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Response of improved *Brachiaria* (*Urochloa*) grass cultivars to foliar diseases and their agronomic performances in Rwanda

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Diseases have emerged as one of the major challenges of *Brachiaria* production in Africa. Nine *Brachiaria* cultivars were evaluated for leaf rust, leaf spot and leaf blight diseases and agronomic performances in two agro-ecological zones of Rwanda. The relationships between agronomic traits and area under diseases progress curve (AUDPC) were determined using Pearson correlation analysis. Cultivars differed significantly ($p \leq 0.05$) for their response to these three diseases. Basilisk, Marandu, MG4, and Xaraes exhibited moderately resistant to resistant response to all three diseases, but Cayman and Cobra were susceptible to leaf rust. Site \times cultivar \times harvest interaction was significant for diseases and agronomic parameters ($p \leq 0.05$). Cultivars also differed significantly for biomass production and dry matter content ($p \leq 0.05$). The highest biomass producers were Marandu and Xaraes, and Cayman, Cobra and Piata had highest dry matter content. The AUDPC for leaf rust and leaf spot had negative and significant correlation with biomass yield. Our study concludes a satisfactory level of resistance in Basilisk, Marandu, MG4 and Xaraes to all three foliar disease in Rwanda. We recommend routine surveys for emerging and re-emerging *Brachiaria* diseases and studies to develop effective management measures against *Brachiaria* diseases.

Keywords: AUDPC, disease resistance, leaf blight, leaf rust, leaf spot

Introduction

Brachiaria (*Urochloa*) grass is one of the most important tropical forages distributed in the tropical and subtropical regions of eastern and western hemispheres (Renvoize et al. 1996). *Brachiaria* grass possess several characteristics of agricultural and environmental significance, such as high biomass yield, nutritious to livestock, drought and shade tolerance, soil fertility improvement, high nutrient use efficiency, mitigation of the climate change adversity and effective bioagents for pests and parasitic weed management (Subbarao et al. 2009; Maass et al. 2015; Khan et al. 2016). The genus *Brachiaria* consists of approximately 100 species, of which seven perennial species of African origin have been exploited for fodder production, and they have been cultivated in Asia, Australia, the South Pacific, and South America at various scales (Stür et al. 1996; Jank et al. 2014). *Brachiaria* species are a common and valuable constituent of natural vegetation in East Africa (Boonman 1993), but their use as sown pasture for animal production is very recent in the region (Maass et al. 2015; Njarui et al. 2016). A broad adaptation, excellent animal performances and high biomass yields are among the major factors that promote a wider and rapid adoption of *Brachiaria* grass across the tropics and subtropics. However, the productivity of *Brachiaria* grass is affected by different abiotic and biotic factors, including diseases causing high yield losses (Nzioki et al. 2016; Hernandez et al. 2017). Diseases of

Brachiaria grass, their symptoms, geographical distribution, and management options have been reviewed by Valerio et al. (1996). These diseases have negative impact on livestock productivity, because they reduce forage yields and quality.

Brachiaria grass is one of the preferred forages by livestock keepers in Rwanda and in other East African countries (Mutimura and Everson 2012; Maass et al. 2015). As mentioned earlier, diseases are among the major biotic constraints of *Brachiaria* grass production, and diseases, such as leaf rust, leaf spot, and leaf blight are reported to cause economic loss (Lenné and Trutman 1994; Miles et al. 1996; Rao et al. 1996; Alvarez et al. 2014; Maass et al. 2015). For instance, leaf rust can cause up to 100% yield loss, reduces leaf crude protein content to between 49 and 53% and subsides availability of other nutrients (Lenné and Trutman 1994). Similarly, leaf blight reduces forage biomass yield by approximately 50% in the tropics (Alvarez et al. 2013). Recent studies have shown widespread distribution of leaf rust, leaf spot, and leaf blight diseases in Kenya and Rwanda (Nzioki et al. 2016; Uzayisenga et al. 2020). Therefore, sustainability of *Brachiaria* grass production in Africa relies on how well these diseases are managed.

Many pastures including *Brachiaria* grass are considered low-value crops, often cultivated in large acreage and management of diseases using chemical is too costly and

not safe for livestock and environment. Therefore, disease management efforts in *Brachiaria* grass should focus on low-cost control measures like host-plant resistance that is effective, economical, easy to apply and safe for environment. Currently, some improved *Brachiaria* grass cultivars are available to address major production challenges like biomass yield, nutritive quality, drought tolerance, and pests and disease management (Lenné and Trutman 1994; Alvarez et al. 2014; Maass et al. 2015). For example, cultivars Mulato and Mulato II were developed for spittlebug resistance, high forage yield and nutritive quality (Miles et al. 2004; Argel et al. 2007). Cultivar Cayman was developed for water logging tolerance (Pizarro et al. 2013), and some *Brachiaria* hybrids were developed for foliar blight resistance (Alvarez et al. 2014).

Demand for improved *Brachiaria* grass is high in Sub Saharan Africa. Therefore, many livestock development initiatives implemented by National Agricultural Research System (NARS) institutions in Sub-Saharan Africa, international organizations and development agencies have been promoting *Brachiaria* grass in the continent as a nutritious and climate resilient forage. These programmes currently rely on a few improved cultivars initially developed for South America with extremely narrow genetic base (Keller-Grein et al. 1996). In Rwanda, evaluation of *Brachiaria* grass cultivars started in 2007 with the introduction of improved cultivars that included *Brachiaria decumbens* cv. Basilisk, *Brachiaria brizantha* cv. Marandu, *Brachiaria brizantha* cv. Xaraes, *Brachiaria* hybrid cv. Mulato, *Brachiaria* hybrid cv. Mulato II, *Brachiaria* hybrid Bro2/0465, and *Brachiaria* hybrid Bro2/1452 and *Brachiaria* hybrid Bro2/1485 (CIAT 2010; Mutimura and Everson 2012; Mutimura and Ghimire 2021). In 2013, eight improved *Brachiaria* cultivars were introduced and evaluated for adaptation and biomass yield in different agro-ecological zones (Ghimire et al. 2015). These cultivars were successfully integrated into mixed crop-livestock system that subsequently improved forage availability and livestock productivity (Mutimura et al. 2016; Mutimura et al. 2018).

All improved *Brachiaria* grass cultivars that are introduced and promoted in Africa were developed in South America and Australia. Some of these improved cultivars have shown broader adaptation, excellent agronomic performance and high livestock productivity stimulating high demand for *Brachiaria* grass by farmers in Africa. However, many of these cultivars are susceptible to diseases, such as leaf rust, leaf spot, foliar blight, and ergot in Kenya and Rwanda (Nzioki et al. 2016; Uzayisenga et al. 2020). Therefore, expansion of *Brachiaria* acreage without proper disease management measures will increase chances of disease outbreaks and crop failure. The cultivation and scaling up of these improved cultivars over large geographical ranges in Africa requires some consideration of the existing and emerging diseases (Maass 2015), accordingly warranting routine evaluation of the existing and new cultivars against diseases. This study evaluated the response of nine improved *Brachiaria* grass cultivars to three major foliar diseases and assessed the effects of the foliar diseases on the agronomic performance of those cultivars in Rwanda.

Materials and methods

Experimental sites

Field experiments were conducted in two different agro-ecological zones at Gashora and Rubona sites in 2019 and 2020 (Table 1). A previous study showed that leaf rust, leaf spot, and leaf blight of *Brachiaria* grass are endemic in both sites (Uzayienga et al. 2020). The Rubona site is characterised by poor soils (Acrisols; FAO 1987), derived from granitic parent material with moderate agriculture value. Soil pH ranges from 5.6 to 5.9, organic matter (%): 2.1 to 2.4; total soil nitrogen (%): 0.15 to 0.16, extractable P (ppm): 7.10 to 11.17, exchangeable Ca, Mg and K (cmol_c kg⁻¹): 2.02 to 3.15, 0.48 to 1.00 and 0.02 to 0.18, respectively, and soil texture is sandy clay (64.4% sand) (Ndabamenye et al. 2013). Soils in the Gashora site are very weathered and dominated by humic and haplic Ferralsols with means of soil pH: 5.91, organic carbon (%): 1.67, organic matter (%): 2.84, available P (pmm): 8.00, clay (%): 21, silt (%): 14, sand (%): 65, and with sandy loam soil texture (Bucagu et al. 2020).

Plant materials

The *Brachiaria* cultivars used in this study were obtained from Rwanda Agriculture and Animal Resources Development Board (RAB), Rwanda. These cultivars were *Brachiaria brizantha* cv. Marandu (CIAT 6294), *B. brizantha* cv. MG 4 (CIAT 26646), *B. brizantha* cv. Piata (CIAT 16125), *B. brizantha* cv. Xaraes (CIAT 26110), *B. decumbens* cv. Basilisk (CIAT 606), *B. humidicola* cv. Humidicola (CIAT 16888), *Brachiaria* hybrid cv. Cayman (CIAT BR02/1752), *Brachiaria* hybrid cv. Cobra (CIAT BR02/1794), *Brachiaria* hybrid cv. Mulato (CIAT 36061) and *Brachiaria* hybrid cv. Mulato II (CIAT 36087).

Field experimentation

Nine improved *Brachiaria* grass cultivars were evaluated in four replicates using a randomised complete block design (RCBD) in two sites. In addition to the main treatments, a leaf blight susceptible cultivar, Mulato (Argel et al. 2007; Alvarez et al. 2014), was planted as disease spreader rows four weeks prior to planting of test cultivars to check whether the disease was present naturally in the test sites and to trap early inoculum for the disease development. The test cultivars were surrounded by two spreader rows of Mulato planted at 50 cm between rows and 25 cm between plants. Each test cultivar was planted on 3.5 m row accommodating 14 plants per replicate at a spacing of 25 cm within rows and 1 m between rows, and a 2 m spacing was kept between replicates (Figure 1). Planting was done using minimum of two rooted tillers per hill. A basal dressing of cattle manure (10 t ha⁻¹) and NPK17-17-17 (100 kg ha⁻¹) were applied at the time of planting in the top soil (0–30 cm depth) in each planting hole, and urea was top-dressed two weeks after planting in rows (broadcast at 5 cm radius at each tiller) at the rate of 50 kg N ha⁻¹. Irrigation and weeding were performed manually as required. All test cultivars in the experimental plots were subjected to standardisation cut at 5 cm above the ground level four weeks after planting to stimulate tillering and uniform regrowth. For each cultivar, six

Table 1: Biophysical characteristics of Gashora and Rubona experimental sites in Rwanda

Variables	Experimental sites	
	Gashora	Rubona
District	Bugesera	Huye
Agro-ecological zone	Mayaga and Bugesera	Central plateau and granitic ridges
Altitude (m asl)	1 333	1 673
Latitude	2°11'17.8" S	2°29'01.4" S
Longitude	30°14'36.2" E	29°46'00.9" E
Rainfall distribution (bimodal)		
First rains	March to May	March to May
Second rains	October to December	October to December
Total annual rainfall (mm)		
Mean	1 038	1 298
Minimum	891	1 025
Maximum	1 255	1 993
Average annual temperature (°C)		
Mean	20.3	19.5
Minimum	19.5	18.1
Maximum	22.0	20.5
Topography (% slope)	Gentle (2%)	Gentle (2%)
Soil textural classification	Sandy loam	Sandy clay
Soil types/parent material	Acrisol/shale and granitic rocks	Acrisol/granitic rocks
Agriculture value	Poor to moderate	Moderate

RMA (Rwanda Meteorology Agency) 2020

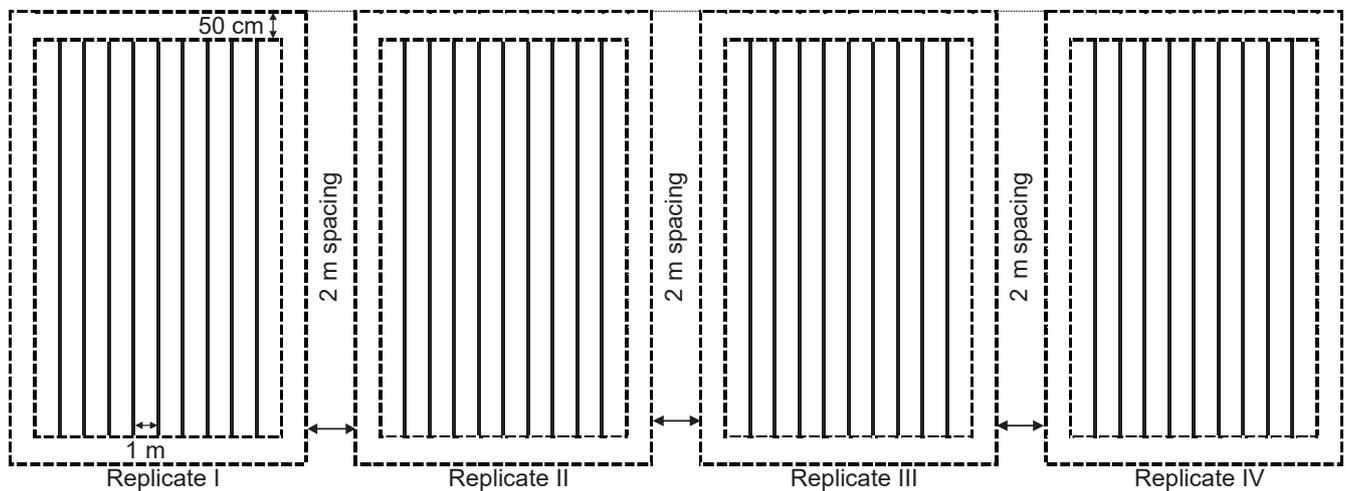


Figure 1: Experiment layout: Nine test cultivars were surrounded by two spreader rows of Mulato (----: dotted lines) planted in row to row spacing of 50 cm and between the plant spacing of 25 cm. Each test cultivar was planted on a 3.5 m row (—: full lines) accommodating 14 plants per replication at spacing of 25 cm within rows and 1 m between rows, and 2 m spacing was kept between replications

stools showing uniformity in appearance and growth were selected in each replication and tagged for assessing diseases and agronomic parameters. Border effect was eliminated during data collection by excluding at least one stool from either side of a row. The field experiments covered three consecutive growing seasons: March to July 2019 (wet to semi-dry season characterised by high rain intensity, but shorter rains), August to December 2019 (dry to wet season, characterised by long rain- patterns/ distribution with medium rain intensity), and January to May 2020 (wet season characterised by shorter rains with high intensity).

Assessment of disease incidence and severity

Disease incidence and severity were recorded every four weeks after the standardisation cut up to the 20th week for the first, second, and third seasons. Five assessments were made for each of the three consecutive seasons. Disease incidence was assessed on six tagged stools per cultivar in each replication and was determined as the number of stools showing disease symptoms, then converted to percentage of the total number of assessed stools, i.e. samples collected from each replicate. On the same stools, severity of leaf rust, leaf spot, and leaf blight was assessed using the disease rating scales described in Table 2. The

Table 2: Severity rating scale for major foliar diseases of *Brachiaria* grass

Disease	Rating scale	Description	Source
Leaf rust	0	No infection	Peterson et al. (1948), CIMMYT (1985)
	1	5% of infection of rust on plant	
	2	10% of infection of rust on plant	
	3	20% of infection of rust on plant	
	4	40% of infection of rust on plant	
	5	60% of infection of rust on plant	
Leaf spot	0	Free from infection	Modified from Stubbs et al. (1986)
	1	1% of lesions on leaves or very few lesions	
	2	5% of lesions on leaves or light lesions	
	3	25% of lesions on leaves or moderate lesions	
	4	50% of lesions on leaves	
	5	80 % of lesions on leaves or heavy lesions	
Leaf blight	0	No disease symptom	CIAT (2004)
	1	0.1 to 1.9% showing symptoms on leaves	
	2	2 to 5.9% showing symptoms on leaves	
	3	6 to 15.9% showing symptoms on leaves	
	4	16 to 19.9 % showing symptoms on leaves	
	5	20 to 100% showing symptoms on leaves	

area under disease progress curve was calculated from severity data collected over the five different time points in each season, as described by Shaner and Finney (1977).

The response of the test cultivars to leaf rust was determined based on infection types and the area under the disease progress curve (AUDPC). The leaf rust infection types were recorded at eight-week-old stools for all three seasons (two harvests in 2019 and one harvest in 2020) using a five-category scale, namely immune, resistant, moderately resistant, moderately susceptible, and susceptible (Roelfs et al. 1992). Similarly, the response to leaf spot and leaf blight was determined based on AUDPC data where lower AUDPC values correspond to resistance and higher AUDPC values correspond to susceptibility. The AUDPC values <3 500 correspond to resistant, values between 3 500 and 4 500 correspond to moderately susceptible, and the values >4 500 correspond to susceptible reaction (Magar et al. 2015; Pantha et al. 2017; Kumari et al. 2018).

Evaluation of agronomic parameters

The data on plant height and number of tillers per stool were taken every four weeks following the standardisation cut for each harvest, i.e. growth period/season. Plant height was recorded from the base of the stool up to the longest leaf of every tagged stool (Rayburn and Lozier 2007). The dry matter (DM) yield and dry matter content were recorded for each harvest. Harvesting was carried at 20 weeks' interval all through the seasons. For determination of dry matter content, 200 g subsample from fresh biomass was put in paper bags, and oven dried at 105 °C for 24 hours. The total dry matter yield (kg ha⁻¹ DM) and the percentage dry matter were calculated as described by Wassie et al. (2018) and Oliveira et al. (2019).

Meteorological data

The rainfall and temperature data during the experimental period from March 2019 to May 2020 for Gashora and Rubona experimental sites was obtained from the Rwanda

Meteorology Agency (RMA 2020). Thirty-year average data available at <https://www.besttimetovisit.com.pk/> were used for any missing monthly rainfall and temperature data.

Statistical analyses

Data on disease parameters (incidence, severity and AUDPC) and agronomic traits (plant height, number of tillers, dry matter yield and the dry matter content) was subjected to analysis of variance (ANOVA) using GenStat for Windows 20th Edition (VSN International 2019). To account for the overall trend of disease incidence, disease severity, plant height, and number of tillers, data were subjected to general linear model predictions using repeated measures (Littell et al. 1991). All data were analysed at the cultivar × site × harvest/season interaction level and then presented based on the significance of their interactions ($p \leq 0.05$). The means of disease and agronomic parameters were compared by Least Significant Difference (LSD) mean separation test at 0.05 probability level. Because the data were analysed at cultivar × site × harvest/season interaction, all cultivars, sites, and harvests/seasons were considered together to calculate Pearson correlations that allowed to illustrate the relationships among the agronomic traits (plant height, number of tillers, dry matter yield) and the AUDPC for leaf rust, leaf spot and leaf blight diseases.

Results

Meteorological data at experimental sites

Monthly rainfall and monthly average temperature for Gashora and Rubona are presented in Figure 2. Sites differed distinctly in terms of annual rainfall and monthly rainfall differed between seasons (Figure 2). In all three seasons, Gashora had higher mean monthly temperature than Rubona (first season = 22.7 °C vs 20.1 °C, second season = 23.4 °C vs 20.5 °C, and third season = 21.0 °C vs 20.2 °C). However, the differences in monthly temperatures between the sites were minimal for all three seasons.

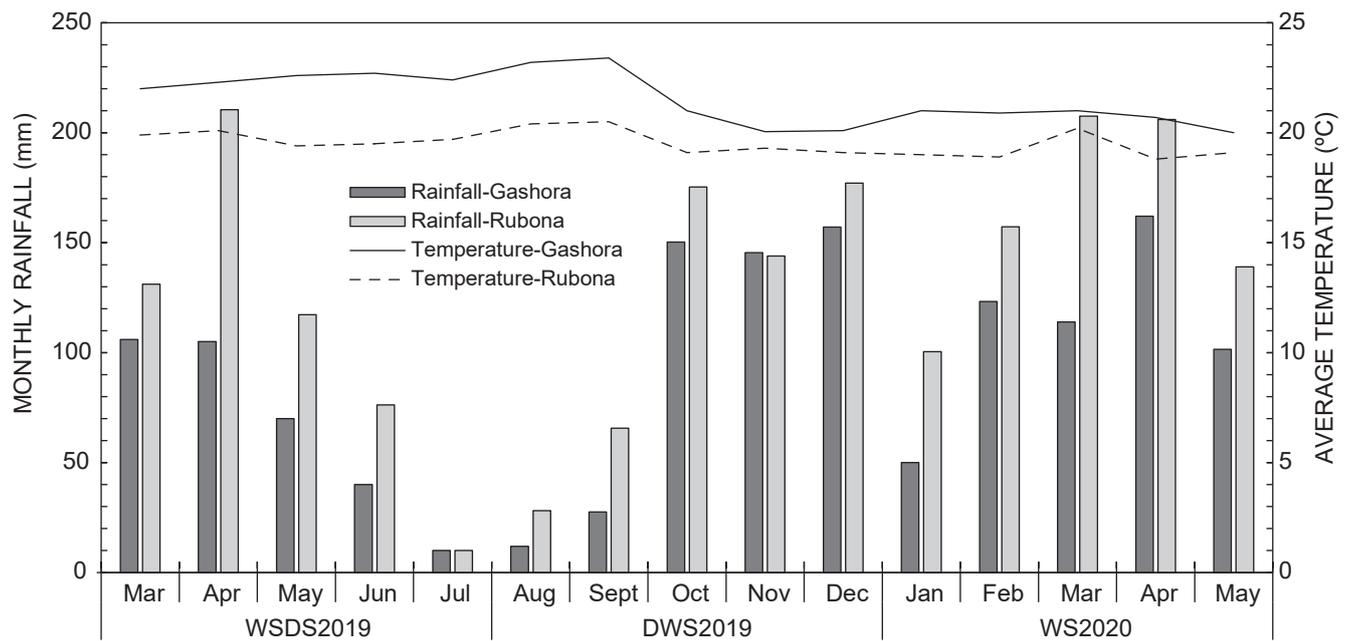


Figure 2: Monthly rainfall and monthly average temperature at Gashora and Rubona in Rwanda during crop growing season: March–July 2019 (wet to semi-dry season = WSDS), August to December 2019 (dry to wet season = DWS), and January to May 2020 (wet season = WS). These seasons correspond to the first, second and third harvests, respectively

Responses of improved *Brachiaria* cultivars to foliar diseases

The effect of cultivar, site, harvest, and interaction of cultivar by site and harvest was significant for leaf rust incidence, severity and AUDPC ($p < 0.001$; Table 3). The leaf rust incidence among the cultivars for all sites and harvests together ranged from 31.9% to 100.0% with the lowest incidence in Basilisk at Gashora in the third harvest and the highest incidence in Cayman, Mulato II and Cobra, mostly at Rubona in all harvests. Similarly, leaf rust severity ranged from 5.4% to 81.8% with the lowest severity in Basilisk in the third harvest at Gashora and the highest in Cayman in the third harvest at Rubona. The AUDPC for leaf rust was the lowest in Basilisk (754) and MG4 (949) in the third harvest at Gashora and the highest in Cayman (10 177) in the first harvest at Rubona. Across all sites and harvests, the cultivars Cayman and Cobra were the most susceptible to leaf rust disease, whereas Basilisk, Humidicola, Marandu, MG4, Piata and Xaraes were moderately resistant. Cultivar Mulato II was moderately susceptible.

There was significant effect of all treatments (except for site on incidence and AUDPC) and their interactions on incidence, severity and AUDPC of leaf spot disease ($p < 0.001$; Table 4). The incidence of leaf spot was the lowest in Cayman at Rubona in the first harvest and the highest in Humidicola at Rubona in the third harvest. The severity of leaf spot was the lowest in Cayman at Rubona in the first harvest and the highest in Humidicola at Rubona in the first harvest. The AUDPC for leaf spot ranged from 25 to 5 996, where Cayman had the lowest values at Rubona in the first harvest and Humidicola had the highest value at Gashora in the first harvest. All

cultivars across the sites and harvests showed resistant reaction to leaf spot, except Cayman, Humidicola, and Piata, which were moderately susceptible/susceptible.

All treatments and their interactions had significant effect on the incidence, severity and AUDPC of leaf blight ($p \leq 0.001$; Table 5). Cultivar Humidicola had the lowest incidence and severity of leaf blight in the first harvest at Gashora. Cultivar Cayman had the highest leaf blight incidence and severity in the third harvest at Rubona. Humidicola in the first harvest at Gashora and Cayman in second harvest at Rubona had the lowest values of AUDPC (0.0%) for leaf blight disease, but Cayman had the highest value (2 317) in the third harvest at Rubona.

Evolution of disease incidence at Gashora and Rubona sites

Results of the evolution of foliar diseases from four weeks to the 20th week showed that incidence of leaf rust, leaf spot and leaf blight increased with the number of weeks after standardisation cut and/or harvest (Figures 3, 4 and 5). Higher incidence of leaf rust disease ranging from 80–100% was observed for moderately susceptible and susceptible cultivars at Rubona at four weeks for all harvests considered together. It reached 100% at eight weeks and 12 weeks for moderately resistant cultivars. Over time, leaf rust incidence was the lowest in moderately resistant cultivars at Gashora (Figure 3). The leaf spot disease showed high diversity of cultivar responses throughout the crop growth periods (Figure 4). Leaf blight incidence was low in all cultivars until 16 weeks then spiked at 20 weeks. Exception at 16 weeks, leaf blight incidence was consistently higher at Rubona than Gashora (Figure 5).

Table 3: Incidence, severity, and field responses of nine improved *Brachiaria* cultivars to leaf rust disease at Gashora and Rubona, Rwanda, in 2019 and 2020

Site	Harvest	Cultivar	Incidence (%)	Severity (%)	AUDPC	Host response	
Gashora	First harvest	Basilisk	71.7 ^{ijk}	15.1 ^{wxyzA}	1 802 ^{stuv}	MR	
		Cayman	95.0 ^{bc}	59.3 ^c	7 618 ^c	S	
		Cobra	100.0 ^a	40.9 ^e	5 069 ^e	S	
		Humidicola	62.8 ^m	14.1 ^{xyzAB}	1 792 ^{luvw}	MR	
		Marandu	83.9 ^{de}	19.6 ^{qrstuv}	2 437 ^{nopqr}	MR	
		MG4	45.8 ^{gr}	13.8 ^{yzAB}	1 698 ^{uvw}	MR	
		Mulato II	98.6 ^{ab}	28.8 ^{klmn}	3 441 ^{ijkl}	MS	
		Piata	70.3 ^{jk}	13.5 ^{zAB}	1 622 ^{uvwxy}	MR	
		Xaraes	82.2 ^{de}	22.1 ^{opqrs}	2 830 ^{mno}	MR	
	Second harvest	Basilisk	57.2 ⁿ	18.0 ^{stuvwxy}	2 010 ^{rstu}	MR	
		Cayman	80.6 ^{ef}	37.1 ^{efgh}	4 358 ^{fg}	S	
		Cobra	77.2 ^{fgh}	24.7 ^{nop}	2 951 ^{lmn}	S	
		Humidicola	63.3 ^m	17.7 ^{luvwxyz}	2 108 ^{qrstuv}	MR	
		Marandu	52.8 ^{op}	15.1 ^{wxyzA}	1 691 ^{uvw}	MR	
		MG4	58.6 ⁿ	18.4 ^{rstuvwxy}	1 986 ^{stuv}	MR	
		Mulato II	72.8 ^{jl}	21.9 ^{opqrst}	2 490 ^{nopqr}	MS	
		Piata	55.6 ^{no}	15.8 ^{wxyzA}	1 785 ^{luvw}	MR	
		Xaraes	63.6 ^m	18.5 ^{stuvw}	2 146 ^{qrstuv}	MR	
	Third harvest	Basilisk	31.9 ^s	5.4 ^E	754 ^z	R	
		Cayman	75.6 ^{ghj}	36.2 ^{fgh}	4 319 ^{fg}	S	
		Cobra	77.2 ^{fgh}	30.0 ^{ijkl}	3 469 ^{kl}	S	
		Humidicola	42.8 ^{gr}	7.9 ^{CDE}	1 063 ^{xyz}	R	
		Marandu	50.8 ^p	10.6 ^{BCD}	1 233 ^{wxyz}	R	
		MG4	42.2 ^r	7.2 ^{DE}	948 ^{yz}	R	
		Mulato II	64.4 ^{lm}	19.8 ^{qrstuv}	2 354 ^{opqrs}	MS	
		Piata	46.4 ^q	10.6 ^{BCD}	1 247 ^{wxyz}	MR	
		Xaraes	58.1 ⁿ	10.2 ^{BCD}	1 275 ^{wxyz}	MR	
	Rubona	First harvest	Basilisk	65.0 ^{lm}	13.5 ^{zAB}	1 670 ^{uvw}	MR
			Cayman	100.0 ^a	70.5 ^b	8 927 ^b	S
			Cobra	98.3 ^{ab}	50.2 ^d	6 389 ^d	S
Humidicola			86.1 ^d	20.6 ^{pqrst}	2 538 ^{mnpqrs}	MR	
Marandu			73.3 ^{hij}	16.0 ^{luvwxyzA}	2 007 ^{rstu}	MR	
MG4			65.0 ^{lm}	11.9 ^{ABC}	1 403 ^{wxy}	MR	
Mulato II			94.2 ^c	40.7 ^e	5 142 ^e	MS	
Piata			77.8 ^{fg}	18.0 ^{rstuvwxy}	2 260 ^{pqrst}	MR	
Xaraes			68.1 ^{kl}	13.8 ^{yzAB}	1 656 ^{uvw}	MR	
Second harvest		Basilisk	98.3 ^{ab}	22.3 ^{opqr}	2 528 ^{mnpqrs}	MR	
		Cayman	100.0 ^a	58.2 ^c	7 108 ^c	S	
		Cobra	98.9 ^{ab}	39.9 ^{ef}	4 861 ^{ef}	S	
		Humidicola	98.9 ^{ab}	25.5 ^{mno}	2 983 ^{lmn}	MR	
		Marandu	98.6 ^{ab}	23.3 ^{opq}	2 649 ^{mnpq}	MR	
		MG4	97.5 ^{abc}	20.3 ^{qrstuv}	2 323 ^{opqrst}	MR	
		Mulato II	100.0 ^a	34.3 ^{ghi}	4 149 ^{gh}	S	
		Piata	97.2 ^{abc}	29.6 ^{klmn}	3 462 ^{kl}	MS	
		Xaraes	99.4 ^a	23.4 ^{opq}	2 764 ^{mnp}	MR	
Third harvest		Basilisk	98.6 ^{ab}	33.5 ^{hij}	4 080 ^{ghi}	MR	
		Cayman	100.0 ^a	81.8 ^a	10 177 ^a	S	
		Cobra	100.0 ^a	38.2 ^{efg}	4 490 ^{fg}	S	
		Humidicola	96.7 ^{abc}	28.6 ^{klmn}	3 490 ^{kl}	MS	
		Marandu	98.6 ^{ab}	31.9 ^{ijk}	3 726 ^{hij}	MR	
		MG4	98.1 ^{abc}	25.7 ^{lmno}	3 073 ^{klm}	MR	
		Mulato II	100.0 ^a	40.1 ^{ef}	4 799 ^{ef}	MS	
		Piata	96.7 ^{abc}	39.6 ^{ef}	4 778 ^{ed}	MS	
		Xaraes	98.6 ^{ab}	29.6 ^{klmn}	3 573 ^{ijk}	MR	
Source of variation			p-values				
Site			< 0.001	< 0.001	< 0.001		
Harvest			< 0.001	< 0.001	< 0.001		
Cultivar		< 0.001	< 0.001	< 0.001			
Site × harvest		< 0.001	< 0.001	< 0.001			
Site × cultivar		< 0.001	< 0.001	< 0.001			
Harvest × cultivar		< 0.001	< 0.001	< 0.001			
Site × harvest × cultivar		< 0.001	< 0.001	< 0.001			

AUDPC = Area under disease progress curve, S = Susceptible, MS = Moderately susceptible, MR = Moderately resistant, R = Resistant. Values with the same superscript letters within the columns are not statistically different at $p \leq 0.05$

Table 4: Incidence, severity, and field response of nine improved *Brachiaria* cultivars to leaf spot disease at Gashora and Rubona, Rwanda, in 2019 and 2020

Site	Harvest	Cultivar	Incidence (%)	Severity (%)	AUDPC	Host response	
Gashora	First harvest	Basilisk	50.0 ^{ghij}	16.7 ^{lm}	1 875 ^{klmn}	R	
		Cayman	18.3 ^{pqrst}	6.0 ^{vwx}	525 ^{stuvwxy}	R	
		Cobra	25.6 ^{nopqr}	7.8 ^{luv}	708 ^{stuywx}	R	
		Humidicola	89.7 ^a	48.4 ^a	5 996 ^a	S	
		Marandu	6.9 ^{tu}	1.5 ^{zA}	121 ^{xy}	R	
		MG4	35.3 ^{klmn}	16.5 ^{lm}	1 962 ^{ijklmn}	R	
		Mulato II	26.7 ^{mno}	11.2 ^{pqr}	1 063 ^{opqrs}	R	
		Piata	9.2 ^{stu}	2.1 ^{yzA}	175 ^{wxy}	R	
		Xaraes	10.8 ^{stu}	4.2 ^{wxy}	500 ^{stuvwxy}	R	
	Second harvest	Basilisk	64.7 ^{bode}	25.3 ^{ef}	3 004 ^{ef}	R	
		Cayman	70.6 ^{bc}	30.3 ^d	3 733 ^{cd}	MS	
		Cobra	65.0 ^{bode}	23.9 ^{gh}	2 742 ^{efgh}	R	
		Humidicola	87.8 ^a	30.8 ^d	3 725 ^{cd}	MS	
		Marandu	39.7 ^{ijklm}	10.7 ^{pqrs}	1 138 ^{opqrs}	R	
		MG4	50.6 ^{ghij}	14.0 ^{no}	1 567 ^{klmno}	R	
		Mulato II	68.3 ^{bc}	27.6 ^e	3 242 ^{de}	R	
		Piata	36.1 ^{klmn}	10.2 ^{qrst}	1 021 ^{opqrst}	R	
		Xaraes	40.8 ^{ijkl}	8.3 ^{stuv}	996 ^{opqrst}	R	
	Third harvest	Basilisk	64.7 ^{bode}	23.9 ^{gh}	2 821 ^{efg}	R	
		Cayman	70.6 ^{bc}	24.5 ^{fg}	2 938 ^{ef}	R	
		Cobra	65.0 ^{bode}	15.2 ^{mn}	1 908 ^{ijklmn}	R	
		Humidicola	88.1 ^a	22.2 ^{ghi}	2 804 ^{efg}	R	
		Marandu	20.0 ^{pqrst}	4.1 ^{wxy}	492 ^{stuvwxy}	R	
		MG4	31.4 ^{lmnop}	6.2 ^{vw}	767 ^{pqrstuvw}	R	
		Mulato II	52.5 ^{efghi}	18.1 ^{kl}	2 183 ^{ghijk}	R	
		Piata	35.8 ^{klmn}	7.6 ^{uv}	821 ^{pqrstuvw}	R	
		Xaraes	15.8 ^{qrst}	3.2 ^{yz}	408 ^{tuvwxy}	R	
	Rubona	First harvest	Basilisk	51.1 ^{ghij}	12.6 ^{opq}	1 521 ^{lmno}	R
			Cayman	0.0 ^u	0.2 ^A	25 ^y	R
			Cobra	10.0 ^{stu}	3.1 ^{yz}	238 ^{wxy}	R
			Humidicola	96.7 ^a	48.5 ^a	5 958 ^a	S
			Marandu	9.4 ^{stu}	3.6 ^{xyz}	317 ^{uvwxy}	R
			MG4	35.8 ^{klmn}	8.3 ^{stuv}	971 ^{opqrst}	R
			Mulato II	15.0 ^{qrst}	6.2 ^{vw}	604 ^{stuvwxy}	R
			Piata	14.2 ^{qrst}	3.2 ^{yz}	296 ^{uvwxy}	R
			Xaraes	40.8 ^{ijkl}	8.3 ^{stuv}	1 004 ^{opqrst}	R
Second harvest		Basilisk	62.2 ^{bdef}	12.9 ^{nop}	1 562 ^{klmno}	R	
		Cayman	20.8 ^{opqrs}	6.0 ^{vwx}	638 ^{stuvwxy}	R	
		Cobra	12.8 ^{stu}	2.6 ^{yzA}	238 ^{wxy}	R	
		Humidicola	96.9 ^a	43.2 ^b	5 288 ^b	S	
		Marandu	33.6 ^{lmno}	7.5 ^{uv}	858 ^{pqrstuv}	R	
		MG4	55.0 ^{defgh}	11.2 ^{pqr}	1 404 ^{mno}	R	
		Mulato II	26.7 ^{mno}	7.1 ^{uv}	738 ^{qrstuvw}	R	
		Piata	42.5 ^{hijkl}	13.1 ^{nop}	1 350 ^{nopqr}	R	
		Xaraes	48.3 ^{ghijk}	11.6 ^{opqr}	1 400 ^{mno}	R	
Third harvest		Basilisk	69.4 ^{bc}	19.8 ^{ijk}	2 367 ^{ghij}	R	
		Cayman	38.6 ^{klmn}	10.7 ^{pqrs}	1 383 ^{mno}	R	
		Cobra	62.5 ^{bdef}	16.7 ^{lm}	2 008 ^{ijklm}	R	
		Humidicola	100.0 ^a	44.4 ^b	5 592 ^{ab}	S	
		Marandu	68.6 ^{bc}	21.5 ^{hij}	2 558 ^{ghij}	R	
		MG4	41.7 ^{ijkl}	9.1 ^{rstu}	921 ^{opqrstu}	R	
		Mulato II	66.9 ^{bcd}	19.6 ^{kl}	2 467 ^{ghij}	R	
		Piata	73.6 ^b	35.5 ^c	4 342 ^c	MS	
		Xaraes	57.8 ^{cdefg}	17.8 ^{kl}	2 113 ^{hijkl}	R	
Source of variation			p-values				
Site			0.514	0.014	0.200		
Harvest			< 0.001	< 0.001	< 0.001		
Cultivar			< 0.001	< 0.001	< 0.001		
Site × harvest			< 0.001	< 0.001	< 0.001		
Site × cultivar			< 0.001	< 0.001	< 0.001		
Harvest × cultivar			< 0.001	< 0.001	< 0.001		
Site × harvest × cultivar			< 0.001	< 0.001	< 0.001		

AUDPC = Area under disease progress curve, S = Susceptible, MS = Moderately susceptible, R = Resistant. Values with the same superscript letters within the columns are not statistically different at $p \leq 0.05$

Table 5: Incidence, severity, and field response of nine improved *Brachiaria* cultivars to leaf blight disease at Gashora and Rubona, Rwanda, in 2019 and 2020

Site	Harvest	Cultivar	Incidence (%)	Severity (%)	AUDPC	Host response	
Gashora	First harvest	Basilisk	5.8 ^{stuvwx}	1.3 ^{stuvwx}	96 ^{stuv}	R	
		Cayman	6.4 ^{rstuvwx}	1.4 ^{rstuvwx}	108 ^{stuv}	R	
		Cobra	10.8 ^{opqrstu}	2.6 ^{nopqrstuv}	258 ^{pqrstu}	R	
		Humidicola	0.0 ^x	0.0 ^x	0 ^v	R	
		Marandu	6.1 ^{rstuvwx}	1.2 ^{stuvwx}	92 ^{stuv}	R	
		MG4	15.0 ^{lmnopqr}	3.4 ^{klmnopqr}	283 ^{nopqrst}	R	
		Mulato II	9.2 ^{qrstuvw}	1.9 ^{qrstuvw}	175 ^{qrstuv}	R	
		Piata	4.4 ^{tuvwx}	0.9 ^{uvwx}	92 ^{stuv}	R	
		Xaraes	5.8 ^{stuvwx}	1.0 ^{uvwx}	104 ^{stuv}	R	
	Second harvest	Basilisk	30.0 ^{efgh}	6.0 ^{efghi}	650 ^{efghijk}	R	
		Cayman	34.4 ^{ef}	6.8 ^{ef}	683 ^{efghi}	R	
		Cobra	36.1 ^{de}	7.2 ^{de}	792 ^{ef}	R	
		Humidicola	5.3 ^{stuvwx}	1.1 ^{tuvwx}	83 ^{stuv}	R	
		Marandu	25.8 ^{ghij}	5.2 ^{efghijkl}	542 ^{ghijklm}	R	
		MG4	20.8 ^{ijklm}	4.2 ^{hijklmno}	388 ^{lmnopqr}	R	
		Mulato II	30.8 ^{efg}	6.2 ^{efgh}	667 ^{efghij}	R	
		Piata	25.6 ^{ghijk}	5.1 ^{efghijklm}	558 ^{ghijkl}	R	
		Xaraes	18.9 ^{klmno}	3.6 ^{ijklmnopq}	392 ^{lmnopq}	R	
	Third harvest	Basilisk	15.0 ^{lmnopqr}	3.0 ^{mnopqrstu}	425 ^{klmnop}	R	
		Cayman	22.8 ^{ghijkl}	4.5 ^{ghijklmn}	508 ^{hijklmno}	R	
		Cobra	28.9 ^{efghi}	6.4 ^{efg}	763 ^{efg}	R	
		Humidicola	1.1 ^{vw}	0.2 ^w	21 ^{uv}	R	
		Marandu	18.3 ^{ijklmnop}	3.7 ^{ijklmnopq}	429 ^{ijklmnop}	R	
		MG4	5.0 ^{stuvwx}	1.0 ^{uvwx}	150 ^{rstuv}	R	
		Mulato II	15.8 ^{lmnopq}	3.2 ^{lmnopqrst}	442 ^{klmnop}	R	
		Piata	18.3 ^{ijklmnop}	4.3 ^{ghijklmno}	517 ^{hijklmn}	R	
		Xaraes	8.1 ^{qrstuvw}	1.6 ^{qrstuvw}	242 ^{pqrstu}	R	
	Rubona	First harvest	Basilisk	9.4 ^{pqrstu}	2.3 ^{opqrstuvw}	175 ^{qrstuv}	R
			Cayman	10.8 ^{opqrstu}	3.2 ^{lmnopqrst}	263 ^{pqrst}	R
			Cobra	11.7 ^{nopqrstu}	4.1 ^{hijklmnop}	304 ^{mnopqrs}	R
Humidicola			19.2 ^{klmno}	5.3 ^{efghijk}	400 ^{lmnopq}	R	
Marandu			12.8 ^{mnopqrst}	3.4 ^{klmnopqrs}	267 ^{pqrst}	R	
MG4			13.9 ^{lmnopqrs}	4.1 ^{hijklmno}	317 ^{mnopqrs}	R	
Mulato II			19.2 ^{klmno}	5.7 ^{efghij}	450 ^{ijklmnop}	R	
Piata			16.7 ^{klmnopq}	4.8 ^{efghijklm}	363 ^{lmnopqr}	R	
Xaraes			19.2 ^{klmno}	4.8 ^{efghijklm}	363 ^{lmnopqr}	R	
Second harvest		Basilisk	21.4 ^{hijklm}	5.4 ^{efghijk}	450 ^{ijklmnop}	R	
		Cayman	0.3 ^w	0.0 ^x	0 ^v	R	
		Cobra	16.7 ^{klmnopq}	5.3 ^{efghijk}	400 ^{lmnopq}	R	
		Humidicola	3.3 ^{uvwx}	0.7 ^{vw}	50 ^{uv}	R	
		Marandu	20.6 ^{ijklmn}	5.4 ^{efghijk}	417 ^{klmnop}	R	
		MG4	18.3 ^{ijklmnop}	5.0 ^{efghijklm}	375 ^{lmnopqr}	R	
		Mulato II	11.7 ^{nopqrstu}	3.7 ^{klmnopq}	275 ^{opqrst}	R	
		Piata	20.0 ^{ijklmn}	6.0 ^{efghi}	463 ^{ijklmnop}	R	
		Xaraes	20.6 ^{ijklmn}	6.2 ^{efgh}	471 ^{ijklmnop}	R	
Third harvest		Basilisk	30.8 ^{efg}	6.2 ^{efgh}	725 ^{efgh}	R	
		Cayman	92.8 ^a	19.1 ^a	2 317 ^a	R	
		Cobra	79.2 ^b	16.3 ^b	2 029 ^b	R	
		Humidicola	3.3 ^{uvwx}	0.7 ^{vw}	50 ^{uv}	R	
		Marandu	45.0 ^d	9.0 ^d	1 142 ^d	R	
		MG4	20.0 ^{ijklmn}	4.0 ^{ijklmnop}	475 ^{ijklmnop}	R	
		Mulato II	64.2 ^c	13.0 ^c	1 583 ^c	R	
		Piata	56.7 ^c	13.3 ^c	1 517 ^c	R	
		Xaraes	28.6 ^{efghi}	5.7 ^{efghij}	804 ^e	R	
Source of variation			p-values				
Site			< 0.001	< 0.001	< 0.001		
Harvest			< 0.001	< 0.001	< 0.001		
Cultivar		< 0.001	< 0.001	< 0.001			
Site × harvest		< 0.001	< 0.001	< 0.001			
Site × cultivar		< 0.001	< 0.001	< 0.001			
Harvest × cultivar		< 0.001	< 0.001	< 0.001			
Site × harvest × cultivar		< 0.001	< 0.001	< 0.001			

AUDPC = Area under disease progress curve, and R = Resistant. Values with the same superscript letters within the columns are not statistically different at $p \leq 0.05$

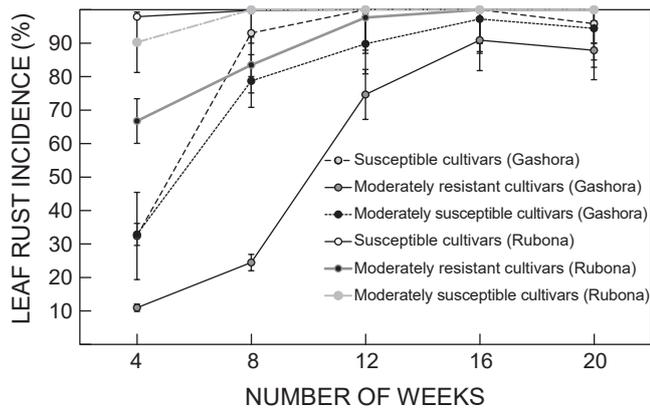


Figure 3: Leaf rust incidence over time (weeks) at Gashora and Rubona sites, Rwanda, in 2019 and 2020. All harvests were considered together and *Brachiaria* cultivars were grouped according to their response to the leaf rust disease as susceptible (Cobra and Cayman), moderately susceptible (Mulato II) and moderately resistant (Piata, Humidicola, Marandu, Basilisk, Xaraes and MG4). The values presented are average for the group, and error bars are mean standard errors

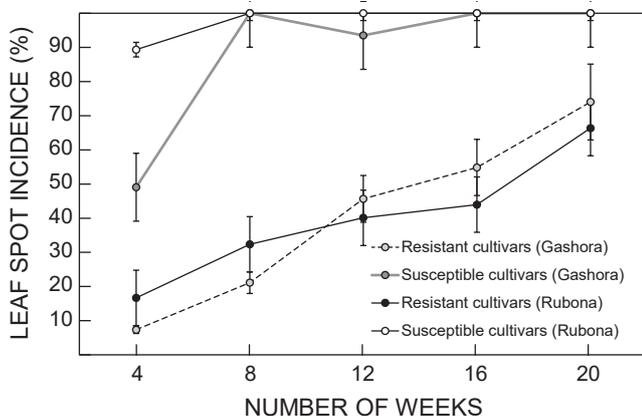


Figure 4: Leaf spot incidence over time (weeks) at Gashora and Rubona sites, Rwanda, in 2019 and 2020. All harvests are considered together and *Brachiaria* cultivars were grouped according to their response to the leaf spot disease as susceptible (Humidicola) and resistant (Piata, Cobra, Marandu, Basilisk, Xaraes, Cayman, Mulato II and MG4). The values presented are average for the group, and error bars are mean standard errors

Agronomic performance of the *Brachiaria* cultivars

The effects of cultivar, site, harvest, and their interactions were significant for plant height, number of tillers, dry biomass yield and dry matter content ($p \leq 0.001$; Table 6), except for the effect of site on dry matter yield ($p = 0.415$). Cayman plants were shorter (34.2 cm) in the second harvest at Rubona than Humidicola, Xaraes and Piata plants (102.8–107.6 cm) in the first harvest at Rubona. The number of tillers per stool among cultivars ranged from 33 (Xaraes) in first harvest at Gashora site to 299 (Humidicola) and 259 (Mulato II) in the third harvest at Rubona site. The dry biomass production ranged between 1.7 t ha⁻¹ (Humidicola at Gashora in the second harvest)

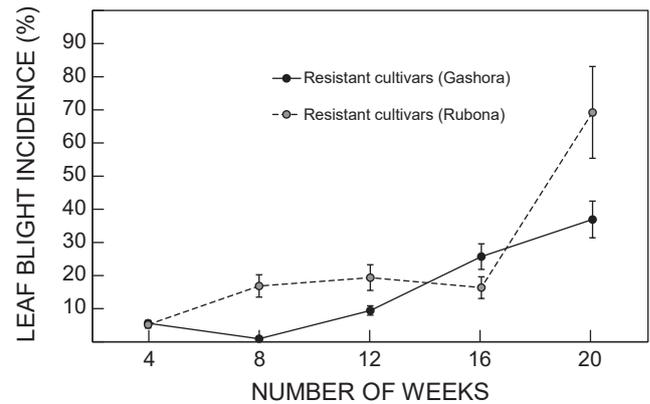


Figure 5: Leaf blight incidence over time (weeks) at Gashora and Rubona sites, Rwanda, in 2019 and 2020. All harvests were considered together and *Brachiaria* cultivars were grouped according to their response to the leaf blight disease as resistant (Piata, Cobra, Humidicola, Marandu, Basilisk, Xaraes, Cayman, Mulato II, MG4). The values presented are average for the group, and error bars are mean standard errors

and 20.1 t ha⁻¹ (Marandu in the first harvest at Rubona) and 20.2 t ha⁻¹ (Xaraes in the third harvest at Gashora). Cultivar Piata had the highest dry matter content in third harvest at Rubona. Cultivar Humidicola had the lowest dry matter content in the third harvest at Gashora.

Correlation between disease intensity and agronomic parameters

Pearson's correlation analysis revealed significant differences ($p \leq 0.05$; Table 7) between agronomic parameters (plant height, tiller number, dry matter yield and dry matter content) and the AUDPC for leaf rust, leaf spot and leaf blight diseases. There was a positive significant correlation of plant height and number of tillers with dry matter yield. Plant height was negatively correlated with number of tillers with no significance. A negative and significant correlation was found between plant height and AUDPCs for leaf rust and leaf blight diseases. A negative and significant correlation was observed between AUDPCs for leaf rust and leaf spot diseases and dry matter yield (Table 7).

Discussion

Diseases are one of the major biotic constraints limiting fodder production and qualities of *Brachiaria* grass with a negative impact on the forage availability and livestock production. Many diseases caused by fungi, bacteria and viruses have been reported on *Brachiaria* grass (Lenné 1990; Valerio et al. 1996; Nzioki et al. 2016; Uzayisenga et al. 2020). Some of these diseases have the potential to cause complete failure of the crop. Therefore, the sustainability of *Brachiaria* grass production in the tropics and subtropics depends on how effectively and economically these diseases are managed. Amongst various disease management methods, the use of resistant cultivars is an effective and least cost control measure

Table 6: Agronomic performance of nine improved *Brachiaria* cultivars at Gashora and Rubona, Rwanda, in 2019 and 2020

Site	Harvest	Cultivar	Plant height (cm)	Number of tillers stool ⁻¹	Dry matter yield (t ha ⁻¹)	Dry matter (%)
Gashora	First harvest	Basilisk	96.4 ^{bcd}	125 ^{klmnopq}	14.6 ^{abcdefghi}	41.3 ^{bcd}
		Cayman	76.3 ^{hijk}	96 ^{pqrst}	6.0 ^{nopqr}	40.5 ^{bcd}
		Cobra	79.9 ^{ghij}	164 ^{ghijkl}	11.7 ^{defghijklmn}	40.7 ^{bcd}
		Humidicola	85.8 ^{efgh}	42 ^{uv}	3.1 ^{qr}	37.6 ^{cdefghi}
		Marandu	84.4 ^{efghi}	66 ^{tuv}	15.1 ^{abcdefg}	38.3 ^{bcd}
		MG4	72.7 ^{klm}	75 ^{stuv}	8.0 ^{ijklmnopqr}	39.5 ^{bcd}
		Mulato II	62.0 ^{nopqrstu}	131 ^{klmnop}	13.4 ^{bcd}	39.3 ^{bcd}
		Piata	68.4 ^{klmn}	42 ^{uv}	7.1 ^{lmnopqr}	38.0 ^{cdefgh}
		Xaraes	67.3 ^{klmnop}	33 ^v	6.4 ^{mnopqr}	38.1 ^{bcd}
	Second harvest	Basilisk	63.3 ^{mnpqrst}	155 ^{ghijkl}	10.8 ^{efghijklmno}	38.3 ^{bcd}
		Cayman	40.9 ^{xy}	133 ^{klmnop}	9.3 ^{ghijklmnopq}	42.6 ^{abc}
		Cobra	39.7 ^{xy}	194 ^{defg}	15.6 ^{abc}	42.9 ^{abc}
		Humidicola	53.0 ^{uvw}	54 ^{uv}	1.7 ^r	29.6 ^{mno}
		Marandu	65.4 ^{mnpqr}	144 ^{hijklmn}	15.6 ^{abc}	34.4 ^{ghijklm}
		MG4	56.0 ^{rstuvw}	112 ^{mnpqr}	8.7 ^{ghijklmnopq}	32.0 ^{klmno}
		Mulato II	46.7 ^{wx}	217 ^{bcde}	18.7 ^{ab}	42.2 ^{abc}
		Piata	65.9 ^{lmnopq}	79 ^{rstu}	10.3 ^{efghijklmnop}	35.9 ^{efghij}
		Xaraes	68.7 ^{klmn}	97 ^{pqrst}	14.7 ^{abc}	34.5 ^{ghijklm}
	Third harvest	Basilisk	75.2 ^{ijkl}	144 ^{hijklmn}	7.1 ^{lmnopqr}	30.2 ^{lmno}
		Cayman	58.8 ^{opqrstuv}	132 ^{klmnop}	11.1 ^{efghijklmno}	30.5 ^{klmno}
		Cobra	58.4 ^{pqrstuv}	175 ^{efghij}	7.5 ^{klmnopqr}	31.4 ^{klmno}
		Humidicola	63.9 ^{mnpqrs}	73 ^{stuv}	3.8 ^{pqr}	27.0 ^o
		Marandu	88.2 ^{cdef}	141 ^{ijklmno}	17.2 ^{abcde}	30.0 ^{lmno}
		MG4	72.8 ^{klm}	107 ^{mnpqrst}	15.2 ^{abc}	31.7 ^{klmno}
		Mulato II	57.0 ^{qrstuv}	197 ^{defg}	10.4 ^{efghijklmno}	31.2 ^{klmno}
		Piata	91.9 ^{cde}	84 ^{qrstu}	14.2 ^{abc}	30.8 ^{klmno}
		Xaraes	86.4 ^{efg}	98 ^{pqrst}	20.2 ^a	28.5 ^{no}
Rubona	First harvest	Basilisk	86.8 ^{ef}	108 ^{mnpqrst}	12.8 ^{bcd}	36.1 ^{defghij}
		Cayman	80.1 ^{ghij}	97 ^{pqrst}	5.6 ^{nopqr}	37.6 ^{cdefghi}
		Cobra	68.1 ^{klmno}	134 ^{ijklmnop}	10.9 ^{efghijklmno}	39.4 ^{bcd}
		Humidicola	102.8 ^{ab}	109 ^{mnpqrs}	6.0 ^{nopqr}	37.5 ^{cdefghi}
		Marandu	97.3 ^{bc}	100 ^{opqrst}	20.1 ^a	33.1 ^{hijklmn}
		MG4	97.2 ^{bc}	98 ^{pqrst}	18.6 ^{abc}	37.7 ^{cdefghi}
		Mulato II	70.1 ^{klmn}	106 ^{nopqrst}	11.8 ^{defghijklmn}	35.8 ^{efghijk}
		Piata	107.6 ^a	73 ^{rstuv}	17.9 ^{abcd}	35.8 ^{efghijk}
		Xaraes	103.6 ^{ab}	68 ^{stuv}	18.2 ^{abcd}	34.6 ^{ghijklm}
	Second harvest	Basilisk	56.3 ^{rstuv}	183 ^{efghi}	14.0 ^{abc}	35.8 ^{efghijk}
		Cayman	34.2 ^y	122 ^{lmnopq}	3.5 ^{qr}	38.2 ^{bcd}
		Cobra	35.5 ^y	186 ^{efgh}	6.3 ^{mnpqr}	31.9 ^{klmno}
		Humidicola	75.9 ^{ijk}	192 ^{defg}	7.8 ^{ijklmnopqr}	40.4 ^{bcd}
		Marandu	55.0 ^{stuvw}	185 ^{efgh}	12.0 ^{defghijklmn}	30.9 ^{klmno}
		MG4	51.7 ^{wv}	166 ^{ghijk}	8.6 ^{ghijklmnopq}	33.1 ^{hijklmn}
		Mulato II	36.3 ^y	203 ^{def}	8.4 ^{hijklmnopqr}	30.4 ^{lmno}
		Piata	64.4 ^{mnpqrs}	136 ^{ijklmnop}	12.0 ^{cd}	38.4 ^{bcd}
		Xaraes	67.5 ^{klmnop}	123 ^{klmnopq}	11.8 ^{defghijklmn}	32.5 ^{ijklmno}
	Third harvest	Basilisk	64.4 ^{mnpqrs}	229 ^{bc}	11.9 ^{defghijklmn}	41.8 ^{abc}
		Cayman	52.6 ^{uvw}	148 ^{hijklm}	4.7 ^{opqr}	43.4 ^{ab}
		Cobra	56.7 ^{qrstuv}	213 ^{cde}	7.4 ^{klmnopqr}	38.5 ^{bcd}
		Humidicola	105.2 ^{ab}	299 ^a	8.7 ^{ghijklmnopq}	35.3 ^{ghijkl}
		Marandu	66.1 ^{lmnopq}	251 ^{bc}	15.0 ^{abc}	37.9 ^{cdefgh}
		MG4	64.5 ^{mnpqrs}	195 ^{defg}	10.6 ^{efghijklmno}	39.6 ^{bcd}
		Mulato II	54.0 ^{tuvw}	259 ^{ab}	10.4 ^{efghijklmnop}	39.0 ^{bcd}
		Piata	87.4 ^{def}	230 ^{bcd}	15.3 ^{abc}	47.0 ^a
		Xaraes	76.9 ^{ghijk}	203 ^{def}	14.4 ^{abc}	38.0 ^{cdefgh}
Source of variation			<i>p</i> -values			
Site		< 0.001	< 0.001	0.415	< 0.001	
Harvest		< 0.001	< 0.001	0.025	< 0.001	
Cultivar		< 0.001	< 0.001	< 0.001	< 0.001	
Site × harvest		< 0.001	< 0.001	< 0.001	< 0.001	
Site × cultivar		< 0.001	< 0.001	< 0.001	< 0.001	
Harvest × cultivar		< 0.001	< 0.001	< 0.001	< 0.001	
Site × harvest × cultivar		< 0.001	< 0.001	< 0.001	< 0.001	

Values with the same superscript letters within the columns are not statistically different at $p \leq 0.05$

Table 7: Pearson's correlation coefficients between agronomic parameters and AUDPC for three major foliar diseases of *Brachiaria* grass, Rwanda, in 2019 and 2020

	Plant height	Number of tillers stool ⁻¹	AUDPC leaf rust	AUDPC leaf spot	AUDPC leaf blight	Dry matter yield	Dry matter (%)
Plant height	1.000						
Number of tillers	-0.021	1.000					
AUDPC leaf rust	-0.295**	0.137**	1.000				
AUDPC leaf spot	0.037*	0.148**	-0.081**	1.000			
AUDPC leaf blight	-0.134**	0.178**	0.311**	0.085**	1.000		
Dry matter yield	0.284**	0.363**	-0.119**	-0.103**	-0.012 ^{ns}	1.000	
Dry matter (%)	-0.118**	-0.015 ^{ns}	0.194**	0.137**	0.171**	0.067**	1.000

** Correlation is significant at the 0.01 level (two-tailed), * Correlation is significant at the 0.05 level (two-tailed), ns = not significant at the 0.05 level (two-tailed), AUDPC = Area under disease progress curve. All cultivars, sites and harvests were considered together

that can be easily adopted by farmers, including resource-limited smallholder livestock keepers from the developing countries. In this study, we evaluated nine improved *Brachiaria* grass cultivars against three major foliar diseases, namely leaf rust, leaf spot and leaf blight, in two sites, each representing different agro-ecological zones of Rwanda for three consecutive harvests. In addition, each cultivar's agronomic performances were documented and relationships between diseases and selected agronomic traits were determined.

The *Brachiaria* grass cultivars evaluated in this study reacted differently to leaf rust, leaf spot and leaf blight diseases. Moreover, the interaction effect of cultivar × site × harvest was obvious on the foliar disease development. These results could be combined effects of (i) difference in the genetic background of cultivars, (ii) variation in the virulence level of pathogen, and (iii) the biophysical characteristics of experimental sites that support or limit the disease development (Agrios 2005). The observation that genotypes (e.g. Basilisk and Cobra) expressed symptoms of all three diseases may indicate the absence of host immunity against a specific fungus associated with each disease.

The effect of *Brachiaria* cultivar, experimental site and harvest, and interaction of cultivar × site × harvest on the foliar disease development were evident. Earlier studies reported the presence of susceptible and resistant traits in *Brachiaria* grass germplasms to leaf rust and foliar blight (Torres and Trutmann 1991; Alvarez et al. 2014), implying varying level of susceptibility to diseases among *Brachiaria* cultivars (Kamidi et al. 2016).

The evaluation of *B. brizantha*, *B. decumbens*, *B. dictyoneura* and *B. humidicola* accessions against leaf rust in two regions of Colombia indicated susceptibility of all cultivars, except *B. decumbens*, in both regions (Torres and Trutmann 1991). Surveillance of *Brachiaria* grass diseases in Kenya and Rwanda revealed differences in the level of disease development in a cultivar between study sites and season (Nzioki et al. 2016; Uzayisenga et al. 2020), ratifying the influence of the biophysical characteristics of test locations on the disease development.

Environmental factors played important roles in the initiation and development of diseases. Though the differences in mean temperature between experimental sites were minimal, there were noticeable differences between sites for rainfall. A significant variation in the incidence and severity of *Brachiaria* foliar diseases in

different districts of Rwanda with diverse agroclimatic conditions has been reported previously (Uzayisenga et al. 2020). A high level of leaf rust development at Rubona in this study could be associated with moist conditions, because of high and well distributed rainfall throughout the crop growing periods. Rubona received 1.65 times greater rainfall than Gashora during the wet to semi-dry season of 2019, as well as in the wet season of 2020. The effect of climatic variables, such as temperature and humidity on wheat rust disease development had been reported by Barrera et al. (2012) and Sandhu et al. (2017). The high incidence and severity of leaf rust and blight at Rubona could have been favoured by high rainfall regime that is associated with moist environment. On the contrary, the relatively dry weather at Gashora might have supported leaf spot disease development. High incidence and severity were registered as the week advanced and to some extent in the subsequent harvests. These findings suggest that continuous presence of a perennial crop like *Brachiaria* grass in the field favoured pathogen population build-up over seasons and occurrence of the disease early in the season affecting crop performance and yields. In most cultivars, leaf rust incidence declined after 16 weeks, which might be because of the removal of rust spores, and climatic conditions, including rain. Another probable reason is adult plant resistance to rust disease.

The *Brachiaria* cultivars Basilisk, Marandu, MG4, and Xaraes were moderately resistant to all three foliar diseases and they had higher biomass yields than other cultivars confirming their suitability for cultivation in wider geographical regions. The low level of leaf-blight-disease development in all cultivars could be because of a low natural disease pressure in experimental sites and/or presence of intrinsic resistance in some cultivars (Kelemu et al. 1995; Alvarez et al. 2014) that merits further investigation. Alternative disease management options for rust-susceptible cultivars that produced high dry matter content (e.g. Basilisk and Cobra in this study) can be another area for further investigation, because this trait has a significant role in feed availability and improving livestock productivity.

Significant negative correlation between AUDPC of foliage diseases and dry matter yield indicate negative impact of these diseases on herbage yield of improved *Brachiaria* cultivars. This might be attributed to the reduction of the photosynthetic area in the diseased leaf tissues as reported for wheat diseases (Kandel et al.

2014; Lamsal et al. 2017; Pandey et al. 2018), as well as pathogen's dependence on host for nutrients and water. We observed significant and negative correlation between leaf rust and foliar blight and plant height conferring the negative effect of diseases on plant growth and development. Other studies have also reported negative correlation between wheat spot blotch disease and plant height (Joshi et al. 2002; Rosyara et al. 2009; Neupane et al. 2013).

The use of *Brachiaria* grass for pasture improvement and ruminant feeding in Africa started through the introduction of improved cultivars and hybrids mostly from the South America (Maass et al. 2015; Njarui et al. 2016). Within a very short period, *Brachiaria* grass has become a forage of choice for many livestock farmers on the continent to address challenges, including shortage of livestock feeds, poor nutritive value of local forages, extended and frequent drought, and declining productivity of extensively cultivated Napier grass (Ghimire et al. 2015; Negawo et al. 2017). The importance of *Brachiaria* grass as an additional forage option in Sub Saharan Africa to improve livestock productivity through improving supply of quality herbage have been established recently (Mutimura et al. 2016; Njarui et al. 2016; Mutimura et al. 2018).

There are reports on attack of improved *Brachiaria* cultivars by multiple diseases caused by fungi, bacteria and viruses affecting the yields and qualities of forage and seed crops (Nzioki et al. 2016; Kamidi et al. 2016; Uzayisenga et al. 2020). There is a need to develop new cultivars with improved disease resistance qualities, exploring genetic diversity available in genebanks and natural populations preferably from East Africa, which is considered a centre of diversity of the genus *Brachiaria* (Keller-Grein et al. 1996).

Conclusion

This study revealed a wide variation in nine improved *Brachiaria* grass cultivars to leaf rust, leaf blight and leaf spot diseases in Rwanda. Besides variable responses to diseases, cultivars were also different for important agronomic traits, such as plant height, tiller numbers, biomass yield and dry biomass content. This study identified Basilisk, Marandu, MG4, and Xaraes as moderately resistant/resistant to all three foliar diseases and had high biomass yields. These cultivars are more appropriate for upscaling *Brachiaria* grass in wider geographical regions in Rwanda and neighbouring countries. There are reports available on the short life of disease-resistant cultivars of many agriculturally important crops; therefore, activities, such as periodic disease surveys, breeding new disease-resistant cultivars and development of other disease management options, should be given high priority for effective and sustainable management of *Brachiaria* grass diseases.

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