Provisioning ecosystem services of fertilized meadows and pastures differ in their response to organic management

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Abstract

The provisioning Ecosystem Services (ES) of organically managed grasslands could be compromised, compared to grasslands under non-organic management, due to restrictions regarding mineral fertilization. We investigated this by measuring forage yield increase per day and feed value in 25 pairs of organic and non-organic fertilized meadows (mown) and pastures (grazed) in the canton of Solothurn (Switzerland). Lower forage yield and feed value in organic pastures were related to lower phosphorus (P) in topsoil compared to non-organic pastures. However, in meadows, organic management had no effect on forage yield and feed value as soil P was hardly affected by organic management. From these findings we conclude that forage provision does not considerably differ between organic and non-organic meadows, but in pastures we see potential indications of nutrient limitation under organic management. Future research should thus assess organic pasture management in more detail to close this production gap.

Keywords: ecosystem services, grassland, organic management, provisioning services, weeds

Introduction

Organic grasslands do not receive synthetic pesticides or mineral fertilizers (Swiss Federal Council, 2018). This could lead to reduced yields (i.e. provisioning Ecosystem Services; ES). However, organic management could potentially help the grasslands to provide a wider range of other, non-monetary ES (e.g. Knudsen *et al.*, 2019; Mäder *et al.*, 2002;). In this study, we focus on the provisioning ES of grasslands in Swiss agriculture, aiming to find out whether organic grasslands have lower biomass yields and lower feed quality than non-organically managed grasslands.

Materials and methods

Intensively managed meadows (n=26) and intensively managed pastures (n=24) within the *ServiceGrass* project in the Canton of Solothurn (Switzerland) were included in this study. The grassland sites belong to 18 organic and 18 non-organic farms, with one organic farm always in close vicinity to a non-organic farm, resulting in a spatially balanced design. In summer 2021, soil cores were taken to 20 cm depth (20 cores pooled per grassland) and analysed for soil phosphorus (P) concentrations (Olsen extraction). Interviews were conducted with the farmers to gather information about fertilization practices. Utilizable nitrogen (N) fertilization was calculated from this information according to Swiss regulations (Richner *et al.*, 2017). Aboveground biomass was sampled between mid-May and mid-June 2021, with four pooled samples of an area of 50×50 cm per site, dried and subsequently weighed. Forage increment per day was calculated as biomass (g) per growing day (days since 1 March) per m^2 (hereafter *forage increase*). Feed value was calculated as an indicator value (Briemle and Dierschke, 2002), using mean species cover from two 2×2 m vegetation relevés per site. *t*-tests were conducted to identify differences among organic and conventional grasslands in soil P, N fertilization, forage increase and feed value. To analyse the effect of organic management on forage increase and feed value via changes in soil P and N fertilization, a structural equation model (SEM) was computed with the R (R Core Team, 2021) package lavaan (Rosseel, 2012). The full model was specified as shown in Figure 1A, first without and

then with a multigroup comparison of pastures vs meadows. These two models were compared using the Akaike information criterion (AIC) and sample-size adjusted Bayesian information criterion (BIC). Subsequentially, non-significant pathways were sequentially deleted from the model to achieve a most robust final SEM.

Results and discussion

Over all plots, forage increase tended to be 15% smaller in organic compared to non-organic managed grasslands (mean=3.9 vs 4.7; $P>0.1$, t-test), as was feed value (mean=6.6 vs 7.1, $P=0.033$, t-test). The AICc for the SEM including a group comparison of pasture and meadow (Figure 1B) was lower than for the SEM without the group comparison (AIC=527 vs 533, BIC=498 vs 522), indicating that the responses of forage increase and feed value to the environmental, fertilizer and management variables studied here differed between meadows and pastures.

For *pastures* (predominantly grazed), the SEM showed a marginally significant negative effect of organic management on soil P (standardized coefficient -0.33; $P=0.062$; Figure 1B). The mean soil P differed quite strongly, with 22 mg kg^{-1} in organic and 41 mg kg^{-1} in non-organically managed pastures ($P=0.049$; t-test). Soil P was additionally influenced by N fertilization (stand. coeff. 0.38; $P=0.029$). However, N fertilization itself was not influenced by organic management (mean=46.3 vs 79.8 kg N ha^{-1} organic vs non-organic, $P>0.1$, t-test). This lack of an effect of organic management on N fertilization compared to the direct effect of organic management on soil P could be due to soil P showing the effect of fertilizing events from past years, whereas N fertilization merely reflects fertilization in 2020, the year of the farmer interviews. Soil P in turn positively influenced forage increase (stand. coeff. 0.54, $P=0.002$) and feed value (stand. coeff. 0.74, $P<0.001$), leading to 45% lower mean forage increase in organic (2.7 g day^{-1}) than in non-organic (4.1 g day^{-1}; $P=0.073$, t-test) and mean feed value (6.4 vs 7.1; $P=0.055$, t-test). Thus, in pastures, organic management influenced forage increase and feed value via lower soil P.

In *meadows* (predominantly cut), the SEM showed no evidence for organic management influencing either soil P or N fertilization (Figure 1B). Indeed, organic and non-organic meadows did not differ strongly in N fertilization (mean=86.7 vs 107.5 kg N ha^{-1}; $P>0.1$, t-test) and soil P (mean=32.2 vs 40.7 mg kg^{-1}; $P>0.1$, t-test). As a consequence, no evidence for any effect of organic management on forage increase and feed value was detected in the SEM (Figure 1B) and means for forage increase (5.1 and 5.2 g day^{-1}, respectively) and feed value (6.8 and 7.1) were quite comparable between organic and non-organic meadows (both $P>0.1$, t-tests). N fertilization in meadows, in contrast to pastures, did not influence soil P, but both factors had direct positive effects on forage increase and feed value (Figure 1B).

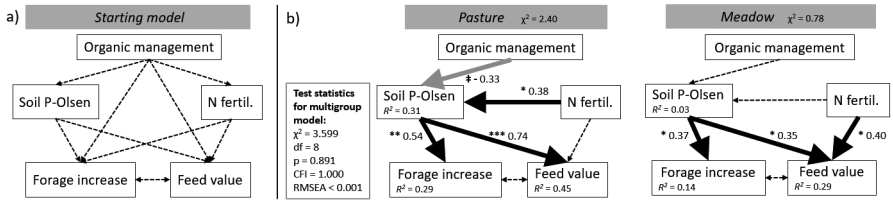

Figure 1. (A) full starting model for structural equation modelling (SEM); and (B) final multigroup SEMs comparing the influence of organic management on forage increase (g day^{-1}) and feed value in pastures vs meadows with statistics for the overall multigroup model on the left of the path-models. Dashed lines indicate non-significant pathways. For significant pathways, standardized coefficients are displayed next to the arrows, grey solid arrows indicating negative, black solid arrows positive effects. Significance levels of the coefficients (*P-value*): 0.1 ≥ '‡' ≥ 0.05 ≥ '*' ≥ 0.01 ≥ '**' ≥ 0.001 ≥ '***'.

The yield reductions in organically managed grasslands found in other studies (Mäder *et al.*, 2002; Oberson *et al.*, 2013; Steinwender *et al.*, 2000) fits to our overall results averaged over pastures and meadows. Interestingly, we find different responses of the two management types, with meadows showing no reduction and pastures a strong reduction in forage increase and forage yield. The meadow response is similar to findings of Klaus *et al.* (2013) regarding no significant yield differences in organic vs non-organic grasslands in Germany. Our results suggest a necessity to differentiate between predominantly grazed pastures and predominantly cut meadows when assessing the interrelated drivers of provisioning ES. This will also help to investigate the reasons for lower soil P in organic pastures.

Conclusions

Our findings suggest that in the studied region forage increase and feed value were not compromised in organic compared to non-organic intensively managed meadows. However, in intensively managed pastures, lower forage yield and quality were related to differences in soil P due to organic management. Further research investigating the reasons for lower soil P is necessary to understand and resolve this issue and to close the yield gap in organic pastures, and to understand why meadows differed in their response.

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