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ARTICLE

Morphometric Attributes of Two Native Forage Species According to Water Source Distance in Semiarid Central Grasslands of Argentina

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ABSTRACT

The semiarid grasslands of Argentina's central region have been modified by domestic livestock grazing, both in their composition and structure. The increase in the proportion of woody and non-forage species and the decrease in forage species are some of the most evident results of this process. There is limited available information about the effect of differential grazing pressures on morphometric attributes of native species, and it also depends on the life histories of the species in this grassland. The objective of this work was to evaluate some morphometric aspects in the grasses *Poa ligularis* Nees ex Steud and *Piptochaetium napostaense* (Speg.). Hack according to distance from the water source in communities in the central semiarid region of Argentina. The study area included areas of low grassland, golden forests, and secondary forests in grasslands (6 fields with 9 paddocks). Grazing pressure was established based on the distance to the water source, so sampling areas were designated near the water source (grazing pressure is greater) and far from the water source (grazing pressure light) in each of the pastures. In both species, specimens were selected at random, and the following attributes were measured: crown diameter at ground level (cm), burial depth (cm), average tiller weight per plant (g. Marcello^{-1}), and the density of tillers per unit of crown surface (tillers.cm^{-2} crown). The morphometric attributes evaluated showed differences according to the distance to the watering hole and in the different pastures. Both species presented similar behaviors for the attributes. There were significant differences in the depth of burial and the average weight of tillers per plant, being greater in the areas close to the water source. Regarding the distance to the watering hole, there were no significant differences in crown diameter and tiller density, but the highest values were recorded for the former near the watering hole and for the second far from the watering hole. In pastures with low grassland or secondary forest on the plain, the greatest depth of burial and weight of tillers was recorded closer to the water. In forest areas, the highest density of tillers was found far from the water. For crown diameter, although there was no interaction, the largest diameters were found in plain grassland areas near the waterhole. In general, both species had a differential behavior depending on the grazing pressure that was evident along the physiognomic gradient from plain grassland to forest and that could be interpreted as a strategy to perpetuate themselves against herbivory.

KEYWORDS

Grazing pressure; tiller density; tiller weight; crown burial depth; *Poa ligularis*; *Piptochaetium napostaense*

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1 Introduction

The plant communities of the central semiarid region of Argentina have been modified by domestic livestock grazing, both in their composition and structure [1–3]. Processes such as a woody species increase in the intermediate strata of the golden woodland, the advance of these species in the low grasslands, a non-forage species increase in the grassy-herbaceous layer and different desertification levels are the result of a non-conservative use history [1,4–7]. The most notable consequence was a livestock receptivity loss of the system, with a strong decrease in the forage species productivity in the grassy-herbaceous stratum [8].

In these semi-arid environments, water availability is an important limitation of livestock production that has conditioned the paddock size depending on the location of the water source [3,9]. The technologies associated with grazing management (fencing, water sources, firebreaks) have also contributed to a heterogeneous use of grasslands, concentrating pressure in areas near the water sources [10–13]. In addition, inadequate stocking rate has been another factor that has affected the production of these systems due to excessive or insufficient grazing [1,14]. In this way, two of the main forage species such as *Poa ligularis* Nees ex Steud and *Piptochaetium napostaense* (Speg.) Hack have had different degrees of grazing pressure according to their location in the paddock [15,16]. These C3 species, characteristic of winter grasslands, allow also for use in autumn and early spring and represent two of the species with the highest forage value in the region [17,18].

New management proposals aimed at rehabilitating grasslands have led to the use of smaller paddocks, with a better distribution of water sources, high-density rotational grazing, and extended no-grazing periods for grassland species [19].

There is limited available information about the effect of differential grazing pressures on morphometric attributes of native species, and it also depends on the life histories of the species in this grassland. In the field, it is common to observe differences in the structure of plants in grazed areas compared to non-grazed ones [20,21]. In this sense, it is known that the grasses of this region have not evolved with a strong herbivory interaction [22–25].

Therefore, when thinking about this interaction, trade-offs appear in the allocation of resources towards aerial parts (intercalary, axillary, and apical meristems) and underground parts (roots and modified leaves) [26–31] in response to a recent story. In this regard, an essential part of grasses is the crown that gathers the buds that will give rise to tillering. The degree of grazing could then determine whether there is a mobilization of photoassimilates from them to the aerial meristems or whether there is a contribution to the root system [16,32]. The distance to the water source would then be a gradient that expresses differential grazing pressure in these systems, so it would be expected to find differences in the architecture of the forage species throughout it.

The objective of this work was to evaluate some morphometric aspects of two winter foraging species in communities of the central semiarid region of Argentina in areas near and far from the water source. This was achieved from the evaluation of the crown diameter, weight, and density of tillers and the depth of crown burial of *Poa ligularis* and *Piptochaetium napostaense* in low grasslands, and the grassy-herbaceous layer of golden woodland.

2 Materials and Methods

2.1 Study Site

This study was carried out in representative sites of the calden woodland and low grasslands, located in the Central-Northern of La Pampa Province in Central Argentina (Fig. 1). It occupies the subregion of hills and valleys in the Eastern physiographic region The region's climate is temperate-semi-arid with rainfall ranging from 400 to 600 mm mainly concentrated in the summer-autumn season. The average annual temperature ranges around 15°C. As for the relief, it ranges from undulating to hilly with predominantly Entic Haplustollsoils and Typic Ustipsamments [21].

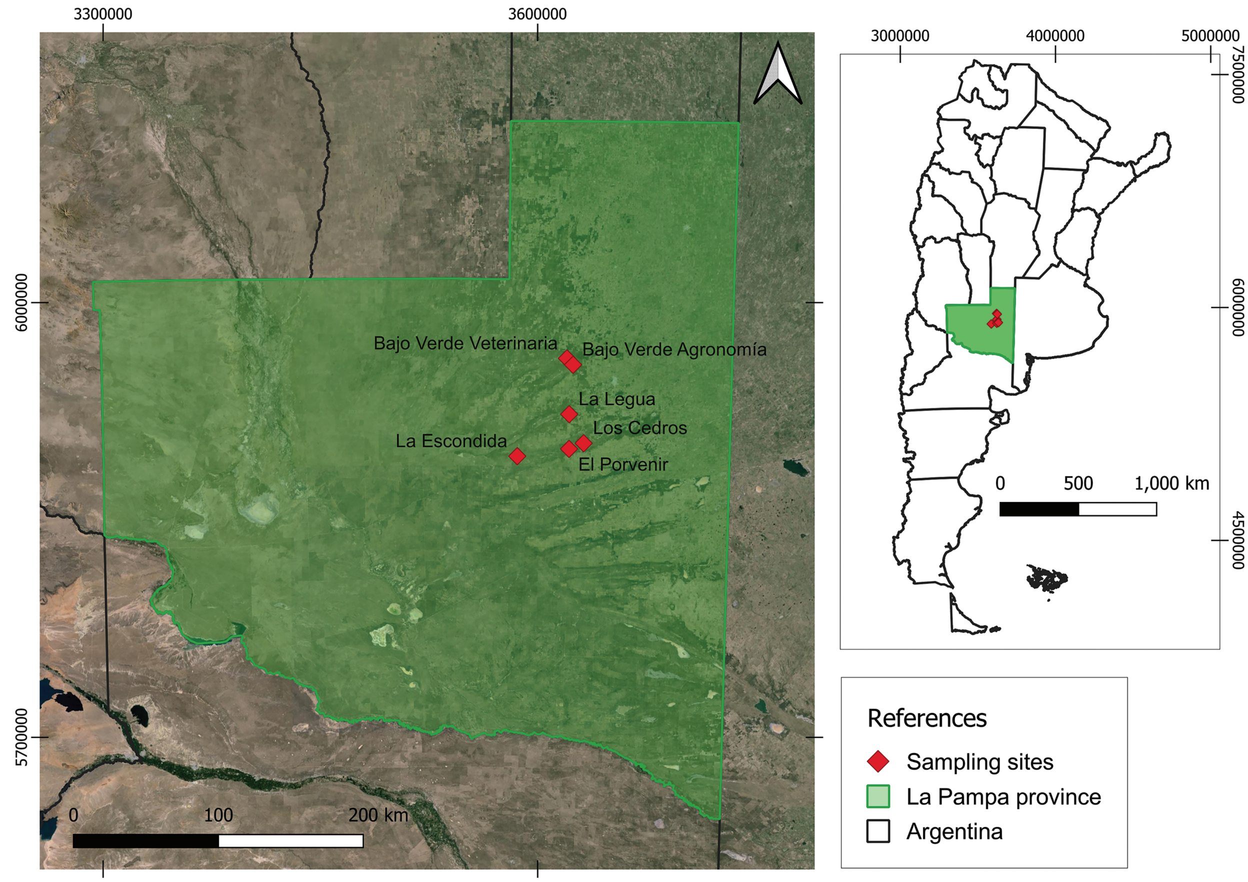

Figure 1: Study area. Location of the establishments where the sampling was carried out. Note: La Legua 1 and 2: LG1 and 2; Bajo Verde Agronomía 1 and 2: BVA1 and 2; Bajo Verde Veterinaria 1 and 2: BVV1; El Porvenir: EP; Los Cedros: LC and La Escondida: LE

The study area included low grassland areas (La Legua 1-LG1; La Legua 2-LG2), calden woodlands (Bajo Verde Agronomía 2-BVA2; Bajo Verde Veterinaria 1 and 2-BVV1 and 2; El Porvenir-EP) and secondary woodlands on grasslands (Bajo Verde Agronomía 1-BVA1; Los Cedros-LC; La Escondida-LE) (Table 1). These communities share practically the same species with profound changes mainly in the vertical structure. The grassy-herbaceous layer in general was characterized by forage species such as the *P. napostaense*, *P. ligularis*, and non-forage them as *Nassella tenuissima* (Trin.) Barkworth, *Jarava ichu* Ruiz & Pav. and *Amelichloa brachychaeta* Godr. Regarding the woodland physiognomy, the main species is *Neltuma caldenia* (Burkart) C.E. Hughes & G.P. Lewis and other accompanying species are *Geoffroea decorticans* Burkart, *Schinus fasciculatus* (Griseb.) I.M. Johnst and *Jodina rhombifolia* (Hook. & Arn.) Reissek, with variants in the development of the vertical structure and greater contribution of the intermediate woody layer in the secondary woodlands on the grasslands where juvenile *N. caldenia* trees predominate.

Table 1: Physiognomy of the plant communities within the study area, brief characterization of each one and names (with their abbreviations) of the establishments selected for sampling

Community's physiognomy	Vertical structure and floristic composition	Establishment paddocks
Low grassland	One-two layers, with shrub-tree coverage of up to 15% and calden specimens with heights of up to 4 meters. Grassy-herbaceous layer with low contribution of non-forage species.	La Legua 1–LG1 La Legua 2–LG2
Calden woodland	Three-four layers, tree cover between 50%–70% and height of calden specimens up to 8 meters. Mixed grass-herbaceous layer.	Bajo Verde Agronomía 2–BVA2 Bajo Verde Veterinaria 1–BVV1 Bajo Verde Veterinaria 2–BVV2 El Porvenir-EP
Secondary calden woodlands on grasslands areas	Two-three layers, coverage of shoots/young trees of up to 65%, they do not exceed 3 meters in height. Variable grassy-herbaceous layer.	Bajo Verde Agronomía 1–BVA1 Los Cedros–LC La Escondida-LE

2.2 Location of the Sampling Areas

The study was conducted across 6 establishments (Fig. 1) where 9 paddocks of over 50–100 hectares were selected with a similar use history (rotational grazing in the last 15 years). Grazing pressure was established based on the distance to the water source; thus, sampling areas were designated near the water source (grazing pressure is higher), close, approximately 75 meters from the water source and far, approximately 1000 meters or more from the water source, where livestock rarely come to graze. We worked with two species *P. ligularis* (Pli) and *P. napostaense* (Pna) due to their importance in terms of forage quality and contribution to the grass-herbaceous stratum. The 6 establishments were dedicated to raising cattle and the average stocking rate of each of the fields was around 0.2 $UG.ha^{-1}$.

2.3 Sampling Design

In each paddock and for each situation (near and far from the watering hole), 21 specimens of each species were randomly collected (n = 42; N = 378). At the beginning of autumn 2017, the crown diameter (CD) at ground level (cm) and burial depth (CBD) being the distance from the base where the roots are inserted to the point where the plant emerges from the soil surface (cm) were measured in the field [32]. The collected material was prepared in the laboratory for the determination of the tillers weight average (TW) per plant ($g.tillers^{-1}$) and the tillers density (TD) per unit of crown surface ($tillers.cm^{-2}$ crown) for each specimen.

2.4 Statistical Analysis

The data were analyzed using Generalized Linear Mixed Models with a comparison of means using the LSD method. For the selection of the models, the AIC value was considered, using the model that minimizes said index. The assumptions of normality and homoscedasticity were checked; when necessary, heteroskedastic models (TD and CD) were adjusted. Principal component analysis (PCA) and cluster analysis (average linkage, euclidean distance) were performed for both species according to sampling sites and attributes. The statistical packages Infostat version 2018 [33].

3 Results

The morphometric attributes evaluated showed differences according to the distance to the water source and in the different paddocks. In terms of the distance to the water source, there were significant differences for both species in the CBD ($p_{Pliv} < 0.0001$; $p_{Pna} < 0.0001$) and in the TW average per plant ($p_{Pli} = 0.023$; $p_{Pna} = 0.01$), being greater in nearby areas (Table 2). Although there were no significant differences for CD ($p_{Pli} = 0.1686$; $p_{Pna} = 0.518$) and TD ($p_{Pli} = 0.3470$; $p_{Pna} = 0.232$), the highest values were recorded for the first one near the water source and for the second far from it.

Table 2: Summary measurements of the evaluated attributes (mean, minimum and maximum values, and standard deviation) according to water source distance for *Poa ligularis* and *Piptochaetium napostaense*

Attributes	Water source distance	Summary measures	*Poa ligularis*	*Piptochaetium napostaense*
Crown burial depth: CBD (cm)	Near	Mean	3.68 a	2.49 a
		Min/max	1–6.5	1–5
		SD	±0.97	±0.61
	Far	Mean	3.07 b	2 b
		Min/max	1.5–7.5	1–3.7
		SD	±0.82	±0.53
Crown diameter: CD (cm)	Near	Mean	4.32 a	4.51 a
		Min/max	0.9–12.5	1–12.5
		SD	±1.93	±2.01
	Far	Mean	4.12 a	4.42 a
		Min/max	0.9–9	1–9.5
		SD	±1.65	±1.62
Average tiller weight per plant: TW (gr.tiller^{-1})	Near	Mean	0.17 a	0.08 a
		Min/max	0.05–0.46	0.02–0.27
		SD	±0.09	±0.04
	Far	Mean	0.16 b	0.077 b
		Min/max	0.06–0.38	0.03–0.21
		SD	±0.06	±0.02
Average tiller density per unit of crown surface: TD (tillers.cm^{-2})	Near	Mean	2.69 a	3.54 a
		Min/max	0.9–7.1	0.6–6.4
		SD	±1	±1.4
	Far	Mean	2.77 a	4.07 a
		Min/max	0.8–6.2	1–9.5
		SD	±0.9	±1.51

Note: CBD: crown burial depth; CD: crown diameter; TW: average tiller weight per plant; TD: average tiller density per unit of crown surface. Different letters indicate significant differences according to water source distance within the same attribute ($p < 0.05$).

Both species presented similar behaviors for the attributes, however Pli presented a greater depth of CBD and a greater TW average both near and far from the water source. While Pna presented higher TD also for near and far de water source.

Regarding the paddocks, all the measured attributes presented significant differences for both species ($p_{Pli} < 0.0001$; $p_{Pna} < 0.0001$). There was an interaction between paddocks and the water source distance in the TW average, CBD and TD per plant ($p_{Pli} < 0.0001$; $p_{Pna} < 0.0001$). Specifically, in paddocks with low grassland or secondary woodland in grasslands, the greatest CBD ($_{Pli}$ = 4.83 cm; $_{Pna}$ = 3.40 cm) and TW ($_{Pli}$ = 0.31 g. tiller^{-1}; $_{Pna}$ = 0.16 g.tiller^{-1}) were found near the water source. In woodlands areas, the highest TD ($_{Pli}$ = 3.71 tiller.cm^{-2}; $_{Pna}$ = 4.54 tiller.cm^{-2}) was found far from the water source. For CD, although there was no interaction ($p_{Pli} = 0.1919$; $p_{Pna} = 0.2437$), the largest diameters were found in areas of low grassland near the water source ($_{Pli}$ = 6.75 cm; $_{Pna}$ = 7.03 cm).

From the cluster classification analysis, two groupings were identified (Fig. 2). A first group contemplates the paddocks with physiognomy of low grassland and secondary woodlands on the grasslands in areas near the water source and the second group includes the secondary woodlands on the grasslands far from the waterhole and the rest of the paddocks with woodland physiognomy.

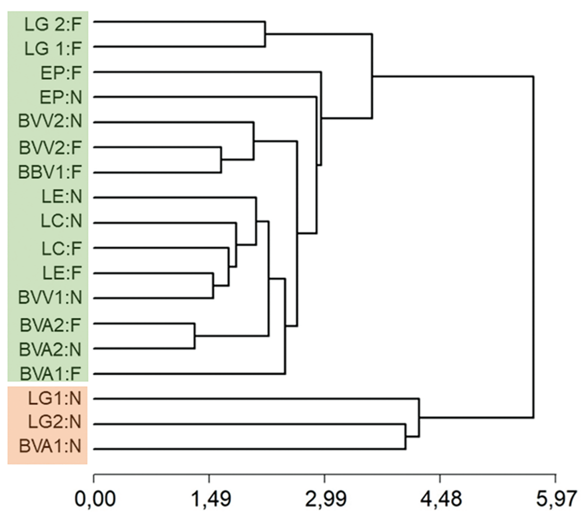

Figure 2: Cluster analysis. Cluster with the morphometric attributes crown burial depth; average tiller weight per plant; average tiller density per unit of crown surface of *Poa ligularis* and *Piptochaetium napostaense* together according to water source distance and pastures. Cophenetic correlation: 0.887. Note: LG1 and 2: La Legua 1 and 2 (Low grassland); BVA2: Bajo Verde Agronomía 2; BVV1 and 2: Bajo Verde Veterinaria 1 and 2; EP: El Porvenir (Calden woodland); BVA1: Bajo Verde Agronomía 1; LC: Los Cedros; LE: La Escondida (Secondary calden woodland on grassland areas). N: near water source and F: far from the water source. The two groups are indicated in different colours

The PCA showed the distribution and relationship between the attributes of both species and the paddocks according to the water source distance (explained 75.9% of the variance; axis 1: 58.4% and axis 2: 17.5%). The first axis allowed to distinguish the paddocks with the physiognomy of low grassland and secondary woodland on grasslands from those with a physiognomy of woodland (Table 1). The second axis provided information regarding the distance to the water source (Fig. 3). In this way, the paddocks with low grassland and some secondary woodlands on grasslands near the water source were characterized by the greatest CBD, TW and CD; while the remaining paddocks with secondary woodland on grassland and woodlands had higher TD.

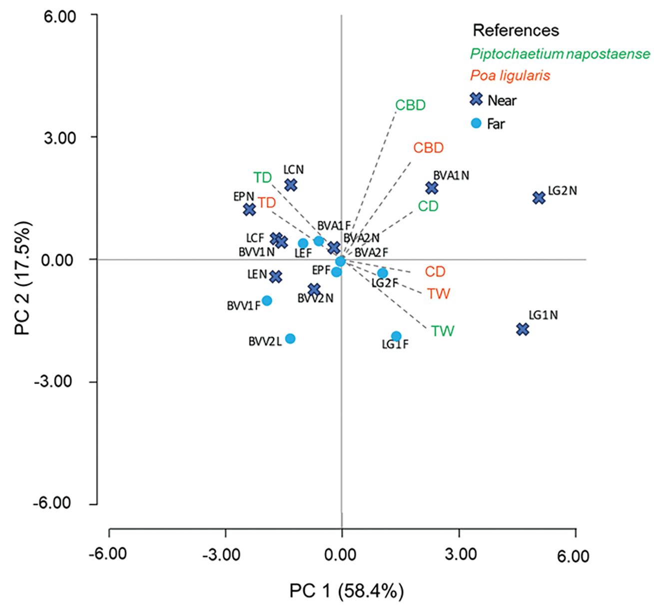

Figure 3: Principal component analysis for different attributes of *Poa ligularis* and *Piptochaetium napostaense*. Note: LG1 and 2: La Legua 1 and 2 (Low grassland); BVA2: Bajo Verde Agronomía 2; BVV1 and 2: Bajo Verde Veterinaria 1 and 2; EP: El Porvenir (Calden woodland); BVA1: Bajo Verde Agronomía 1; LC: Los Cedros; LE: La Escondida (Secondary calden woodland on grassland areas). N: near water source; F: far water source. CBD: crown burial depth; CD: crown diameter; TW: average tiller weight per plant; TD: average tiller density per unit of crown surface (Explained 75.9% of the variance)

4 Discussion

The grasslands forage species of the central semiarid region of Argentina, unlike what occurs in other grasslands in the world, have evolved with low grazing pressure exerted by a few species of wild herbivores [22,23]. In the last century, the introduction of domestic livestock has increased grazing pressure with effects on species of these grasslands that are still unclear.

Somehow these species persist in many of these systems although with variable coverage. The results obtained in this work show changes in the architecture of the species in response to grazing pressure in the different systems.

Near the water source, the widespread effect of herbivory is observed not only in overgrazing but also in greater trampling, excrement, and nutrient concentration [11,12,34,35] that generate differential environments. In this regard, in these situations, plants rarely achieve the complete life cycle and are in almost permanent tissue regeneration. Grazing causes the mobilization of reserves within the plant from the underground part to the aerial part for a short time [36], long enough to initiate self-sufficiency in photoassimilates. This produces an initial vigor in the plants that could lead to local extinction depending on how recurrent the grazing is, the intensity and the accompanying environmental factors. Pli and Pna are two species highly selected by domestic livestock that tend to disappear under conditions of high grazing under grazing pressure [37–42].

In this work, it was observed that in places with greater grazing pressure, these species were found more buried, results that coincide with others carried out in the same region [15,32]. Furthermore, this greater depth coincided with a greater tiller weight. In some way, this highlights that individuals must choose between investing in continuous regrowth or improving root growth and bud protection to avoid extinction, at least locally.

The existing information on the physiological aspects accompanying trade-offs in resource allocation is scant and sometimes contradictory. For example, Souto et al. [39] mention for Pli that a high frequency of defoliation can increase the death of buds at the base of the stems, which could explain the low density of tillers that was found in areas near the water source areas. However, authors such as Gastal et al. [43] and Assuero et al. [31] mention a higher density of tillers in grass species with a high rate of leaf renewal or with greater grazing pressure, respectively. This demonstrates the variability that exists in terms of the response to grazing depending on the species considered.

In terms of the crown burial depth in response to frequent defoliation, it could be interpreted as a storage strategy for reallocating reserves to a few tillers capable of reaching reproductive stages [44] serving as a last chance for self-perpetuation. This is supported by the tiller weight observed in this study, which was greater in individuals with lower tiller density. In this regard, authors have reported higher growth rates and biomass production per tiller in those with greater weight and lower tiller density per plant [45–48].

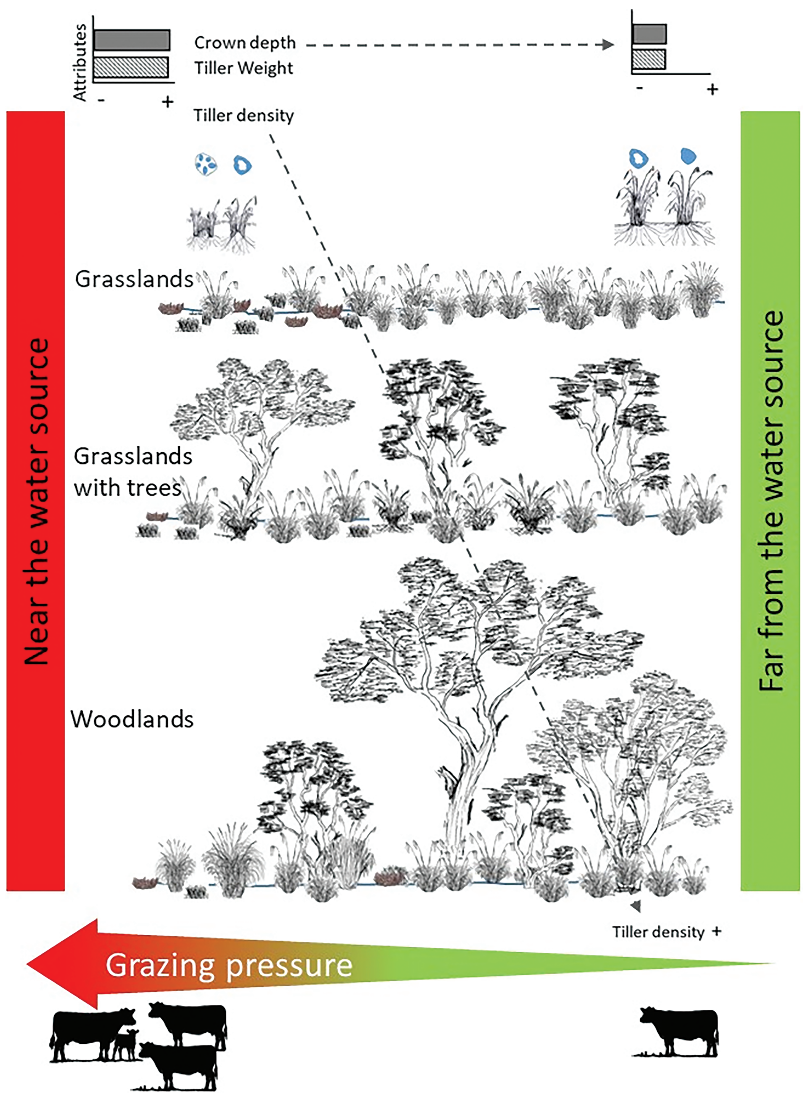

Figure 4: Conceptual model on the morphometric attributes of *Poa ligularis* and *Piptochaetium napostaense* according to distance from the water source

Regarding crown diameter, its variability can be attributed to the effect that recent grazing (time elapsed) has on this attribute, which masks the effect of the water source distance. The tillering dynamics in these grasses is centrifugal with the presence of senescent material in the center and active tillers on the periphery. This is true for both grazed and ungrazed plants, however, in the former, the action of the recurring cut causes different stages of separation to occur at the same diameter until they become independent plants [29].

Finally, overall, both species exhibited differential behavior in response to grazing pressure, which was evident across the physiognomic gradient from low grasslands to woodland (Fig. 4). In this sense, changes in the communities' vertical structure seem to be an important component in the livestock behavior reflected in grazing pressure [6]. In this way, grassland environments have a greater stocking rate concentration around the water, with limited movement and use of the most distant areas [11,13]. In contrast, in communities with woody cover and good accessibility, the spatial heterogeneity given by forage and non-forage patches would promote livestock dispersion in the paddock. All this would translate into greater pressure on the plants near the water [3,49]. In these areas, a greater crown burial depth with heavier and less dense tillers would respond to an acquired phenotypic plasticity [47] that would allow greater grazing tolerance of these species.

Future work should consider whether these adjustments constitute a long-term survival strategy or a short-term morphophysiological response to face different grazing pressures. As well as delve into other aspects of the system such as accessibility, quality of light, and water interception marked by the structural complexity that occurs in the forest systems of this region and that may influence these attributes.

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Author Contributions: Study conception and design: Héctor Daniel Estelrich; data collection: Héctor Daniel Estelrich; analysis and interpretation of results: Carla Etel Suárez, María Sol Rossini; draft manuscript preparation: Carla Etel Suárez, María Sol Rossini; review and editing: Carla Etel Suárez, María Sol Rossini, Ernesto Francisco Atilio Morici, Héctor Daniel Estelrich. All authors reviewed the results and approved the final version of the manuscript.

Availability of Data and Materials: Partial data used for this study is available within the text, more information can be requested by contacting the corresponding authors.

Ethics Approval: Not applicable.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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