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Production of nutrients in dual-purpose wheat pastures managed with different doses of nitrogen as topdressing – exponential model

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Abstract: The aims of this study were to evaluate the yield and composition of dual-purpose wheat pasture BRS Tarumã managed with various urea nitrogen (N) doses and validate an exponential model and compare nutrient production costs. The completely randomized design had four replications per treatment (0, 150, 250, 350, and 450 kg N ha^{-1}). For the 350 and 450 kg ha^{-1} treatments, the cycle was 212 d whereas that of the control was 167 d. The control accumulated 1,771 kg ha^{-1} dry matter. In contrast, the 450 kg ha^{-1} treatment accumulated 7,011 kg ha^{-1} DM. Topdressing nitrogen (150, 250, 350, and 450 kg ha^{-1}) increased the traditional average daily accumulation rate by 586% relative to the control. However, the degree-days method determined a daily accumulation rate 652% higher than the control. The levels of dry matter and other nutrients in BRS Tarumã wheat pasture were influenced by the doses of nitrogen in the topdressing under the same environmental conditions (temperature and rainfall). An exponential model explained the dynamics of nutrient accumulation and was based on the thermal sum of each nitrogen dose impacting the cost per kilogram of pasture produced.

Key words: chemical composition, degree-days, nonlinear regression, nutrient, thermal sum, *Triticum aestivum*.

INTRODUCTION

Dual-purpose winter cereal cultivation has increased over the past two decades in Southern Brazil in response to the cultivars developed by the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) and other public and private companies. Several studies (Fontaneli et al. 2009, Meinerz et al. 2011, 2012, Santos et al. 2011, 2015, Lehmen et al. 2014) have been conducted in Rio Grande do Sul, Brazil, in which several dual-purpose winter cereal species developed by EMBRAPA (*Avena sativa* L.; *Avena strigosa* L.; *Hordeum vulgare* L.; *Secale cereale* L.; *Triticum aestivum* L.; x *Triticosecale* Wittmack) have been evaluated. The aim was to increase forage (green or silage) and/or grain production or to intensify an Integrated Crop-Livestock System (ICLS). Although pasture and grain production intensify ICLS, it is still informative to assess the association between animal production on these pastures and the genetic improvements of the plant species comprising them, especially in terms of the chemical composition of the leaf blades.

Dual-purpose wheat has been used for raising beef cattle (Bartmeyer et al. 2011) and producing milk with a subsequent grain harvest (Henz et al. 2016a). Dual-purpose wheat BRS Tarumã pasture was managed with 130 kg N ha^{-1}

in topdressing and grazed by Holstein cows with average live weight and milk production of 570 kg and 19 kg d^{-1}, respectively (Quatrin et al. 2017). The authors obtained an average total digestible nutrient content of 78.39% for the three grazing. Therefore, dual-purpose wheat BRS Tarumã pasture has high nutritional value. The average leaf blade proportion was 72.7% before grazing and 40.2% immediately afterwards. According to Müller et al. (2009) and Moreno et al. (2014) the basal growth temperature of the species must be established to be able to manage it physiologically and according to environmental conditions.

Ruminant production chain efficiency can be improved by integrating legumes into the system. These plants naturally incorporate nitrogen and cause no collateral damage (Lindström et al. 2014, Lüscher et al. 2014, Olivo et al. 2016). In Rio Grande do Sul, however, nitrogen is added to production systems mainly in the form of urea or other chemical fertilizers conjugated to other minerals like ammonium sulphate. These are applied when the soil is adequately hydrated. Water and nitrogen are the two most limiting resources in plant production (Pan et al. 2017) and, by extension, animal production as well (Pembleton et al. 2013). The latter authors confirmed that nitrogenous fertilization in topdressing stimulated nonlinear growth of *Lolium perenne* pasture according to a logistic model. Zaka et al. (2017) determined that the growth of alfalfa (*Medicago sativa*) and fescue (*Festuca arundinacea*) was also explained by a logistic model and was a function of the thermal sum. According to Lara & Rakocevic (2014), exponential modeling based on degree-days mathematically interprets plant growth dynamics under different management conditions. Thornley & France (2004) recommended the use of the nonlinear exponential, logistic, and Gompertz models to evaluate the correlations between plant production and the availability of substrates such as carbon and/or nitrogen.

The objectives of this study were to evaluate nutrient production in dual-purpose wheat (*Triticum aestivum*) BRS Tarumã managed with various urea nitrogen doses (0, 150, 250, 350, and 450 kg N ha^{-1}) under the same temperature and rainfall conditions, validate the efficacy of an exponential growth model, explain nutrient accumulation rates based on the thermal sum, and compare nutrient production costs.

MATERIALS AND METHODS

The experiment was conducted at the Instituto Federal Sul Riograndense, Campus Pelotas Visconde da Graça (CaVG), Pelotas, Rio Grande do Sul, Brazil (31°42′39.89″S; 52°18′33.13″W), with average altitude of 6 m. The soil was a Planosol Solodic (Hydromorphic Planosol), Planosol Solodic Ta-A moderate with medium sandy and medium clayey texture (EMBRAPA 2013). The pre-experiment nutrient levels were: organic matter, 2.4%; calcium, 2.0 $cmol_c$ dm^{-3}; magnesium, 0.5 $cmol_c$ dm^{-3}; aluminum, 1.1 $cmol_c$ dm^{-3}; hydrogen + aluminum, 6.2 $cmol_c$ dm^{-3}; effective cation exchange capacity (CEC), 3.7 $cmol_c$ dm^{-3}; pH, 4.7; aluminum saturation, 29.7%; base saturation, 29.8%; SMP index, 5.7; clay, 24.0%; sulfur, 11.9 mg dm^{-3}; phosphorus, 6.8 mg dm^{-3}; CEC at pH 7, 8.8 $cmol_c$ dm^{-3}; potassium, 44.0 mg dm^{-3}; copper, 1.1 mg dm^{-3}; zinc, 2.4 mg dm^{-3}; and boron, 0.4 mg dm^{-3}.

The Köppen climate classification is Cfa: humid temperate with hot summers (Alvares et al. 2013). Table I lists the climatological norms between 1981 and 2010 and the mean temperature and rainfall for the experimental period (April–November 2014).

On April 15, 2014, the soil was turned over with a rotating hoe then sown with dual-purpose

Table I. Climatological norms between 1981 and 2010 for Pelotas, Rio Grande do Sul, Brazil, and meteorological conditions between sowing and the end of the experimental period.

Period	Meteorological conditions			
	Climatological norms (1981 – 2010)		Experiment (2014)	
	Average temperature (°C)	Rainfall (mm)	Average temperature (°C)	Rainfall (mm)
April	18.8	106.6	17.5	2.6
May	15.1	129.1	20.2	91.4
June	12.7	114.8	14.1	155.0
July	12.2	99.6	14.3	204.8
August	13.5	126.5	14.5	82.5
September	15.0	122.9	16.5	180.3
October	17.8	87.1	19.4	213.8
November	20.0	102.3	20.2	85.4
Sum	--	888.9	--	1,015.8

Source: Instituto Nacional de Meteorologia (INMET 2018).

wheat (*Triticum aestivum*) BRS Tarumã at 140 kg viable pure seeds ha^{-1} to a depth of 0.02 m depth in 18 rows per plot with 0.17 m between rows.

The experimental design was a completely randomized with four replications per treatment on 9 m^2 plots. The treatments were 0, 150, 250, 350, and 450 kg N ha^{-1} in the form of urea (Table II). Basal fertilization was conducted in the sowing line as 300 kg ha^{-1} of 5-20-20 NPK.

Partially dry matter (PDM) was measured using samples cut when the canopy was 0.20 m tall. Samples were hand-cut with scissors at 0.05 m above the ground within a 0.5 m × 0.5 m square. After the samples were collected, the remaining plots were cut with a costal machine at a height of 0.05 m above the soil. The residue was removed from the plots to simulate grazing because grazing animals remove parts of the plants and facilitate regrowth. The samples were weighed on a precision balance, packed in labeled paper bags, and dried in an oven at 55 °C for 72 h until a constant mass was attained. They were then milled with a 1.0-mm sieve, dried in an oven at 105 °C for 16 h, and their total dry matter (TDM) content was measured. Their dry matter (DM) content was calculated by multiplying PDM by TDM/100.

Total digestible nutrient (TDN), neutral detergent fiber (NDF), acid detergent fiber (ADF), and crude protein (CP) analyses were conducted at the Laboratório de Análises Físico-Químicas Ltda. (LABNUTRIS) with a Perten DA7250 (Serial No. 1512617; Perten Instruments, Hägersten, Sweden) according to PTNF-001 Rev. 00 of the Compêndio Brasileiro de Alimentação Animal and Method No. 11 – NIR – Near Infrared Spectroscopy.

The traditional daily accumulation rate (TDAR) was calculated by dividing the DM production per period by the interval between days. Degree-days (DG) were determined according to Müller et al. (2009). The basal temperature was 0 °C. The daily accumulation rate according to degree-days (DAR-DG) was established using TDAR and DG.

After the DM ha^{-1} were determined for all samples, they were combined with the chemical composition analyses to obtain the yields per ha. The control was evaluated with PROC REG in

Table II. Treatments used during the cultivation of dual-purpose wheat BRS Tarumã.

Time and dose of urea application	Treatments = Nitrogen doses (kg N ha^{-1})				
	0	**150**	**250**	**350**	**450**
1st dose – tillering	SAC	100	100	100	100
2nd dose	SAC	50	50	50	50
3rd dose	SAC	NA	50	50	50
4th dose	SAC	NA	50	50	50
5th dose	SAC	NA	NA	50	50
6th dose	SAC	NA	NA	50	50
7th dose	SAC	NA	NA	NA	50
8th dose	SAC	NA	NA	NA	50

SAC = no topdressing fertilization; NA = Not applied.

SAS v. 9.1 (SAS Institute Inc., Cary, NC, USA (2012)). Data for the other treatments were processed in PROC NLIN following an exponential growth model:

$$PNutAj. = \sum PNutCuts \times \left(1 - \left(e^{(-GR \times (DG - L))}\right)\right) \quad (1)$$

where:

PNutAj.= production of each nutrient adjusted by the exponential model;

$\sum PNutCuts$ = sum of the production of each nutrient in the cuts;

GR= growth rate;

DG= degree-days;

L= latency;

The coefficient of determination was calculated as follows to evaluate the nonlinear regression adjustments:

$$r^2 = 1 - (Mean\ square\ of\ the\ error | Total\ mean\ square) \quad (2)$$

To determine the cost of nutrients produced per ha, the basal fertilization, seed, and topdressing fertilization costs were considered. Input prices at the time of sowing were considered. In this way, logistic planning was simulated based on the local prices in Pelotas.

The effect of including nitrogen topdressing on BRS Tarumã dual-purpose wheat pasture was assessed by calculating nitrogen utilization efficiency as follows:

$$Conversion\ of\ N = \frac{(\sum Prod.Nut.Treat\ with\ N - \sum Prod.Nut.ConrolTreat)}{Kg\ of\ N\ applied\ in\ topdressing\ by\ treatment} \quad (3)$$

where:

$Conversion\ of\ N(Kg.Kg\ of\ N\ applied)$ = kg N applied per treatment (disregarding the nitrogen in the control) required to produce each kg nutrient.

$\sum Prod.Nut.Treat\ with\ N$ = sum of each nutrient produced in the pasture per treatment after adding N.

$\sum Prod.Nut.ControlTreat$ = sum of each nutrient produced in the control.

Applied topdressing nitrogen utilization efficiency was calculated as follows:

$$Efficiency\ of\ N(\%) = \left(\frac{(\sum Prod.Nut.Treat\ with\ N - \sum Prod.Nut.ControlTreat)}{\sum Prod.Nut.ControlTreat}\right) * 100 \quad (4)$$

RESULTS

An initial 100 kg N ha^{-1} (Table II) was sufficed to stimulate pasture tillering (Table III). In the first cut, the control required 7 d longer to reach tillering than the other treatments. Nevertheless, even the control did not require a very long time because it acquired nitrogen from the soil and the basal fertilization.

Table III shows that nitrogen topdressing increased the cycle of BRS Tarumã dual-purpose wheat pasture utilization. At 350 and 450 kg N ha^{-1}, the cycle was 212 d which permitted a greater number of cuts and shorter intervals between them. For the 150 and 250 kg N ha^{-1} treatments, the cycle was 188 d but the number of cuts differed from those for the other treatments. However, plant growth was evaluated in terms of the dynamic interaction between the meteorological conditions (solar radiation, temperature, and rainfall) and soil

Table III. Intervals between cuts, days of dual-purpose wheat pasture BRS Tarumã cultivation managed with different nitrogen doses, and number of cuts per treatment.

Variable	Nitrogen fertilization doses (kg N ha^{-1})				
	0	150	250	350	450
	Intervals between cuts				
Sowing up to the 1st cut	45	38	38	38	38
Between the 1st and 2nd cuts	91	17	17	17	17
Between the 2nd and 3rd cuts	31	22	22	22	22
Between the 3rd and 4th cuts	--	20	20	20	20
Between the 4th and 5th cuts	--	39	15	15	15
Between the 5th and 6th cuts	--	31	16	16	16
Between the 6th and 7th cuts	--	--	19	19	19
Between the 7th and 8th cuts	--	--	20	20	20
Between the 8th and 9th cuts	--	--	21	21	21
Between the 9th and 10th cuts	--	--	--	24	24
Total days of cultivation	167	188	188	212	212
Number of cuts in the cycle	3	6	9	10	10

nitrogen availability. The absence of nitrogen in the topdressing (control) resulted in a nutrient deficit and limited crop performance in 167 d.

The control required relatively more degree-days (Table IV) than the 150 kg N ha^{-1} treatment during the whole cycle. However, both TDAR and DAR-DG (Table V) were much smaller in the former than the latter. Therefore, nitrogen deficiency impairs plant physiological development. There were 91 d between the first and second cuts of the control. There were 1,367.25 degree-days, and the TDAR and DAR-DG were only 12.8 kg DM ha^{-1} d^{-1} and 0.756 kg DM ha^{-1} DG^{-1}, respectively.

Nitrogen was applied twice in the 150 kg N ha^{-1} treatment. The intervals between cuts (Table III) indicated that the effect continued until the fourth cut. By that time, the growth rate of this treatment was lower than that of the 250 kg N ha^{-1} treatment. The 250, 350, and 450 kg N ha^{-1} treatments all required the same amount of degree-days (Table IV) until the ninth cut. Nevertheless, the 350 and 450 kg N ha^{-1} treatments retained enough nutrients for regrowth, so another cut was made 212 d after sowing.

In the first cut, the TDAR and DAR-DG for the 150, 250, 350, and 450 kg N ha^{-1} treatments were 586% and 652% higher than those of the control, respectively (Table V). It was impossible to compare the different degree-day requirements for effective plant growth in the subsequent cuts.

The accumulated DM, TDN, NDF, ADF, and CP are presented in Figures 1, 2, 3, 4, and 5 for the 0, 150, 250, 350, and 450 kg N ha^{-1} treatments, respectively. Plant development in the control is not explained by a first-order linear model because the nitrogen deficit there was severe enough to limit increases in the levels of DM and other nutrients. In the other treatments, DM, TDN, NDF, ADF, and CP were adjusted according to the exponential growth model.

Table IV. **Thermal sum expressed in degree-days for dual-purpose wheat pasture BRS Tarumã managed with different nitrogen doses.**

Thermal sum (Degree-days)	Nitrogen fertilization doses (kg N ha^{-1})				
	0	150	250	350	450
Degree-days until the first cuts	772.35	685.65	685.65	685.65	685.65
Between the 1st and 2nd cuts	1,367.25	229.95	229.95	229.95	229.95
Between the 2nd and 3rd cuts	524.95	320.55	320.55	320.55	320.55
Between the 3rd and 4th cuts	--	324.45	324.45	324.45	324.45
Between the 4th and 5th cuts	--	564.15	214.50	214.50	214.50
Between the 5th and 6th cuts	--	525.00	230.65	230.65	230.65
Between the 6th and 7th cuts	--	--	311.40	311.40	311.40
Between the 7th and 8th cuts	--	--	332.55	332.55	332.55
Between the 8th and 9th cuts	--	--	390.75	390.75	390.75
Between the 9th and 10th cuts	--	--	--	511.55	511.55
Total	2,664.55	2,649.75	3,040.45	3,552.00	3,552.00

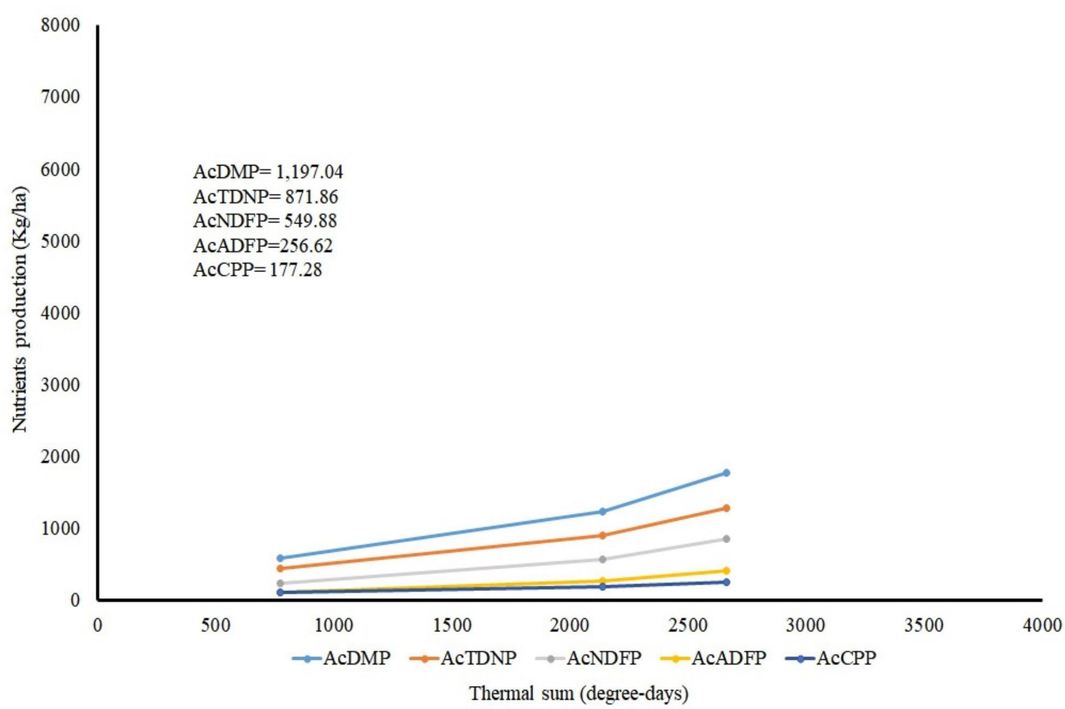

Figure 1. **Accumulated dry matter production (AcDMP), accumulated total digestible nutrients production (AcTDNP), accumulated neutral detergent fiber production (AcNDFP), accumulated acid detergent fiber production (AcADFP), and cumulative crude protein production (AcCPP) per ha for dual-purpose wheat pasture of BRS Tarumã managed without nitrogen topdressing application.**

Table V. Traditional daily accumulation rate (TDAR) and daily accumulation rate for each accumulated degree-day (DAcRDG) for dual-purpose wheat pasture BRS Tarumã managed with different nitrogen doses.

Variable	Nitrogen fertilization doses (kg N ha^{-1})				
	0	150	250	350	450
Traditional daily accumulation rate (TDAR) (kg DM ha^{-1} d^{-1})					
Between the 1st and 2nd cuts	7.14	40.58	43.52	39.41	44.11
Between the 2nd and 3rd cuts	12.80	30.45	31.81	33.18	34.09
Between the 3rd and 4th cuts	--	27.50	42.50	45.50	40.00
Between the 4th and 5th cuts	--	21.79	36.66	44.00	56.00
Between the 5th and 6th cuts	--	21.54	19.06	32.50	38.75
Between the 6th and 7th cuts	--	--	16.84	38.94	46.84
Between the 7th and 8th cuts	--	--	19.25	27.00	32.50
Between the 8th and 9th cuts	--	--	18.33	28.33	34.52
Between the 9th and 10th cuts	--	--	--	14.58	13.33
Average	9.97	28.37	28.50	30.34	34.01
Daily accumulation rates according to degree-days (DAcRDG) (kg DM ha^{-1} degree-$days^{-1}$)					
Between the 1st and 2nd cuts	0.475	3.000	3.218	2.913	3.261
Between the 2nd and 3rd cuts	0.756	2.090	2.183	2.277	2.339
Between the 3rd and 4th cuts	--	1.695	2.619	2.804	2.465
Between the 4th and 5th cuts	--	1.506	2.564	3.076	3.916
Between the 5th and 6th cuts	--	1.272	1.322	2.254	2.688
Between the 6th and 7th cuts	--	--	1.027	2.376	2.858
Between the 7th and 8th cuts	--	--	1.157	1.624	1.954
Between the 8th and 9th cuts	--	--	0.985	1.522	1.855
Between the 9th and 10th cuts	--	--	--	0.684	0.625
Average	0.615	1.913	1.884	1.953	2.196

Figure 1 shows the low yields per ha for the control. The DM mean values indicated that the crop would not sustain grazing animals. Figures 2, 3, 4, and 5 show that fibrous carbohydrates had the highest yields per ha. Temperate pastures are sources of carbohydrates (energy) and nitrogen (crude protein). Cycles and nutrient yields per ha increase with topdressing nitrogen fertilization rates.

Table VI presents variables used to evaluate the effects of topdressing nitrogen fertilization on dual-purpose wheat BRS Tarumã pasture. The cost shown refers only to the inputs used for pasture establishment and cultivation. In terms of conversion to nutrients per kg N, the 150 kg N ha^{-1} treatment was the most efficacious. In terms of efficiency, however, the 450 kg N ha^{-1} treatment was the best. Regarding the biological metrics, efficiency increased with nitrogen dose. The control yields were discounted in all calculations.

Table VI. Costs of inputs used, nutrient yields, conversion of applied nitrogen to nutrients, nitrogen utilization efficiency, and costs per kg nutrients produced in dual-purpose wheat pasture BRS Tarumã managed with different nitrogen doses.

Variable	Nitrogen fertilization doses (kg N ha^{-1})				
	0	150	250	350	450
Costs of inputs and costs per ha (BRL ha^{-1})					
Basal fertilization	294.00	294.00	294.00	294.00	294.00
Seeds	210.00	210.00	210.00	210.00	210.00
Nitrogen fertilization	0.00	342.00	570.00	798.00	1,026.00
Cost with inputs	504.00	846.00	1,074.00	1,302.00	1,530.00
Nutrient production (kg ha^{-1})					
Accumulated dry matter production	1,771	4,430	4,880	6,335	7,011
Accumulated total digestible nutrients production	1,275	3,234	3,583	4,608	5,126
Accumulated neutral detergent fiber production	843	2,014	2,172	2,871	3,145
Accumulated acid detergent fiber production	400	949	1,018	1,366	1,475
Accumulated crude protein production	248	850	1,105	1,400	1,607
Conversion of applied nitrogen to nutrients (kg kg^{-1} N, discounting control)					
Dry matter	--	17.73	12.44	13.04	11.64
Total digestible nutrients	--	13.06	9.23	9.52	8.56
Neutral detergent fiber	--	7.80	5.32	5.79	5.11
Acid detergent fiber	--	3.66	2.47	2.76	2.39
Crude protein	--	4.02	3.43	3.29	3.02
Nitrogen utilization efficiency (% relative to control)					
Dry matter	--	150.15	175.55	257.68	295.87
Total digestible nutrients	--	153.55	180.96	261.30	301.90
Neutral detergent fiber	--	138.82	157.58	240.47	272.95
Acid detergent fiber	--	137.01	154.43	241.23	268.33
Crude protein	--	242.98	345.95	464.42	547.91
Costs per kg nutrient produced (BRL kg^{-1})					
Dry matter	0.2846	0.1910	0.2201	0.2055	0.2182
Total digestible nutrients	0.3952	0.2616	0.2997	0.2825	0.2985
Neutral detergent fiber	0.5977	0.4201	0.4944	0.4535	0.4865
Acid detergent fiber	1.2588	0.8915	1.0543	0.9530	1.0374
Crude protein	2.0324	0.9947	0.9712	0.9302	0.9523

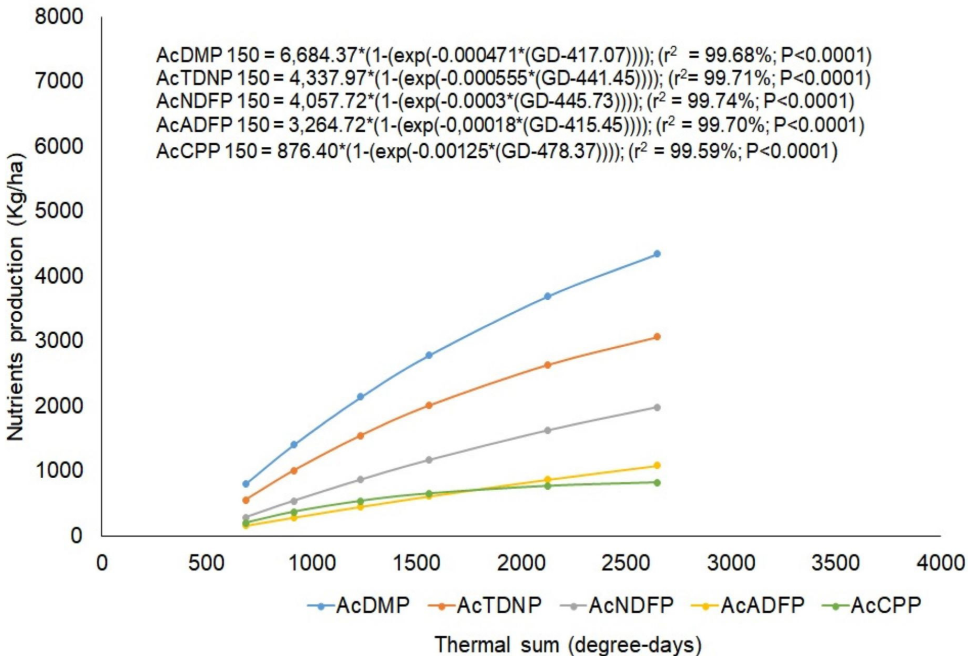

Figure 2. Accumulated dry matter production (AcDMP), accumulated total digestible nutrients production (AcTDNP), accumulated neutral detergent fiber production (AcNDFP), accumulated acid detergent fiber production (AcADFP), and cumulative crude protein production (AcCPP) per ha for dual-purpose wheat pasture of BRS Tarumã managed with 150 kg N in topdressing.

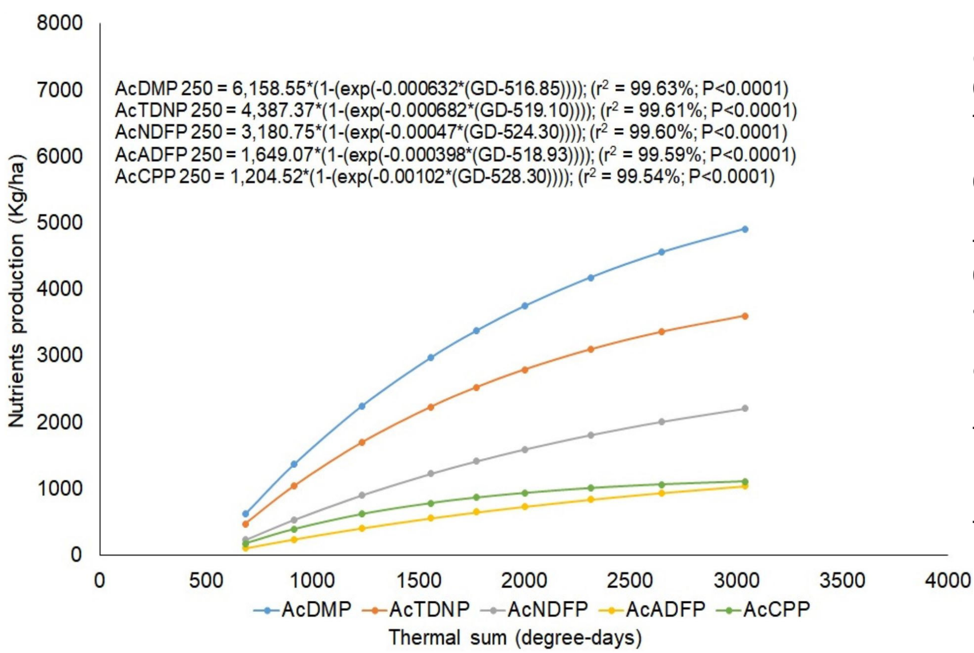

Figure 3. Accumulated dry matter production (AcDMP), accumulated total digestible nutrients production (AcTDNP), accumulated neutral detergent fiber production (AcNDFP), accumulated acid detergent fiber production (AcADFP), and cumulative crude protein production (AcCPP) per ha for dual-purpose wheat pasture of BRS Tarumã managed with 250 kg N in topdressing.

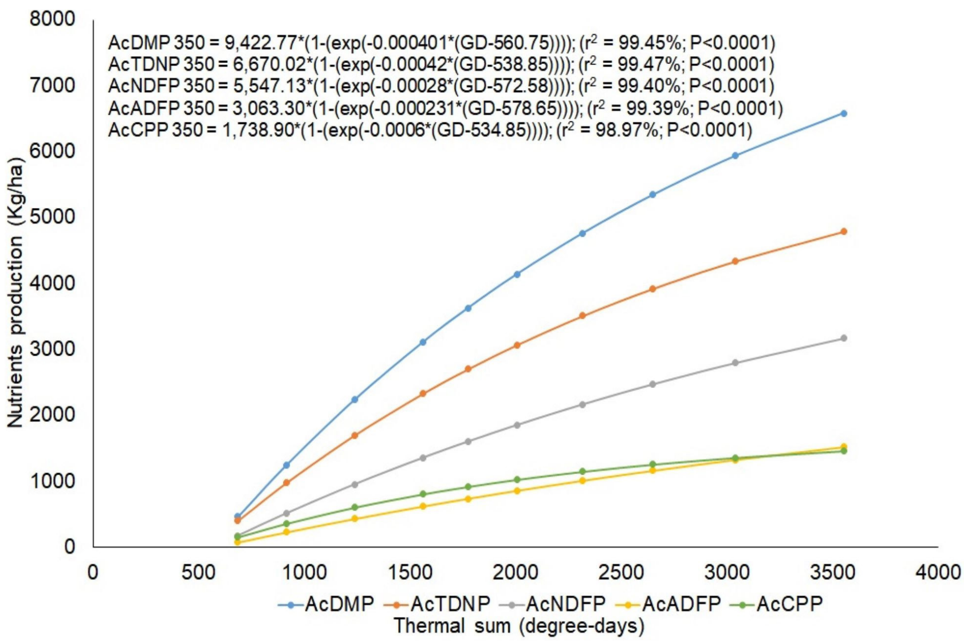

Figure 4. **Accumulated dry matter production (AcDMP), accumulated total digestible nutrients production (AcTDNP), accumulated neutral detergent fiber production (AcNDFP), accumulated acid detergent fiber production (AcADFP), and cumulative crude protein production (AcCPP) per ha for dual-purpose wheat pasture of BRS Tarumã managed with 350 kg N in topdressing.**

The absence of nitrogen fertilization in the topdressing reduces nutrient production to the extent that the pasture does not support grazing or, by extension, economic return. Therefore, there would only be expenses rather than profitability in this treatment. The various levels of topdressing nitrogen fertilization (150, 250, 350, and 450 kg N ha^{-1}) increased production costs but allowed economic returns because they could support grazing animals. Therefore, they would ultimately become financially viable. However, the 150 and 350 kg N ha^{-1} gave the best results since they had comparatively lower nutrient costs per ha. Since production systems are dynamic, however, there may not be one single ideal treatment. Rather, the application rates may have to be adjusted for optimization.

DISCUSSION

Topdressing nitrogen fertilization is a simple and easy approach to increasing the pasture production cycle (Henz et al. 2016b). Ruminant production systems dependent on grazing pastures (pasture and semi-confinement systems) must maximize pasture utilization to reduce production costs. However, Alizadeh et al. (2017), Lam et al. (2018), and van der Weerden et al. (2016) reported that the greenhouse gas (GHG) nitrous oxide is generated from nitrogen fertilizer (urea, ammonium sulfate, and ammonium nitrate) use in pastures. On the other hand, the same authors conceded that these fertilizers also enhance both plant and animal production. Intensifying nitrogen fertilization use increases pasture grazing and pasture cut frequency and, by consequence, animal production (Soussana & Lemaire 2014).

According to The Royal Society (2009), global agricultural production must be intensified sustainably. Yields must be increased without adverse environmental impact or the expansion of arable land cultivation. Considering the results obtained for the control in the present study, the lack of any topdressing nitrogen fertilization would necessitate the expansion of the cultivated area because of low production rates. This approach would result in economic

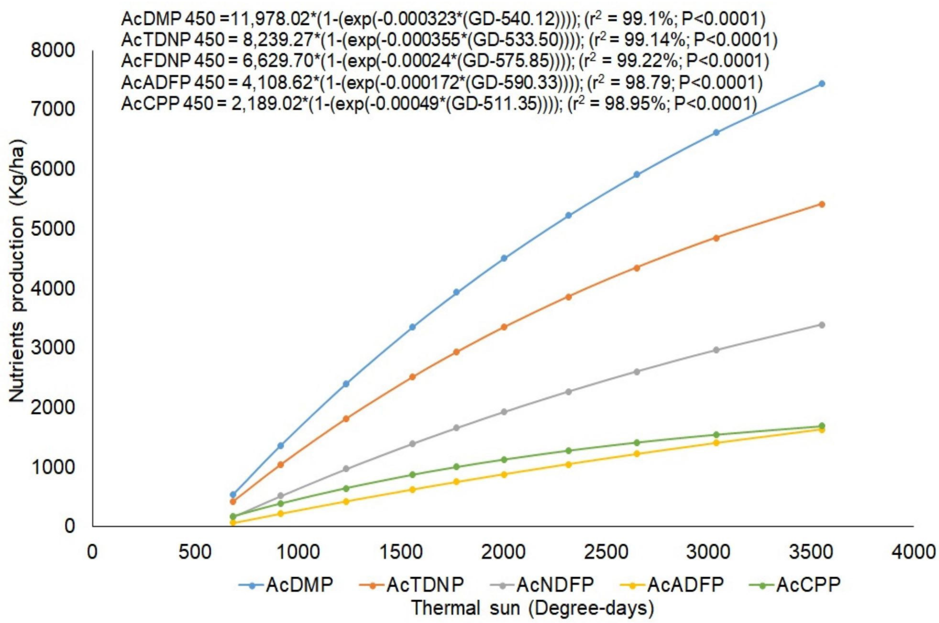

Figure 5. Accumulated dry matter production (AcDMP), accumulated total digestible nutrients production (AcTDNP), accumulated neutral detergent fiber production (AcNDFP), accumulated acid detergent fiber production (AcADFP), and cumulative crude protein production (AcCPP) per ha for dual-purpose wheat pasture of BRS Tarumã managed with 450 kg N in topdressing.

losses. Therefore, the absence of nitrogen in topdressing is not feasible. Tedeschi et al. (2015) stated that sustainability must be economically viable, environmentally correct, and socially fair. Nitrogen deficiency limits plant growth even when the environmental conditions are conducive to crop development (Thornley & France 2004).

Pembleton et al. (2016) evaluated wheat pasture production (100 kg N ha^{-1}) in three regions of Australia (Elliott Tasmania, Dookie Victoria, and Terang Victoria), and obtained average dry matter levels of 6.25, 9.67, and 7.0 t/ha, respectively. Measurements were made under normal local conditions and after simulating various scenarios, including increasing temperature with or without decreasing rainfall. In every case, production increased with an increase in average temperature. Therefore, wheat pasture productivity tends to increase with increasing temperature.

The areas between the DM and TDN yield curves represent the indigestible pasture component. This fraction increases with time. Even if the management keeps the plants in a vegetative stage for grazing, some of them will put forth inflorescences to produce seeds. Simultaneously, lignin production increases, which reduced the digestibility of the fibrous portion (Van Soest 1994). Nevertheless, the physiological state of the animals also influences digestibility (Weiss et al. 1992).

Bartmeyer et al. (2011) evaluated BRS 176 dual-purpose wheat under grazing and verified that pasture NDF content rose and TDN content fell as grazing time increased from 15–45 d. Despite the decrease in the energetic value of the pasture, there was a linear increase in live weight gain per hectare [15.84 + 10.305 × DG, where DG = days of grazing (P = 0.01)]. Therefore, BRS 176 wheat could increase gain per animal and unit pasture area. According to Lopes et al. (2007), a high productivity level is necessary for effective economic performance.

The differences between the accumulated TDN and NDF yields (150, 250, 350, and 450 kg N ha^{-1}) are the sums of the digestible NDF, crude protein and other unidentified nutrients which form part of the cellular content (digestible starch, pectin and soluble sugars). The latter are also essential components of animal feed. Henz et al. (2016b) evaluated the effects of 0, 75, 150, 225, and 300 kg N ha^{-1} on the non-fibrous carbohydrate (NFC) levels in dual-purpose wheat BRS Tarumã by the simple linear regression model and obtained the following equation: NFC = 16.61 - 0.029 × ND, where ND = nitrogen doses (P = 0.0186). The NFC levels decreased with increasing N dose but remained high even at the maximum N levels. Starch and soluble sugars in pasture are vital for ruminal microbial protein production (Tylutki et al. 2008).

Figures 2, 3, 4, and 5 show that nutrient yields increase with nitrogen rate both in the cell wall (NDF and ADF) and the cell content. The CP production also increases with applied nitrogen dose but not proportionately. Wheat plants are genetically selected to produce energy (fiber and non-fibrous carbohydrates) in pasture and starch in the grains. The NDF and ADF differ in terms of their hemicellulose content (Van Soest 1994). Hemicelluloses are complex non-cellulosic polysaccharides, which constitute, approximately, a third part of the plant cell wall (Kaur et al. 2017). They include xyloglucan, which contains a β-(1,4)-linked glucan backbone substituted with α-(1,6)-linked xylosyl residues or xylosyl, galactosyl, and fucosyl side chains (Lionetti et al. 2017). Therefore, hemicelluloses are generally more digestible than cellulose (Van Soest 1994).

According to Marin et al. (2016), significant increases in fertilizer demand and the lack of investment in new crops in recent decades have made Brazil a major net importer of fertilizers. Therefore, it is important to know how to use fertilizers effectively to optimize crop yield sustainably. The present study showed that the strategic use of topdressing nitrogen fertilization increases plant nutrient yields exponentially compared to those obtained with nitrogen-free topdressing. Pasture assessments with nonlinear models are seldom performed but help improve the accuracy of pasture management in relation to the nitrogen levels in topdressing.

CONCLUSIONS

The production of dry matter and other nutrients in BRS Tarumã wheat pasture is affected by the rates of nitrogen in the topdressing under the same environmental conditions (temperature and rainfall). An exponential model explains the dynamics of nutrient accumulation based on the thermal sum for each dose of nitrogen and impacting the cost per kilogram of pasture produced.

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