Yield parameters and water productivity of tropical and overseeded winter forages

Arthur Carniato Sanches; Débora Pantojo de Souza; Fernanda Lamede Ferreira de Jesus; Fernando Campos Mendonça; Eder Pereira Gomes; José Ricardo Macedo Pezzopane; Rodrigo Couto Santos; Adriano Bicioni Pacheco; Cristiane Fernandes Lisboa; Raimundo Rodrigues Gomes Filho

Corresponding Author's name, address, affiliation and e-mail: Rodrigo Couto Santos,
Rodovia Dourados-Itahum, km 12. Campus Universitário (Unidade II) - Caixa-Postal: 533,
CEP: 79804-970. Dourados, MS – Brasil, Faculty of Agricultural Sciences / Federal
University of Grande Dourados, rodrigocouto@ufgd.edu.br, fone: +55(67)981908799

Abstract

Intensive pasture exploitation with tropical forages is one of the most efficient forms ruminant production. However, the results depends on the knowledge about these forages and the experience in its management. The objective of this work was to evaluate water productivity (WP) and yield parameters of Megathyrsus maximum cv. Mombaça "Guinea grass" and Cynodon spp. "Bermuda grass", in single culture and overseeded with oats + ryegrass in autumn/winter period. Irrigation management was done considering a depletion factor of 0.3 (70% of the humidity the field capacity). The experimental design was a randomized complete block design with four replications, in which the forages are the treatments with evaluation at the time of the cycles. For all evaluated parameters, the best results were obtained with the Guinea grass in exclusive cultivation. The TFP (Total Forage Productivity) of Guinea grass was superior to Bermuda grass (59.3 and 30.2 Mg ha^{-1}, respectively), in accordance with its average LAI (Leaf area index) values of 4.8 and 2.5, respectively. The most efficient use of water occurred for Guinea grass in exclusive cultivation, and the intercropped crops did not present increases in the WP. In the autumn/winter period, the accumulated TFP of the exclusive crop of Guinea grass was higher than the other crops. However, the SDM of Bermuda grass was higher than the other crops. In winter, the highest LAI occurred in Guinea grass in exclusive cultivation, followed by the overseeded Guinea grass, 4.8 and 4.5, respectively. Consortia did not increase forage yield during the winter. The consortiums did not increase forage yield during the winter.

Keywords: Pasture irrigation, tropical forages, dry matter yield and water use efficiency.

1. Introduction

A great challenge for human society is the production of enough food to feed a growing population, which is highly dependent on the expansion of irrigated agricultural land (Liu 2011). However, the use of innovative practices that increase the efficiency of water use is a constant challenge toward the goal of food security (Liu 2011; Levidow et al. 2014). Forages are a major component of global agroecosystems that contribute significantly to world food production. Contrary to popular belief, forages benefit the ecosystem via soil erosion prevention, air and water purification, impact mitigation of greenhouse gasses, and providing wildlife habitats (Putnam and Orloff 2014).

In recent years, the increased use of technologies has allowed for increased cattle productivity, and this is dependent on the constant improvement of their main food resource – pastures (Soares et al. 2015). In a climate that favors plant growth, the key to ruminant production is in a diet derived from forage, grown either for grazing or for storage and later use (Morris & Kenyon 2014; Chobtang et al. 2017a, 2017b).

Pasture irrigation is a promising technique to maintain crops during periods of drought, when forage plants display pronounced seasonality, which is reflected in livestock production (Mochel Filho et al. 2016). However, when the productivity of irrigated and non-irrigated pastures is compared, irrigation yields an increase in average daily forage accumulation between 25 and 55 kg ha^{-1} d^{-1} (Gomes et al. 2015b; Sanches et al. 2015, 2016, 2017; Dantas et al. 2016).

Thus, the use of irrigation has led to the development water productivity (i.e. water use efficiency), which seeks to quantify the unit return of each unit of water volume used in the production of dry matter (Neal et al. 2011). Dantas et al. (2016) compared water use efficiency in tropical forages during different seasons and observed that it was higher in autumn than in winter, measuring 8.8 and 6.5 kg ha^{-1} mm^{-1}, respectively. In a study with *Brachiaria decumbens* (Syn. *Urochloa decubens*), yields of 44.3 and 21.2 kg ha^{-1} mm^{-1} were obtained at supplemental irrigation depths of 3.8 and 10.5 mm d^{-1}, respectively (Lopes et al., 2014).

Although water use efficiency is an important indicator, it should not be used in isolation, as it may result in inaccurate cultivation strategies that do not generate a return on investment. As in the case of fertilizers, the benefits obtained from irrigation follow a law of diminishing returns. De Paula Lana (2009) developed a function that allows for the calculation of an optimal economic level of fertilization that is based on the benefit-cost ratio. Like fertilizers, water is a scarce resource and when applied by irrigation, one has to aim for the best possible return in crop yields.

Forage production throughout the year does not constantly meet the requirements of the animals, and although irrigation attenuates over the course of the seasons, it does not eliminate it (Sanches et al. 2015). Thus, the consortium between summer and winter forages or overseeded winter forage, can optimize forage production in the winter period and prolong the annual period of pasture utilization, as well as improve forage quality (Silveira et al. 2015).

In pastures of *Cynodon spp.*, there is a possible synergy with overseeded winter forages, indicated by the low oscillation of the qualitative variables and significant quantitative contributions to forage production (Castagnara et al. 2012; Da Silva et al. 2012; Neres et al. 2012; Aguirre et al. 2014, 2016; Gomes et al. 2015a; Sanches et al. 2015). Two studies with coast-cross grass in Santa Maria/RS, (Aguirre et al. 2014, 2016) showed positive effects of overseeding in the winter, with a daily forage accumulation rate of 44.7 and 37.8 kg DM d^{-1}, for crops overseeded with clover and exclusive coast-cross grass, respectively.

In studies with Tifton 85 grass in the northwest region of Paraná (Gomes et al., 2015a; Sanches et al. 2015), it was observed that oat overseeding significantly increased the leaf/stem ratio between 50 and 60%. In Dois Vizinhos-PR, an experiment was conducted with Cynodon nlemfuensis Estrela Africana that was overseeded with *Lotus corniculatus L.* and ryegrass (Silveira et al., 2015); however, the consortium did not change the total forage production.

The objective of this study was to evaluate water productivity, botanical composition, and yield parameters (total forage productivity - TFP, canopy height - CH and leaf area index - LAI) of Guinea grass (*Megathyrsus Maximum* Mombaça, Syn. *Panicum Maximum*) and Bermuda grass (*Cynodon spp*.) in exclusive cultivation throughout the year, and when overseeded with black oats + ryegrass during the autumn/winter cultivation period.

2. Material and Methods

2.1 Experimental site and forages

The experiment was conducted between February 2016 and February 2017 in an experimental area of the Department of Biosystems Engineering at the "Luiz de Queiroz" School of Agriculture - ESALQ / USP, in Piracicaba-SP, Brazil (lat. 22º42'S, long. 47º37 'W, altitude 546 m).

According to the Köppen classification, the climate of the region is of a Cwa - subtropical or tropical type (Pereira et al. 2016). During the experimental period, the accumulated rainfall was 1457.6 mm and total water supplementation by irrigation was 570.7 mm (Figure 1).

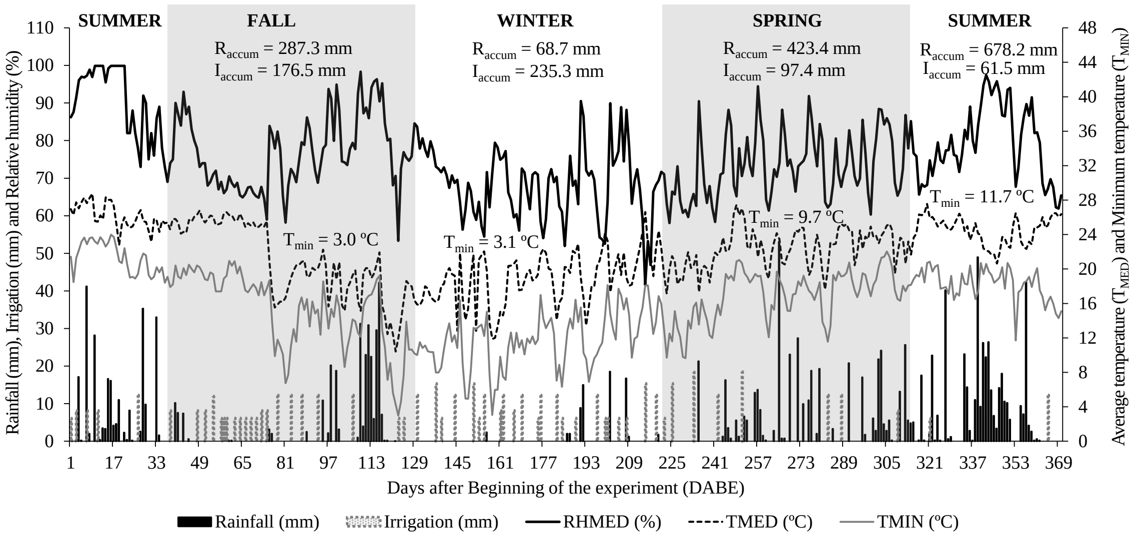

Figure 1. Precipitation values (mm), relative humidity (%), minimum temperature (ºC) and average temperature (ºC) during the experimental period between 02/2016 and 02/2017 (Piracicaba City 2016/17).

Legend: Raccum = accumulated rainfall in the period, Iaccum = accumulated irrigation in the period, Tmin = minimum temperature presented in the period.

The soil in the experimental area is classified as Clayey Oxisol 'Nitossolo Vermelho Eutroférrico Latossólico in brazilian classification' (Weil and Brady, 2016). In the previous year (2015), conventional soil preparation included plowing and harrowing, weed control, pH correction with the application of 4 mg ha^{-1} dolomitic limestone and basic fertilization according to criteria established by Raij et al. (1997) and based on chemical and granulometric analysis (Table 1).

Table 1. Chemical and granulometric analysis of the soil of the experimental area in the 0-20 cm and 20-40 cm layers (Piracicaba City 2016)

Layer	pH	P	K	Ca	Mg	H+Al	Al	CEC	Sand	Silt	Clay
(cm)	$CaCl_2$	mg dm^{-3}	cmol$_c$ dm^{-3}					cmol$_c$ dm^{-3}	(%)	(%)	(%)
0 – 20	5,3	72	0,94	3,9	1,8	3,1	0,2	9,74	35,7	19,2	45,1
20 – 40	4,9	31	0,44	1,3	1,0	4,2	0,2	6,94	29,3	18,7	52,0

P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; H + Al = potential acidity; Al = exchangeable aluminum; CEC = cation exchange complex.

During the experiment, nitrogenous fertilization fractionated with urea was applied after each growth/cut cycle at the rates of 80 kg ha^{-1} $cycle^{-1}$ and 50 kg ha^{-1} $cycle^{-1}$ of N in the spring/summer and autumn/winter periods, respectively. Recent studies of irrigated pastures have shown that nitrogen split application provides good productive results, with fertilization varying between 40 kg ha^{-1} $cycle^{-1}$ and 100 kg $ha^{-}1$ $cycle^{-1}$ (Magalhães et al. 2012; Gomes et al. 2015b; Sanches et al. 2017).

The forages we used were Guinea grass (Megathyrsus maximum cultivar Mombaça, Syn. Panicum Maximum) and Bermuda grass (Cynodon spp.), in either exclusive cultivation or overseeded with the winter forages black oats (Avena strigosa. Embrapa 29 - Garoa) and ryegrass (Lolium multiflorum Fepagro São Gabriel) in the fall/winter period. The experiment was conducted with four treatments and four replicates, totaling 16 experimental plots that were designed as follows: treatment 1, Guinea grass grown alone from 02/12/16 to 13/02/17, with 12 regrowth cycles (12 RC); treatment 2, Guinea grass + black oat + ryegrass grown from 05/07/16 to 09/22/16 (4 RC); treatment 3, Bermuda grass grown alone from 02/19/16 to 02/15/17 (14 RC); and treatment 4, Bermuda grass + black oats + ryegrass grown from 04/30/16 to 10/14/16 (6 RC) (Table 2).

Table 2. Dates and cut periods of the exclusive and overseeded grasses performed during the experimental period (Piracicaba City 2016/17)

RC	Treatment 1**	Treatment 2***	Treatment 3**	Treatment 4***
	Period (Cycle interval - Start and End)			
1º	02/12 - 03/11/2016	------	02/19 - 03/18/2016	-------
2º	03/12 - 04/08/2016	------	03/19 - 04/08/2016	-------
3º	04/09 - 05/06/2016	------	04/09 - 04/29/2016	-------
4º *	05/07 - 06/15/2016	05/07 - 06/15/2016	04/30 - 06/01/2016	04/30 - 06/01/2016
5º	06/16 - 07/25/2016	06/16 - 07/21/2016	06/02 - 07/01/2016	06/02 - 06/28/2016
6º	07/26 - 09/03/2016	07/22 - 08/22/2016	07/02 - 08/06/2016	06/29 - 07/22/2016
7º	09/04 - 10/01/2016	08/23 - 09/23/2016	08/07 - 09/08/2016	07/23 - 08/12/2016
8º	10/02 - 10/29/2016	-------	09/09 - 10/11/2016	08/23 - 09/08/2016
9º	10/30 - 11/25/2016	-------	10/12 - 11/01/2016	09/09 - 10/14/2016
10º	11/26 - 12/19/2016	-------	11/02 - 11/22/2016	-------

11º	12/20 - 01/16/2017	-------	11/23 - 12/13/2016	-------
12º	01/17 - 02/13/2017	-------	12/12 - 01/04/2017	-------
13º	-------	-------	01/05 - 01/25/2017	-------
14º	-------	-------	01/26 - 02/15/2017	-------

*First winter cut: fixed with 40 days for exclusive and overseeded, and 33 days for exclusive and overseeded *Cynodon spp*. **exclusive grass cuts, ***overseeded cuts in grasses.

2.2 Experimental site and forages

The irrigation was performed using a fixed and automated conventional sprinkler system with 12 x 12 m (emitters x lines) spacing. The irrigation time was variable according to the water consumption of the crops, which was measured with weighing lysimeters. The application intensity of the sprinklers (Ai) was 12.3 mm h^{-1} with a pressure of 250 kPa. Irrigation was composed of low flow sectorial sprinklers that had restricted irrigation at a 90º angle and a flow rate of 0.592 m^3 h^{-1}.

The applied irrigation blade (IB) was determined by the ratio of the volume consumed by the lysimeter (liters) and its area (m^2), with an effective depth (Z) equal to 60 cm. The previously established irrigation interval was based on a 70% limit of the water availability factor. The moisture at field capacity (θ_{fc}) was considered to be the moisture corresponding to the value of the matrix potential, Ψ_m = 0.1 bar (Benevenute et al. 2016). The values of current moisture (θ_c) were estimated by means of the soil water retention curve, which was obtained with the aid of a tensor table and Richards extractor in the Laboratory of Soils and Water Quality of ESALQ/USP and was adjusted with the equation described by Van Genuchten (1980):

$$\theta_c = 0.2938 + \left[\frac{(0.4934 - 0.2938)}{\left[1+(0.113\Psi_m)^{1.3211}\right]^{0.2431}}\right]; (R^2=1.00 \text{ e } P<0.01) \quad (1)$$

where:

Θ_c = current volumetric humidity (cm^3 cm^{-3})

Ψ_m = current matrix potential of water in the soil (bar).

2.3 Experimental management

RC was fixed for the exclusive crops of Guinea grass and Bermuda grass at 21 d and 28 d after the cut (DAC) in spring/summer, and 33 and 40 DAC in autumn/winter, respectively. The height after cutting (residue) was adopted according to the literature at 30 cm for Guinea grass (Simonetti et al. 2016) and 10 cm for Bermuda grass (Sanches et al. 2017). For the overseeded plots, the cutting cycles were variable as a function of the growth of the winter forages as measured with an LAI 2000, in which the first cycle consisted of 40 DAC and 33 DAC in the overseeded cultivation with Guinea grass and Bermuda grass, respectively, in order to establish winter forages. The overseeded Guinea grass a had a post-cut height (residue) of 15 cm; in the Bermuda grass, the height remained the same throughout the growth cycles. The cutting and collecting procedures were repeated until the oats and ryegrass were extinguished from the pastures.

2.4 Parameters evaluated

In the laboratory, samples from the exclusive cultures of Guinea grass and Bermuda grass were submitted to botanical separation (leaf, stem, and dead material) and dried in a forced air circulation oven at 65ºC for

72 hours. The dry matter of the forages was determined: TFP (total forage productivity), LY (leaf yield), SY (stem yield), DMY (dead material yield). In the overseeded cultures, the samples were separated such that the Guinea Grass was separated from the oat + ryegrass, and the Bermuda grass from the oat + ryegrass. Thus, TYOR (total yield of oats + ryegrass), YOLR (yield of oat leaves + ryegrass), and YOSR (yield of oat stems + ryegrass) could be determined; the dead material was not identified and separated because it was in the process of decomposition.

At the end of the cycle, the leaf area index (LAI) and final height of the forage canopy (H) were evaluated. We evaluated the LAI, with a LI 3000C table sensor (LI-COR Environmental, Nebraska, USA). Therefore, 10 samples were chosen randomly to calculate the specific area ($cm^2\ g^{-1}$) by the area (cm^2) in the sensor divided by the dry mass (g) of the tiller (Costa et al. 2016). With the specific area, the LAI was determined according to the equation:

$$LAI = SA * FY; \qquad (2)$$

where;

LAI = leaf area index (dimensionless);

SA = specific area ($cm^2\ g^{-1}$);

FY = forage yield ($g\ cm^2$);

In order to estimate the water consumption and the water productivity (WP) of the forages, the precipitated and irrigated total were used (Figure 1) from the experimental period in each cycle, taking into account efficient water use. Water productivity was calculated using the following equation:

$$WP = \frac{TFP}{10*(R+I)} \qquad (3)$$

where;

WP - Water productivity in ($kg\ m^{-3}$)

TFP - Total Forage Productivity ($kg\ ha^{-1}$)

R + I - Rainfall and Irrigation (mm)

2.5 Data analyses

The experimental data were submitted to analysis of variance ($p \leq 0.05$) and significant averages were compared with the Tukey test ($p \leq 0.05$) using SAS for Windows 7 and Assistat 7.7 (Francisco and Carlos 2016).

3. Results and Discussion

3.1 Biometric and Productive parameters of forages

The highest average leaves and forage yield of the Guinea grass corresponded to the highest leaf area indexes (LAI). Analyzing daily TFP values (Table 3), we measured 162.4 and 86.0 $kg\ ha^{-1}\ d^{-1}$ of dry mass for Guinea grass in exclusive and overseeded crop, respectively. Additionally, in exclusive and overseeded Bermuda grass crops, we measured 82.6 $kg\ ha^{-1}\ d^{-1}$ and 66.9 $kg\ ha^{-1}\ d^{-1}$ of dry mass, respectively. In irrigated cultivation with nitrogen fertilization between August and December, Mochel Filho et al. (2016) conducted an experiment with Guinea grass in Parnaíba-PI that accumulates 141.5 $kg\ ha^{-1}\ day^{-1}$ of forage, which was slightly lower than that reported by Silva et al. (2009), who worked with the same grass in Araras-SP and observed daily forage accumulation rates that were higher than 200 kg ha^{-1} day^{-1} in January, 2001.

Table 3. Average data per cycle of total forage productivity, leaf yield, stem yield, dead material yield, canopy height, leaf area index and water productivity (Piracicaba City 2016/17)

	TFP (kg ha^{-1})	LY (kg ha^{-1})	SY (kg ha^{-1})	DMY (kg ha^{-1})	H (m)	LAI	WPA (kg m^{-3})
Guinea grass	4941 A	4175 A	666 A	100 A	91,3 A	4,8 A	3,3 A
Mom + Oat + Rye	3009 B	2149 B	753 A	107 AB	61,4 B	4,3 B	2,5 B
Cynodon	2154 C	1151 C	873 A	130 A	27,8 D	2,5 C	1,9 C
Cyn + Oat + Rye	1873 C	1108 C	750 A	15 B	44,3 C	2,9 C	1,9 C

Legend: TFP = total forage productivity, LY = leaf yield, SY = stem yield, DMY = dead material yield, H = forage canopy height, LAI = leaf area index, WP = water productivity.

Sanches et al. (2016) performed experiments with Cynodon spp. cultivar Tifton 85 under irrigation in the northwest of Paraná and observed of daily forage accumulation rates of 102.7 kg $ha^{-1}d^{-1}$, which were higher than the values found for the Bermuda grass (Cynodon spp.) used in this experiment. A probable justification for this difference is the fact that Cynodon spp. were sown months before the experiment and were likely to be a mix between Tifton and Star grass or coast-cross cultivars, which are less productive than Tifton 85.

The average height of the Guinea grass in exclusive cultivation (91.3 cm) was consistent with the literature (Silva et al. 2009; Simonetti et al. 2016); however, the height of the canopy in the overseeded consortium with ryegrass and Guinea grass had an average intermediate value of 61.4 kg ha^{-1} d^{-1} (Table 3), which may be due to the lower cut management, the 15 cm from the soil, in an attempt to guarantee the establishment of winter forages.

The productive values during the summer forage seasons for Guinea and Bermuda grass are presented in Table 4. The highest TFP were observed in the spring/summer period for both Guinea and Bermuda grass, consistent with the results from Aguirre et al. (2016), who worked with coast-cross grass and found greater dry matter yields in the spring/summer period that corresponded to 61.5% of the total annual production. In our experiment, about 60% of the TFP was obtained in the spring/summer period for Bermuda grass Sanches et al. (2016) conducted an experiment with Cynodon spp. cultivar. Tifton 85 in Mariluz-PR and found 71% of the production in irrigated Cynodon in the same period, which confirms that most of the TFP is produced in the hottest and brightest seasons of the year.

Table 4. Mean TFP, LY, SY and LAI data accumulated during the year between seasons for Guinea grass and Cynodon spp. in exclusive cultivation Piracicaba City 2016/17)

		Fall	Winter	Spring	Summer	Average	CV%
PTF	Guinea	13138.6 aB	12752.9 aB	15645.1 aAB	17756.6 aA	14823.3 a	4.97
	Cynodon	5512.9 bB	6584.3 bB	10876.6 bA	7181.0 bB	7538.7 b	15.44
	Average	9325,8 B	9668.6 B	13260.8 A	12468.8 A	11181.0	---
LY	Guinea	10862.6aA	10833.8aA	14177.5 aA	14228.8 aA	12525.7 a	7.31
	Cynodon	2774.8 aA	3762.9 aA	5656.5 aA	3924.6 aA	4029.7 b	16.24
	Average	6818.7 C	7298.4 BC	9917.0 A	9076.7 AB	8277.7	---
SY	Guinea	2029.8 aB	1301.5 bB	1362.7 bB	3304.3 aA	1999.6 b	11.39
	Cynodon	2297.6 aB	2256.0 aB	4929.7 aA	2732.8 aB	3054.0 a	19.89
	Average	2163.7 B	1778.8 B	3146.2 A	3018.6 A	2526.8	---
LAI	Guinea	5.29 aAB	4.76 aB	6.59 aA	6.67 aA	5.83 a	6.83
	Cynodon	2.51 bA	2.41 bA	2.89 bA	2.31 bA	2.53 b	15.44
	Average	3.90 AB	3.59 B	4.74 A	4.49 AB	4.18	---
WP	Guinea	2.62 aB	3.92 aA	3.13 aB	2.53 aB	3.05 a	5.17
	Cynodon	1.90 bA	1.49 bAB	2.18 bA	1.00 bB	1.64 b	14.96
	Average	2.26 AB	2.70 A	2.66 A	1.77 B	2.35	---

Legend: TFP = total forage productivity, LY = leaf yield, ST = stem yield, LAI = leaf area index, WP = water productivity. Capital letters for lines and lower case letters for columns.

Comparing the production of tropical forages throughout the seasons, Guinea and Bermuda grass did not present significant differences in leaf yield; however, Guinea grass was average the higher producer of leaf yield. The stems yield of Bermuda grass was higher in winter and spring, and had the highest overall average. These results may be related to their morphological characteristics, cespitose growth in the habitat, launching of tillers with stolons, and the high stem yield of the Cynodon genus (Gomes et al. 2015a; Aguirre et al. 2016; Sanches et al. 2016, 2017).

The highest values of TFP and LY occurred in the exclusive Guinea grass cultivation plots, with no positive interaction between Guinea grass and the overseeded crops that included oats and ryegrass (Table 5). During the experiment, it was observed that some allelopathy rather than a synergism could have occurred between these species. Cavalli et al. (2016) carried out an experiment with Sudan grass in São José do Cedro-SC and observed allelopathic effects on plant and root growth between Sudan grass and the overseeded black oats and ryegrass.

Table 5. Productive and biometric data in the winter period for the treatments (Piracicaba City 2016/17)

	TFP (kg ha^{-1})	LY(kg ha^{-1})	SY (kg ha^{-1})	DMY (kg ha^{-1})	H (m)	LAI	WP (kg m^{-3})
Guinea grass	12752.9 a	10833.8 a	1301.5 b	617.6 a	82.6 a	4.8 a	3.92 a
Mom + Oat + Rye	9612.7 b	6249.0 b	2956.3 a	407.5 ab	62.0 b	4.5 a	3.05 b
Cynodon	6584.3 c	3762.9 c	2256.0 ab	565.4 a	25.7 d	2.4 b	1.49 c
Cyn + Oat + Rye	7283.4 c	4392.4 c	2854.6 a	36.5 b	43.4 c	2.9 b	2.05 c
CV (%)	10.60	13.00	19.07	48.28	4.09	11.,39	11.31

Legend: TFP = total forage productivity, LY = leaf yield, ST = stem yield, DMY = dead material yield, H = canopy height, LAI = leaf area index, WP = water productivity. Lower case letters for columns.

The exclusive and overseeded Bermuda grass plots, had the lowest values planting designs of TFP and LS, without significant differences between these values. The Cynodon crops overseeded with ryegrass did not present a significant difference in these variables, which was consistent with the results obtained by Gomes et al. (2015a), who did not report significant effects of Tifton 85 with oat overseeding on TFP. Conversely, Sanches et al. (2015) indicated significant and positive results in Tifton 85 when overseeded with oats. These results indicate that there could be interference on TFP and LF from other factors that were possibly not verified in these and our present work.

The amount of dead material was lower in the plots that included the overseeded crops that included oats and ryegrass in addition to Bermuda grass, in relation to the others conditions. This result shows a positive synergism between the three forages, which also produced a good amount of TFP and high stem yield when the overseeding is compatible. Neres et al. (2012) described the importance of forage compatibility, and in their experiment, they identified problems with the height of the overseeded pigeon pea crop that promoted shading of the Bermuda grass and reduced the overall forage yield.

In the different growth cycles, the Guinea grass had high production in the 6th cycle (7759.6 kg ha^{-1} cut^{-1}; Figure 2). In the period (6th cycle), the average and minimum temperatures were 19.4ºC and 6.3°C, respectively (Figure 1), which do not justify such a high production. However, in the previous cycle, there was a management error in forage harvesting (cut), as can be observed by the absence of stem production in the 5th cycle, caused by error in plant height after cutting (residue). Thus, much of the forage from the 5th cut was not harvested and remained in the field, where it may have contributed to the high yield in the next cycle. In addition, this condition favors development of plants due to the greater leaf area that remained after cutting, which increases the accumulation of photosynthetic products. In a study by Silva et al. (2009), significant differences in the cutting heights were observed, similar to the observations from this work.

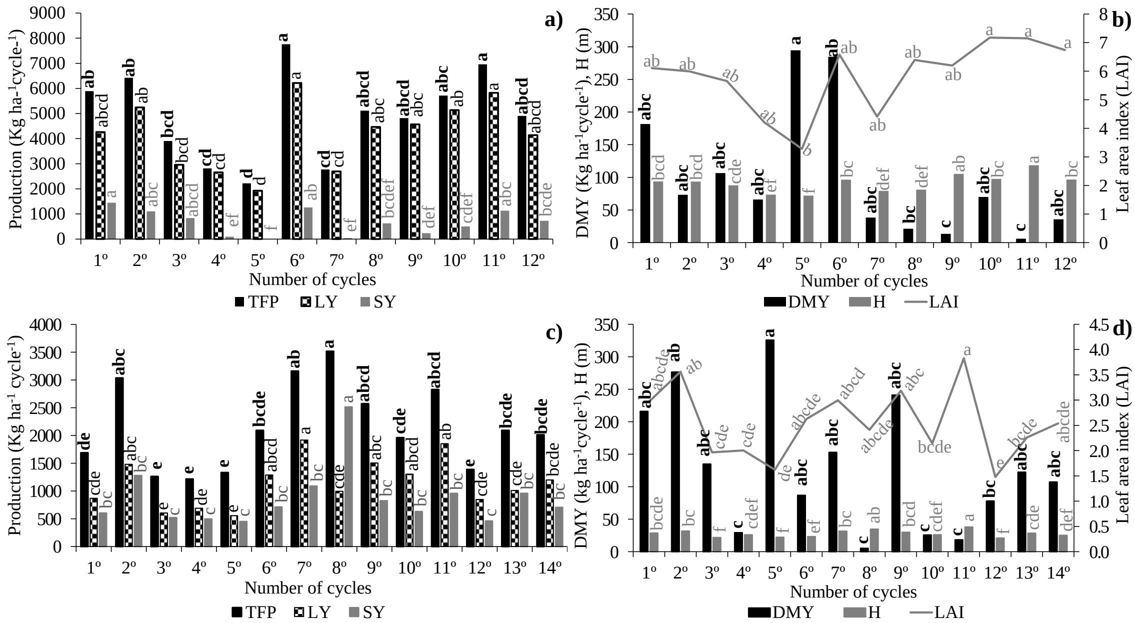

Figure 2. Average data for total forage productivity (TFP), leaf yield (LY), stems (SY), dead matter yield (DMY), height (H), and leaf area index (LAI) per cut cycle for Guinea grass (a and b) and Bermuda grass (c and d) (Piracicaba City 2016/17).

The values for TFP and LY in Guinea grass were lower in the autumn/winter cycles, especially in cycles 4, 5, and 7, which presented the lowest averages of TFP of 2,813.5 kg ha^{-1} cycle^{-1}, 2,219.6 kg ha^{-1} cycle^{-1}, and 2,773.7 kg ha^{-1} cycle^{-1}, respectively, with an average accumulation rate of 72.3 kg ha^{-1} d^{-1}. The spring/summer period corresponded to cycles 1, 8, 9, 10, 11, and 12, with an average forage accumulation rate of 203.7 kg ha^{-1} day^{-1}, which was similar to the results obtained in other studies that reported a marked reduction in the annual period of seasonal of production (Castagnara et al. 2012).

Bermuda grass had significant production variability between the growth cycles, with the highest TFP occurring in the 8th cycle at the beginning of spring (3,515.7 kg ha^{-1}), and the lowest yields in the 3rd, 4th, 5th, and 12th cycles (Figure 2c). Aguirre et al. (2014) reported high forage yields in coast-cross grass of 5,204 kg DM ha^{-1} in the 2nd autumn cycle; however, we observed larger forage yields for Bermuda grass in spring/summer in the present work.

In the 5th cycle (winter), Bermuda grass had the highest production of dead material (Figure 2d), with approximately 24% of the total and 9.3% on average produced in the fall/winter cycles. Gomes et al. (2015a) worked with an oat overseed and Cynodon spp. Tifton 85 crop and found that in a single winter cycle, dead material composed 25.7% of all dry matter produced and a mean of 12.2% dead material produced in the winter cycles.

In the overseeded crop (Figure 3), Guinea grass planted with oats + ryegrass presented higher production in the 3rd cycle with 4,237.2 kg ha^{-1} TFP, a high accumulation rate of 132.4 kg ha^{-1} d^{-1}, and 86 kg ha^{-1} d^{-1} average production throughout the period. In some intercropping of grasses with winter forage, the rates of forage accumulation varied between 66.5 - 143.5 kg ha^{-1}d^{-1} (Da Silva et al. 2012; Aguirre et al. 2014; Gomes et al. 2015a; Sanches et al. 2015; Silveira et al. 2015).

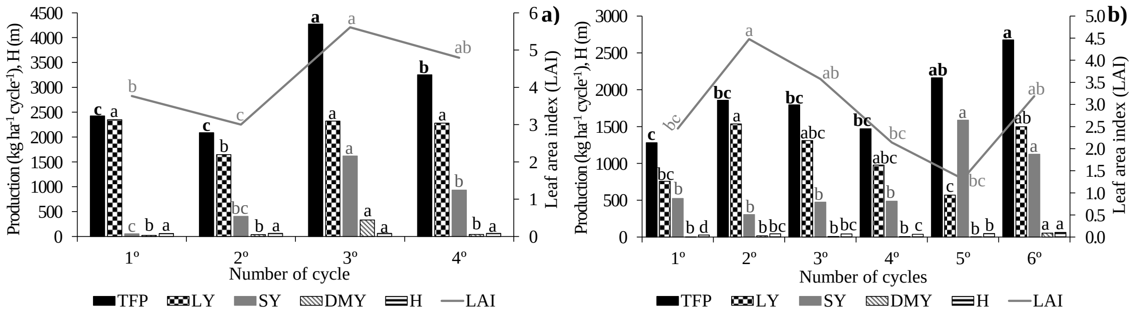

Figure 3. Mean data per cycle for the overseeded crops of Guinea grass + oat + ryegrass (a) and Bermuda grass + oat + ryegrass (b) (Piracicaba City 2016).

Leaf area index (LAI) was directly proportional to the total forage production (TFP) in the overseeded Guinea grass (Figure 3a), similar to the observations of Silva et al. (2009), who reported a direct relationship between forage production and LAI in Guinea grass.

Bermuda grass Grown with oat + ryegrass had the highest TFP in the 6th cycle at the beginning of spring, with production of 2676 kg ha^{-1} and a forage accumulation rate of 74.3 kg ha^{-1} d^{-1}. These results are consistent with the work of Sanches et al. (2015), who obtained an accumulation rate of 74.2 kg ha^{-1} d^{-1} in Tifton 85 grass grown with irrigated oat crops. Cycles 2 to 5 occurred in the winter, with an accumulated TFP of 7,283.4 kg ha^{-1}, which were higher than that of African Star grass + ryegrass + Lotus corniculatus that produced 6,676.2 kg ha^{-1} in three winter cycles in Dois Vizinhos-PR (Silveira et al. 2015).

During the experimental period, the mean percentage contribution of winter forages (oats + ryegrass) to the total production was 42% and 90%, in the Guinea and Bermuda grass crops, respectively. During the winter, Bermuda grass had a low contribution to forage production, which was predominantly from oats and ryegrass. In contrast, Gomes et al. (2015a) observed that Cynodon provided 65% of total forage in oat cultivation in the fall/winter period.

3.2 Water productivity

When we evaluated water use efficiency in our different crop conditions, the exclusive Guinea grass cultivation had an average annual water productivity of 3.3 kg m^{-3} DM, which was higher than the others crops. In Northeastern Germany, a study on pasture silage and maize with water supplied by rainfall and irrigation had values of 1.5 kg m^{-3} and 2.6 kg m^{-3} of DM (Kraus et al. 2015). Lopes et al. (2014) conducted an experiment with *Brachiaria decumbens (Syn. Urochloa)* under different irrigation depths and found WA values between 2.2 kg m^{-3} and 4.4 kg m^{-3} for green forage biomass. Considering an average of 30% for dry matter (higher than the standard of 20%) and changing WP to dry mass, we would obtain approximate values of 0.7 and 1.3 kg m^{-3}, respectively. Comparing the results from this current study, the Guinea grass grown as both exclusive and overseeded crops had higher water use efficiency, with WP values of 3.3 kg m^{-3} and 2.5 kg m^{-3}, respectively.

The WP in Guinea grass was higher than in the Bermuda grass during all growing seasons (Table 4). The lowest WP values occurred in the hot and rainy summer periods in Bermuda and Guinea grass crops, concurrent with a large accumulation of rainfall in the summer, which was approximately 47% of the annual total, which justifies the highest WP observed in Guinea grass crops in the last season. Moreover, the rainfall is not completely used in the summer due to the high intensity or the soil moisture before rainfall. Winter rains are more likely to be utilized due to their lower intensity and frequency, and because the soil is drier in this season. The water productivity of the crops is strongly influenced by rainfall during the experimental period, for example, Dantas et al. (2016) observed greater water use efficiency in the autumn than in the winter, with increases of 603 kg ha^{-1} DM (0.23 kg m^{-3}) in *Brachiaria brizantha*.

Compared to the winter cycles, the highest WP was obtained in the Guinea grass grown in exclusive crop plots, followed by Guinea grass overseeded with oats + ryegrass (Table 5). In other reports of oats and ryegrass over seeding in autumn/winter periods, variations in WP between 0.95-2.5 kg m^{-3} (Neal et al. 2011) were observed, indicating that the consortium between Guinea grass and oats + ryegrass contributed to WP decline in relation to the exclusive cultivation conditions.

4. Conclusions

Guinea grass had the highest forage productivity, with TFP of 59.3 mg ha^{-1} $year^{-1}$ and LY of 50.1 mg ha^{-1} $year^{-1}$, as well as the highest average leaf area index of 4.8. Bermuda grass had a total cumulative production of 30.2 Mg ha^{-1} $year^{-1}$ and an average LAI of 2.5. Water productivity was higher for Guinea grass grown in exclusive cultivation compared to overseeding conditions; furthermore, the overseeding of winter forages in tropical climates did not increase water use efficiency in the fall/winter period.

Grasses grown as single cultures in the spring/summer had higher TFP compared to autumn/winter growth seasons, with average yields of 25,729.6 kg ha^{-1} in spring/summer and 18,994.4 kg ha^{-1} in autumn/winter. The highest TFP was measured in Guinea grass during the spring/summer, which accumulated 33401.7 kg ha^{-1} and represented 56% of the total production of the year.

When Bermuda grass was grown as an exclusive crop, it had increased accumulation of stems, mainly in winter and spring seasons. The intercropping of tropical grasses with oats and ryegrass did not have a significant effect on forage production. In the winter growing period, the Guinea grass in exclusive cultivation produced the highest forage yield among all combinational growth conditions.

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