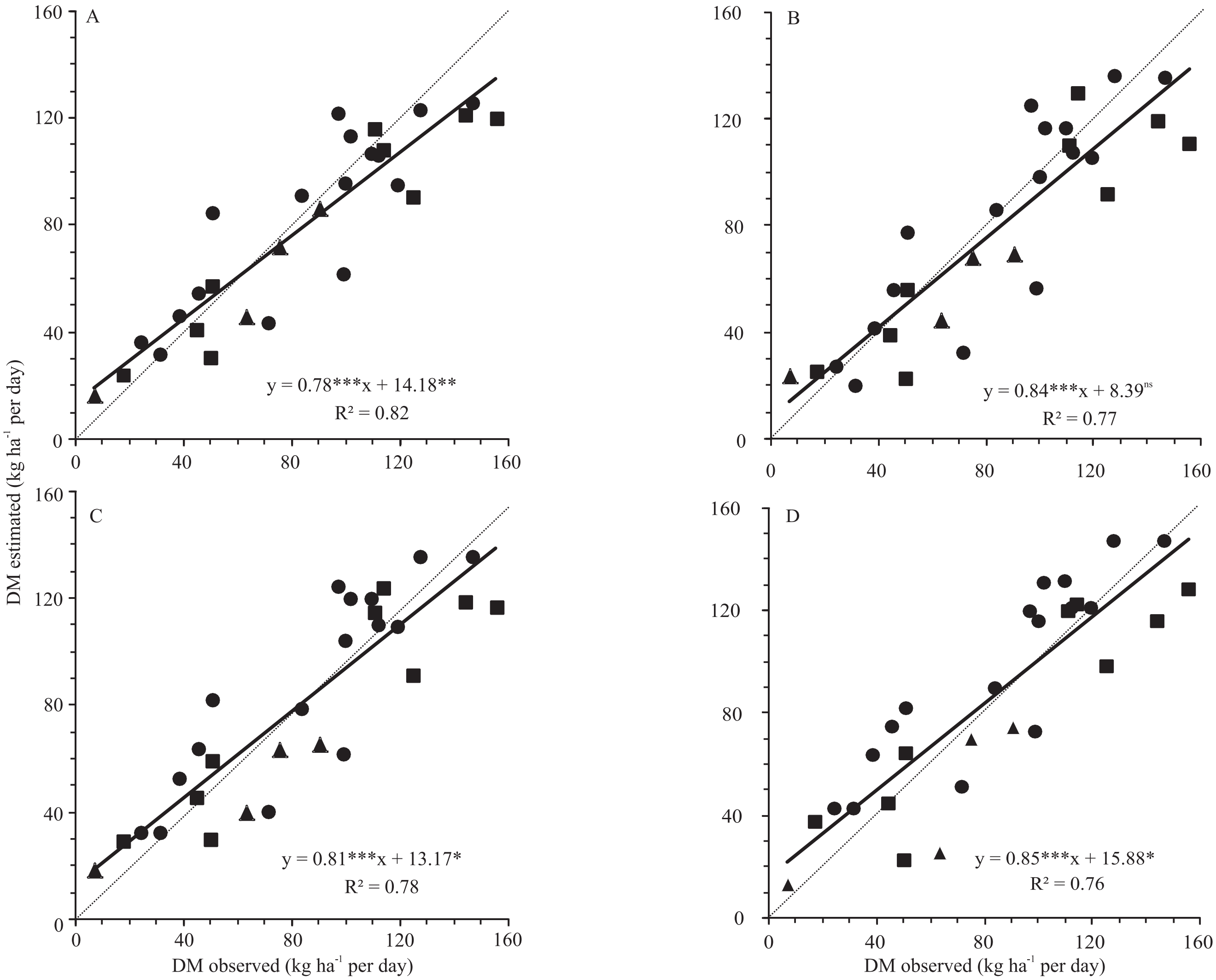

Figure 2. Observed and estimated values of the Tanzania grass dry matter (DM) accumulation rate using the variables: actual evapotranspiration (A), climatic growth index (B), degree days corrected by relative evapotranspiration (DD_{MI}) (C), and degree-days corrected by relative soil water storage (DD_{WS}) (D). Validation with independent data extracted from Penati (2002) (circle), Maya (2003) (square), and Silva et al. (2007) (triangle). ^{ns}Not significant. ***, ** and *Significant at 1, 5, and 10% probability, respectively.

Conclusions

1. Tanzania grass dry matter accumulation rate estimate in function of agrometeorological variables can be used to simulate and model forage production when the limiting factor is meteorological in nature.

2. Linear regression models based on actual evapotranspiration, degree-days corrected by water availability, and the climatic growth index provide the best estimates of Tanzania grass dry matter production.

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