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Full Length Research Paper

On-farm evaluation of improved *Brachiaria* grasses in low rainfall and aluminium toxicity prone areas of Rwanda

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The aim of this study was to determine the production of improved *Brachiaria* grass in comparison with indigenous *Brachiaria* under low rainfall and aluminium toxicity areas of Rwanda. Three varieties and five hybrids of *Brachiaria* grass from CIAT and two local grasses (control) were used for on-farm participatory trials without fertilizer application. Twelve farms were selected in each study area and on each farm ten grasses were established in 2 × 3 m plots. Herbage was harvested six times during the year at two monthly intervals. Each cut, dry matter (DM) was measured. The crude protein (CP), calcium (Ca) and phosphorus (P) were also measured once in the wet season and once in the dry season. In the low rainfall area, *Brachiaria brizantha* cv. Toledo and *Brachiaria decumbens* (local) had the highest DM yields (5.71 and 5.61 t ha^{-1} respectively), while DM of the rest of the grasses ranged from 1.2 to 5.13 t ha^{-1}. In the acidic soil area, *Brachiaria* hybrid Bro2/1485 had higher DM (5.95 t ha^{-1}) than the rest of the grasses (1 to 4.47 t ha^{-1}). The highest quality grass was *Brachiaria* hybrid Bro2/1485 which obtained a CP value of 12.15% in the low rainfall area, whereas in the acidic soil area hybrid cv. Mulato II obtained the highest CP value of 11.6%. In the low rainfall area the *Brachiaria* hybrid cv. Mulato obtained a high mean Ca value of 2.15% while in the acidic soil area, cv. Marandu obtained a high Ca value of 2.41% during the wet and dry seasons. The cv. Toledo had high P (0.28%) compared to the other grasses (0.07 to 0.11%) in the low rainfall area. In the acidic soil area, the *Brachiaria* hybrid Bro2/1485 had high P of 0.53% as compared to other grasses in which P varied between 0.16 and 0.47%. Local control grasses had lower nutrients than the improved *Brachiaria* grass in the low rainfall and acidic soil area. Although, *Brachiaria* hybrid cv. Mulato II was not the most productive grass, it was selected by farmers as the preferred cultivar at both sites because of its adaptability to low rainfall and acidic soil stress, and its production of green forage year round without any input of fertilizer.

Key words: Dry matter production, forage quality, forage selection.

INTRODUCTION

The major limitations of livestock production are the lack of suitable fodder crops that can produce green forage year round. This situation becomes severe in the areas constrained by low rainfall and acidic soils (Leeuw et al., 1992). In Rwanda, low rainfall occurs in the Eastern region and in particular, the Bugesera district (Butterworth, 1985) while the acidic soils are the major constraints in the Nyamagabe district located in the South-Western part of the country. In these areas, soils are highly deficient in plant nutrients (Beinroth, 2001) and when combined with fluctuations of rainfall, crop-livestock

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production decreases (Verdoodt and Van Ranst, 2006). During the dry season, farmers from these contrasting districts rely on non-conventional feeds of low nutritive value to their cattle. For example, farmers collect indigenous grasses including *Brachiaria* grass from the roadsides to feed their cattle in these areas. Brachiaria is a graminaceous plant which grows naturally in Rwanda but its production is limited by long dry periods and acidic soil combined with aluminium toxicity. The problems in each district are crucial constraints for provision of animal feeds. Adapted forage germplasm is therefore needed to enhance the productivity and resilience of crop-livestock systems growing under these conditions. Improved *Brachiaria* grasses are exceptionally tolerant to the combination of aluminium toxicity and drought (Miles et al., 2004) and could play a role in smallholders' crop-livestock systems in such areas. Furthermore, high yields, quality and ease of propagation of improved *Brachiaria* grasses are central to their establishment and utilisation under smallholders' crop-livestock systems for improved milk and meat production. Evaluation of the potential and use of improved *Brachiaria* grasses together with other available forages will be of primary importance for sustainable supply of feed resources in the study sites.

Many studies on forage focused on on-station evaluation especially, on grasses like *Pennisetum purpureum* (Napier grass), *Panicum* sp., *Adropogon gayanus* and legumes like *Stylosanthes* sp., *Lablab* sp., *Mucuna pruriens* among others (Tedonkeng et al., 2007). However, few studies were on-farm with farmer participation (Mekoya et al., 2008). In Rwanda, forage studies focused on on-station evaluation of grasses and legumes (for example, Napier grass, *Cenchrus ciliaris*, *Chloris gayana*, *M. pruriens*) (Myambi, 2006). However, when successful species were presented to farmers to promote sustainability of forage production they failed because of farm prevailing conditions. Some of the reasons were the inability of new forages to adapt to on-farm drought and acidic soils with aluminium toxicity. Improved *Brachiaria* grass (for example, cv. Mulato II, cv. Toledo) were therefore developed to adapt to the low rainfall and acidic soil to help farmers tackle the issue of forage shortage under these conditions. These *Brachiaria* grasses have also shown good agronomic characteristics. For example, in 2004, cv. Mulato II produced more than 15 t DM ha^{-1} in a sandy clay soil with pH of 4.6 in Panama, whereas cv. Mulato produced 3.9 t ha^{-1} per harvest time in Mexico (Pedro et al., 2007). Considering the production of improved *Brachiaria* grass and its adaptation to the various geographical areas, improved *Brachiaria* grass may be able to address the lack of fodder in the areas of low rainfall and acidic soils. This will also allow the farmers to select the best varieties adapted to their respective areas while helping to increase profit from cattle production (Rivas and Holmann, 2005). The objectives of this study were (1) to determine the production and quality of improved *Brachiaria* grasses (varieties and hybrids) through on-farm trials in the low rainfall, acidity and aluminium toxicity stress conditions and (2) to determine the criteria of selection of new *Brachiaria* grass by farmers in the area of the study.

MATERIALS AND METHODS

Site selection

Two districts with different constraints in farming systems were selected for the participatory evaluation of forages. The main biophysical aspects in the selected sites are represented in Table 1. The on-farm trial was carried out on three villages in each district (Figure 1).

Farmer selection

Twelve farmers per district were selected. The selection of farmers was done in conjunction with local extension personnel, by targeting farmers that were seeking new forage options for an integrated crop-forage management system.

Experimental forage

Varieties and hybrids of *Brachiaria* grass, which were bred for tolerance to infertile, acidic soil and drought conditions, were selected. This included hybrids and varieties that are resistant to spittlebugs and adapted to a combination of low fertility, high aluminium (Al), acidic soils and drought tolerance. Varieties and hybrids of *Brachiaria* which were used in the experiment were *Brachiaria decumbens* cv. Basilisk (CIAT 606), *Brachiaria brizantha* cv. Toledo (CIAT 26110), *Brachiaria brizantha* cv. Marandu (CIAT 6294), *Brachiaria* hybrid cv. Mulato (CIAT 36061), *Brachiaria* hybrid cv. Mulato II (CIAT 36087), *Brachiaria* hybrid Bro2/0465, *Brachiaria* hybrid Bro2/1452 and *Brachiaria* hybrid Bro2/1485.

On-farm establishment of Brachiaria grasses

Brachiaria grass seeds were supplied by CIAT and the different species of *Brachiaria* were multiplied by seed at the nursery of Karama research station of Rwandan Agricultural Research Institute (ISAR). From the plants, established vegetative material was taken to the different sites. Control grass species in the on-farm trials in the Bugesera and Nyamagabe districts were *B. decumbens* indigenous grass and *C. ciliaris* (Buffel grass) naturalised grass.

The experimental design comprised 10 plots (2 × 3 m) which included five hybrids, three cultivars of *Brachiaria* and two local forage grass controls *B. decumbens* (indigenous grass) and naturalised *C. ciliaris*. The distribution of treatments (forage grasses) considered farms as replicates, and this means that soil properties, climate, plot size, plot management and number of forages varieties were the same to allow statistical analysis. Before trial establishment, soil samples from four selected farms within each cell in the Bugesera and Nyamagabe districts were analyzed for pH, Al^{3+} and available phosphorus following the recommendations of Anderson and Ingram (1993) for tropical soils standard methods of analysis.

Table 1. Biophysical characteristics of selected sites.

Site	Altitude (m a.s.l)	Average rainfall (mm year^{-1})	Average temperature year^{-1}	Geographical coordinates	Topography	Main soil types
Bugesera district	1425	750	21.5°C	Long.30°25'E, Lat. 2° 30' S	Undulating	Sandy and clay soils
Nyamagabe district	1800	1800	16.5°C	Long. 29°56'E,Lat. 24° 47' S	Steep slopes	Clay and kaolin soils

Adapted from Munyemana, 2001.

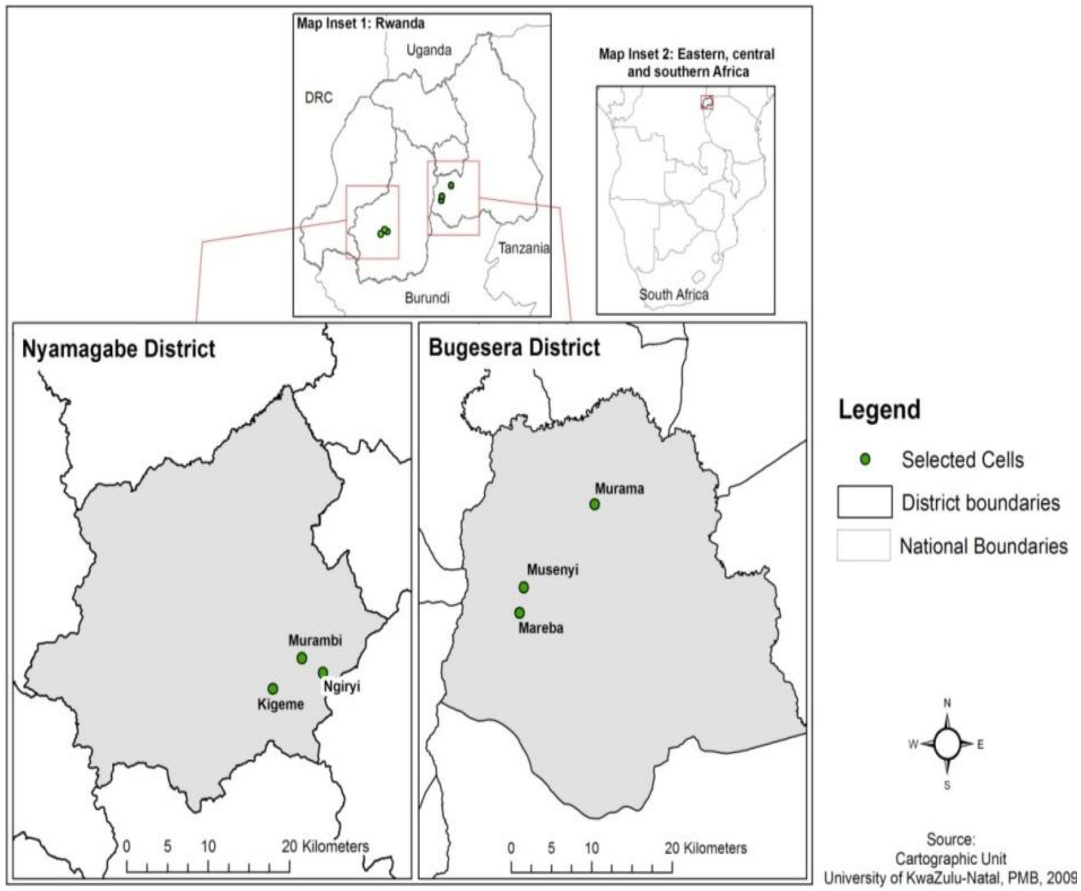

Figure 1. Location of study sites in Rwanda.

Table 2. Soil analysis in the Bugesera and Nyamagabe districts.

Parameters	Bugesera mean ± SE	Nyamagabe mean ± SE	F-ratio	P. value	$LSD_{0.05}$
pH	5.75±0.06	5.09±0.10	6.25	0.002**	0.23
Al^{3+}(meq 100 g^{-1})	0.24±0.09	1.47±0.13	12.53	0.001**	0.31
Avail. P (meq 100 g^{-1})	6.88±1.04	4.30±0.66	1.23	0.037*	2.41

**= P (<0.001), *= (p<0.05); SE = Standard error; Avail; P= Available phosphorus; Al^{3+}= Aluminium; meq 100 g^{-1} = Milliequivalent per 100g of soil; $LSD_{0.05}$= Least significant Different at level of 5%.

Evaluation of quantity and quality of forage

Forage yield evaluation took place six times a year at approximately two monthly intervals with cutting at 10 cm height recommended by Tudsri et al. (2002). Biomass was harvested in a 1 m^2 quadrat randomly placed within each 2 × 3 m plot at each following harvest time:

1. During peak of first rainy season
2. During beginning of first dry season
3. During the second rainy season
4. During the end of second rainy season
5. During the dry season
6. During the rainy season

After collecting samples from 1 m^2 quadrat, the whole plot was cut to allow the homogenous regrowth for the next cut. Biomass samples from 1 m^2 quadrat were oven dried at 105°C to constant mass to give dry matter production estimates during the study period (Griggs et al., 2007). Samples taken from dried grasses were chemically analysed according to the recommendations of AOAC (1990) once in the wet season and once in the dry season for crude protein content, phosphorus and calcium.

Participatory variety selection

At the end of the trail, a participatory variety selection (PVS) was done in order to know which varieties and/or hybrids of *Brachiaria* were selected and preferred by farmers according to their criteria. Participatory variety selection is used in many on-farm research trials to allow the farmers to judge and select the best crop varieties and/or hybrids established on their farms (Misiko et al., 2008). The PVS approach is aimed to adopt and disseminate new technologies in suitable niches for high production of the new options (Gowda et al., 2000). Farmers who had *Brachiaria* grass participated in the variety selection. Farmers met on one plot of grass treatments in each area. Based on identified criteria, they gave negative and positive aspects to each variety and hybrid used in the experiment. From the criteria given, the farmers rank forage. Forage that possessed many positive criteria were likely to get a high rank.

Statistical analysis

The soil samples taken in the two districts were compared using one-way analysis of variance (ANOVA). This was calculated by using general linear model procedures of Genstat–version 9 (2006) at 5% confidence level. For the statistical analysis of on-farm grass trials, the number of cuts of grass over time was considered as repeated measures. The residual or restricted maximum likelihood (REML) multivariate model was used to assess the relationship among the variables (dry matter, crude protein, calcium and phosphorus). However, the REML analysis does not give an F-statistic but gives a Wald statistic. The Wald test uses Chi-square (χ^2) probability in comparison to F-probability. According to Virk and Witcombe (2008), the two models give the same results and the significance levels increase as the sample size increases.

RESULTS

Soil analysis

Results from the analysis of variance (ANOVA) showed a significant difference (p<0.05) between parameters (Table 2). The comparison of pH between two sites shows that pH in the Bugesera district was higher (5.75) than in the Nyamagabe district (5.09). This means that there was no issue of soil acidity in Bugesera whereas it was in Nyamagabe.

The aluminium concentration in the soil was found to be higher in the Nyamagabe district than in the Bugesera district (Table 2). As the soil pH decreased, Al increased for the Nyamagabe and Bugesera, respectively. The level of Al that causes toxicity to the plants is 2 meq 100 g^{-1} of soil. The results showed that Al concentration in selected cells of the Nyamagabe district was more likely to reach the level of toxicity (Al^{3+} =1.4 meq 100 g^{-1} of soil) than in the selected cells of the Bugesera district (Al^{3+} = 0.24 meq 100 g^{-1} of soil). Therefore, the acidic soils and high Al will inhibit crop and fodder production in the Nyamagabe district.

The available phosphorus (P) analysis indicated that there was a significant difference (p<0.05) between the two sites. Available phosphorus was more variable between villages in the low rainfall area (the Bugesera district) than in the acidic soil area (the Nyamagabe district) and the low rainfall area having a higher available P (6.88 meq 100 g^{-1}) than in the acidic soil area (4.30 meq 100 g^{-1}).

Dry matter analysis

The mean total dry matter (DM) yield of each grass in the low rainfall area was significantly different (p<0.05). The highest mean annual dry matter yield was achieved by *B. brizantha* cv. Toledo (5.71 t ha^{-1}) and *B. decumbens* (local) (5.61 t ha^{-1}). They were followed by cv. Mulato II (5.13 t ha^{-1}), Mulato (5.03 t ha^{-1}), Basilisk (4.79 t ha^{-1}), hybrid Bro2/1485 (4.67 t ha^{-1}) and Marandu (4.58 t ha^{-1})

Table 3. Means of DM yield (t ha^{-1}) of treatments for each harvest time in the low rainfall area (Bugesera district).

Season	Harvest time (two month intervals)						
	Wet	Dry	Wet	Dry	Dry	Wet	$\bar{X}$
Treatments	**Nov**	**Jan**	**Mar**	**May**	**Jul**	**Sep**	
B. brizantha cv. Marandu	7.46^{bc}	6.71^{abc}	6.87^{abc}	3.29^{bc}	1.90^{bc}	1.25^{bc}	4.58^{bcd}
B. brizantha cv. Toledo	4.09^{ab}	11.18^{bc}	11.05^{bc}	3.77^{bc}	2.42^{c}	1.72^{c}	5.71^{d}
B. decumbens cv. Basilisk	5.16^{abc}	8.09^{abc}	8.49^{bc}	4.00^{bc}	1.46^{b}	1.53^{bc}	4.79^{bcd}
B. decumbens cv. Local	4.70^{abc}	11.89^{c}	11.10^{c}	3.22^{bc}	1.45^{b}	1.31^{bc}	5.61^{d}
Brachiaria hybrid Bro2/0465	2.14^{a}	4.31^{ab}	4.39^{abc}	2.44^{ab}	1.46^{b}	1.04^{b}	2.63^{ab}
Brachiaria hybrid Bro2/1452	3.51^{ab}	4.27^{ab}	4.19^{ab}	2.60^{bc}	1.77^{bc}	1.47^{bc}	2.97^{abc}
Brachiaria hybrid Bro2/1485	3.76^{ab}	9.86^{bc}	9.50^{bc}	2.63^{bc}	1.34^{ab}	0.95^{b}	4.67^{bcd}
Cenchrus ciliaris	2.42^{a}	1.55^{a}	1.34^{a}	0.98^{a}	0.54^{a}	0.30^{a}	1.19^{a}
Brachiaria hybrid cv. Mulato	8.29^{c}	9.47^{bc}	7.51^{abc}	2.63^{bc}	1.24^{ab}	1.02^{b}	5.03^{cd}
Brachiaria hybrid cv. Mulato II	7.07^{bc}	8.00^{abc}	8.27^{bc}	4.15^{c}	1.88^{bc}	1.39^{bc}	5.13^{cd}
LSD (α=0.05)	4.06	7.43	6.88	1.60	0.86	0.62	2.01

Means in the column followed by the same superscript letter are not significantly different (p >0.05); LSD: Least Significant Difference at level of 5%; $\bar{X}$= Overall mean.

(Table 3). The lowest mean annual DM yield was obtained by *C. ciliaris* (1.19 t ha^{-1}).

At the first cut during the wet season in the low rainfall area, the *Brachiaria* hybrid cv. Mulato had highest DM (8.29 t ha^{-1}) (Table 3). It was followed by *B. brizantha* cv. Marandu (7.46 t ha^{-1}) and *Brachiaria* hybrid cv. Mulato II (7.07 t ha^{-1}). The lowest DM for the same harvest time was obtained by *Brachiaria* hybrid Bro2/0465 (2.14 t ha^{-1}) and *C. ciliaris* (2.24 t ha^{-1}). However, in the second and third harvest time in the same area, *B. decumbens* (local) had a DM of 11.89 and 11.10 t ha^{-1}, respectively. It was followed by *B. brizantha* cv. Toledo which had a DM of 11.18 and 11.05 t ha^{-1} for the second and third cutting respectively. At the fourth harvest during the dry season, the mean DM yields of almost tested grasses were not different and varied from 2.6 to 4.15 t ha^{-1}. However, hybrid Bro2/0465 and the control *C. ciliaris* yielded the lowest DM during this period in the same low rainfall area (Table 3). At fifth harvest during the dry season the mean DM of cv. Toledo, cv. Marandu, hybrid Bro2/1452 and cv. Mulato II were not different and ranged from 1.77 to 2.42 t ha^{-1}. At this harvest time, the control *C. ciliaris* yielded the lowest DM (0.54 t ha^{-1}).

At sixth harvest time the mean DM of cv. Marandu, cv. Toledo, cv. Basilisk, Local, hybrid Bro2/1452 and Mulato II were not different and ranged from 1.31 to 1.72 t ha^{-1}. The lowest DM yields (0.3 to 1.04 t ha^{-1}) were obtained by hybrids Bro2/0465, Bro2/1485, cv. Mulato and control grass *C. ciliaris*. Although sixth harvest was done during the rainy season, the DM decreased because it followed two previous harvests done during the dry season and possibly due soil depletion, as fertilizer was not used in this study.

In the acidic soil area, the mean total DM yield of each grass was a significantly different (p<0.05). The highest mean annual dry matter yield was achieved by *Brachiaria* hybrid Bro2/1485 (5.95 t ha^{-1}), cv. Basilisk (4.57 t ha^{-1}) and cv. Marandu (4.47 t ha^{-1}). They were followed by cv. Toledo (4.18 t ha^{-1}), cv. Mulato II (4.18 t ha^{-1}), local *Brachiaria* (3.72 t ha^{-1}) and cv. Mulato (3.48 t ha^{-1}) (Table 4). The lowest mean annual DM yield was obtained by control *C. ciliaris* (1 t ha^{-1}).

The DM of the first harvest time was higher than the following harvest time (Table 4). It was also higher than yields found in the Bugesera district because that period was the first rainy season which was insufficient for the plant growth in the Bugesera district, but was enough in the Nyamagabe district. This first harvesting time was the cutting two months following grass establishment. Some of the hybrids established quickly and produced high yields within two months of planting (for example, hybrid Bro2/1485 yielded 14.96 t ha^{-1}). However, some hybrids had poor establishment and low yields at this time (for example, hybrid Bro2/0465 yielded 1.66 t ha^{-1}). In this acidic soil area (the Nyamagabe district), initial high yields of some grasses decreased significantly by the second cutting time. For example, the hybrid Bro2/1485 yielded 6.2 t $ha^{-1}$and cv. Basilisk obtained 5.09 t ha^{-1}. For the all harvests in the acidic soil area, the DM yield showed that cv. Marandu, cv. Toledo, cv. Basilisk, Local *Brachiaria* (control), *Brachiaria* hybrid Bro2/1485, cv. Mulato and cv. Mulato II performed better than the two hybrids (*Brachiaria* hybrid Bro2/0465 and *Brachiaria* hybrid Bro2/1452) and control *C. ciliaris* under this condition (Table 4).

The differences between treatments within each site per harvest time showed that the Bugesera district had higher DM yield than the Nyamagabe district for all cutting time (Tables 3 and 4). However, *Brachiaria* hybrid Bro2/1485 obtained a higher DM in the Nyamagabe

Table 4. Means of DM yield (t ha^{-1}) of different treatments for each harvest time in the acidic soil area (Nyamagabe district).

Season	Harvest time (two month intervals)						
	Wet	Dry	Wet	Dry	Dry	Wet	$\bar{X}$
Treatments	**Nov**	**Jan**	**Mar**	**May**	**Jul**	**Sep**	
B. brizantha cv. Marandu	8.44^{cd}	4.97^{bc}	4.82^{bc}	2.22^{c}	4.23^{c}	2.12^{d}	4.47^{cd}
B. brizantha cv. Toledo	8.64^{cd}	4.46^{bc}	4.57^{bc}	2.16^{c}	3.61^{bc}	1.64^{bcd}	4.18^{c}
B. decumbens cv. Basilisk	11.26^{de}	5.09^{bc}	5.13^{bc}	1.66^{bc}	3.10^{bc}	1.20^{bcd}	4.57^{cd}
B. decumbens cv. Local	7.49^{abcd}	4.90^{bc}	4.90^{bc}	1.19^{abc}	2.82^{bc}	1.01^{abc}	3.72^{c}
Brachiaria hybrid Bro2/0465	1.66^{a}	2.73^{ab}	2.97^{ab}	1.61^{bc}	1.82^{ab}	1.26^{bcd}	2.01^{ab}
Brachiaria hybrid Bro2/1452	2.04^{ab}	1.40^{a}	1.04^{a}	0.91^{ab}	1.79^{ab}	0.72^{ab}	1.32^{a}
Brachiaria hybrid Bro2/1485	14.96^{e}	6.20^{c}	6.20^{c}	2.17^{c}	4.18^{c}	1.97^{cd}	5.95^{d}
Cenchrus ciliaris	3.20^{abc}	0.93^{a}	1.23^{a}	0.21^{a}	0.28^{a}	0.13^{a}	1.00^{a}
Brachiaria hybrid cv. Mulato	8.19^{bcd}	3.78^{abc}	3.78^{abc}	1.64^{bc}	2.12^{ab}	1.35^{bcd}	3.48^{bc}
Brachiaria hybrid cv. Mulato II	6.80^{abcd}	5.26^{bc}	5.64^{bc}	2.14^{c}	3.64^{bc}	1.60^{bcd}	4.18^{c}
LSD (α=0.05)	6.19	3.05	3.00	1.15	1.96	1.00	1.48

Means in the column followed by the same superscript letter are not significantly different; LSD: Least Significant Difference at level of 5%; $\bar{X}$= Overall mean.

district than that observed in the low rainfall area (Tables 3 and 4). The significant difference ($p<0.05$) between the two sites in terms of grass DM yield may be due to difference in stress conditions encountered in each area.

In both sites DM yield of tested grasses were evaluated during the rainy and dry seasons. In the low rainfall area, in the third rainy season (September) when treatments were on their sixth harvest time the DM of Marandu, Toledo, Basilisk, *B. decumbens* (control), *Brachiaria* hybrid Bro2/1452 and Mulato II (1.25 to 1.72 t ha^{-1}) were not significantly different ($p>0.05$) (Table 3). During the first dry (January) season at the second harvest time Toledo and *B. decumbens* (local) produced the highest dry matter recorded during the study (11.89 t ha^{-1} and 11.18 t ha^{-1} respectively). The lowest DM yield was produced by the control grass *Cenchrus ciliaris* (1.55 t ha^{-1}). By the second dry season (May) at the fourth harvest the DM of all treatments decreased and only Mulato II and Basilisk were able to produce 4.15 and 4.00 t ha^{-1} of DM respectively (Table 3). The yield of the control, *B. decumbens* (local) (3.22 t ha^{-1}) was not significantly different from the top producers, but the control *C. ciliaris* had the lowest yield (0.98 t ha^{-1}). By the third dry season (July) at fifth harvest, the yield decreased further with the top producers Toledo, Marandu, Mulato II and hybrid Bro2/1452 only yielding 1.7 to 2.42 ha^{-1}. The decrease of DM during this harvest time was evident as it was the peak of the dry season and the reason might be the moisture in the soil that was likely to be too low for growth of the plants in the low rainfall area.

In the acidic soil area (the Nyamagabe district), the trend of mean DM of treatments showed that the DM of the first cut in the rainy season produced higher dry matter but declined with increasing number of harvest times (Table 4). All harvest times in the wet season showed that *Brachiaria* hybrid Bro2/1485 produced higher DM than other treatments except for the third cut in the wet season where Marandu produced 2.12 t ha^{-1} of DM versus 1.97 t ha^{-1} of DM for *Brachiaria* hybrid Bro2/1485 (Table 4). The lowest dry matter production from the wet and dry seasons in acidic soil area was found in *C. ciliaris* and followed by *Brachiaria* hybrid Bro2/1452. The DM of the dry and wet seasons in the low rainfall area showed that the wet season yielded slightly higher DM than the dry season for each treatment. The DM obtained by Marandu in the wet and dry seasons was not significantly different from that of Toledo, Basilisk, *B. decumbens* (control), hybrid Bro2/1485, cv. Mulato and cv. Mulato II in the low rainfall area (Figure 2B). However, the DM of these treatments was higher than that of the hybrids Bro2/1452, Bro2/0465 and control *C. ciliaris*.

Under acidic soil stress, the comparison of mean total DM of grasses harvested in the dry season and rainy season in the acidic soil area showed that each tested grass yielded higher DM in the wet season (Figure 2A). The trends of DM from the two seasons in the acidic soil area showed that *Brachiaria* hybrid Bro2/1485 had higher DM yield (7.85 and 4.44 t ha^{-1}) than the rest of tested grasses. Even though the DM in the wet season was greater than in the dry season, some varieties and hybrids had very low yields in the wet season. These were *Brachiaria* hybrids Bro2/0465, Bro2/1452 and control *C. ciliaris* (Figure 2A). Although low rainfall area faces the long dry season compared to acidic soil area, tested grasses obtained higher DM during the dry season in the low rainfall area than the acidic soil area. This may be caused by combination of Al-toxic and dry encountered in the acidic soil area at this period.

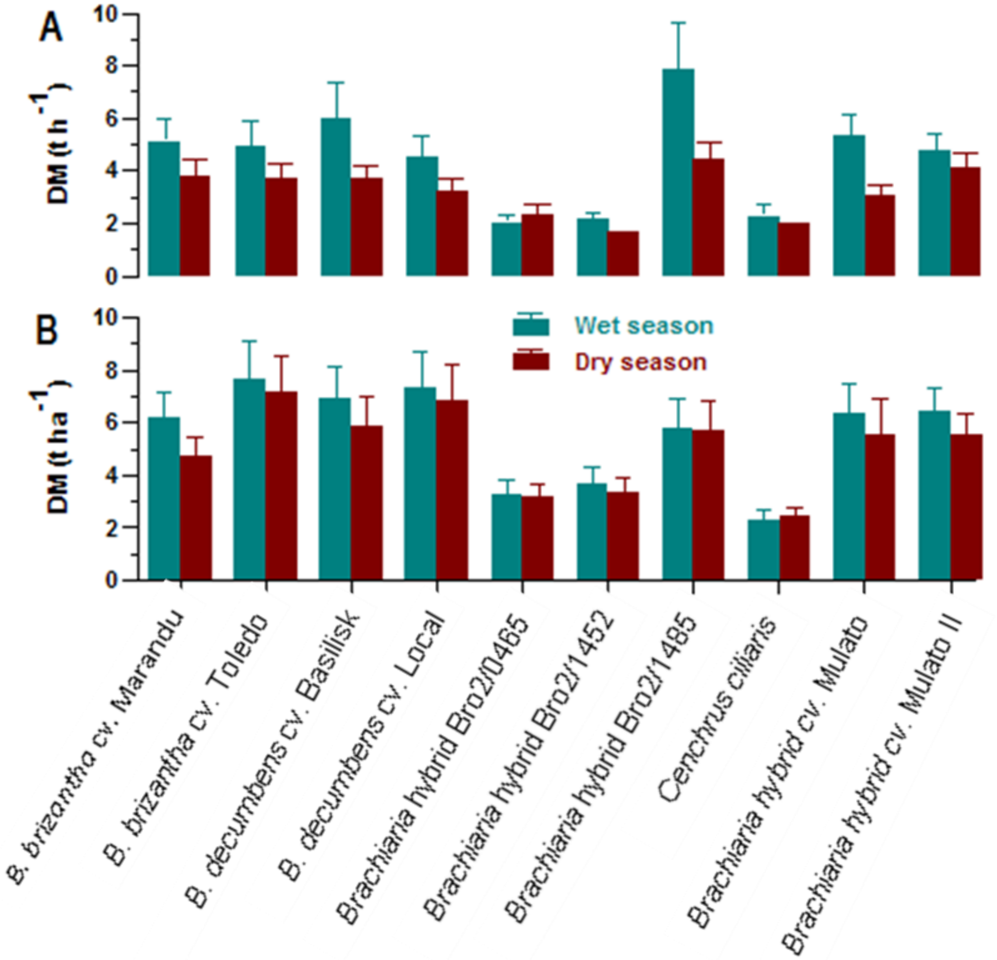

Figure 1. Mean DM (t ha^{-1}) from the wet and dry seasons in the acidic soil area (A) and low rainfall area (B).

The means of dry matter production in each treatment from all harvest times were compared in both study sites. It was found that DM production of each grass in the low rainfall area was greater than in the acidic soil area except for *Brachiaria* hybrid Bro2/1485 (Figure 3). However, when comparing the DM production per site and per harvest time, (Figure 4) the first harvest time the DM of all treatments was greater in the acidic soil area than in the low rainfall area. The establishment of the grasses in the two sites was done in the short rainy season which is always less effective on sandy soil of the low rainfall area than on clay soil of the acidic soil area. It was likely to promote better establishment of grasses in the Nyamagabe district than in the Bugesera district.

Following this first harvest, the seasonal trend of DM was higher in the low rainfall area (the Bugesera district) except for the harvest time in July (Figure 4). The July harvest time was done during the peak of the dry season. At this time all grasses in the Bugesera district were dry while grasses in the Nyamagabe district had some green leaves indicating some moisture was retained in the soil. However, in the Nyamagabe district, the dry season of July had higher DM production than the previous harvest of May (dry season). This may be explained that the green leaves of the July might have less water content than the May harvest.

Crude protein, calcium and phosphorus analysis

The highest quality grass in the low rainfall area (the Bugesera district) in terms of crude protein (CP) was *Brachiaria* hybrid Bro2/1485 (15.69%). There was, however, no significant difference in the wet season between cv. Marandu, *Brachiaria* hybrid Bro2/1452, cv. Mulato and Mulato II (9.83–12.29%) (Table 5). The control grasses had a low CP content during the wet season in the low rainfall area (5.07 to 6.68%). During the dry season, the CP content decreased for all tested grasses except for *C. ciliaris* which had slightly higher CP

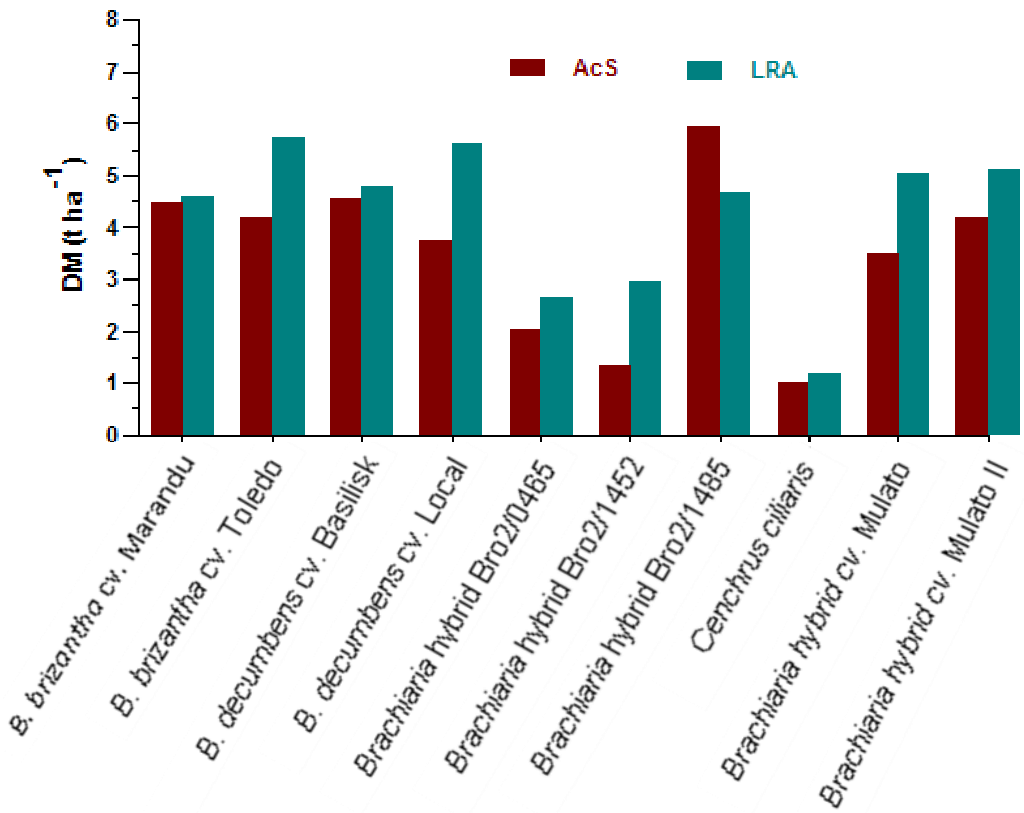

Figure 3. Total dry matter yield of grasses under low rainfall area (LRA) and acidic soil area (AcS) stress conditions.

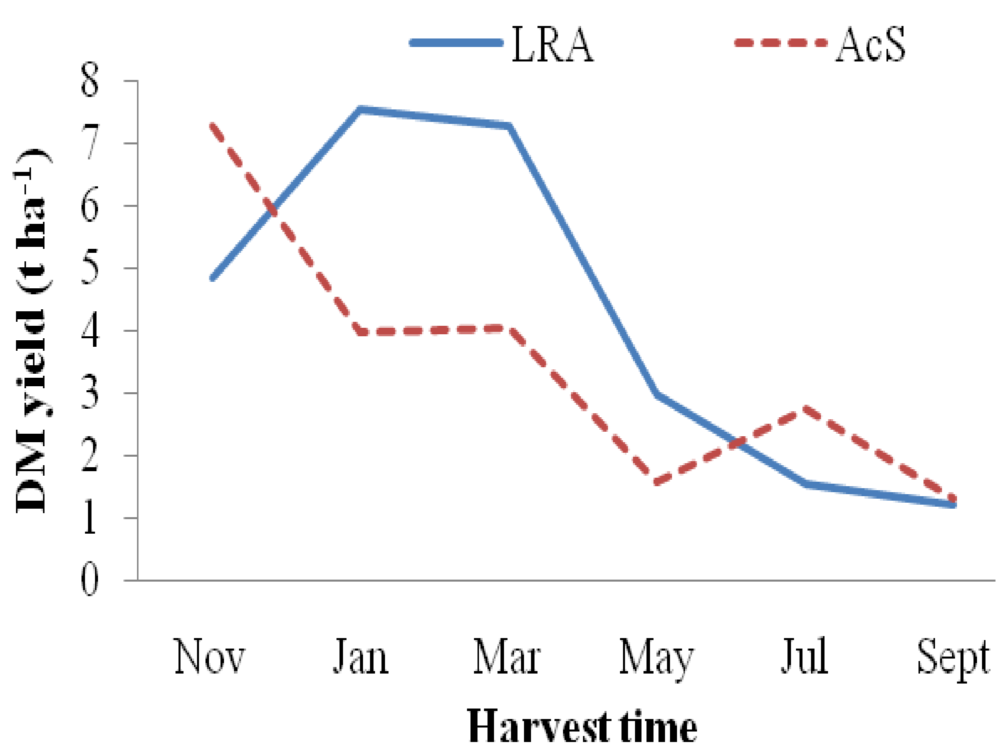

Figure 4. Seasonal trends of all treatments in the contrasting LRA and AcS environments.

Table 5. Mean values of crude protein of tested grasses during the wet and dry seasons of both areas.

Treatments	Bugesera district Crude protein (%)		Nyamagabe district Crude protein (%)	
	Wet	Dry	Wet	Dry
B. brizantha cv. Marandu	9.83^{abc}	8.29^{bcd}	10.91^{abc}	6.69^{cd}
B. brizantha cv. Toledo	7.58^{ab}	7.32^{abc}	12.38^{bc}	7.74^{cde}
B. decumbens cv. Basilisk	6.71^{ab}	7.49^{cbc}	9.43^{ab}	6.41^{bcd}
B. decumbens cv. Local	6.68^{ab}	6.43^{ab}	11.68^{abc}	4.92^{ab}
Brachiaria hybrid Bro2/0465	8.20^{ab}	6.73^{abc}	9.21^{ab}	5.77^{abc}
Brachiaria hybrid Bro2/1452	10.91^{abc}	6.95^{abc}	8.90^{ab}	4.34^{a}
Brachiaria hybrid Bro2/1485	15.67^{c}	8.62^{cd}	12.69^{bc}	7.25^{cde}
Cenchrus ciliaris	5.07^{a}	5.82^{a}	7.88^{a}	5.55^{abc}
Brachiaria hybrid cv. Mulato	11.94^{bc}	7.81^{bc}	11.56^{abc}	7.07^{cd}
Brachiaria hybrid cv. Mulato II	12.29^{bc}	9.85^{d}	14.29^{c}	8.91^{e}
$LSD_{0.05}$	6.67	1.91	4.40	1.70

Means in the column followed by the same superscript letter are not significantly different; $LSD_{0.05}$: least significant different at level of 5%.

Table 6. Mean values of calcium of tested grasses during the wet and dry seasons of both areas.

Treatments	Bugesera district Calcium (%)		Nyamagabe district Calcium (%)	
	Wet	Dry	Wet	Dry
B. brizantha cv. Marandu	1.54^{ab}	1.43^{ab}	2.47^{d}	2.35^{d}
B. brizantha cv. Toledo	1.91^{b}	1.96^{bc}	1.89^{abcd}	1.89^{abcd}
B. decumbens cv. Basilisk	1.73^{b}	1.56^{abc}	1.51^{ab}	1.51^{a}
B. decumbens cv. Local	1.98^{b}	1.97^{bc}	2.20^{cd}	2.20^{cd}
Brachiaria hybrid Bro2/0465	2.16^{b}	2.04^{bc}	1.82^{abc}	1.76^{abc}
Brachiaria hybrid Bro2/1452	1.72^{b}	1.97^{bc}	2.03^{bcd}	2.11^{bcd}
Brachiaria hybrid Bro2/1485	1.81^{b}	1.87^{bc}	2.05^{bcd}	1.99^{abcd}
Cenchrus ciliaris	0.89^{ab}	1.10^{a}	1.30^{a}	1.57^{ab}
Brachiaria hybrid cv. Mulato	2.13^{b}	2.17^{c}	2.31^{cd}	2.13^{bcd}
Brachiaria hybrid cv. Mulato II	1.87^{b}	1.73^{abc}	2.36^{cd}	2.14^{bcd}
$LSD_{0.05}$	0.74	0.69	0.60	0.58

Means in the column followed by the same superscript letter are not significantly different; $LSD_{0.05}$: Least Significant Different at level of 5%.

in the dry season than in the wet season in the low rainfall area (5.82 versus 5.07%) (Table 5). In this area during the dry season, Mulato II had the highest CP content (9.85%). It was followed by Marandu and hybrid Bro2/1485 which had 8.29 and 8.62% of CP respectively. The lowest CP content during the dry period in the low rainfall area was found in the two local control grasses *B. decumbens* (indigenous) and *C. ciliaris*, which obtained 6.43 and 5.82% respectively.

In the acidic soil area (the Nyamagabe district), during the wet season the highest quality grasses in terms of CP were cv. Marandu, cv. Toledo, Local *Brachiaria*, were hybrid Bro2/1485, cv. Mulato and cv. Mulato II (10.91 to 14.29%). The lowest CP (7.88%) was found in *C. ciliaris* (control) in this area during the wet season (Table 5). During the dry season in the acidic soil area, the decrease of CP was more marked. The CP content in all tested grasses declined significantly during this season (Table 5). The lowest CP content was found in *Brachiaria decumbens* (local), *Brachiaria* hybrid Bro2/0465, *Brachiaria* hybrid Bro2/1452 and *Cenchrus ciliaris* which obtained 4.92; 5.77; 4.34 and 5.55% respectively (Table 5). The most marked decrease in quality was recorded for *B. decumbens* which decreased from 11.68% CP in the wet season to 4.92% in the dry season.

In the low rainfall area, during the wet season the calcium content was not significantly different ($p>0.05$) between the tested grasses (Table 6). Calcium values ranged from 0.89% for *C. ciliaris* to 2.16% for *Brachiaria* hybrid Bro2/0465. However, during the dry season the

Table 7. Mean values of phosphorus in the treatments during the wet and dry seasons of both sites.

Treatments	Bugesera district		Nyamagabe district	
	Phosphorus (%)		Phosphorus (%)	
	Wet	Dry	Wet	Dry
B. brizantha cv. Marandu	0.16^{abc}	0.17^{ab}	0.41^{abc}	0.42^{b}
B. brizantha cv. Toledo	0.28^{c}	0.29^{b}	0.29^{ab}	0.29^{ab}
B. decumbens cv. Basilisk	0.18^{abc}	0.20^{ab}	0.39^{abc}	0.39^{b}
B. decumbens cv. Local	0.25^{bc}	0.25^{ab}	0.47^{bc}	0.47^{b}
Brachiaria hybrid Bro2/0465	0.21^{abc}	0.21^{ab}	0.41^{abc}	0.35^{ab}
Brachiaria hybrid Bro2/1452	0.11^{ab}	0.12^{a}	0.40^{abc}	0.40^{b}
Brachiaria hybrid Bro2/1485	0.23^{bc}	0.23^{ab}	0.54^{c}	0.53^{b}
Cenchrus ciliaris	0.05^{a}	0.10^{a}	0.21^{a}	0.11^{a}
Brachiaria hybrid cv. Mulato	0.17^{abc}	0.26^{ab}	0.39^{abc}	0.39^{b}
Brachiaria hybrid cv. Mulato II	0.23^{bc}	0.23^{ab}	0.43^{abc}	0.43^{b}
$LSD_{0.05}$	0.17	0.18	0.24	0.24

Means in the column followed by the same superscript letter are not significantly different; $LSD_{0.05}$: Least Significant Different at level of 5%.

concentration of calcium differed between treatments. It was found that mean values of Ca in cv. Toledo, cv. Basilisk, *Brachiaria decumbens* (local), *Brachiaria* hybrid Bro2/0465, *Brachiaria* hybrid Bro2/1452, *Brachiaria* hybrid Bro2/1485, cv. Mulato and cv. Mulato II were not significantly different (1.56 to 2.17%). The lowest Ca content was recorded for *C. ciliaris* (1.10%) (Table 6).

In contrast to the low rainfall area, the calcium content in treatments from the acidic soil area during the wet season showed that Marandu had the highest concentration of calcium (2.47%) which was significantly different ($p<0.05$) from Basilisk, *Brachiaria* hybrid Bro2/0465 and *C. ciliaris* (1.3 to 1.82%) (Table 6). Similarly, during the dry season in the acidic soil area, the mean values of calcium content in Marandu was significantly higher (2.35%) than that found in Basilisk, *Brachiaria* hybrid Bro2/0465 and *C. ciliaris* (1.51 to 1.76%). The remaining treatments were not different from Marandu in calcium content (1.89 to 2.14%) The comparison of the two sites showed that at both sites there was no significant different in the calcium content between the wet and dry season (Table 6).

The phosphorus (P) content in the treatments during the wet season in the low rainfall area was significantly higher for cv. Toledo (0.28%) than *Brachiaria* hybrid Bro2/1452 (0.11%) and *C. ciliaris* (0.05%). The mean values of P content of the remaining treatments were not significantly different from P content in cv. Toledo (Table 7). In the low rainfall area during the dry season, the only difference in P content was again observed between cv. Toledo, and *Brachiaria* hybrid Bro2/1452 and *C. ciliaris* (which obtained the P content of 0.28; 0.10 and 0.10% respectively) and other treatments (Table 7).

In the acidic soil area, similar values of P content in treatments were measured. It was observed that during the wet season P in grasses was significantly higher in *Brachiaria* hybrid Bro2/1485 (0.54%) than in cv. Toledo (0.29%) and *C. ciliaris* (0.21%). The mean values of P content in the rest of the treatments were not significantly different (Table 7). However, during the dry season in the acidic soil area, the difference of mean values of P content in treatments was only observed between *C. ciliaris* and the rest of treatments. *C. ciliaris* (control) obtained 0.11% of P which was the lowest mean value of P recorded in all treatments (Table 7).

The quality of tested grasses in general shows that during the wet and dry season, treatments obtained high CP, Ca and P in the acidic soil area as compared to the low rainfall area. This might be possible because almost the harvests in the acidic soil area grasses were still young resulting in high concentration of nutrients.

Participatory variety selection

At the end of the on-farm trial, a participatory variety selection (PVS) was done in the study sites. The PVS showed the selection and rank of *Brachiaria* varieties and hybrids according to the farmers' criteria in the Bugesera and Nyamagabe districts (Table 8). In this exercise, drought tolerance, biomass production and palatability were the major criteria mentioned by farmers in the Bugesera district because during the dry season there was not enough feed for livestock. In the Nyamagabe district, the farmers' major criteria were palatability, acidic soil tolerance, herbage production and erosion control. Although the criteria for selection were almost the same in both sites, each site differed in their species choice. The top four ranked grasses in the Bugesera district were cv. Marandu, cv. Basilisk, cv. Mulato and. Mulato II. In the

Table 8. Farmer participatory variety selection and ranking of *Brachiaria* grass in the Bugesera and Nyamagabe districts.

Grass	The Bugesera district			The Nyamagabe district		
	Negative aspects	**Positive aspects**	**Rank**	**Negative aspects**	**Positive aspects**	**Rank**
Brachiaria hybrid Bro 2/0465	Does not resist to cutting, does not grow tall, and low biomass, not tolerant to drought	Roots can control erosion, highly palatability	8	Low biomass, not tolerant to poor soil fertility, difficult to cut because it is a short grass	Erosion control, palatable	10
Brachiaria hybrid cv. Mulato II	No negative aspect	High biomass, palatable, less hair, drought tolerance, quick regrowth, perennial, easy to cut and carry	1	No negative aspects	Medium biomass,palatable, less hair, drought tolerance, medium regrowth, perennial, easy to cut and carry, acidic soil tolerance, disease tolerance	1
B. brizantha cv. Marandu	Dry up when drought persists, difficult to cut	High biomass, palatable, quick regrowth, perennial	2	Difficult to cut	Medium biomass, medium acidic soil tolerance, palatable, disease tolerance, medium regrowth	6
Brachiaria hybrid Bro 2/1485	Less palatability, difficult to cut, less biomass, less regrowth after cut	Drought tolerance, perennial	10	No negative aspects	Palatable, drought tolerance, Medium regrowth, perennial, easy to cut and carry, acidic soil tolerance, medium disease tolerance, high biomass, medium soil erosion control	1
Brachiaria hybrid cv. Mulato	Less biomass, less regrowth after cut	Palatable, smoothness, easy to cut and drought tolerance	3	Low biomass, poor acidic soil tolerance, poor drought tolerance and poor disease tolerance	Medium palatability, medium easy to cut, medium regrowth and medium erosion control	7
B. brizantha cv. Toledo	Strong stem which makes it less palatability and difficult to cut	Drought tolerance, high biomass, erosion control, quick regrowth, perennial	5	Difficult to cut	High biomass, medium palatability, acidic soil tolerance, medium disease tolerance, erosion control, medium drought tolerance, medium regrowth	5
Cenchrus ciliaris	Less palatability, difficult to cut, less biomass	Drought tolerance, quick regrowth, perennial,	7	Low biomass, low palatability, poor acidic soil tolerance, poor drought tolerance	Medium regrowth, easy to cut, medium disease tolerance	9
B. decumbens cv. Local	Difficult to cut, less regrowth, not able to control erosion	Palatable, drought tolerance, perennial, high biomass	6	No negative aspects	Medium biomass, palatable, easy to cut, medium acidic soil tolerance, disease tolerance, erosion control, drought tolerance and medium regrowth	1

Table 8. Contd.

Brachiaria hybrid Bro 2/1452	Low palatability, low biomass, difficult to cut and less regrowth	Drought tolerance, perennial, erosion control	9	Low biomass, low palatability, poor acidic soil tolerance, poor drought tolerance, poor erosion control, low regrowth	Disease tolerance	8
B. decumbens cv. Basilisk	Does not resist to multiple cuts	Drought tolerance, easy to cut, erosion control, high biomass, quick regrowth, palatable	4	No negative aspects	High biomass, medium palatability, easy to cut, acidic soil tolerance, disease tolerance, medium erosion control, medium drought tolerance and medium regrowth	4

Nyamagabe district, the highest ranks were given to indigenous *Brachiaria,* hybrid Bro2/1485, cv. Basilisk and cv. Mulato II with three grasses being shared the same highest rank (Table 8). The highest ranked *Brachiaria* across the two sites was the *B*. hybrid cv. Mulato II. In both districts, the farmers mentioned that the highest rank given to Mulato II was due to its palatability and its ability to remain green year round. The most highly ranked grasses by farmers in the Bugesera and Nyamagabe districts had high values of crude protein, calcium and phosphorus. Indeed, farmers selected the tall *Brachiaria* because of its ease to cut and carry it. While hybrid Bro2/1485 was ranked lowest in the low rainfall, it was ranked highest in the acidic soil area because of its adaptability to acidic soil and its ability to produce high biomass (Figure 2A and Table 8). The indigenous grass (*B. decumbens*) used as control was among the highest ranked in the Nyamagabe district, but in the Bugesera, neither *C. ciliaris* nor *B. decumbens* (indigenous) received a high rank.

DISCUSSION

Soil quality

In the Nyamagabe district, the pH was lower than in the Bugesera district. According to Hovsepyan and Bonzongo (2009) the soil becomes acid when the pH value is below 5.5 and the pH value in the Nyamagabe district was 5.09 and thus an acidic soil area. The acidity of soil in the Nyamagabe district has also been reported by Munyemana (2001). The Al content of the soil was also higher (1.47 meq) in the Nyamagabe than in the Bugesera district (0.24 meq). Previous studies have reported that aluminium concentration in the soil of the Nyamagabe was higher (4 meq 100 g^{-1} of soil) than the level of toxicity (2 meq 100 g^{-1} of soil) and this was due to high leaching of organic matter. Furthermore, when pH of the soil is below 5.5 (Vitorello et al., 2005), the presence of Al^{3+} becomes toxic and can inhibit the growth of roots which reduces access to water and results in poor growth and death of the plant (Kinraide, 1991). The death occurs when roots of a plant are exposed to the dryness and there is no uptake of water and nutrients (Kari, 2006). The results from this study support the findings of Kinraide (1991) who reported that the low soil pH can be the source of aluminium toxicity as its presence was significant in the soil of the Nyamagabe district. By contrast, the higher pH (5.7) of the selected cells of the Bugesera district had low Al (0.2 meq 100 g^{-1} of soil) which is unlikely to cause toxicity. As stated by Mimmo et al. (2009), soils in the tropics are highly weathered and deficient in nutrients, which allow the presence of Al to become toxic and to inhibit the uptake of phosphorus by the plant. This could be the cause of high Al in the Nyamagabe district as the heavy rain (average of 1800 mm $year^{-1}$) on high steep slopes (50%) causes soil erosion in the area (Olson, 1994).

The available phosphorus in the soil varies according to the soil types and depends on crop type. According to Valkama et al. (2009), the P is low in clay soil when it is below six milliequivalent (meq) 100 g^{-1} of soil. Furthermore, in the tropical countries, according to the Olsen method, the P is low when it is below ten. The available phosphorus which was significantly different ($p<0.05$) between the two districts showed that the Bugesera had higher available P (6.88 meq) than the Nyamagabe district (4.30 meq). However, as both the P values were below 10 (according to the Olsen method) and these sites are in a tropical country, they are considered to be critically low.

Dry matter yield of tested grasses

The dry matter content in the diet of animal is important because its increase leads to the increase of energy. According to Meissner (2000), the deficit of energy in the animals' diet leads to low production of livestock. The grasses that have high DM content are likely to boost energy in forage for cattle. The DM of cv. Mulato was slightly less than that found by Jimenez et al. (2008) who recorded that cv. Mulato yielded 9.7 t of DM ha^{-1} in the rainy season and 1.41 t of DM ha^{-1} in the dry season. At the second harvest time DM obtained by indigenous *Brachiaria* (the local control grass.) in the dry season was higher (11.89 t ha^{-1}) than that found by Romero and Gonzalez (2004) in Costa Rica, where *B. decumbens* produced 2.3 t ha^{-1} per cut. However, cv. Toledo yielded a similar DM in the wet season (11.05 t ha^{-1}) as that found by Jimenez et al. (2008) in Mexico where cv. Toledo yielded 11.17 t ha^{-1}. In the dry season, our results on DM of cv. Toledo were greater (5.59 t ha^{-1}) than what these authors found over three annual seasons (2.40 t ha^{-1}). The increase in DM of cv. Toledo from the first to the second cut may be due to increasing number of tillers per plant. The DM yield in the low rainfall area for cv. Mulato II (5.13 t ha^{-1}) was higher than that recorded by CIAT (2004a) who reported 2.3t ha^{-1} for cv. Mulato II cut every six weeks over two years, on medium soil fertility in Costa Rica.

The DM produced by cv. Toledo, cv. Mulato and cv. Mulato II at fourth harvest at the beginning of dry season (end of May) decreased to 3.77; 2.63 and 4.15 t ha^{-1} respectively. These DM yields were slightly less than those found in cv. Toledo and cv. Mulato (4.7 and 3.1 t ha^{-1} respectively) but slightly higher than those reported for cv. Mulato II (2.8 t of DM ha^{-1}) by CIAT (2007b) in Las Segovias, Latin America. By the fifth harvest, at the end of dry season the yields of DM for cv. Toledo, cv. Mulato and cv. Mulato II had decreased further to 2.42; 1.24 and 1.88 t ha^{-1} respectively. These were similar to those reported for cv. Mulato and cv. Mulato II (1.2 and 1.9 t ha^{-1}, respectively) but slightly higher than that reported for in cv. Toledo (1.8 t ha^{-1}) by CIAT (2007b) in Las Segovias in the same dry season. Furthermore, the DM of cv. Toledo in the second rainy season was greater (11.03 t ha^{-1}) than that reported by Pedro et al. (2004) who reported that cv. Toledo yielded 3.8 t DM ha^{-1} every two months in the dry season and 5.1 t DM ha^{-1} in the rainy season from 11 contrasting sites in Colombia. When we compare DM yields of grasses during the wet and dry season in the low rainfall area, we found that the DM yield was higher in the wet season than the dry season. The DM obtained in cv. Toledo (5.71 t ha^{-1}) was significantly higher than that found in cv. Marandu by Rao et al. (1998), who reported that cv. Marandu yielded greatest higher DM in the wet and dry seasons than the hybrids, cv. Basilisk, *B. Brizantha* cv. La Libertad and *B. ruziziensis* in a field of Colombia with some fertilizer application. The DM yield of *B. decumbens* in the dry season was greater than that found by Stür et al. (1996) who reported that in the Northeast Thailand, the mean DM during the dry season was 3.1 t ha^{-1}. The DM yielded by cv. Marandu, cv. Toledo, cv. Basilisk and cv. Mulato during the dry season was 3.97; 5.79; 4.52 and 4.44 t ha^{-1} respectively in the low rainfall area. These yields are higher than those found by Pedro (2006) in Costa Rica, during the dry season for the same cultivars (Marandu, Toledo, Basilisk and Mulato) which yielded 2.75; 2.37; 3.20 and 2.25 t ha^{-1} of DM, respectively. The tested grasses that obtained high DM content during the wet and dry season, have shown their adaptation and therefore will increase livestock production in the low rainfall area.

In the acidic soil area, the DM yield of tested grasses decreased with increasing number of harvest times. According to Mapiye et al. (2006), the successions of cutting reduce enormously the DM yield because of exhaustion of nutrients in the soil. With the exception of *Brachiaria* hybrid Bro2/0465 all grasses at the first harvest time yielded higher DM than the rest of cutting times. Although the area is constrained by acidic soil, this harvest time took place at the end of the rainy season when grasses were well established. This supports Tudsri et al. (2002) who stated that cutting done at the end of the rainy season, gives high forage production. The high DM yield of cv. Basilisk was significantly higher than values reported by Ndikumana and Leeuw (1996) who recorded that cv. Basilisk yielded a DM of 3.8 t ha^{-1} in the dry season and 8.6 t ha^{-1} in the wet season across eight sites in infertile soils of western and central Africa over 12 weeks. Furthermore, the DM of *Brachiaria* hybrid Bro2/1485 was significantly higher than that of Ricaurte et al. (2008a) in Matazul, Colombia; they found that hybrid Bro2/0465 had higher DM than hybrid Bro2/1485 but cv. Toledo and cv. Mulato II produced higher DM than the three hybrids (Bro2/0465, Bro2/1452 and Bro2/1485). The mean values of DM found in the acidic soil area were slightly less than those found by Pedro et al. (2007). They found that *B. brizantha* cv. Toledo, *Brachiaria* hybrid cv. Mulato and cv. Mulato II yielded 2.2; 2.1 and 2.3 t ha^{-1} of DM respectively over two years on inceptisols medium fertility soil (pH = 5.4) of Costa Rica with high moisture tropical conditions. Nevertheless, the mean DM of *B. decumbens* (indigenous) found in the year in the acidic soil condition was 3.72 t $ha^{-1}$of DM, slightly higher than 2.11 t of DM $ha^{-1}$of *B. decumbens* found by Enoh et al. (2005) in Ngaondere, Cameroon for the period of one year.

During the dry seasons, the DM of treatments decreased gradually from the first dry season to the second, but increased slightly in the third dry season. This increase of DM in the third dry season could be explained by the fact that the low percentage of water in the grasses increases the percentage of DM. Mandret (1990) found that the percentage of DM increased quickly during the dry period by up to 80 to 90%. With a low production of biomass of *Brachiaria* in the acidic soil, the DM of the third dry season increased slightly due to low content of water in the grasses.

As in the wet season, *Brachiaria* hybrid Bro2/1485 yielded highest DM in the dry period (4.18 t ha^{-1}). The high DM production of hybrid Bro2/1485 in acidic soil was also reported by Ricaurte et al. (2008b). These authors reported that hybrid Bro2/1485 is able to persist in acidic soil in combination with a toxic level of Al. According to Richards (2008), grass can produce high yield in abiotic stress (for example, acidic soils, and drought) by developing a vigorous root system, which enables it to access water and nutrients. In the acidic soil area, cv. Marandu, cv. Toledo, cv. Basilisk, indigenous *Brachiaria* (control), hybrid Bro2/1485, cv. Mulato and cv. Mulato II yielded a higher DM than the other. Although these treatments showed their adaptation by producing high DM. Rao et al. (1998) stated that the rapid establishment of cv. Marandu and its high DM production are due to rapid uptake of nutrient, but this can lead to low persistence especially in the acidic soil stress conditions if fertilizer is not applied.

The mean DM of all treatments in the two contrasting environments were significantly different ($p<0.05$) among treatments. This indicates that grasses were more tolerant of the dry stress conditions, while others could tolerate acidic soil stress conditions.

Quality of tested grasses

Quality of forage refers to its nutrient content. The nutrients are intended to increase livestock production (Meissner et al., 2000). The authors said that the major nutrients for animals are crude protein, calcium and phosphorus. For example, a late stage pregnant cow requires 11% of CP, 0.37% of Ca and 0.26% of P daily (Meissner et al., 2000). These nutrients in forage vary according to many factors such as forage species and climate (Baron and Belanger, 2007). In the low rainfall area the CP value for cv. Mulato during the wet season was slightly lower (11.94%) than that reported by Plazas (1998), who found that CP of cv. Mulato in 90 days regrowth in Colombia was 13.1%. During the dry season, CP for all treatments decreased and this decrease of CP during the dry season was found by Tedonkeng et al. (2007). Although, CP decreases during the dry season, Vega et al. (2006) stated that other factors like maturity of the grass can be the source of declining CP. As the harvest time was planned for two monthly intervals during this study, the decrease of CP in grasses may be caused by the dry season. Looking at the CP value of improved grasses tested in the low rainfall area, cv. Mulato II (12.29%) and cv. Mulato (11.94%) will meet the CP requirements of a pregnant cow, unlike the control grasses in the low rainfall area. In addition, during the wet season in the low rainfall area, the hybrid Bro2/1485 produced a CP of 15.67% that is able to meet the CP requirement of 15% per day recommended by Meissner et al. (2000) for a dairy cow in lactation, which produces more than 29 L of milk per day.

In both seasons, *C. ciliaris* (control) obtained the lowest CP in the low rainfall area. The seasonal decrease of CP in *C. ciliaris* has been reported by many authors. For example, according to Yayneshet et al. (2009), in the short rainy season CP content in *C. ciliaris* was 5.12% in semi-arid region of northern Ethiopia. The grasses used as the control in this study yielded the lowest CP in the low rainfall area. The CP of indigenous *Brachiaria* was similar to the results found by Enoh et al. (2005) who reported that CP level in *B. decumbens* after twelve weeks (three months) of harvest was of 5.8% in Adamawa plateau of Cameroon. Nevertheless, our results on CP of the indigenous *Brachiaria* were lower than that found by Evitayani et al. (2005). They stated that in the tropical region of Indonesia, *Brachiaria decumbens* collected in the natural grassland of Sumatra during the wet and dry seasons, CP was 12.8 and 8.7%, respectively.

The tested grass in the acidic soil area showed that cv. Mulato II had the highest CP value (14.29%) during the wet season. In this period, cv. Mulato II can meet the CP requirement of 14% daily for a lactating cow which produces between 14 and 21 L per day (Meissner et al., 2000). The control grasses (local *Brachiaria* and *C. ciliaris*) yielded low CP in both season in fact that they could not even meet the CP requirement of 13% per day for a cow producing less than 14 L of milk per day in the acidic soil area. In this area, The CP found in cv. Mulato was less (11.56%) than that reported by Vendramini et al. (2008) who recorded a CP of 14% in this hybrid in Florida. The mean CP recorded for cv. Mulato in this study (11.56%) falls within the range (9 to 16%) reported by Pedro et al. (2005). During the wet season, the CP content in the indigenous *B. decumbens* (9.48%) was low compared to the CP of 11.4% reported by Romero and Gonzalez (2004). In the dry season, the CP of *B. decumbens* (indigenous) decreased from 9.48 to 4.92%. This decrease supports Holmann and Peck (2002) who found that during the wet season the CP content was 10.3% in *B. decumbens* (local) and declined to 3% during the dry season. The other control grass, *C. ciliaris* had a low CP of 5.55% in both seasons. The low concentration of CP in *C. ciliaris* was also reported by Sanderson et al. (1999) in Texas, who found that the CP content in *C. ciliaris* was 5.83% during the warm season. A similar decrease in quality of forage, especially CP during the dry period was also found by Yayneshet et al. (2009). The decrease of CP during the dry season affected also the top producer (cv. Mulato II) in the area which decreased to 8.91%. It was followed by cv. Toledo and hybrid Bro2/1485 which obtained a CP of 7.74 and 7.25% respectively. The CP obtained by cv. Toledo (10.06%) in the acidic soil during the wet and dry season was higher than that found by Jimenez et al. (2008) in Mexico who reported that *B. brizantha* yielded CP of 8.03% for 6 months (January to June).

It was found that in both seasons Ca ranged between 1.43 and 2.41%. The mean value of Ca found in cv.

Mulato, cv. Mulato II, *B. decumbens* cv. Basilisk and *B. brizantha* was higher than that found by Pedro et al. (2007) for the same hybrids and varieties. At the first and second harvesting time the results found in *B. decumbens* for Ca was 2.19% content. These results are higher than that found by Prezotto et al. (2005) who recorded that the Ca level found in *B. decumbens* (local) for two harvest periods was 0.42%. In terms of the Ca content in the tested grasses, it was apparent that although, differences occurred they would be able to meet the Ca requirement of any physiological stage of cattle in the acidic soil area. Furthermore, during the wet and dry seasons, *Brachiaria* hybrid Bro2/1485 yielded high P followed by *B. decumbens* (control). The P content for *B. decumbens* was slightly higher than that of Prezotto et al. (2005), who reported that P of 0.22% in *B. decumbens* was obtained in Brazil. In the acidic soil area, during both seasons most grasses showed that they can meet cattle requirements in P. However, *C. ciliaris* (control) had low P (0.11 to 0.21%) indicating that it cannot meet the lowest P requirement (0.26% per day for the growth of a heifer (Meissner et al., 2000).

Calcium (Ca) and phosphorus (P) are important minerals in the diet of animals because they are involved in the growth of bones (Miles and Manson, 2000). These authors confirmed that Ca and P are high in milk and a cow will need sufficient of these minerals in its daily diet. For example, a dairy cow which produces between 21 and 29 L of milk per day requires 0.54% of Ca and 0.38% of P per day (Meissner et al., 2000). For this reason, it is important to provide forage of high mineral content to dairy cows. Tested grasses in the low rainfall area showed that there was no significant difference (p>0.05) between Ca in grasses during the wet season, nor between the wet and dry season. However, a significant difference was found between Ca of grasses during the dry season with cv. Mulato having a higher Ca content (2.17%) than the control grass *C. ciliaris*. During the wet and dry seasons in low rainfall area cv. Marandu obtained slightly higher Ca contents (1.54 and 1.43% respectively) than that found by Itamar et al. (2009), who reported that cv. Marandu obtained 1.3% in Brazil. The Ca in all tested grasses during the wet season showed that they can meet the Ca requirement of 0.6% per day recommended by Meissner et al. (2000) for a dairy cow able to produce more than 29 litres of milk per day. Furthermore, P content analysed in tested grasses showed that cv. Toledo had 0.28% in the wet season and 0.29% in the dry season in the low rainfall area. These values were not significantly different from local *Brachiaria* (0.25%). However, the P of cv. Toledo can meet the P requirement of 0.26% per day for a late stage pregnant cow, while neither P of local *Brachiaria* nor of *C. ciliaris* can meet this requirement. The P of local *Brachiaria* (control) in both seasons was less than that of Prezotto et al. (2005) who recorded P value of 0.91% in *B. decumbens* during the second cut. However, it was similar to that of Evitayani et al. (2005) who recorded (0.19 and 0.21%) during the dry and wet seasons respectively in Indonesia. In the wet season, the P content in cv. Basilisk (0.18%) was similar to that of Rao et al. (1996), who reported P value was 0.10% in the low rainfall area.

The level of nutrient content (CP, Ca and P) found in grasses tested under the acidic soil area was higher than that of the low rainfall area. This may be explained by the climatic conditions found in the low rainfall area that allows grasses to mature rapidly and leads to low mineral content (Eriksen and Whitney, 1981). In general, the Ca found in the treatments (*Brachiaria* grasses) was similar to that found in some forage legumes (*Stylosanthes* sp., *Arachis* sp.) reported by Mutimura et al. (2009). The Ca content in the tested grasses was high for graminaceous plants, and was similar to the results of Collins and Fritz (2003) who reported that the Ca content in Orchard grass *(Dactylis glomerata L)* was 2.3%. In addition, some researchers on tropical grasses also found that Ca content in the grasses was sufficient to meet cattle and sheep's requirement for the Ca mineral (Youssef and Braithwaite, 1987). These authors confirmed the Ca content in tested grasses in meeting the Ca requirements for cattle. However, according to McDowell and Valle (2000), some forage grasses and legumes collected from different regions of Latin America and Africa showed low concentrations of Ca (< 0.3%). This shows that our results on Ca were higher than those found by these authors. It is likely that the grasses tested will be able to meet the CP, Ca and P requirements of the most ruminants in the low rainfall and acidic soil areas.

Variety selection

The inclusion of farmers in the variety selection enabled them to select the best variety and/or hybrid of the new forage according to their experiences. Farmers were able to select varieties, which performed well in their local environments. According to Nkongolo et al. (2008), participatory variety selection (PVS) helps the farmers to select better technologies by comparison to the indigenous forage used by farmers. The criteria chosen by farmers in both districts to select the *Brachiaria* grasses were similar and the most important were 'palatability', 'high biomass production', 'drought tolerance', 'easy to cut', 'acidic soil tolerance' and 'regrowth capacity'. These criteria were also similar to those identified by farmers in Malitbog, Philippines (palatability, regrowth capacity and drought tolerance) when they were selecting new forage options (Nacalaban et al., 1998). Pandit et al. (2007) reported that the interest of farmers on the new forage depended upon their needs especially quality, production and adaptation of the forage to their local climate conditions. The most highly selected *Brachiaria* grass was also the grass which had the highest DM and nutrient concentration. For example, the hybrid Bro2/1485 which yielded high DM in the acidic soil area was ranked high in the same area. The hybrid cv. Mulato II had high CP in both areas and it was selected by farmers in both contrasting environments. This relationship between farmers' indigenous knowledge on selecting new forages and their chemical composition supports Mekoya et al. (2008) who found that nutritive values of fodder from laboratory analyses in two districts of Ethiopia corresponded with the ranks of those feeds given by farmers. The participatory evaluation by farmers in the trial is important for the adoption of new forage technology and its expansion to other smallholder farmers. Most farmers from both sites stated that they would like to extend cv. Mulato II to a larger plot for the cut and carry system of forage for their livestock.

Conclusion

The soil analyses confirmed that the main constraints to forage production in the Nyamagabe district were low pH (5.09) and aluminium toxicity (1.47 meq). On-farm trials were established to enable farmers to evaluate different varieties and hybrids of improved *Brachiaria* to increase fodder production under these conditions. The most preferred variety of *Brachiaria* which was selected by farmers across the two sites was cv. Mulato II. It was selected by the farmers because of its adaptation to the two contrasting sites and its production of green forage (leaves and stems) during every season of the year. The most productive grass in terms of DM in the low rainfall area was cv. Toledo (5.71 t ha^{-1}) and in the acidic area the hybrid Bro2/1485 (5.95 t ha^{-1}). The highest DM producer in the low rainfall was not significantly different ($p>0.05$) from the local *Brachiaria* which had 5.6 t ha^{-1}. In the acidic soil area, the two control grasses (local *Brachiaria* and *C. ciliaris*) had low DM yields (3.72 and 1 t ha^{-1}, respectively) as compared to the top producer in this site. The high nutrient content of the improved *Brachiaria* grasses is likely to increase milk yield which will encourage farmers to multiply these grasses to a large scale.

The chemical analyses of each grass used in this study, indicated that the hybrid Bro2/1485 and cv. Mulato II had the highest nutrient content (CP >11 %) in both sites. The control entries had the lowest CP contents which were 5.44 and 6.56% for *C. ciliaris* and local *Brachiaria* grass, respectively. The mineral content varied according to species and sites. In the low rainfall site, cv. Mulato had the highest Ca (2.15%) whereas cv. Toledo obtained the highest P (0.28%). In the acidic soil site, the highest Ca content was obtained by cv. Marandu (2.41%) while the hybrid Bro2/1485 obtained the highest P (0.53%). The control grass (*C. ciliaris*) had the lowest minerals (Ca <1.4% and P<0.16%) compared to the rest of treatments in both sites. Since the minimum nutrient requirements for a late stage pregnant cow are 11% CP, 0.37% Ca and 0.26% P, the results of this study indicate that control grass *C. ciliaris* does not meet these requirements. Control grass *B. decumbens* (local) cannot also meet the requirement of CP, which is a crucial nutrient in animal nutrition. However, cv. Mulato II, selected by the farmers can provide adequate nutrients.

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