Effects of irrigation on phosphorus in soil, soil microbes and plants of semi-natural grasslands

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Abstract

Water and phosphorus (P) are two critical resources for high nature value farming in semi-dry mountains. They are major drivers of grassland productivity but can negatively affect plant diversity. Soil moisture is known to affect soil microbial activity and plant P nutrition but the effects of irrigation on soil P status, soil microbial P and plant P nutrition in semi-natural grasslands remain largely unexplored, which impedes the optimization of fertilization. The aim of this study was to assess the mid-term effects of irrigation on P availability in the soil, the size of the soil microbial P pool and plant P nutrition in semi-dry mountain grasslands. At the end of a five-year irrigation-fertilization factorial experiment on eleven semi-natural grasslands of an inner-alpine valley, soil P availability and herbage P content did not significantly differ between the irrigated and the not irrigated treatments. Fertilization increased herbage P content from 2.2 to 3.1 mg P kg^{-1} dry mass (P<0.001). The size of the microbial P pool remained unaffected by irrigation and fertilization. We conclude that for semi-natural mountain grasslands, no correction factor for irrigated compared to not irrigated meadows is necessary to estimate the P fertilization requirement per unit of herbage yield.

Keywords: irrigation, fertilization, P availability, soil microbial P, nutrition index

Introduction

Irrigation and fertilization of mountain grasslands must be finely tuned in order to save resources and because mountain ecosystems are sensitive to agricultural inputs. Grassland-based ruminant production strategies require herbage that has adequate P content. In the short-term, water shortage may negatively affect grassland P uptake (Meisser *et al.*, 2013). In the mid-term, irrigation might nevertheless decrease the size of the plant available P pool because of greater P offtake and losses (Condron *et al.*, 2006). Moreover, water availability might alter the competition for P between plants and soil microorganisms (Dijkstra *et al.*, 2015). The impact of irrigation on grassland P nutrition thus remains difficult to quantify. The objective of this study was to assess the mid-term effects of irrigation on P availability in the soil, the size of the microbial P pool, and plant P nutrition in semi-dry mountain grasslands.

Materials and methods

The study was carried out on 11 semi-natural montane to subalpine hay meadows on loam soils from an inner-alpine valley with continental climate and annual average precipitation of 570 mm. Four treatments, arranged in a RCB design with the 11 meadows used as blocks (no replicates within meadow), were applied from 2010 to 2015. These treatments were I_0F_0: neither fertilized nor irrigated; I_1F_0: only irrigated; I_0F_1: only fertilized; and I_1F_1: both irrigated and fertilized. Irrigation was 20 mm water per week from May to mid-September, except when over 20 mm of rain fell during the previous week. Fertilization was applied as manure pellets dissolved in water with an N:P:K ratio of 1.0:0.36:2.7. The fertilization level was adjusted to the productivity potential of the meadows, which correlates with altitude (880 to 1,770 m), by categorizing them into three altitudinal groups with fertilization levels of 1.0, 0.75 and 0.5 from the lowest to the highest altitudinal group. For P, this resulted in yearly inputs of 19.4, 14.5 and 9.7 kg P ha^{-1} respectively. In spring 2016, plant samples were harvested when the dominant grass species were at late boot to mid-heading stage. Plants were sorted into grasses, legumes and forbs, and analysed for P and N content. The P nutrition index (PNI) of the grass fraction was calculated following Duru and Ducroq (1997). For the soil, we show the results for the 0-5 cm soil layer sampled in spring 2016. The pool of P extractable with anion exchange resin (Resin P) was used as an indicator of plant available soil P (Myers *et al.*, 2005). For resin extraction, field-moist soil samples were shaken with distilled water and a resin-strip for 16 hours at a soil:water ratio of 1:15. Soil microbial P was assessed by the difference between the amount of P extracted by hexanol-fumigation combined with resin extraction and the amount of P extracted by resin extraction without hexanol (Kouno *et al.*, 1995). Hexanol-labile P was corrected for incomplete P recovery due to sorption by adding a P-spike of 50 mg P kg^{-1} soil to a third subsample. Soil organic carbon (SOC) was extracted by the Walkley-Black method. The effects of irrigation and fertilization were analysed by ANOVA with the irrigation-effect as irrigated (I_1F_0 and I_1F_1) vs not irrigated (I_0F_0 and I_0F_1), and the fertilization-effect as fertilized (I_0F_1 and I_1F_1) vs unfertilized (I_0F_0 and I_1F_0). The meadows were included as random factors in the model. No significant irrigation × fertilization interaction was observed.

Results and discussion

Irrigation and fertilization increased P offtake by 28% (P<0.05) and 131% (P<0.001) respectively at the last harvest of the treatment application period (summer 2015). Fertilization had a carry-over effect on biomass in spring 2016, but irrigation did not (Table 1). Soil P availability (Resin P) was low in the unfertilized treatments and, correspondingly, herbage P content was substantially improved by fertilization (Table 1).

The five-year period with summer irrigation did not affect herbage P content in spring. This contrasts with the short-term results of Meisser *et al.* (2013) who observed a substantially larger herbage P content after a growing season without drought stress than following a severe summer drought. Resin P was not yet affected by irrigation, which is in contrast to the long-term (52-years) results of Condron *et al.* (2006). Resin P explained 51% of the variability in PNI of the grass fraction, with a similar relationship for the irrigated and the non-irrigated plots (Figure 1). Microbial P remained unaffected by the treatments (Table 1). Converted to kg ha^{-1}, the size of the microbial P pool was approximately 4.5 times larger than the average annual P fertilization, which shows the importance of this P pool in permanent grassland soils. Soil microbial activity is known to influence plant P availability (Dijkstra *et al.*, 2015). In our experiment, soil P availability and herbage P content were not correlated to the size of the microbial P pool (data not shown). SOC content was, on average, higher than 5% (Table 1) and it explained only 29% of the variability in soil microbial P (Figure 2). Further studies are thus required to assess the main factors of microbial P variability in grassland soils rich in organic matter.

Table 1. Standing biomass, herbage P content and P nutrition index (PNI) in the spring succeeding five years of contrasting irrigation and fertilization, as well as the content of resin-extractable P, microbial P and organic carbon (SOC) in the 0-5 cm soil layer. The irrigation-effect is the contrast of (I_1F_0, I_1F_1) vs (I_0F_0, I_0F_1) and the fertilization-effect the contrast of (I_0F_1, I_1F_1) vs (I_0F_0, I_1F_0).[1]

Treatment	Biomass (t DM ha^{-1})	Herbage P (g kg^{-1} DM)	PNI	Resin P (mg kg^{-1} soil)	Microbial P (mg kg^{-1} soil)	SOC (%)
I_0F_0	1.36	2.2	51	1.5	88	5.5
I_1F_0	1.40	2.3	51	1.4	95	5.0
I_0F_1	2.03	3.1	78	7.4	88	5.8
I_1F_1	1.74	3.0	79	5.2	94	5.3
Mean SD	0.48	0.5	13	2.3	18	1.6
Irrigation-Effect	ns	ns	ns	ns	ns	ns
Fertilization-Effect	***	***	***	***	ns	ns

[1] DM = dry matter; SD = standard deviation; *** P<0.001; ns = not significant.

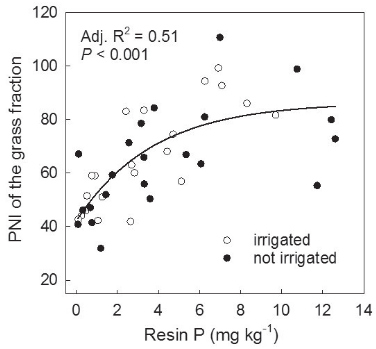

Figure 1. Relationship between the P nutrition index (PNI) of the grass fraction and the resin P in the topsoil layer (0-5 cm).

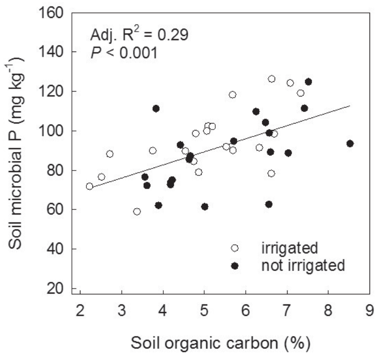

Figure 2. Relationship between the soil microbial P content and the soil organic carbon content in the topsoil layer (0-5 cm).

Conclusions

After five years of experimentation in semi-dry mountain grasslands, a weekly irrigation of 20 mm during the dry season did not affect soil P availability, the size of the microbial P pool, or plant P nutrition. We thus conclude that for semi-natural mountain grasslands, no correction factor for irrigated compared with non-irrigated meadows is necessary to estimate the P fertilization requirement per unit of herbage yield.

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