Importance of Grazing Management in Improving Water Use Efficiency of Tropical Forage Grasses

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Key words: Drought management; livestock intensification; rotational grazing

Abstract
The growing number of extreme weather events has created the need to identify tropical forage grasses with greater water use efficiency (WUE) to cope with water-limited conditions. WUE can be defined as the ratio of forage biomass produced per unit of water used. However, WUE is a dynamic ratio that changes according to environmental gradients (e.g., water or nutrient availability) or ontogenetic drift (e.g., changes in root to shoot biomass allocation across phenological stages). Furthermore, genetic improvement leading to greater WUE is likely to result in smaller plants that produce less than the required forage biomass to sustain good animal performance. Bearing that in mind, other alternatives for improving WUE must be taken into consideration. Grazing management is one among such alternatives. Results from a greenhouse experiment conducted with a number of forage grasses (*Cenchrus ciliaris, Chloris gayana*, *Megathyrsus maximus*, *Urochloa* spp.) at the Alliance of Bioversity-CIAT showed that different grazing intensities lead to various WUEs. Improved WUE values in grasses can be achieved through grazing management if it moderates the process of evapotranspiration by 1) reducing leaf area per plant; and 2) maintaining soil cover from pasture growth and productivity. Our results suggest that WUE in pastures planted with tropical forage grasses can be enhanced through moderate rotational grazing.

Introduction
Climate change and associated extreme weather events bring uncertainty about the timing and frequency of future drought events across the globe (IPCC 2014). In the American tropics, livestock production is mostly based on pastures planted with grasses of African origin. Productivity of these grasses, and thereby that of livestock, is markedly reduced by drought. As a result, increasing efforts to identify tropical forage grasses with greater drought resistance are underway (Cardoso and Rao, 2019). Greater water use efficiency (WUE) is one of the plant traits sought to increase resistance to drought conditions. WUE can be defined as the ratio of forage biomass produced per unit of water used. However, WUE is a dynamic ratio that changes according to environmental gradients (e.g., water or nutrient availability) or ontogenetic drift (e.g., changes in root to shoot biomass allocation across phenological stages). Furthermore, genetic improvement leading to greater WUE is likely to result in smaller plants that produce less than the required forage biomass to sustain good animal performance. Since forage yield is of great importance for livestock production, other alternatives for increasing WUE must be taken into consideration. Grazing management of pastures planted with tropical forage grasses can improve WUE values if it moderates the process of evapotranspiration by 1) reducing leaf area per plant; and 2) maintaining soil cover from pasture growth and productivity (Sollenberger et al., 2019).

Rotational grazing is a type of grazing management that allows producers to manipulate the amount of available forage biomass to feed livestock. Available forage biomass greatly influences the amount of water used by the plant at any given time. That is, the greater the forage surface area, the more water extracted from soil and lost through the process of plant transpiration. Rotational grazing offers a way to manage water available in the system by controlling the growth (size) of the plant. Because of actively managing plant size by grazing, any water saved and not used by the plant might remain to be stored in soil. Such water stored in soil might contribute to sustain forage productivity under drought conditions.

The objective of this work was therefore to study changes in WUE by simulated grazing under greenhouse conditions in a set of forage grasses commonly used in the tropics (*Cenchrus ciliaris*, *Chloris gayana*, *Megathyrsus maximus*, *Urochloa* spp.). For that purpose, three rotational grazing methods (low, moderate and heavy) were simulated at different intervals for 100 days under two watering scenarios (well-watered and water-limited conditions). This information should help to guide decisions about grazing management with the aim to increase WUE of pastures.

Methods and Study Site
The establishment, growing conditions, harvesting of plants and determination of WUE of plants used in the present experiment were previously described by Cardoso et al. (2015). The trial was carried out in a greenhouse at the regional office for the Americas of the Alliance Bioversity-CIAT (ABC) in Palmira,

Colombia (latitude 3 ° 29 'N; longitude 76 ° 21 'W; altitude 965 m). The soil used in this study to fill lysimeters (120 cm height x 7.5 cm diameter) was a Mollisol collected at ABC facilities at 0–0.20 m from the soil surface, and the soil was sieved to pass a 2 mm mesh. Plant material consisted of seven genotypes of different forage grasses. The genotypes studied were *Urochloa humidicola* cv. Tully, *U. brizantha* cv. Piata, *U.* hybrid cv. Mulato II, *Megathyrsus maximus* cvv. Mombaza and Sabanera, *Chloris gayana* ILRI-645, and *Cenchrus ciliaris* ILRI-10097. Three simulated grazing treatments were imposed to plants: low, moderate and intensive grazing. Low grazing consisted of clipping plants to a height of 20 cm above soil surface. Moderate grazing: plants clipped to a height of 10 cm. Intensive grazing: plants clipped to a height of 2 cm. Low and moderate grazing were performed every 20 days, while intensive grazing was performed every 25 days for 100 days under well-watered conditions (soil kept at field capacity). The same grazing treatments were repeated on the same plants but under water-limited conditions (soil kept at 50% of field capacity) for another 100 days. Prior to harvest, leaf rolling scores were recorded as described in Cardoso et al. (2015) and any dead leaf material was separated and its mass recorded. Leaf rolling scores were recorded on a scale from 1 to 5, where 1 is absence of rolling and 5 is fully rolled leaves with their tips burned. The trial was organized as a factorial combination of seven genotypes by three grazing intensities (low, moderate and high) in a four-replicate complete randomized block. All statistical analyses were performed in R software (v 2.15.2). The data were analyzed using two-way ANOVA and post-hoc analyses (Duncan).

Results

Our results showed significant genotypic differences in forage biomass accumulation under three grazing intensities in well-watered and water-limiting conditions (Table 1). Overall, there was more forage accumulation under low grazing intensity and well-watered conditions (Table 1). The lowest forage accumulation was under heavy grazing and water-limited conditions (Table 1). WUE was not significantly different under three grazing intensities in well-watered conditions (Table 2). Under water-limiting conditions, WUE values were significantly different among the three grazing intensities (Table 2). All genotypes tested under water-limiting conditions showed the greatest WUE with moderate grazing treatment (Table 2). Under well-watered conditions, there were no major symptoms of stress. Under limited water conditions, plants that were subjected to low grazing intensity showed greatest symptoms of stress (i.e., greater leaf rolling scores and dead leaf tissue)

Table 1. Cumulative dry mass production of seven tropical forage grasses over a period of 100 days under different grazing intensities and watering conditions. Data shown are means of four replicates of plants evaluated under greenhouse conditions. Different letters represent statistical differences at $\alpha = 0.05$.

	Dry mass forage (g plant^{-1})					
	Well-watered			Water-limited		
	Grazing intensity			Grazing Intensity		
	Low	Moderate	High	Low	Moderate	High
U. humidicola cv. Tully	39.8bc	32.3b	30.3b	22.3b	24.7bc	14.1a
M. maximus cv. Sabanera	83.5g	67.5e	62.2e	30.1bc	43.6d	22.5a
M. maximus cv. Mombaza	99.1h	81.9g	75.5f	29.7bc	47.5e	21.5b
C. gayana ILRI-645	67.7e	53.1d	47.9cd	26.1c	37.0d	25.7c
U. brizantha cv. Piata	55.8d	47.7cd	44.1c	28.4c	36.4d	23.8c
U. hybrid cv. Mulato II	54.5d	50.7d	41.8c	29.9bc	37.1d	25.6bc
C. ciliaris ILRI-10097	33.2b	27.0a	24.5a	19.1ab	24.7bc	18.3ab
Average	60.5e	51.5d	46.6c	26.5c	35.9d	21.6ab

Table 2. Water use efficiency of seven tropical forage grasses over a period of 100 days under different grazing intensities and watering conditions. Data shown are means of four replicates of plants evaluated under greenhouse conditions. Different letters represent statistical differences at $\alpha = 0.05$.

	Water Use Efficiency (g plant biomass/liter of water consumed)					
	Well-watered			Water-limited		
	Grazing intensity			Grazing Intensity		
	Low	Moderate	High	Low	Moderate	High
U. humidicola cv. Tully	6.0abc	6.2abc	5.8ab	2.2c	3.2e	2.7d
M. maximus cv. Sabanera	5.3a	5.5a	5.4a	2.0bc	3.0de	1.1a
M. maximus cv. Mombaza	5.5a	5.4a	5.5a	1.5ab	2.5cd	1.4ab
C. gayana ILRI-645	5.9ab	5.9ab	6.0abc	1.5ab	2.5cd	1.0a
U. brizantha cv. Piata	6.3bcd	6.8cd	6.5bcd	2.5cd	3.5ef	1.0a
U. hybrid cv. Mulato II	5.9ab	6.0abc	5.9ab	1.8bc	2.8d	1.5ab
C. ciliaris ILRI-10097	6.7cd	7.1d	7.4d	3.1de	4.1g	3.1de
Average	5.9ab	6.1abc	6.1abc	2.1c	3.1e	1.7b

Table 3. Leaf rolling scores and dead leaf dry mass of seven tropical forage grasses over a period of 100 days under different grazing intensities and water-limiting conditions. Data shown are means of four replicates of plants evaluated under greenhouse conditions. Different letters represent statistical differences at $\alpha = 0.05$.

	Leaf rolling scores			Dead leaf dry mass (g plant^{-1})		
	Water-limited			Water-limited		
	Grazing intensity			Grazing Intensity		
	Low	Moderate	High	Low	Moderate	High
U. humidicola cv. Tully	3c	1a	1a	2.6e	0.4ab	0.3a
M. maximus cv. Sabanera	5e	2b	3c	3.2g	0.3a	0.2a
M. maximus cv. Mombaza	5e	2b	3c	5.1f	1.2c	1.0c
C. gayana ILRI-645	5e	2b	2b	2.4e	1.1c	0.5ab
U. brizantha cv. Piata	4d	2b	3c	0.8bc	0.3a	0.3a
U. hybrid cv. Mulato II	4d	2b	3c	1.4cd	0.5ab	0.2a
C. ciliaris ILRI-10097	3c	1a	2b	0.5ab	0.1a	0.1a
Average	4d	2b	2.4b	2.3e	0.6ab	0.4ab

Discussion

Our results showed that simulated grazing had an effect in WUE values of forages. This study indicated that WUE efficiency of forages can be improved by the managing leaf area size (to reduce transpiration, yet covering enough soil surface to prevent water losses from evaporation alone). Such combination was achieved by moderate grazing and its relevance was highlighted under water-limiting conditions (Table 2). In contrast, plants under low grazing intensity rapidly consumed the water stored in soil, leading to earlier symptoms of stress (more leaf rolling and leaf senescence) under water-limiting conditions (Table 3). Heavy grazing in water-limiting conditions caused no major symptoms of stress (low levels of leaf rolling and leaf senescence), but resulted in lower biomass yield (Tables 1 and 2). Our results suggest that moderate grazing management shows promise for mitigating the impacts of drought events and improve resiliency of pastures planted with tropical grasses. Further research is needed to test our results under field conditions.

Acknowledgements
This work was done as part of the CGIAR Research Program on Livestock. We thank all donors that globally support our work through their contributions to the CGIAR system.

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