Fertilizer regime modifies grassland sensitivity to interannual climate variability

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Abstract

Improved understanding of the interactions between management practices and climate variability is critical for the development of sustainable grassland management and the provision of bundles of ecosystem services in a changing environment. Here we used a long-term fertilizer field trial to examine the impacts of climate variability (annual temperature, rainfall) on an upland grassland subjected to a gradient of nutrient availability. We tested for the effect of climatic indices, fertilizer regime, and their interactions, on annual biomass production, forage quality (crude protein content, digestibility) and plant diversity (species richness, equitability). During the 15-year study period we recorded significant interannual variation in both climate and grassland properties. We found that fertilizer treatments, mean annual temperature and annual precipitation all affected the grassland variables in this study, but interactions between climate and management treatment were generally limited. Contrary to expectations, interactions were driven by the PK rather than the NPK treatment. These results highlight the importance of management for projected responses to future climate change in models of grassland function.

Keywords: upland grasslands, production, forage quality, rainfall variability, nitrogen

Introduction

Managed grasslands are an integral part of livestock farming systems and provide multiple provisioning, regulation and cultural services, as well as representing reservoirs of plant and animal biodiversity (Bengtsson *et al.*, 2019). Increasing evidence suggests that the type and intensity of grassland management practices (mowing/grazing, fertilizer inputs) may condition grassland yield responses to variation in abiotic drivers such as water availability via changes in plant community composition and associated plant traits (Bharath *et al.*, 2020). For example, high nitrogen inputs could enhance grassland sensitivity to drought due to the increased water demand in high biomass systems or root:shoot allocation patterns adapted to light, rather than below-ground resource acquisition. This is of particular relevance in the context of increasing periods of drought/water stress and climate variability predicted with ongoing climate change (IPCC, 2021). Improved understanding of the interactions between management practices and climate variability is a necessary step in the development of sustainable grassland management and the identification of agricultural 'best practices' to improve the resistance of grassland forage production in a changing environment. In the present work, we investigate the interactive effects of fertilizer regime and climate variability (temperature, rainfall) on yield, forage quality and plant diversity in an upland grassland subjected to a gradient of nutrient availability treatments over a 15-year period, and examine whether high N inputs modify grassland response patterns to interannual climate variation.

Materials and methods

The field experiment is located in the Massif-central region in France (45°43023″ N, 03°1021″ E, 880 m a.s.l., mean annual temperature 8.7 °C, annual rainfall 770 mm) on a Cambisol soil, and forms part of the ANAEE-F ACBB long-term agroecosystems management trial set up onsite in 2005. Prior to the experiment establishment, the site was managed for hay production with mineral fertilizer inputs (average 200 kg N ha^{-1} yr^{-1}) for over 10 years. In 2003 and 2004, the site was mown three times per year without any fertilizer input. From 2005, three treatments were applied: NPK (251 kg N ha^{-1}, 28 kg P ha^{-1}, 177 kg K ha^{-1}); PK (21 kg P ha^{-1}, 128 kg K ha^{-1}); and 'None' (no fertilization), with four field repetitions (field size 400 m^2). Each treatment is mown three times per year and fertilizer application is fractioned, with inputs in early spring and then after the first and the second cuts. At each cut, biomass is sampled at a height of 5.5 cm above soil surface (four quadrats of 0.36 m^2 per field), oven-dried (60 °C for 48 h) and weighed. Dry samples are then ground and analysed for total N content (Dumas method) and dry matter digestibility (DMD) with near infrared spectroscopy (NIRS, Foss). Botanical surveys are carried out each year in May using the transect method to determine species presence/absence at 40 points per field. In the present study, we analysed data for 2006-20. Biomass production, DMD and crude protein content (N*6.25) were expressed as annual values based on the three cuts per year and weighted (by mass) means. Species relative frequency was calculated per field, and within-plot species richness (RS) and evenness were estimated (Pielou, 1972) (no data for 2009). Annual precipitation and mean air temperature data were obtained from an onsite meteorological station (INRAE CLIMATIK). Effects of treatment (fixed factor), climatic variable (covariate) and any interactions were assessed using GLM models.

Results and discussion

Climate indices varied over the 15-year study period; mean annual temperature ranged from 7.2-9.8 °C (mean 8.77, CV 7.9%), whereas annual rainfall ranged from 585-990 mm (mean 789 mm, CV 13.2%). Warmer years also tended to be drier years (marginally significant negative correlation between the two climatic indices). During the study, the NPK treatment showed consistently higher production and forage quality, but lower diversity (evenness) compared to the PK and 'No Fertilizer' treatments (Table 1).

Increasing mean annual temperature was generally associated with a decrease in biomass production and crude protein content, but an increase in grassland diversity (species number, evenness) (Table 1, Figure 1). However, the magnitude of temperature effects on biomass production varied depending on fertilizer treatment, with greater temperature-induced decreases recorded in the PK treatment compared to NPK or 'No Fertilizer' (Figure 1).

Table 1. Directionality of responses of grassland properties to climatic variation and fertilizer treatment.[1]

Variable	Mean annual temperature	Total annual rainfall	Fertilizer treatment
Biomass production (g/m^2)	(Figure 1)	↗	NPK > PK > None
Crude protein (%)	↘	(Figure 1)	NPK > PK = None
Dry matter digestibility (%)	n.s.	↘	NPK < PK = None
Species number	↗	↘	NPK < PK < None
Evenness	↗	(Figure 1)	NPK < PK = None

[1] Results represent significant main effects based on GLM analysis (no results are presented for climate variables where fertilizer treatments interact with climate, cf. Figure 1; n.s., non-significant climate effects). Fertilizer treatment rankings apply only for cases with no Tmt × Climate interactions.

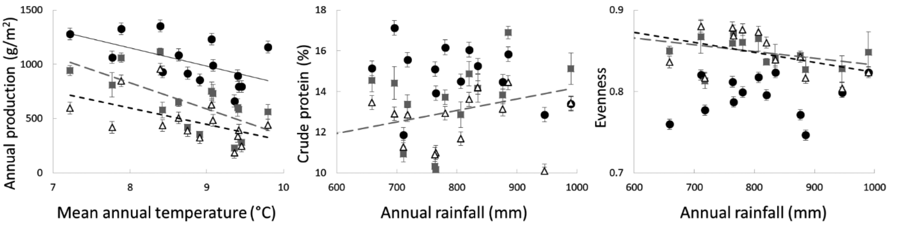

Figure 1. Interactive effects of fertilizer treatments and climate indices recorded during the study. Fertilizer treatments are given by: NPK, black filled circles; PK, grey filled squares, 'None', open triangles.

Digestibility showed no response to temperature, in line with results of previous studies (Dumont *et al.*, 2015). In parallel, annual rainfall had significant positive effect on biomass production but a negative effect on forage digestibility and species richness (Table 1). Effects of annual rainfall on crude protein content and evenness varied depending on fertilizer treatment: crude protein content increased with increasing rainfall in the PK treatment alone, whereas evenness showed a negative relationship with annual rainfall in the PK and 'No Fertilizer' treatments (Figure 1). Contrary to expectations, all interactions recorded between fertilizer treatment and climate index were driven by the PK rather than the NPK treatment. This result may reflect an increased abundance of legume species in the PK treatment, as *Trifolium repens* is known to be sensitive to rainfall deficit (Komainda *et al.*, 2019). Future work should examine responses at different temporal scales and the possible role of belowground responses and species asynchrony in buffering grassland properties against climatic variability.

Conclusions

Interactions between fertilizer treatment and climatic variables assessed at the annual scale were not confined to one particular grassland property or climatic index, but remained relatively limited. In general, interactions were driven by responses in the PK treatment rather than the NPK treatment, possibly linked to greater sensitivity of legumes to climatic variation.

References

Bengtsson J., Bullock J.M., Egoh B., Everson C., Everson T., O'Connor T., O'Farrell P.J., Smith H.G. and Lindborg R. (2019) Grasslands – more important for ecosystem services than you might think. *Ecosphere* 10(2), e02582.

Bharath S., Borer E.T., Biederman L.A., Blumenthal D.M., Fay P.A., Gherardi L.A., Knops J. M.H., Leakey A.D.B., Yahdjian L. and Seabloom E.W. (2020) Nutrient addition increases grassland sensitivity to droughts. *Ecology* 101(5), e02981.

Deroche B., Pradel P. and Baumont R. (2020) Long-term evolution and prediction of feed value for permanent mountain grassland hay: Analysis of a 32-year data set in relation to climate change. *Grass Forage Science* 75, 18-27.

Dumont B., Andueza D., Niderkorn V., Lüscher A., Porqueddu C. and Picon-Cochard C. (2015) A meta-analysis of climate change effects on forage quality in grasslands: specificities of mountain and Mediterranean areas. *Grass and Forage Science* 70, 239-254.

Komainda M., Küchenmeister K., Küchenmeister F., Breitsameter L., Wrage-Mönnig N., Kayser M. and Isselstein J. (2019). Forage legumes for future dry climates: Lower relative biomass losses of minor forage legumes compared to *Trifolium repens* under conditions of periodic drought stress. *Journal of Agronomy and Crop Science*. 205, 460-469.

Pielou E.C. (1972) Niche width and niche overlap: a method for measuring them. *Ecology* 53, 687-692.