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in

Baumont R. (ed.), Carrère P. (ed.), Jouven M. (ed.), Lombardi G. (ed.), López-Francos A. (ed.), Martin B. (ed.), Peeters A. (ed.), Porqueddu C. (ed.).
Forage resources and ecosystem services provided by Mountain and Mediterranean grasslands and rangelands

Zaragoza : CIHEAM / INRA / FAO / VetAgro Sup Clermont-Ferrand / Montpellier SupAgro
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 109

2014
pages 167-171

Medium term effects of water availability and N-P fertilization interactions on the productivity and composition of natural grasslands of Uruguay

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Abstract. Irrigation and fertilization could be a strategy to ensure forage production in a high climate variability scenario in Uruguay. Nevertheless, there are gaps in our knowledge of productive and environmental responses. An experiment was performed to evaluate the effects of supplementary irrigation and N-P fertilization on native grassland forage yield and composition from October 2011 to September 2013. First year results showed, under drought, that the interaction between irrigation and N fertilization explains the variations in productivity and composition. Irrigation enhanced N response doubling forage production and the contribution of valuable species. The second year was rainy and forage production was higher than the first one in all treatments. Besides, N-P interaction was detected, explained by an increase on production caused by P mainly at the higher levels of N. These results underline the importance of studying cumulative effects of fertilization and irrigation for a more sustainable grassland management.

Keywords. Pampas – Biome – Pasture – Productivity.

Effets à moyen terme des interactions entre la disponibilité en eau et la fertilisation N-P dans les prairies naturelles d'Uruguay

Résumé. *En Uruguay, l'irrigation et la fertilisation peuvent être des options pour assurer la production de fourrage dans le cas de scenarios ayant une forte variabilité climatique. Néanmoins, il existe un manque de connaissances sur les réponses environnementales et productives. Un essai a été conduit pour évaluer l'effet d'un supplément d'irrigation et d'une fertilisation N-P sur la production de fourrage et la composition d'une prairie entre octobre 2011 et septembre 2013. En première année (sèche), l'interaction entre irrigation et N fertilisation explique les variations à court terme de la production et de la composition. L'irrigation a amélioré la réponse de l'apport d'engrais en doublant la production de fourrage et la contribution d'espèces de valeur fourragère élevée. En deuxième année (pluvieuse) la production de fourrage a été plus forte que dans la première et ceci pour tous les traitements. Par ailleurs, une interaction N-P a été observée à travers l'augmentation de la production des parcelles fertilisées avec P, principalement à fortes doses de N. Ces résultats montrent l'importance d'étudier les effets cumulatifs de la fertilisation et l'alternance de conditions sèches et humides sur la prairie dans l'objectif d'une conduite durable.*

Mots-clés. *Pampas – Biome – Prairie – Productivité.*

I – Introduction

Native grasslands of Uruguay are part of the "Pampas" biome, one of the largest areas of South American grasslands. This vegetation type supports traditional livestock production and provides many ecosystem services including carbon sequestration, maintenance of high biodiversity in both plants and animals and the preservation of soil fertility (Sala and Paruelo, 1997). Although grasslands represent the largest biome in the region, and provide valuable economic and ecosystem services, in the past decades its area has decreased due to land use changes (Díaz *et al*., 2006). Grasslands have to be considered not only as a mean for food production but also for providing ecosystem services (Lemaire, 2012), so specifically sustainable strategies are needed to maintain or increase the productivity while preserving ecological functions. In this context, there is a growing interest to understand the impact of different management practices on the sustainability of native grassland ecosystems. In Uruguay, grasslands are exposed to a high variability in rainfalls that causes large fluctuations in forage production and quality, which could be even higher in the most likely climate change future scenario (Giménez *et al*., 2009). To mitigate these impacts of climate variability, one of the technological options is to lay out areas of high intensity forage production. To achieve this, supplemental irrigation could be a strategic tool to ensure a feed base for animals, but there are gaps in our knowledge about productive and environmental responses.

In most of the world, pasture productivity is limited by soil water and nutrient availability, even in grasslands with high fertilizer inputs (Gastal and Durand, 2000). As well as water availability improves forage growth, also plant demands increase, so it is expected that the contribution of these soils, typically low in both N and P, would not be enough to cover the nutrients demand, requiring fertilization. In this context, it is necessary to generate technical coefficients of response to irrigation in grasslands of Uruguay and its interaction with N-P fertilization. From this background, we propose a medium term experiment in order to assess the extent of water and fertility limitations to the production and composition of natural basaltic grassland. This paper intends to answer the following questions: (i) how primary production is affected by supplementary irrigation, N-P fertilization, and their interactions? and (ii) what are the main changes in the botanical composition?

II – Materials and methods

Research was conducted from October 2011 to December 2013, in an experimental field near Tacuarembó-Uruguay (31.53´ S, 56.14´ W). The botanical composition of the native grassland was characterized by dominance of warm-season perennial grasses of *Paspalum* genera, mixed in a lesser extent with cool-season perennial grasses. The mean annual rainfall of the site is 1300 mm, with mean temperatures of 25 °C in summer and 12 °C in winter. The experimental design was a split plot with three replications in randomized blocks. In the main plots (24 x 16 m) supplementary irrigation (SI) and rainfed (RF) treatments were located. In the split plots (8 x 4 m) seven fertilization treatments and one unfertilized control were suited. Such fertilization treatments consisted of a dose of P (80 kg P_2O_5 ha^{-1}), three doses of nitrogen (50, 100 and 200 kg N ha^{-1}) and three NP combinations (80 P_2O_5 - 50 N; 80 P_2O_5 -100 N; 80 P_2O_5 - 200 N). SI, when necessary, was performed throughout the growing season (October–April) by spraying, with the goal of maintaining soil humidity above a threshold criterion of 50 % of available water. To do this, soil moisture (0-20 cm) was monitored through water balances using the WinIZAREG model (Pereira *et al*., 2003). N fertilization was done by 1, 2 and 4 applications of 50 kg N / ha for treatments 50, 100, and 200 kg N/ha, respectively.

Aboveground net primary production (ANPP) of forage was assessed by cuts every 40-50 days in spring and summer and 90-120 days during autumn and winter, by clipping at five cm height in 3 central stripes, totalizing 6 m^2. Prior to each cut, botanical composition was evaluated in the high fertilization (80 P_2O_5 – 200 N) and in the control plots, both in SI and RF. The ‘Botanal method’ adapted by Millot and Saldanha (1998) was performed in five 0.25 m^2 quadrants per split plot with a minimum score of 5%. In the first experimental period (10/2011-9/2012) the cumulative rainfalls totalized 1004 mm and 13 additional irrigations were performed which accumulated 324 mm. In the second experimental period (10/2012-9/2013) the cumulative rainfalls totalized 1790 mm and three additional irrigations that accumulated 110 mm were done. An analysis of variance model was adjusted to analyze the cumulative forage production considering the effects of SI, N and P Fertilization and the interaction of factors. Means of significant effects were compared using the LSD test at 5%. A Principal Components analysis of the 13 most abundant species was performed using standardized Euclidean distances.

III – Results and discussion

In the first year of assessment (10/2011-9/2012) ANPP showed a significant interaction between SI and N (Table 1a). This interaction was mainly related to a 20% increase in ANPP on average of N under SI compared to RF. Treatment of 200 kg N under SI resulted in a 100% increase of ANPP compared with the control (RF and unfertilized). These results are in accordance with López *et al*. (2002) who stated that with favorable moisture conditions N fertilization stimulates mineralization in soils with high contents of potentially mineralizable N. In the second year (10/2012-9/2013) ANPP was higher than the previous year and showed a significant triple interaction between SI, N and P fertilization (Table 1b). Treatment of 200 kg N and 80 P_2O_5 under SI resulted in a 110% increase in ANPP when compared with the control situation. The triple interaction was explained by a different response of ANPP increase to N together with P in the SI respect to the RF. Within N treatments, P response in SI was detected in 50 N, while in RF condition the response was in N 200. Besides that, higher ANPP was found in RF situation compared to SI in N 50 in the absence of P, whereas with P fertilization, ANPP was superior in RF at N 100 and N 200. These findings suggest that soil water variability may play an important role in nutrient availability for this kind of grassland.

Table 1. Responses in ANNP to N and SI: 1a) in the first year; 1b) in the second year

1a) 2011/2012			1b) 2012/2013							
SI	N	ANPP	SI	N	P_2O_5	ANPP	SI	N	P_2O_5	ANPP
No	0	2500 a	No	0	0	4088 a	Yes	0	0	3931 a
No	50	2887 b	No	50	0	5682 bc	Yes	50	0	5197 b
No	100	3286 c	No	100	0	6500 ef	Yes	100	0	5814 cd
No	200	3982 e	No	200	0	7506 gh	Yes	200	0	7642 h
Yes	0	2798 b	No	0	80	4267 a	Yes	0	80	4255 a
Yes	50	3410 c	No	50	80	5486 bc	Yes	50	80	6012 cde
Yes	100	3700 d	No	100	80	7024 fg	Yes	100	80	6239 de
Yes	200	4978 f	No	200	80	8498 i	Yes	200	80	7952 h

Means with different letters are significantly ($p < 0.05$) ANPP (kg Dry Matter ha^{-1} yr^{-1}) N= (Nitrogen) SI= Supplementary Irrigation

The principal component ordination of species associated with SI and NP fertilization confirm the relations of the dominant species with treatments, and explains both factors interaction (Fig. 1). The first component explained 45% of the variation and was related to a gradient from the control toward the condition of fertilization plus SI. Meanwhile, the second component explained 33% of variation and clearly separated NP fertilized from SI plots.

Mnesithea selloana and *Axonopus fissifolius* were the species that most increased their contribution in the SI and NP plots. These species have acquisitive traits (Jaurena *et al.,* 2012) to compete in concurrent SI and NP conditions. At the same time, *Paspalum notatum, Paspalum plicatulum*, and *Piptochaetium montevidense* were more related to the control, favored by their conservative strategy of stress tolerance. Sedges and *Botriochloa laguroides* were favored with the exclusive application of SI, while *Paspalum dilatatum* and *Bromus auleticus*, species of high forage value, increased in situations of exclusive NP fertilization, mainly in the RF condition. Higher water availability led to a significant increase in C_4 acquisitive perennial grasses in the NP and SI plots, meanwhile in the exclusively NP fertilized plots it enhanced both C_3 and C_4 acquisitive perennial grasses. This behavior suggests that C_4 grasses capture fertility and water improvements in spring and summer and C_3 grasses take advantage of fertility residual effects in winter and spring. In accordance with Yahdjian *et al*. (2011), both water and N availability limit primary production but probably at different times during the year. Therefore, a combination of plant functional strategies and growing cycles in grassland communities is the key to be adapted to changes or disturbances.

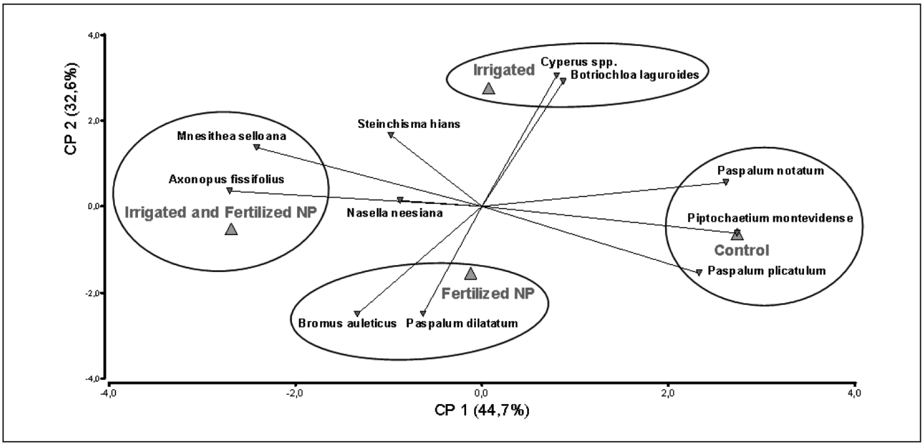

Fig. 1. Principal Component biplot of the main species according to SI and NP treatments.

IV – Conclusions

In summary, the 2-year assessment of NP and SI verified that complex interactions explained the short-term variations in forage productivity. In addition, this NP-SI interaction created conditions that increased the contribution of most valuable forage native species.

N fertilization response in the spring-summer period of a dry year was improved with SI, while in the following wet year the N response was improved with the combined application of N and P. The lack of response to SI in the second year highlights that water limitation may be important in dry years but not in others, and foremost the need to combine SI with NP fertilization.

The present findings underline the importance of studying cumulative effects of fertilization and water management in grasslands for a more sustainable management. From these results we recommend further long term research on the interaction between SI and NP fertilization, not only on the effects on productivity, also in grassland dynamics and the environmental impacts.

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