Seed production of 'Mombasa' grass subjected to different closing cut dates and nitrogen rates

Marcos Weber do Canto[1], Gleice Menezes de Almeida[2], Antonio Carlos Saraiva da Costa[1], Armindo Barth Neto[2], João Ricardo Scaliante Júnior[1] and Carla Faria Orlandini[1]

[1]Universidade Estadual de Maringá, Avenida Colombo, nº 5.790, Jardim Universitário, CEP 87020-900 Maringá, PR, Brazil. E-mail: mwcanto@uem.br, acscosta@uem.br, joaorscaliante@hotmail.com, carlaforlandini@gmail.com [2]Universidade Federal do Paraná, Rua dos Funcionários, nº 1.540, Bairro Juvevê, Caixa Postal 19061, CEP 81531-990 Curitiba, PR, Brazil. E-mail: gleice_m.a@hotmail.com, arm_barth@hotmail.com

Abstract – The objective of this work was to evaluate the effects of closing cut dates (CCD) and nitrogen (N) rates on the components of pure seed yield (PSY) and seed quality in 'Mombasa' grass (*Megathyrsus maximus* 'Mombaça'), besides determining the parameters of apparent N efficiency (ANE) and agronomic N efficiency (AgNE). The field experiments were carried out over two growing seasons, 2010/2011 and 2011/2012, in Umuarama, PR, Brazil. The folllowing treatments were evaluated: CCD on October 10, January 31, February 15, and March 1; and N doses at 0, 75, 150, and 225 kg ha^{-1}. Significant interactions between the CCD and N doses were observed for the panicle tiller number (PTN), pure seeds per panicle, PSY, ANE and AgNE. Values of ANE and AgNE were better for 150 kg N ha^{-1}. There were no effects of CCD and N doses on seed quality. PSY was closely correlated with PTN, pure seeds per panicle, and pure seed number. The CCD treatments of longer growth duration and higher N doses showed the higher PSY. Final CCD delaying until February and N availability reduced yield. Closing cut date and N fertilization affect pure seed yield and yield component responses of 'Mombasa' grass.

Index terms: agronomic nitrogen efficiency, apparent nitrogen efficiency, seed quality, seed yield.

Produção de sementes de capim-mombaça submetido a diferentes datas de rebaixamento e doses de nitrogênio

Resumo – O objetivo deste trabalho foi avaliar o efeito de datas de rebaixamento (DR) e doses de nitrogênio (N) sobre os componente de rendimento de sementes puras (RSP) e de qualidade de sementes em capim-mombaça (*Megathyrsus maximus* 'Mombaça'), além de determinar os parâmetros de eficiência aparente do nitrogênio (EAN) e eficiência agronômica de nitrogênio (EAgN). Os experimentos foram realizados nas estações de crescimento em 2010/2011 e 2011/2012, em Umuarama, PR, Brasil. Os seguintes tratamentos foram avaliados: DR em 10 de outubro, 31 de janeiro, 15 de fevereiro e 1 de março; e as doses 0, 75, 150 e 225 kg ha^{-1} de N. Verificou-se interação significativa entre DR e doses de N quanto ao número de perfilhos com panículas (NPP), sementes puras por panícula, RSP, EAN e EAgN. Os valores de EAN e EAgN foram melhores com 150 kg ha^{-1} de N. A DR e o N não tiveram efeitos sobre a qualidade das sementes. O RSP foi estreitamente correlacionado ao NPP, às sementes puras por panícula e ao número de sementes puras. As DRs com maiores durações de crescimento e doses de N tiveram maiores RSP. O atraso da DR final até fevereiro e a disponibilidade de N reduziram os rendimentos. A data de rebaixamento e a adubação com N afetam as respostas do rendimento de sementes puras e as componentes do rendimento do capim-mombaça.

Termos para indexação: eficiência agronômica de nitrogênio, eficiência aparente de nitrogênio, qualidade de sementes, rendimento de sementes.

Introduction

'Mombasa' Guinea grass, or 'Mombasa' grass, one of the most important cultivars of *Megathyrsus maximus* (Jacq.) B.K.Simon & S.W.L. Jacobs, 2003 (syn. *Panicum maximum* Jacq.) in Brazil, is an erect, perennial, tufted, short-day flowering plant, and its inflorescence is a branched, pyramidal panicle.

The effects of closing cut date (CCD) or grazing termination date on cool-season grasses and cereals to increase grain or seed production have been the subject of frequent studies (Holman et al., 2008; Bartmeyer et al., 2011; Baumhardt et al., 2011; Harrison et al., 2011). This practice has not been studied on 'Mombasa' grass or on the other *M. maximus* cultivars released in Brazil.

In some warm-season grasses, under varying defoliation management and N fertilization rates, estimates of the relationships between seed yield and its components have been addressed in the literature (Adjei et al., 2000; Lemke et al., 2003). Meanwhile, there are contradictory results regarding the responses of Guinea grass to CCD and N fertilizer. This oldest variety of *M. maximus* has early and more profuse flowering (Pedreira et al., 1976; Monteiro et al., 1984) than the cultivar 'Mombasa' (Canto et al., 2012). In an early study on Guinea grass in Brazil, CCDs (in September and January) were evaluated with or without N fertilizer (Pedreira et al., 1976). The authors concluded that the September CCD, which included N, had greater pure seeds per panicle and apparent seed yield (ASY). In contrast, Monteiro et al. (1984) evaluated four CCDs (January 31, February 14 and 28, and March 14, 1977), and N doses up to 145 kg N ha⁻¹, also for Guinea grass, and found higher panicle tiller number (PTN) on January 31, February 14, and March 14 CCDs, and higher ASY on January 31 and February 14 CCD. Higher seed germination and viable germinable seed yield were observed on the February 14 CCD. Interestingly, these authors also found no N effects on PTN, ASY, and pure germinable seed yield.

Nitrogen fertilization is one of the greatest cost inputs in all grass seed crop production systems. An analysis of the data for perennial ryegrass (*Lolium perenne* L.) seed crops showed that the efficiency of N application rates may vary considerably (Koeritz et al., 2015). However, no information has been found on the combined effect of defoliation and N fertilization on *M. maximus* apparent N efficiency (ANE), which is the crop yield per unit of the applied nutrient, and agronomic N efficiency (AgNE), which is the crop yield increase per unit of the applied nutrient, in tropical grass seed crops in field experiments. Information on these parameters can reduce the production costs and minimize environmental degradation.

The objective of this work was to evaluate the effects of closing cut dates and N rates on the components of pure seed yield and seed quality in 'Mombasa' grass (*Megathyrsus maximus* 'Mombaça'), besides determining the parameters of ANE and AgNE.

Materials and Methods

Two trials were carried out in two consecutive growing seasons (October to May 2010/2011 and 2011/2012). The experimental field was located at Universidade Estadual de Maringá, Umuarama county, northwest of the Paraná state (53°17'W, 23°44'S, at 480 m altitude), in Brazil. The climate is "Cfa" according to the classification of Köppen-Geiger, with 1,623 mm average annual rainfall, the largest volumes of which occurring from October to February (long-term average for this months is approximately 170 mm). The dry period occurs from May to August. The climatic data were collected at a weather state station from Simepar (Sistema Metereológico do Paraná), approximately 10 km from the experimental area. The soil is a Argissolo Vermelho distrófico (Typic Paleudult) with a sandy texture (73% sand in the A horizon). Soil samples collected on October 8, 2010, at 0–15 cm soil depth, had the following chemical characteristics: pH H_2O, 5.7; Al, 0.0 $cmol_c$ dm^{-3}; H+Al, 2.12 $cmol_c$ dm^{-3}; Ca, 3.07 $cmol_c$ dm^{-3}; Mg, 1.03 $cmol_c$ dm^{-3}; K, 0.41 $cmol_c$ dm^{-3}; P, 24.2 mg dm^{-3}; and C, 21.35 g dm^{-3}.

The experimental site covers 0.128 ha total area subdivided into 64 subplots of similar size. The experiment was carried out as a split plot arrangement, in a randomized complete block design, with four replicates. In both growing seasons, the main plots included CCDs – on October 10 (CCD1), January 31 (CCD2), February 15 (CCD3), and March 1 (CCD4) –, and the subplots within each main plot included N rates at 0, 75, 150, and 225 kg ha⁻¹ named as N_0, N_{75}, N_{150}, and N_{225}, respectively. The growth duration (calendar days), number of growing degree days (GDD) (ºC days), and day length (h) were calculated for each CCD treatment. The subplot sizes were 4.0 by 5.0 m. In each year on October 10, swards were cut at a 30 cm height at the beginning of each work; after two days, plant residues above-ground were manually removed. In the other CCD treatments, defoliation was performed at the same height, and the removal of plant residues was performed after two days. The N rates as granular ammonium nitrate (NH_4NO_3) were applied by hand onto each plot on the soil surface. N doses were split into two portions (20% on January 15 and 80% on February 15), in each growing season. The applied N highest portion in February was chosen to correspond with the initiation of the spikelets.

Megathyrsus maximus (Jacq.) B.K.Simon & S.W.L.Jacobs, 2003 (Syn. *Panicum maximum* Jacq.) 'Mombasa' grass was sown in 2006, with a tillage establishment followed by the incorporation of 180 kg ha^{-1} P_2O_5 as simple superphosphate, and 60 kg ha^{-1} K_2O as potassium chloride to 0–20 cm soil depth. At sowing, which was carried out in September 2006, 8.0 kg ha^{-1} pure seed were applied to the soil surface and incorporated into 1.5 cm soil by disking. No crop management was undertaken in the years 2007, 2008, and 2009. Grass received 120 kg P_2O_5 ha^{-1} as simple superphosphate, and 60 kg K_2O ha^{-1} as potassium chloride in mid-November of each study year, to ensure that these macronutrients were not limiting. Weeds were removed manually during the experiment.

Flowering time beginning was recorded for a whole subplot, when 5.0 to 10.0 panicles were fully emerged from the sheath through two weekly observations from mid-March. Crop harvest time was based on Barth Neto et al. (2010), who recommended 20 to 30 days after the beginning of flowering of 'Mombasa' grass. Harvest dates for the 2010/2011 growing season were May 15, for swards at CCD1, and May 21, for swards at other CCDs. Equivalent harvest dates for the 2011/2012 growing season were May 18, at CCD1, and May 20, for the other CCDs. These two harvest dates were used to harmonize the differences between flowering stages for the early CCD1 and the other treatments. Growing degree days (GDD) were calculated from the mean of the minimum and maximum temperatures minus 15ºC (base temperature) (Villa Nova et al., 2007).

In each season, two randomly selected 0.35 m^2 (0.5x0.7 m) frames with metallic quadrats from each subplot were hand-clipped to the soil level, at seed maturity, to quantify the total tillers and panicle tiller number (PTN). These samples were oven dried separately at 60ºC to obtain a constant weight and then they were weighed. Vegetative tiller number, PTN, total tillers, mass per tiller with panicle, and aboveground dry matter plant biomass (AGDM) per hectare were evaluated in each sample. To determine the panicle length, 15 panicles per subplot were cut with scissors, and the insertion point of the first ramification to the highest point was measured. These panicle samples were used to evaluate the number of apparent and pure seeds per panicle, wich was dried

in paper bags, and kept in the shade; after five months, seeds were shattered from the panicles by hand. Seed were separated into apparent and pure seed. Thus, seed unit (spikelet or floret) containing a recognizable caryopsis was classified as pure seed. Fully developed caryopses plus empty structures (unfilled and partially filled caryopses) were used to determine apparent seed. Thus, the pure seed number per square-meter was determined.

Seed with endosperms were separated manually from the inert fraction (empty or light spikelets). Physical purity, and the mean mass of 100 apparent and pure seed (g) were assessed, and the seed germination test was measured (in the 2010/2011 growing season only) according to the standing procedures for seed analysis (Brasil, 2009). One thousand seed weight was obtained from the mass sample of pure seed. Germination tests were performed on filter paper moistened with 0.2% solution of potassium nitrate (KNO_3) in a gearbox, at alternant temperatures of 15–35ºC, in a germinator with white fluorescent lights. Normal seedlings were eliminated as they were counted. The count of normal seedlings was performed at 10 and 28 days. Seed germination, which is expressed as a proportion, was calculated as follows: Seed germination = (total number of normal seedlings/total number of seeds) x 100.

The model for the ASY and PSY analyses followed Johnson et al. (2010), as follows: ASY (kg ha^{-1}) = (one thousand apparent seed weight) x (apparent seeds per panicle) x (PTN); and PSY = (one thousand pure seed weight) x (pure seeds per panicle) x (PTN).

The AEN (partial factor productivity from applied N) was defined as PSY divided by the applied N dose, and AgNE was calculated according to the equation described by Mosier et al. (2004) and Rathke et al. (2006), as follows: AgNE = seed yield$_{fertilized}$ - seed yield$_{unfertilized}$ (kg kg^{-1})/N applied.

For separate growing seasons and for seed germination and pure germinable seed yield for 2010/2011, the analysis of variance was used, when significant interactions occurred between the following variables: growing season and CCD; growing season and N dose; and growing season, CCD, and N dose. Regression analysis were used to develop a model for describing the main effect of N, and the interactive effects of CCD and N by using the Mixed procedure of software SAS (SAS Institute Inc., Cary, NC, USA).

Tukey's test was used to discriminate significant differences between ANE and AgNE treatments. Pearson's correlations were calculated for ASY and PSY with some yield components. The effects were considered significant in all statistical calculations for p-values lower or equal to 5% probability.

Results and Discussion

The climatic conditions during the growing seasons can be characterized by rather favourable ones, with warm temperatures and regular rainfalls (Figure 1), and they were close to normal in the northwestern area of Paraná (Wrege et al., 2011). In January 2011, rainfalls were smaller than the average, which may have hampered the growth of the closing cut dates on the October 10 (CCD1) treatment, and rainfall was low in May 2011. In April and May, the average and minimum temperatures were lower than normal.

Growth duration and number of growing degree days (GDD), after the CCD to seed harvest, corresponding to CCD1, CCD2, CCD3, and CCD4 were, respectively: for the 2010/2011 growing season – 217 days and 2035.9, 110 days and 977.2, 95 days and 815.9, 81 days and 653.8; and for the 2011/2012 growing season, they were 221 days and 2127.3, 110 days and 1034.5, 95 days and 834.9, and 80 days and 659.8. In

both growing seasons, the mean day lengths (h) were 12.6 (CCD1), 11.9 (CCD2), 11.7 (CCD3), and 11.5 (CCD4). Limited information is available on the effects of different temperature and photoperiod regimes and their interactions, which can cause stress and affect growth and seed sets in 'Mombasa' grass, and on the sensitivity of the various developmental processes to N nutrition.

The beginning of flowering was anticipated at CCD1 (between April 23 and 28, 2010/2011; and April 22 and 30, 2011/2012), in comparison to the other CCDs (between April 31 and May 3, 2010/2011; and April 30 and May 4, 2011/2012), and it was not affected by N doses. Wind and intense rainfall events were not recorded from flowering to maturity during both growing seasons, which might have adversely affected seed shattering in the panicles. The beginning of flowering in the present study was in the same range as those by Barth Neto et al. (2010) and Canto et al. (2012), who reported that the CCD was February 15. It is likely that the older tillers on CCD1 may have anticipated the flowering.

The interactions between CCD and N and the main effects on all the components of seed yield were observed, except for panicle length in the 2010/2011 growing season, when the main effects of N occurred (Tables 1 and 2). There were no significant
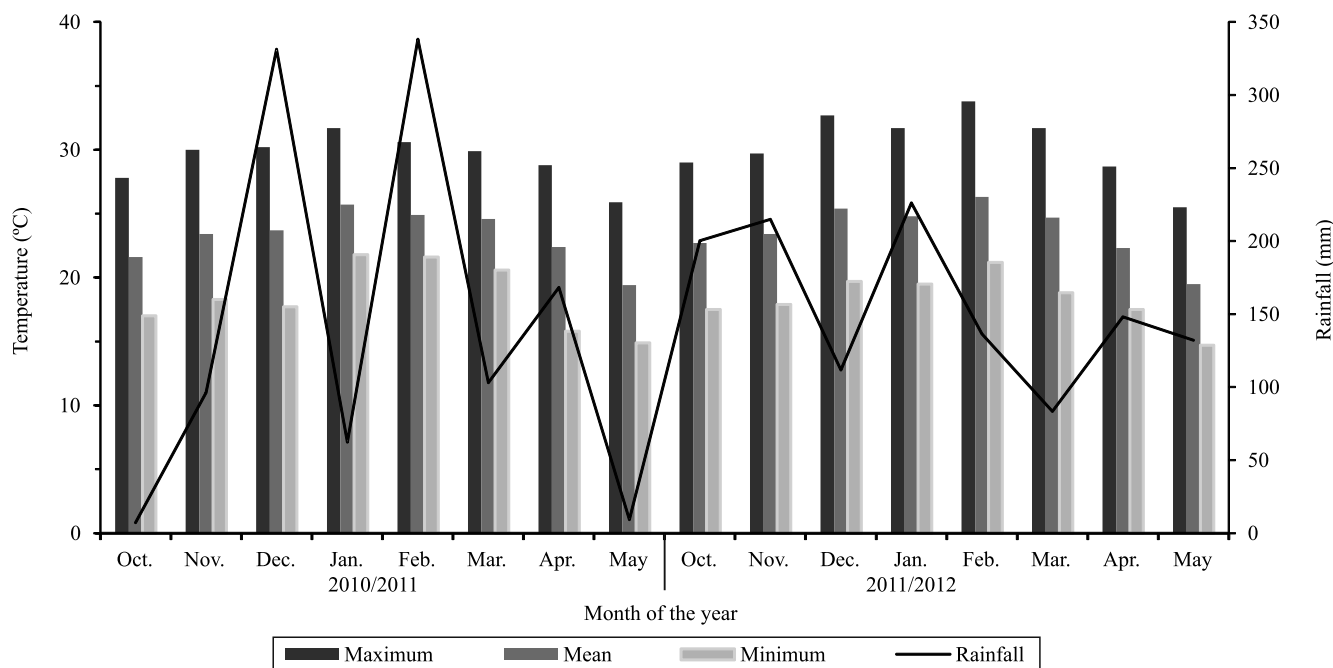

Figure 1. Mean values of maximum, minimum and average temperature, and rainfall during the experimental period.

differences for the physical purity of seed, one thousand seed weight, and seed germination.

A quadratic model was the best fit to the significant interactions for most yield components (Table 3), except for the mass per tiller with panicle on CCD1, CCD2, and CCD3 in 2010/2011, and CCD1 in 2011/2012, total tillers on CCD2, and AGDM ha^{-1} on CCD4 in 2010/2011; for these characteristics, the observed response to N application was linear. In 2010/2011, the interaction between the CCD and N rates was nonsignificant, and there was no significant main effect from the CCD and N rates on the total tillers on CCD1; the recorded average was 90 tillers m^{-2}. On CCD4, the observed means were 13.09 g DM per tiller, 20.5 cm panicle length, and 14 pure seeds per panicle. In the 2010/2011 growing season, the main effects of CCD and the CCD and N interaction were not significant for panicle length; therefore, only the N rate effects are shown. In this growing season, the relationship between N rates and panicle length had a low coefficient of determination which is described by the following quadratic equation: $y = 19.85 + 0.05x - 0.00013x^2$ ($R^2 = 0.36$, $p \leq 0.05$). These results indicate that N deficiency reduced all seed yield components.

The response pattern of mass per tiller with panicle provides evidence that the CCD and N affect the development of fertile tillers. The response of this component, except for CCD4 in 2010/2011, was possibly due to adjustments in the tiller size/density compensation caused by competition for light, nutrients, and other environmental resources. The predicted PTN maximums (2010/2011 and 2011/2012)

were, respectively: 33 and 28 (at 222 and 216 kg N ha^{-1}, CCD1); 39 and 33 (at 177 and 172 kg N ha^{-1}, CCD2); 25 and 23 (204 and 198 kg N ha^{-1}, at CCD3); and 10 and 15 tillers m^{-2} (at 212 and 183 kg N ha^{-1}, CCD4). The maximum PTN on CCD1 and CCD2 are slightly higher than those predicted by Barth Neto et al. (2010) of 23.3 tillers m^{-2} for 231.7 kg N ha^{-1}, and by Canto et al. (2012) of 31.0 tillers m^{-2} for 150 kg N ha^{-1}.

At the most of forage grasses managed for seed production, the number of fertile tillers at harvest has been shown to be a function of the number and developmental state of vegetative tillers present before the apical differentiation (Chastain et al., 2011). Hare et al. (2007) in a study on two hybrids of *Brachiaria* (*Brachiaria ruziziensis* × *B. brizantha* 'Mulato', and *B. ruziziensis* × *B. decumbens* × *B. brizantha* 'Mulato II') observed that the number of mature inflorescence and seeds per inflorescence per area, at harvest, were strongly depend on the stage of plant development at the cutting time. The total tillers result in part from the available N or light. According to Lafarge (2000), plants with similar ages that delay the appearance of tillers tend to have a small number of tillers and are not competitive in the stand.

This finding could have benefited from the production of panicles and seed sets at the CCDs with the highest growth periods and N rates, by the largest increases in leaf area, and longer duration of photosynthetic activity. For the crops with later CCDs and lower rates of N nutrition, the low leaf

Table 1. Statistical analysis of mass per tiller with panicle (MTP), total tillers (TT), panicle tiller number (PTN), pure seed per panicle (PSP), pure seed number (PSN), panicle length (PL), and aboveground dry matter (AGDM) data collected in 2010/2011 and 2011/2012 growing season.

Treatment	Significance of F-test						
	MTP	TT	PTN	PSP	PSN	PL	AGDM
Growing season 2010/2011							
Closing cut date (CCD)	**	*	**	**	**	ns	**
N	**	**	**	**	**	**	**
CCD x N	**	*	**	**	**	ns	**
Growing season 2011/2012							
CCD	**	*	**	**	**	*	**
N	**	**	**	**	**	**	**
CCD x N	*	*	**	**	**	*	**

nsNonsignificant. *, **Significant at 5 and 1% probability, respectively.

Table 2. Statistical analysis of physical purity of seed (PPS), one thousand seed weight (TSW), seed germination (SG), apparent seed yield (ASY), pure seed yield (PSY), viable germinable pure seed yield (VGPSY), apparent N efficiency (ANE) and agronomic N efficiency (AgNE), data collected in 2010/2011 and 2011/2012 growing season.

Treatment	Significance of F-test							
	PPS	TSW	SG	ASY	PSY	VGPSY	ANE	AgNE
Growing season 2010/2011								
CCD	ns	ns	ns	**	**	**	**	**
N	ns	ns	ns	**	**	**	**	**
CCD x N	ns	ns	ns	**	**	**	**	**
Growing season 2011/2012								
CCD	ns	ns	-	**	**	-	**	**
N	ns	ns	-	**	**	-	**	**
CCD x N	ns	ns	-	**	**	-	**	**

nsNonsignificant. *, **Significant at 5 and 1% probability, respectively. CCD, closing cut date.

area had a reduced ability to provide carbohydrates for seed production, along with the brief period for the initiation of spikelets in the new tillers. Moreover, during the experimental period, the environmental conditions showed progressively more dry atmosphere and slightly cooler temperatures (Figure 1) which may have damaged the floral initiation (differentiation of the apical meristem), and contributed to the reduction of pure seeds per panicle. This may have had a drastic effect for CCD4, causing the reduced results for pure

seeds per panicle. Also, pure seeds per panicle of all CCD were severely reduced by the absence of N fertilization. On 'Tanzania' grass (*Panicum maximum* 'Tanzania-1'), in Mexico, the number of pure seeds per panicle reported by Joaquín Torres et al. (2009) was 171 for 0 kg N ha^{-1} and 429 for 200 kg N ha^{-1}.

Other aspect that may have interfered with the interaction of the CCDs and N on the density of fertile tillers and pure seeds per panicle was the export of N by plants removed after defoliation (Table 3). The

Table 3. Regression equations and coefficients of determination (R^2) of nitrogen (N) doses 0, 75, 150, and 225 kg ha^{-1} – respectively N_0, N_{75}, N_{150}, N_{225} –, closing cut dates (CCD), and yield components of 'Mombasa' grass, in the 2010/2011 and 2011/2012 growing seasons.

Closing cut date	N doses in 2010/2011				Regression equation	R^2	N doses in 2011/2012				Regression equation	R^2
	N_0	N_{75}	N_{150}	N_{225}			N_0	N_{75}	N_{150}	N_{225}		
Mass per tiller with panicle (g DM per tiller)												
CCD1 (October 10)	9.7	17.9	21.6	28.2	Y=10.4+0.079x	0.90**	9.2	17.2	19.8	28.8	Y=9.51+0.08x	0.89**
CCD2 (January 31)	9.1	23.4	22.9	30.1	Y=12.0+0.08x	0.63**	10.6	22.5	25.1	27.7	Y=11.02+0.16x-0.0004x²	0.60**
CCD3 (February 15)	8.2	17.1	20.7	24.1	Y=9.8+0.068x	0.75*	8.7	19.6	22.1	26.8	Y=9.19+0.14x-0.00027x²	0.88**
CCD4 (March 1st)	8.2	13.9	15.3	15.0	ns		10.4	18.7	18.1	18.4	Y=10.92+0.11-0.00036x²	0.60*
Panicle tiller number (tillers m^{-2})												
CCD1 (October 10)	3.3	15.8	34.8	33.0		0.90**	4.8	15.8	27.3	26.8	Y=4.12+0.22x-0.00051x²	0.92**
CCD2 (January 31)	3.8	30.8	33.5	34.0		0.93**	5.0	28.0	30.3	33.0	Y=6.06+0.31x-0.0009x²	0.90**
CCD3 (February 15)	3.3	13.5	26.5	24.5		0.90**	4.5	15.5	24.0	24.3	Y=4.21+0.19x-0.00048x²	0.92**
CCD4 (March 1st)	4.6	7.2	10.3	9.8		0.55**	5.0	12.3	14.3	14.5	Y=5.17+0.11x-0.0003x²	0.73**
Total tillers (tillers m^{-2})												
CCD1 (October 10)	72	88	101.3	100.8	ns		61.3	82.0	87.8	100.3	Y=62.3+0.24x-0.00037x²	0.51*
CCD2 (January 31)	152.8	236	253.8	357.0	Y=155.3+0.84x	0.76**	81.3	181.8	244.8	351.3	Y=85.3+1.1x+0.00027x²	0.93**
CCD3 (February 15)	242.0	315.8	447.5	426.3	Y=231.4+1.86x-0.0042x²	0.78**	235.0	309.8	417.5	417.3	Y=227.9+1.62x-0,0033x²	0.78**
CCD4 (March 1st)	220.7	273.9	359.1	377.2	Y=215.78+1.09x-0.0016x²	0.83**	197.5	254.3	281.3	324.8	Y=199.8+0.67x-0.0006x²	0.76**
Pure seeds per panicle												
CCD1 (October 10)	16.7	51.7	83.7	78.0	Y=14.93+0.69x-0.0018x²	0.93**	13.0	49.0	88.3	77.8	Y=10.38+0.77x-0.0021x²	0.91**
CCD2 (January 31)	9.7	37.4	68.0	77.8	Y=8.51+0.49x-0.0008x²	0.85**	11.1	46.8	85.1	77.4	Y=8.66+0.75x-0.0019x²	0.94**
CCD3 (February 15)	9.6	24.1	68.3	63.7	Y=5.76+0.46x-0.0008x²	0.81**	10.8	27.3	72.3	58.2	Y=6.43+0.55x-0.0014x²	0.73**
CCD4 (March 1st)	7.2	15.8	14.9	18.3	ns		7.2	20.7	21.3	20.5	ns	
Pure seed number (seed m^{-2})												
CCD1 (October 10)	49.9	816.3	2910.0	2576.4	Y=-137.84+23.89x-0.049x²	0.83**	61.5	780.7	2410.6	2090.1	Y=-81.58+20.68x-0.0465x²	0.81**
CCD2 (January 31)	35.6	1156.1	2279.4	2644.3	Y=-2.45+19.48x-0.03x²	0.95**	56.1	1317.5	2572.2	2550.2	Y=-7.41+24.48x-0.057x²	0.94**
CCD3 (February 15)	31.0	622.3	1816.2	1567.3	Y=-116.25+13.5x-0.024x²	0.73**	48.5	427.7	1734.6	1426.7	Y=-78.67+14.12x-0.03x²	0.72**
CCD4 (March 1st)	35.3	111.9	153.3	188.8	Y=36.74+1.08x-0.0018x²	0.55**	33.7	254.3	299.5	290.1	Y=39.77+3.38x-0.01x²	0.75**
Panicle length												
CCD1 (October 10)	20.1	23.4	24.1	25.2	-	-	19.8	24.1	23.3	24.1	Y=20.22+0.04x-0.0001x²	0.46**
CCD2 (January 31)	19.1	22.9	23.6	24.7	-	-	21.9	24.0	24.2	25.9	Y=19.25+0.05x-0.0001x²	0.55**
CCD3 (February 15)	18.7	23.3	23.6	24.9	-	-	19.9	24.3	25.6	24.1	Y=18.95+0.058x-0.0001x²	0.63**
CCD4 (March 1st)	17.7	21.2	21.3	21.8	-	-	16.5	22.8	20.3	24.4	Y=17.9+0.046x-0.0001x²	0.37*
Aboveground dry matter (kg ha^{-1})												
CCD1 (October 10)	9962	15649	19225	20516	Y=9953+90.94x-0.195x²	0.89**	10775	16730	20677	22289	Y=10758+94.7x-0.79x²	0.89*
CCD2 (January 31)	11348	19192	20171	21561	Y=11711+106.7x-0.29x²	0.87**	12282	18897	21511	23179	Y=12434+96.55x-0.22x²	0.61*
CCD3 (February 15)	9838	12369	19068	21563	Y=9419+56.2x-0.002x²	0.91**	12034	14586	18681	22008	Y=11918+37.6x+0.034x²	0.89*
CCD4 (March 1st)	6671	8197	8496	9970	Y=6803+13.59x	0.53*	6723	7771	8507	8613	Y=6706+17.9x-0.04x²	0.60*

[ns]Nonsignificant. *, **Significant at 5 and 1% probability, respectively.

relationships between AGDM ha^{-1} and N rates was described by quadratic models in Guinea grass seed crop up to 240 kg N ha^{-1} (Condé & Garcia, 1988) and in 'Mombasa' grass up to 300 kg N ha^{-1} (Barth Neto et al., 2010). However, the AGDM ha^{-1} at harvest was higher than those found by Condé & Garcia (1988), especially at higher N rates. These conflicting results may be attributed to the rows, which were spaced 40 cm apart, and the minor soil fertility conditions compared to the present study. Nevertheless, high AGDM ha^{-1} causes lodging and excessive tillering aside from hampering the harvest.

The interaction CCD x N was nonsignificant, and the effects of CCD and N rates were nonsignificant for any component of seed quality (Table 2). In the 2010/2011 and 2011/2012 growing seasons, the means of physical purity, mass of one thousand pure seed, and seed germination were 33.1 and 33.5%, 1.13 and 1.11 g, and 19% (only 2010/2011), respectively. These values of physical purity and seed germination are consistent with the data of authors who evaluated seed harvested in panicles of *P. maximum* cultivars used in Brazil (Monteiro et al., 1984; Barth Neto et al., 2010; Canto et al., 2012). The factors related to the CCD and N rates which could influence the quality of seed harvested in panicles of 'Mombasa' grass are not clearly known.

There was an interaction between the CCD and N rates for ASY, PSY, both years, and germinable pure seed yield, in 2010/2011 growing season (Tables 2 and 4). The ASY, PSY and germinable pure seed yield were enhanced by the anticipation of the CCD and by high-N treatment. In all of these yields, the responses to N were quadratic. The results showed that on CCD1, CCD2, and CCD3, rates above N$_{150}$ resulted in only slight increases in ASY and PSY. By these results, the ASY, PSY and germinable pure seed yield in 'Mombasa' grass decrease on the later CCDs depending on the applied N rate. Thus, seed producers need to assure that the CCD and N are adequate. More favourable temperature and photoperiod conditions may also have been responsible for the higher seed yields in the initial CCD treatments (Figure 1). The CCDs with greater growth durations and higher N rates caused compensations in the PTN and pure seeds per panicle, benefiting PSY. It must be highlighted, according to Maschietto et al. (2003), that the high abscission of *M. maximus* seed decreases the seed yield estimates and makes them more inaccurate. In the present work, the proportion of seed abscised from panicles was not assessed. For nonfertilized plants with N, the variables ASY and PSY were minimal for all of the CCDs, which is an indication that there was low uptake of soil N and higher N stress in the absence of N application. These results were similar to and

Table 4. Regression equations and coefficients of determination (R^2) of nitrogen doses 0, 75, 150, and 225 kg ha^{-1} – respectively N$_0$, N$_{75}$, N$_{150}$, N$_{225}$ – and closing cut dates (CCD) of 'Mombasa' grass for apparent seed yield and pure seed yield in 2010/2011 and 2011/2012 growing seasons, and viable germinable pure seed yield in the 2010/2011 growing season.

Closing cut date	Nitrogen doses in 2010/2011 growing season				Regression equation	R^2	Nitrogen doses in 2011/2012 growing season				Regression equation	R^2
	N$_0$	N$_{75}$	N$_{150}$	N$_{225}$			N$_0$	N$_{75}$	N$_{150}$	N$_{225}$		
Apparent seed yield (kg ha^{-1})												
CCD1 (October 10)	1.3	21.0	76.2	69.0	$Y=-3.62+0.61x-0.0012x^2$	0.83**	2.2	28.0	76.7	67.4	$Y=-1.88+0.67x-0.0015x^2$	0.83**
CCD2 (January 31)	0.9	31.1	56.7	62.8	$Y=0.152+0.52x-0.001x^2$	0.92**	1.9	50.2	91.7	87.9	$Y=-0.0006+0.92x-0.0023x^2$	0.91**
CCD3 (February 15)	0.8	7.9	46.4	37.9	$Y=-3.13+0.35x-0.00069x^2$	0.72**	1.5	11.5	57.7	45.5	$Y=-3.18+0.46x-0.001x^2$	0.68**
CCD4 (March 1st)	0.9	2.8	3.5	4.1	$Y=0.93+0.027x-0.000062x^2$	0.48*	1.2	7.1	9.7	9.8	$Y=1.19+0.097x-0.00026x^2$	0.77**
Pure seed yield (kg ha^{-1})												
CCD1 (October 10)	0.4	7.3	26.4	22.8	$Y=-1.31+0.22x-0.00047x^2$	0.81**	0.7	9.4	27.9	23.8	$Y=-0.96+0.246x-0.00057x^2$	0.80**
CCD2 (January 31)	0.3	10.3	18.5	20.8	$Y=0.109+0.17x-0.00034x^2$	0.93**	0.7	16.2	31.1	30.0	$Y=-0.089+0.303x-0.0007x^2$	0.90**
CCD3 (February 15)	0.3	2.6	14.8	12.2	$Y=-0.98+0.11x-0.00022x^2$	0.71**	0.5	4.0	19.5	15.1	$Y=-1.09+0.1576x-0.00035x^2$	0.68**
CCD4 (March 1st)	0.3	0.9	1.2	1.4	$Y=0.32+0.0089x-0.000019x^2$	0.48*	0.4	2.4	3.1	3.2	$Y=0.4+0.032x-0.000088x^2$	0.80**
Viable germinable pure seed yield (kg ha^{-1})												
CCD1 (October 10)	0.1	1.5	4.6	4.2	$Y=-0.17+0.038x-0.000081x^2$	0.85**	-	-	-	-	-	-
CCD2 (January 31)	0.1	1.8	3.5	4.0	$Y=0.015+0.03x-0.000054x^2$	0.94**	-	-	-	-	-	-
CCD3 (February 15)	0.1	0.5	2.6	2.4	$Y=-0.15+0.019x-0.000032x^2$	0.76**	-	-	-	-	-	-
CCD4 (March 1st)	0.1	0.2	0.2	0.3	$Y=0.059+0.002x-0.000005x^2$	0.51*	-	-	-	-	-	-

[ns]Nonsignificant. *, **Significant at 5 and 1% probability, respectively.

slightly lower than those reported for a sandy soil by Barth Neto et al. (2010), who observed a maximum ASY and PSY of 89.1 kg ha^{-1} (for 241.2 kg N ha^{-1}) and 28.2 kg ha^{-1} (for 250 kg N ha^{-1}), respectively.

This study was not carried out in rows of plants used in crops for *M. maximus* seed in soil that underwent a sweeping harvest method. Therefore, the extrapolation of these seed yield data should not be recommended for these crops. Nevertheless, further defoliation practices and N fertilization studies should also be conducted to increase the yield and cost-effectiveness of seed crops of 'Mombasa' grass with a sweeping seed harvest. A CCD with N_{150} may be indicated in Oct. and Jan. It is possible to state, however, that the CCD2 with N_{150} may be the most appropriate treatment. Apart from slightly reducing the ASY and PSY in 2010/2011, CCD2 would enable systems in which the production of forage and seed is combined with the use of forage for grazing, green forage, and silage. Although ASY had a slight increase because of N_{225} on CCD1 and CCD2, in comparison to the N_{150} dose, there are some aspects which limit the recommendation of these dates, as N higher cost, the likely higher soil acidification (Silveira et al., 2007), and issues related to environmental pollution, especially regarding groundwater and N leaching.

The CCD and N doses affected the ANE and AgNE differently (Table 5). The effects of different N rates were not observed for the ANE and AgNE on CCD4 in 2010/2011. The CCD x N rate interactions exhibit relatively low ANE and AgNE. In general, at CCD1, CCD2, and CCD3, ANE and AGNE were better for N_{150}. The decrease in ANE and AgNE for N_{150}, in comparison to N_{225}, suggest that the highest increments in PSY are achieved for the first increments in N

inputs, and that the efficiency declines afterward. This is a possible area for future research and improvements in N nutrition dynamics. Experiments on N uptake and N efficiency use with different N sources, and the response of various *M. maximus* cultivars are also required.

A correlation of the yield components indicated that the mass per tiller with panicle, pure seeds per panicle, pure seed number, and PTN were large and highly significant with ASY and PSY (Table 6). There was no significant correlation among the seed physical purity and one thousand seed weight in 2010/2011, with ASY and PSY. However, in 2011/2012, the seed physical purity and one thousand seed weight showed a significant and low correlation. In both growing seasons, the mass per tiller with panicle was positively and significantly related to ASY and PSY. In seed crops of Guinea grass, Monteiro et al. (1984) reported a coefficient correlation of 0.73 and 0.33 between tiller vigour with ASY and PSY, respectively. Singularly, there is evidence that heavier tillers and good N nutrition showed the greatest potential for flowering and seed production, in warm-season grasses (Canto et al., 2012). In a study with several newly native grasses, López-García et al. (2011) found that inflorescence density was positively correlated to seed yield. Because of the high correlation of the PTN and greater ease of determination, this characteristic is the most appropriate indicator of ASY and PSY. Furthermore, because of high seed shattering in panicles that can be caused by wind and rain events prior to harvesting, both ASY and PSY could be inferred by measuring the PTN. The variables ASY and PSY were positively correlated with PTN and

Table 5. Effects of closing cut dates (CCD) and nitrogen (N) doses on apparent N efficiency (ANE) and agronomic N efficiency (AgNE) on 'Mombasa' grass seed crop in 2010/2011 and 2011/2012 growing seasons[1].

N	ANE (kg kg^{-1})				AgNE (kg kg^{-1})			
(kg ha^{-1})	CCD1	CCD2	CCD3	CCD4	CCD1	CCD2	CCD3	CCD4
	Growing season 2010/2011							
75	0.097b	0.138a	0.034c	0.012[ns]	0.092b	0.134a	0.031b	0.008[ns]
150	0.176a	0.123a	0.098a	0.008[ns]	0.173a	0.121a	0.097a	0.006[ns]
225	0.101b	0.092b	0.054b	0.006[ns]	0.099b	0.091b	0.053c	0.005[ns]
	Growing season 2011/2012							
75	0.125b	0.216a	0.053b	0.032a	0.117b	0.207a	0.047b	0.027a
150	0.186a	0.207a	0.129a	0.021b	0.182a	0.203a	0.126a	0.018b
225	0.105c	0.133b	0.067b	0.014b	0.102c	0.130b	0.065b	0.012b

[1]Means followed by equal letters in the column, in each growing season, do not differ significantly by Tukey test, at 5% probability.

pure seeds per panicle largely because the early CCDs and highest N rates increased these yield components.

The correlation between ASY and PSY with pure seed number was high, as expected, because the pure seed number is calculated from seed yield (Table 4). Barth Neto et al. (2010) reported that 'Mombasa' grass PSY was strongly and positively correlated with pure seeds per panicle and pure seed number. Joaquín Torres et al. (2009) found that PTN and panicle length are the seed yield components with the highest correlation with PSY for 'Tanzania' grass. However, in the present study, the correlation coefficient of panicle length with PSY was low in both growing seasons. A similar result for the relationship of pure seed number per square-meter and seed yield was also found by Huettig et al. (2013), in six cultivars of tall fescue, *Schedonorus phoenix* (Scop.) Holub. Thus, considering the large annual quantities of required seed for sowing pastures of this grass in Brazil, seed growers may benefit from additional studies on different seed growing regions, by examining climatic factors, CCD, and N fertilization effects during the growth and seed set period, and seed quality for 'Mombasa' grass and other *M. maximus* cultivars widely used in this vast region.

Conclusions

1. The delaying of the final closing cut date until February and N availability reduce 'Mombasa' grass (*Megathyrsus maximus*) yields.

2. Closing cut date and N application interactively affect the seed yield components of 'Mombasa' grass, particularly the panicle tiller number and pure seeds per panicle.

3. The closing cut dates and N rates do not affect the seed quality components of 'Mombasa' grass.

4. Nitrogen rate at 150 kg ha^{-1} is adequate for optimizing the apparent N efficiency and agronomic N efficiency for seed production of 'Mombasa' grass.

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Table 6. Pearson correlation coefficients between seed yield components, and seed quality components with apparent seed yield (ASY, kg ha^{-1}) and pure seed yield (PSY, kg ha^{-1}) observed at 2010/2011 and 2011/2012 growing seasons.

Variables	Growing season 2010/2011		Growing season 2011/2012	
	ASY	PSY	ASY	PSY
Mass per tiller with panicle (g DM per tiller)	0.80*	0.79*	0.73*	0.72*
Tiller-panicle number (tillers m^{-2})	0.94*	0.94*	0.93*	0.92*
Pure seed per panicle	0.95*	0.95*	0.95*	0.96*
Pure seed number (seed m^{-2})	0.98*	0.98*	0.98*	0.98*
Panicle lenght (cm)	0,62*	0,63*	0.52*	0.51*
Aboveground dry matter (kg ha^{-1})	0.86*	0.85*	0.85*	0.84*
Physical purity of seed (%)	-0.01^{ns}	0.07^{ns}	0.32*	0.36*
One thousand seed weight (g)	0.12^{ns}	0.12^{ns}	0.34*	0.34*

^{ns}Nonsignificant. *, **Significant at 5 and 1% probability, respectively.

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