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Plant Ecol (2014) 215:1037–1046
DOI 10.1007/s11258-014-0360-9

Do different irrigation techniques affect the small-scale patterns of plant diversity and soil characteristics in mountain hay meadows?

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Received: 7 January 2014 / Accepted: 23 May 2014 / Published online: 19 June 2014
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Abstract Traditional management practices are suggested to maintain species-rich grasslands. In the Valais, an arid region of Switzerland, hay meadows are traditionally irrigated using open water channels. However, in the past decades this irrigation technique has been increasingly replaced by sprinkler irrigation, which is assumed to result in a more homogeneous water distribution than open water channels. This study examined whether the change in irrigation technique affected the small-scale distribution of plants and soil characteristics in hay meadows in the Valais. Three plots consisting of 13 subplots of increasing size (0.1 × 0.1 to 6.4 × 6.4 m) were installed in six traditionally and six sprinkler-irrigated meadows. In all subplots, plant species richness and soil characteristics [moisture, pH, total organic nitrogen, organic matter content (SOM), total and plant available phosphorus] were recorded. The type of irrigation technique did not affect the shape of the plant species–area relationship. In none of the meadows did the species area–curves reach the asymptote within the range of plot sizes examined. Mantel *r* statistics showed that spatial autocorrelation in the soil characteristics examined was low and their small-scale distributions were not influenced by the irrigation technique except for soil pH and SOM. Our results indicate a pronounced small-scale heterogeneity in the distribution of plant species and soil characteristics for both types of irrigation technique. This can partly be explained by the fact that sprinklers distribute the water less homogeneously than commonly assumed. As applied in the Valais, sprinkler irrigation does not reduce the spatial heterogeneity and hence biodiversity of hay meadows.

Keywords Semi-natural grassland · Water management · Land use change · Species–area relationship · Spatial autocorrelation · Valais (Switzerland)

Communicated by B. G. Warner.

Electronic supplementary material The online version of this article (doi:10.1007/s11258-014-0360-9) contains supplementary material, which is available to authorized users.

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Introduction

Semi-natural grasslands including hay meadows are habitats, which were formed by traditional management practices. These habitats harbour numerous species whose primordial habitats have been vastly destroyed (Baur et al. 1997, 2004), and therefore, they are of high conservation value (Poschlod and

WallisDeVries 2002; Baur et al. 2006). Since the mid twentieth century, changes in land use including intensification and abandonment resulted both in a decline in the area of semi-natural grasslands (Strijker 2005) and in a decrease in plant species richness, especially in grassland specialists (Poschlod and WallisDeVries 2002; Tasser and Tappeiner 2002; Homburger and Hofer 2012; Riedener et al. 2014).

The maintenance of hay meadows and their typical species composition also depends on irrigation, particularly in arid regions such as the south-facing slopes of the Valais in the Swiss Alps. In this region, a dense net of open water channels was constructed from the eleventh century onwards to transport glacial melt water from mountain streams to meadows at lower elevations (Leibundgut 2004). With this water, the hay meadows are flooded at regular intervals. The farmers put a temporary dam across the water channel causing an overflow with a resulting flooding of the down-slope parts of the meadow (Crook and Jones 1999). This traditional irrigation technique is very labour intensive (Meurer and Müller 1987). Therefore, the modernization and rationalization of agricultural practices in the Valais have increasingly led to the replacement of the traditional irrigation technique by sprinkler irrigation systems in the past decades (Meurer and Müller 1987; Crook and Jones 1999).

Various elements of meadow spatial heterogeneity affect plant species richness at different scales (Weiher and Howe 2003; Olofsson et al. 2008; Giladi et al. 2011). At the landscape level, different types of land use lead to a mosaic of different habitats, which may impact plant species richness and dispersal of organisms (Gaujour et al. 2012). At the level of a few square metres, microhabitat conditions including the distribution of soil nutrients and water become more important for the spatial arrangement of co-existing plant species and hence plant species richness (Shmida and Wilson 1985; Zhou et al. 2008; Shi et al. 2010). In hay meadows, different management practices including the type of irrigation technique may influence meadow spatial heterogeneity and thus plant species richness. In the present study, we focused on the potential impact of different irrigation techniques on the small-scale heterogeneity of plant diversity and soil characteristics.

Traditional and sprinkler irrigation are assumed to differ in their kind of small-scale water distribution. Sprinklers may distribute the water homogeneously from above over the meadow, whereas in traditional irrigation different parts of the ground are inundated irregularly, depending on the microrelief of the meadows (Meurer and Müller 1987). This spatially unequal water distribution can increase the small-scale variation in both soil moisture and nutrients and may, therefore, lead to a mosaic of different microhabitats and hence to an increased floristic and faunistic diversity (Rosenzweig 1995; Werner 1995; Diacon-Bolli et al. 2012).

The shapes of species–area relationships have been used to explore spatial patterns of plant diversity in grasslands (Connor and McCoy 1979; Rosenzweig 1995). Meadows with a homogeneous plant distribution reach the maximum species richness (asymptote of the curve) at a smaller area and show a steeper increase in the cumulative species number than meadows with a heterogeneous plant distribution. The recorded spatial small-scale distribution of plant species and thus the shape of the species–area relationship of a meadow can be influenced by different factors including meadow spatial heterogeneity (Kallimanis et al. 2008; Shen et al. 2009; Kolasa et al. 2012), competitive interactions (Tilman 1982), shape and size of sampling plots (Condit et al. 1996), shape of the habitats (Harte et al. 1999), grain size of the vegetation (He and Legendre 2002; Braschler et al. 2004; Hortal et al. 2006), and the length of time taken to conduct sampling (Preston 1960; White 2004). Meadow spatial heterogeneity is assumed to increase with increasing sampling area and may, therefore, be an important descriptor of the species–area relationship (Rosenzweig 1995; Proença and Pereira 2013).

In the present study, we examined the potential influence of the two irrigation techniques on the small-scale distribution of plant species and soil characteristics of extensively managed hay meadows in the Valais. A previous study conducted in the same region showed that traditionally and sprinkler-irrigated hay meadows did not differ in plant diversity and species composition on the basis of 100 m^2 plots (Riedener et al. 2013). However, effects of different irrigation techniques on the small-scale spatial patterns ranging from 0.01 to 40 m^2 have not been investigated so far.

As a result of unequal water distribution by traditional irrigation, we expect that traditionally irrigated meadows show a higher variation in the pattern of plant distribution than sprinkler-irrigated meadows. Therefore, the shape of the species–area curves should differ between the two types of irrigation. In sprinkler-irrigated meadows, the slope of the species–area curve should be steeper and reach the asymptote at a smaller spatial scale than in traditionally irrigated meadows. Spatial autocorrelation can be used as an indicator for spatial heterogeneity of different soil characteristics. High positive values of autocorrelation indicate a high spatial dependency of soil characteristics. The spatial dependency may change in different comparisons of various soil properties. Furthermore, we assume that soil characteristics show a more heterogeneous spatial distribution in traditionally irrigated meadows than in sprinkler-irrigated meadows. In particular, we addressed the following questions: (1) Do traditionally and sprinkler-irrigated meadows differ in the shape of their plant species–area relationships and in the small-scale spatial pattern of soil characteristics? and (2) Are soil characteristics spatially autocorrelated and if yes, at which spatial scale?

Methods

Study area and survey design

The study was conducted in two areas located on the south-facing slope of the Rhone valley in the canton Valais (Switzerland), namely in Ausserberg (46°19′N, 7°51′E, elevation: 1,191–1,255 m a.s.l.; hereafter referred to as AU) and Guttet–Erschmatt (46°19′N, 7°40′E, elevation: 1,281–1,400 m a.s.l.; GE). The two areas are 15 km apart. Mean annual air temperature in this region is 9.4 °C and annual precipitation is 596 mm (MeteoSwiss 2013).

The vegetation types of the hay meadows investigated belonged to the *Trisetetum* association (Ellenberg 1986). Information on management was obtained by personal interviews with farmers. On most of these meadows, the traditional irrigation technique was replaced by sprinkler irrigation 8–25 years ago. Nowadays, only 10–30 % of the meadows of this region are still irrigated in the traditional way resulting in a mosaic of traditionally and sprinkler-irrigated meadows (K. Liechti, pers. com.). The majority of sprinklers were installed at permanent positions, but on two meadows there were also mobile sprinklers. Management intensity of the investigated meadows is relatively low (see Table S1 for details). The meadows investigated were mown once or twice a year and grazed for a few days in autumn by sheep or cattle. Fertilizer (manure; mean ± SE, 10.8 ± 3.2 m^3 ha^{-1} y^{-1}) was applied every year or every second year in autumn, except for two meadows in AU, which were not fertilized at all. Irrigation occurred every 2nd or 3rd week during the vegetation period (from May to the end of September in both irrigation techniques). Irrigation frequency and the amount of water applied per irrigation event did not differ between the two irrigation techniques (amount of water: ANOVA, $F_{1,9} = 1.51$, $p = 0.25$). Moreover, traditionally and sprinkler-irrigated meadows did not differ in the amount of fertilizer or grazing intensity (ANOVA, both $p > 0.32$). Neither did meadows in the two study areas differ in the amount of water received or grazing intensity (ANOVA, both $p > 0.10$). However, the amount of fertilizer was marginally higher in GE than in AU (ANOVA, $F_{1,9} = 4.62$, $p = 0.06$).

Six pairs of hay meadows were chosen in the two study areas, each pair consisting of a traditionally and a sprinkler-irrigated meadow. Four pairs of meadows were located in AU and two pairs in GE. The distance between pairs of meadows was 1 km in GE and ranged from 50 m to 2 km in AU (see Table S1 for distances between meadow pairs).

Traditionally and sprinkler-irrigated meadows did not differ in size, elevation, exposure and inclination (ANOVA, all $p > 0.19$). Neither did meadows in the two study areas differ in exposure or inclination (ANOVA, both $p > 0.29$). Average exposure was SSE (157 ± 10°) and average inclination was 18 ± 1°. However, mean elevation of the hay meadows was 1,222 ± 7 m a.s.l. (±SE) in AU and 1,339 ± 26 m a.s.l. in GE (ANOVA, $F_{1,9} = 33.54$, $p < 0.001$). Furthermore, meadows were smaller in AU than in GE (AU: 3,049 ± 623 m^2, GE: 6,198 ± 1,507 m^2; ANOVA, $F_{1,9} = 5.44$, $p = 0.045$).

Vegetation surveys

In each meadow, three starting points (lower left corner of a plot) were randomly chosen to install three plots of increasing size using a nested design (Fig. 1). Each plot was built up an initial area of 0.1 × 0.1 m (subplot 1). This area was duplicated twelve times to reach a size of 6.4 × 6.4 m (subplot 13). The plots had a minimum distance of 2 m to water channels and trails and of 3 m to roads to minimize potential edge effects. The distances among the three starting points

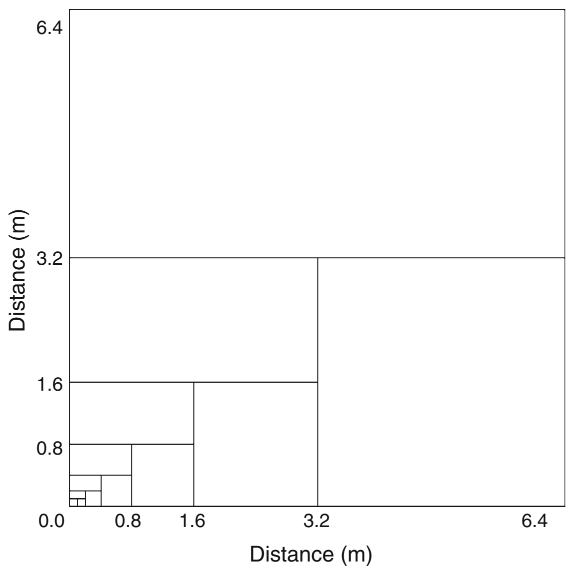

Fig. 1 Nested plot design consisting of 13 subplots of increasing size. The area of the first subplot (0.1 × 0.1 m) is doubled 12 times to reach a total area of 6.4 × 6.4 m

within a meadow ranged from 8 to 40 m. All vascular plant species present in subplot 1 were recorded. In subplot 2 and the succeeding subplots only additional species were recorded. Plant surveys were conducted by R. L. M. and E. R. between May and June 2012. Pseudoturnover, i.e. the turnover accounting for two sampling persons, ranged from 5.3 to 9.8 % (Nilsson and Nilsson 1985).

Soil characteristics

To analyse the spatial variation in soil characteristics, soil samples were collected in the most central plot of the three plots in each meadow. Beginning in subplot 1, three soil samples were taken close to its centre to a depth of 5 cm using a soil corer (diameter 5 cm, volume 100 cm^3) in October 2012. This procedure was repeated in subplot 2 and in the following subplots. The three samples of a subplot were mixed and pooled resulting in 13 soil samples per plot. In this way, 156 soil samples were obtained in the six traditionally irrigated and six sprinkler-irrigated meadows. The soil samples were sieved (mesh size 2 mm) and dried for 96 h at 50 °C. Soil pH was assessed in distilled water (1:2.5 soil:water) (Allen 1989). Total soil organic matter content (SOM, %) was determined as loss-on-ignition of oven-dried soil at 750 °C for 16 h (Allen 1989) and total soil organic nitrogen content (OrgN, %) was assessed using the standard method of Kjeldahl (Bremner 1965). Finally, total phosphorus content (PT, µg PO_{4^-}/g) and plant available phosphorus content (PP, µg PO_{4^-}/g) were extracted using hydrochloric acid (PT) and ammonium acetate (PP) and determined by photometric analyses (Allen 1989).

Soil moisture (%) was measured on the same spots as soil samples were taken on the same day in October 2013 using a soil moisture sensor (FOM/mts). This resulted in three measurements per subplot. The mean of the three measurements in a subplot was used in the data analysis. Average air temperature in the 2 weeks before soil moisture measurements was 16.8 °C and mean precipitation was 1.1 mm, with the last rain occurring three (GE) and 4 days (AU) prior to sampling dates (Weather Underground 2014).

Data analyses

Statistical analyses were performed using the software R (R Development Core Team 2012, version 2.15.2). We examined the potential influence of the two irrigation techniques on the species–area relationship at two levels. At the plot level, we calculated the intercepts and slopes (both log-transformed) of each of the 36 species–area relationships. To test whether the two types of irrigation affected the intercepts and slopes of species–area relationships, nested analyses of variance (ANOVA) were used with the factor irrigation type nested in study area. To minimize local variation in environmental factors (exposition, inclination, soil type), we considered differences in the cumulative species curves between pairs consisting of a traditionally irrigated and its nearest situated sprinkler-irrigated meadow (hereafter meadow-pair level). For this purpose, we calculated mean species richness for each subplot size (ranging from 0.01 to 40.96 m^2) for each meadow and determined the intercept and slope of the resulting species–area relationship of this meadow. Paired t tests were applied to examine whether pairs of differently irrigated meadows ($n = 6$) differed in the intercepts and slopes of their species–area relationships.

We constructed two types of distance matrices to analyse differences in the spatial pattern of the soil characteristics between traditionally and sprinkler-irrigated meadows. The first distance matrix considered the geographical coordinates of the 13 sampling points (midpoint of each subplot) to calculate Euclidean distances among all sampling points using the *ecodist* package (Goslee and Urban 2007). The pairwise distances among the 13 sampling points within a plot ranged from 10 to 570 cm ($n = 78$) and were the same for all plots and for all soil characteristics investigated. The second distance matrix had exactly the same structure, but considered a particular soil characteristic instead of geographical coordinates. The distance matrices were calculated separately for all plots for the following characteristics: soil moisture, soil pH, SOM, total soil organic nitrogen content (OrgN), total phosphorus content (PT) and plant available phosphorus content (PP) resulting in a total of 12 distance matrices. Due to a missing value in the sprinkler-irrigated meadow GE2 only 11 distance matrices were obtained for PT. We performed Mantel tests with 999 permutations for each distance matrix of the soil characteristics and calculated Mantel correlograms using the *mantel* and *mgram* functions of the *ecodist* package (Goslee and Urban 2007). To examine whether the Mantel coefficients (r_M) of the soil characteristics differed between irrigation techniques, we created reference bands for equality derived from the standard errors of the difference between r_M at each lag distance (Bowman and Young 1996) using the *sm.ancova* function of the *sm* package with a smoothing parameter $h = 20$ (Bowman and Azzalini 2013). At scales at which the plotted means of r_M exceeded this reference band, irrigation technique had a significant influence on the spatial pattern of the soil characteristic investigated (Bowman and Young 1996).

Finally, to assess the spatial scale of positive autocorrelation of soil characteristics, we determined the largest lag distance with a significant positive r_M value for each soil characteristic and for each Mantel correlogram for both irrigation techniques separately. If there was no positive autocorrelation within a Mantel correlogram, we took 0 as lag distance. In the results section, we present the mean lag distance for each irrigation type and soil characteristic.

Results

A total of 149 vascular plant species were recorded in the two types of meadows, 122 species (81.9 %) in traditionally irrigated meadows and 133 species (89.3 %) in sprinkler-irrigated meadows. Considering single meadows, the cumulative number of species ranged from 57 to 82 species (mean ± SE 68.8 ± 4.0) in traditionally irrigated meadows and from 63 to 78 species (70.0 ± 2.8) in sprinkler-irrigated meadows.

Species–area relationship

At the plot level (40.96 m^2), plant species richness ranged from 39 to 70 species (mean ± SE 53.1 ± 2.1) in traditionally irrigated meadows and from 47 to 64 species (53.9 ± 1.1) in sprinkler-irrigated meadows. The relationship between cumulative species richness and area was significant in all 36 plots (all $p < 0.0001$). However, in none of the species–area curves an asymptote was reached (Fig. 2). Neither the intercepts nor the slopes of the species–area curves were influenced by the type of irrigation (ANOVA, intercept: $F_{1,32} = 0.019$, $p = 0.89$; slope: $F_{1,32} = 0.17$, $p = 0.68$). However, the interaction between study area and irrigation technique had a significant effect on the intercepts ($F_{2,32} = 3.60$, $p = 0.039$), but not on the slopes of the species–area curves ($F_{2,32} = 1.23$, $p = 0.31$). Intercepts were higher in the study area GE (mean ± SE 3.34 ± 0.04) than in AU (3.23 ± 0.03).

At the meadow-pair level, neither the intercepts (paired t test, $t = -0.01$, d.f. $= 5$, $p = 0.99$) nor the slopes ($t = -0.80$, d.f. $= 5$, $p = 0.46$) of the mean species–area curves differed between meadows with either irrigation technique.

Spatial variation in soil characteristics

In general, the mean values of the Mantel coefficients (r_M) of the assessed soil characteristics decreased with increasing distance between the sampling points except for total soil organic matter content (SOM) and total soil organic nitrogen content (OrgN), which both increased with increasing distance in the sprinkler-irrigated meadows (Fig. 3).

The type of irrigation did not affect the spatial variation in soil moisture, OrgN, total phosphorus content (PT) and plant available phosphorus content (PP) (non-parametric ANCOVA, test of equality, soil moisture: $p = 0.93$; OrgN: $p = 0.52$; PT: $p = 0.90$; PP: $p = 0.99$; Fig. 3a, d–f). In contrast, irrigation technique affected the spatial pattern of soil pH and

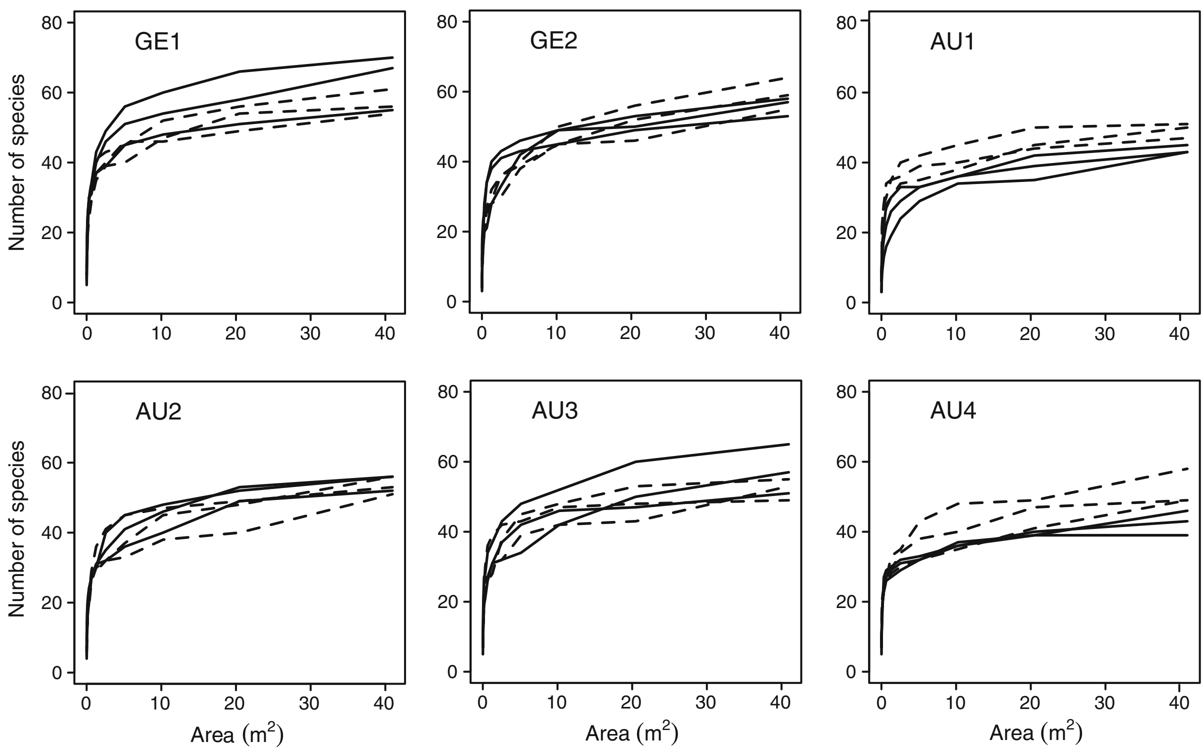

Fig. 2 Species–area curves of six pairs of traditionally and sprinkler-irrigated meadows, two in Guttet–Erschmatt (GE) and four in Ausserberg (AU). In each meadow pair, three plots were examined in a traditionally irrigated meadow (*dashed lines*) and three in a sprinkler-irrigated meadow (*solid lines*)

SOM (pH: $p = 0.011$; SOM: $p = 0.019$; Fig. 3b, c). For both soil characteristics the means of r_M exceeded the reference band at sampling distances between 440 and 520 cm. However, none of the means within this range showed a positive autocorrelation (Fig. 3b, c). In contrast, the mean r_M values of pH between 40 and 120 cm were significantly positively autocorrelated in the sprinkler-irrigated meadows, whereas no similar autocorrelation was found in the traditionally irrigated meadows (Fig. 3b).

The pattern of autocorrelation of soil characteristics did not differ between the two irrigation techniques. In most soil characteristics, no positive spatial autocorrelation among samples was found. Only in a few cases, average spatial autocorrelation ranged from a few to 60 cm (Appendix; Fig. S2).

Discussion

The present study showed that traditionally and sprinkler-irrigated hay meadows did not differ in the shape of the plant species–area relationships and in the small-scale patterns of soil characteristics (exceptions being the spatial distribution of soil pH and SOM).

Plant species richness of hay meadows

Based on a total plot area of 122.88 m^2, we recorded on average 69.4 plant species per meadow. In a previous study conducted in the same region (eight of the 16 meadows were also considered in the present study), an average of 54 species was found per meadow in a single plot of 100 m^2 (Riedener et al. 2013). This difference can be explained by a smaller sampling area, different arrangements of sampling plots (one 10 × 10 m plot versus three 6.4 × 6.4 m plots randomly distributed across a meadow), and the slightly but not significantly lower plant diversity in meadows located in Birgisch–Mund not considered in the present study.

Plant species richness recorded in the plots of the present study (39–70 species per 40.96 m^2) was relatively high compared to plots in other *Trisetetum-*

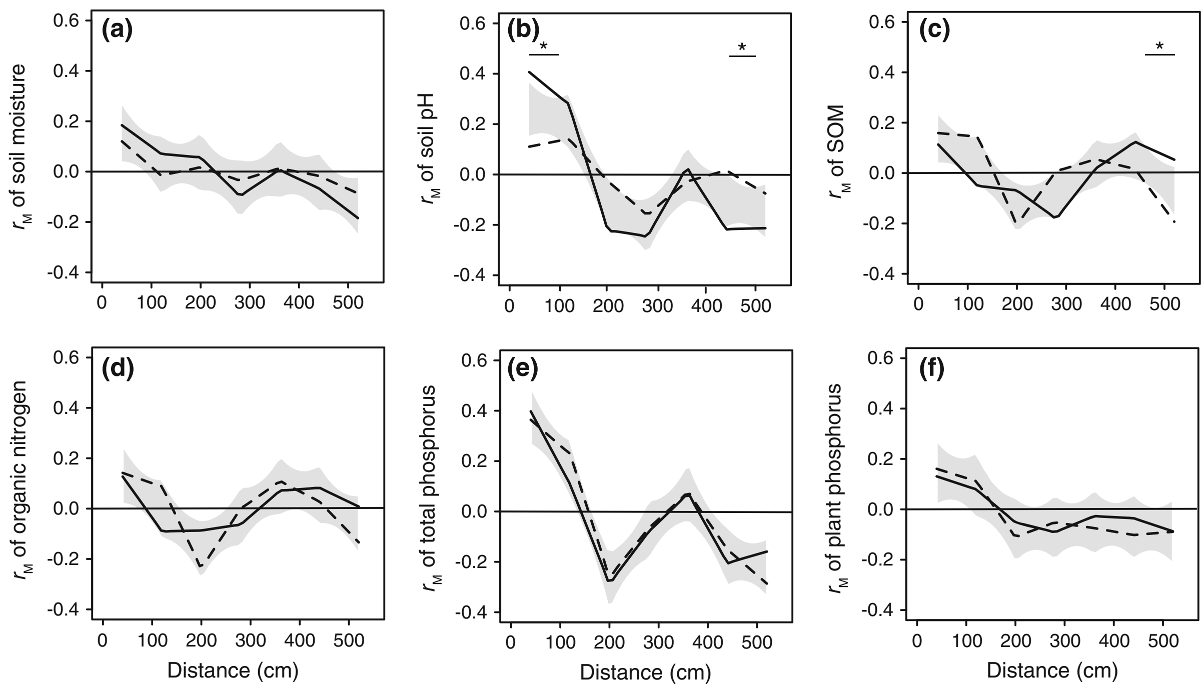

Fig. 3 Non-parametric curves for the mean Mantel coefficients (r_M) of the six soil characteristics in traditionally (*dashed lines*) and sprinkler-irrigated (*solid lines*) meadows. Reference bands for equality of r_M in the two differently irrigated meadows are presented. At distances where the means of r_M exceeded the reference band, the two curves differ significantly from each other, as indicated by the *asterisk*. Smoothing parameter $h = 20$. *SOM* soil organic matter content

meadows situated on similar elevations in the Swiss Alps (31–34 species per 100 m^2, Homburger and Hofer 2012 and 23–43 species per 25 m^2, Volkart and Godat 2007). However, none of the species–area curves reached the asymptote within the range of the plot sizes examined in the present study. This was also true when the data from the three plots of a meadow were combined (total area: 122.88 m^2; data not shown). This indicates a high plant diversity, as well as a pronounced variation in the spatial distribution of single plant species within a meadow compared to vegetation surveys in other *Trisetetum* meadows (Marschall 1947; Ellenberg 1986; Lüth et al. 2011). The pronounced variation in the spatial distribution of single plant species can be explained by various factors including clonal reproduction, uneven distribution of soil nutrients, variation in soil depth and seed distribution.

Effect of irrigation technique on species–area curves

We assumed that traditionally irrigated meadows have an uneven distribution of water, which results in a higher variation in the spatial distribution of plant species than in sprinkler-irrigated meadows. As a consequence, the slopes of the species–area relationships should differ between meadows irrigated by different techniques. However, this was not the case in our study. A possible explanation for the discrepancy is that the water distribution of sprinklers is more heterogeneous than commonly assumed (Meurer and Müller 1987). In fact, sprinkler irrigation systems in the study areas obtain their water from channels, and hence only rely on natural water pressure gradients from the sloping land (Crook 1997). Seasonal variation in water supply can, therefore, influence the reach of a sprinkler and thus the distribution of water. Furthermore, spray water can be misdirected by wind (Meurer and Müller 1987) and additional water can be supplied by uphill-situated meadows irrigated in the traditional way (R. L. M., pers. obs.). Moreover, the spatial arrangement of sprinklers at permanent positions and the seasonal relocation of mobile sprinklers may lead to a mosaic of partly overlapping circular areas with increased water supply and gaps that are tenuously irrigated. Hence, as practiced in our study areas, the distribution of water by sprinklers might be as heterogeneous as in the traditional irrigation technique. As a consequence, the two differently irrigated meadow types show a similar spatial distribution of plant species.

However, differences in the intercept of the species–area relationship were recorded between the two study areas. Irrespective of plot size, plant diversity was higher in Guttet–Erschmatt (GE) than in Ausserberg (AU; Fig. 2). This might be a result of site-specific differences in elevation (Kreft et al. 2008), different grazing animals (GE: horses and occasionally cattle, AU: cattle and sheep), amount of fertilizer, or meadow size (Gaujour et al. 2012).

Effect of irrigation technique on the spatial pattern of soil characteristics

Mantel correlograms revealed that traditionally and sprinkler-irrigated meadows did not differ in the spatial patterns of the soil characteristics examined, except in soil pH (see below). This result is in agreement with the findings of the plant species–area relationship.

Mantel correlograms also provide insight into the occurrence and spatial scale of autocorrelations (Borcard and Legendre 2012). In general, r_M decreased with increasing distances between sampling points, indicating a decreasing dependency the longer the distances between the sampling points were. Average positive autocorrelations were only found over distances ranging from 7 to 60 cm (Appendix). This suggests a high heterogeneity in soil characteristics even at a very small spatial scale. Thus, the heterogeneity in soil nutrients and soil moisture observed in this study could have led to the spatial heterogeneity in plant species and the high plant species richness, thereby supporting the view that heterogeneity in soil characteristics is positively linked to plant species richness (Harner and Harper 1976; Davies et al. 2005; Zhou et al. 2008).

For soil pH, a positive autocorrelation was recorded in sprinkler-irrigated meadows over a distance of 40–120 cm (Appendix). In contrast, no autocorrelation was found in traditionally irrigated meadows. As suggested by Meurer and Müller (1987), these differences might be explained by differences in the sediment content of the water used for irrigation. In sprinkler irrigation, melt water passes a settlement tank prior to entering the tubes, which substantially reduces sediments and organic materials and thus prevents the clogging of nozzles. In the traditional irrigation technique, unfiltered melt water is used. Through this sediment input irrigation additionally contributes to soil development (Meurer and Müller 1987). These differences in the sediment input and differences in the spatial distribution of water could have affected the pattern observed for soil pH. In contrast, small-scale differences in soil characteristics were hardly influenced by differences in the bedrock type, because in the present study, soil characteristics including soil pH were measured in the upper most 5 cm of the soil layer.

Irrigation technique affected the spatial pattern of soil pH and SOM at sampling distances of 400 and 520 cm. However, in both cases, r_M values were not significantly different from zero indicating that there was no autocorrelation at this distance.

Conclusion

The present study demonstrated a pronounced small-scale heterogeneity in the spatial distribution of both plants and soil characteristics in the hay meadows investigated. However, this variation was not influenced by the irrigation technique used. As it is applied on the slopes of these study areas, sprinkler irrigation does not appear to alter the spatial pattern of plant diversity compared with the traditional irrigation technique. Furthermore, our study areas are characterised by a patchy landscape consisting of small meadows, pastures, fallow land, hedgerows, few buildings and roads with adjacent forest. Therefore, the lack of any influence of irrigation technique on the spatial pattern of plant diversity and soil characteristics should not be extrapolated to large, homogeneous grassland areas that are more intensively irrigated.

Acknowledgments Special thanks go to the farmers and landowners for permitting field surveys on their land, to K. Liechti and R. Rodewald for preparatory work and to A. Baur and two anonymous reviewers for their valuable comments on the manuscript. Financial support was received from the National Research Programme NRP 61 (Sustainable Water Management).

Appendix

See Appendix Table 1.

Table 1 Positive spatial autocorrelation obtained from individual Mantel correlograms for the six soil characteristics in (a) traditionally and (b) sprinkler-irrigated meadows

Plot	Soil moisture	Soil pH	SOM	Nitrogen	Total phosphorus	Plant available phosphorus
(a) Traditional irrigation						
GE1	0.00	0.00	0.00	0.00	119.99	0.00
GE2	0.00	0.00	0.00	0.00	40.00	40.00
AU1	40.00	0.00	0.00	40.00	40.00	0.00
AU2	0.00	0.00	0.00	0.00	0.00	119.99
AU3	0.00	0.00	0.00	119.99	119.99	0.00
AU4	0.00	0.00	0.00	0.00	40.00	0.00
Mean	6.67	0.00	0.00	26.67	60.00	26.67
Median	0.00	0.00	0.00	0.00	40.00	0.00
(b) Sprinkler irrigation						
GE1	0.00	119.99	0.00	0.00	40.00	0.00
GE2	40.00	119.99	0.00	0.00	NA	0.00
AU1	0.00	40.00	0.00	0.00	40.00	0.00
AU2	0.00	40.00	0.00	0.00	0.00	0.00
AU3	0.00	0.00	0.00	0.00	119.99	0.00
AU4	0.00	40.00	0.00	40.00	40.00	0.00
Mean	6.67	60.00	0.00	6.67	48.00	0.00
Median	0.00	40.00	0.00	0.00	40.00	0.00

The table shows the maximal distance (cm) for positive autocorrelation among the samples of a given soil characteristic within a plot, as well as mean and median for each soil characteristic. No positive autocorrelation indicates a high variability among samples

SOM soil organic matter content

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