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Effects of irrigation on vegetation, mesofauna and organic matter decomposition in Mediterranean vineyards

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ABSTRACT

Increasing temperatures and resulting stronger spring and summer drought have exponentially increased irrigation in Mediterranean vineyards. So far, little is known about the potential effects of irrigation on vineyard agroecosystems. The aim of this study is to assess the effect of vineyard irrigation on vegetation, soil mesofauna, the decomposition of organic matter, grapevine yield and berry sugar content. Five pairs of vineyards were selected in South-eastern France (Luberon), each comprising an irrigated and a non-irrigated vineyard. The irrigated vineyards received on average 60 mm of water which doubles usual summer rainfall. Under-vine vegetation and soil mesofauna were analysed during the growing season (April) and the following summer drought (August). Organic matter decomposition was tested using tea bags that were buried from January to May in the grapevine row. We found a significant difference in vegetation cover between treatments in April but not in the following August. Springtail and mite abundance were only different between treatments in August being higher in irrigated vineyards. In August, we also found significant differences between treatments in the structure of the soil mesofauna community. The effect of irrigation on the decomposition of organic matter was not significant. Grapevine yield was higher in irrigated vineyards but no effect on the chlorophyll index of grapevine leaves was found. This study highlighted the effect of irrigation showing that even moderate irrigation has significant effects on Mediterranean vineyard ecosystems. The strong increase of irrigated vineyards advocates for further research to obtain a better understanding of irrigation consequences under different pedoclimatic conditions.

1. Introduction

Climate change models predict a rise of temperature, a change in seasonality of precipitations and temperatures, and an increase in periods of drought (IPCC et al., 2022; Mukherjee et al., 2018). These climatic changes do not only affect natural habitats but also agroecosystems (Li et al., 2009), resulting in water stress for crops and non-crop vegetation (Kirschbaum, 1995). Climate change scenarios predict a loss of 40 % of suitable grapevine regions for a temperature increase of 2°C and 50 % loss for an increase of 4°C until 2050 (Hannah et al., 2013). The Mediterranean region is expected to be particularly impacted by climate change that likely results in an extension of summer drought (Cramer et al., 2018; Hoerling et al., 2012).

Vineyard ecosystems are affected by climate change through its effects on vegetation, soil biodiversity and soil functioning. In particular, drought changes the composition of plant communities, favouring drought-tolerant species (Martinez-Vilalta and Lloret, 2016). Drought is also known to reduce the activity of soil bacteria, nematodes and micro-arthropods (Tsiafouli et al., 2015; Whitford, 1989), to decrease mesofauna abundance (Ferreira et al., 2015; Frampton et al., 2000; Lindberg et al., 2002) and to change the mesofauna community structure and composition. Drought effects on soil organisms may be direct or mediated by changes in plant species composition and biomass production (Alon and Sternberg, 2019; Vicente-Serrano et al., 2013). Such plant community-mediated changes in soil organisms, in turn, affect nitrogen and carbon cycling (Bezemer et al., 2010). In addition, summer drought and increasing temperatures also change the chemical characteristics of grapevine berries, in particular the sugar content (Ion et al., 2020).

Different solutions have recently been developed to mitigate the

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effect of climate change on grapevine, such as drought-adapted grapevine varieties or a shift of viticulture to higher altitude and latitude (Hannah et al., 2013). The most common adaptive practice is, however, drip irrigation (Graveline and Grémont, 2021; Nicholas and Durham, 2012). In France, vineyards were historically not irrigated, as irrigation was first authorized in 2006 and has been increasing in frequency and intensity since then (Graveline and Grémont, 2021). Several studies revealed that irrigation does not only reduce yield loss due to water stress (Ion et al., 2020; Irvin et al., 2016), but also limits the alcohol content by lowering sugar concentration (Ion et al., 2020; Irvin et al., 2016; Winter et al., 2018). Drought-induced high sugar and alcohol content are currently great problems in viticulture reducing the wine quality.

Previous studies focused on the effect of irrigation on grapevine (Acevedo-Opazo et al., 2010; Mirás-Avalos and Araujo, 2021), while little is known about the effect of irrigation on vineyard ecosystems. Irrigation affects spontaneous vineyard vegetation, particularly the plant community composition. In irrigated perennial crops, fast growing plant species adapted to mesophilic conditions may outcompete drought-tolerant species adapted to Mediterranean climate (Juárez-Escario et al., 2018). Fagúndez et al. (2016) found a decrease of plant species richness in irrigated Spanish wheat fields. Water addition may further delay plant phenology, in particular the flowering period (Oliva et al., 1994; Ragasova et al., 2017) and increase vegetation cover (Dubovyk et al., 2015; Müller et al., 2016). Previous studies on forests (Guidi et al., 2022; Lindberg et al., 2002) and agroecosystems (Ferreira et al., 2015; Frampton et al., 2000) have provided evidence for direct or vegetation-mediated effects of irrigation, leading to an increase in soil mesofauna abundance, and changes in soil mesofauna community composition (Lindberg et al., 2002, Ferreira et al., 2015). Such effects on soil mesofauna were stronger under dry climate (Holland et al., 2013).

Soil organisms provide key ecological functions and services that may be altered by irrigation, such as litter decomposition (Liu et al., 2022) and carbon sequestration (Guidi et al., 2022; Kirschbaum, 1995). Litter decomposition is closely related to nutrient cycling, and thus soil organisms also play an important role in plant nutrition (Costantini et al., 2018; Gulvik, 2007; Rusek, 1998). Soil organisms such as soil mesofauna are further involved in the preservation of a soil structure that favours crop production (Coleman et al., 2017; Lavelle et al., 2006) and may contribute to the biocontrol of pests and diseases (Coleman et al., 2017; Crossley et al., 1992; McMurtry et al., 2015).

Among mesofauna organisms, springtails and mites are the most abundant groups (Gulvik, 2007; Rusek, 1998). They are known as sensitive bioindicators of soil quality, reflecting the impact of environmental change and disturbance (George et al., 2017; Gulvik, 2007; Socarrás, 2013). Predatory mites, feeding on a wide variety of prey (e.g. small invertebrates, springtails, arthropod eggs, fungi, mites) (Crossley et al., 1992; Potapov et al., 2022) are already used as biocontrol agents in agroecosystems (mesostigmatic mites: Biswas and Karmakar, 2022; Castilho et al., 2015; McMurtry et al., 2015; prostigmatic mites: Hernandes et al., 2015; Muñoz-Cárdenas et al., 2015). Springtails may also be an efficient biocontrol agent since several groups are feeding on fungi (Coleman et al., 2017; Rusek, 1998) including pathogens (Gruss et al., 2022). However, phytophagous mites increase during irrigation, which can increase the risk of pest infestation (Bernard et al., 2005).

In France, irrigation has increased by 100% reprsenting a common practice in particular in Mediterranean Southern France (Agreste, 2022). Therefore, a better understanding of irrigation effects on biodiversity is needed. Our study aims at analysing the effect of irrigation on under-vine vegetation, soil mesofauna and organic matter decomposition. We focused on springtails and mites, the two most abundant mesofauna groups. Grapevine performance was also considered, including chlorophyll content, yield and berry sugar content in order to evaluate the agronomic benefits of irrigation. We hypothesized that irrigation (1) increases the under-vine vegetation cover and plant species richness, (2) consequently increases the abundance of mites and springtails and changes their community structure, and (3) increases organic matter decomposition. We further tested whether these putative irrigation effects persist until the following spring, and how grapevine performance is affected.

2. Methods

2.1. Study site

The study was conducted in the Luberon mountain range (South-eastern France). This study area is characterized by a Mediterranean climate with hot and dry summer and mild winters. Rainfall occurs in autumn and spring with a mean annual precipitation of 701 mm (Pertuis meteorological station). In the study year (2022), the annual precipitation (513 mm) was lower than average, with only 69 mm during the irrigation period from 1st May to 15st August. The annual temperature of 14.4°C corresponded to the long-term average.

Five pairs of vineyards were selected in the Northern Luberon (Appendix A Fig. 1). Each pair included one irrigated and one non-irrigated vineyard of the same grape variety (Grenache, Syrah) and similar age (about 20 years). The average distance between the pairs was 500 m. Twenty percent of the vineyards were tilled in one out of two inter-rows, while the other vineyards were fully covered with vegetation. The inter-row vegetation is managed by mulching three or four times a year (mown without removing the biomass), starting in May. All inter-row and under-vine vegetation is spontaneous. Under-vine vegetation was controlled chemically (glyphosate) or mechanically (same type within a pair). Herbicides were applied in May or June and application was repeated in July when regrowth was too high. In early January, the basal part of grapevine trunks was covered with 5 cm of soil that was removed in late May. Grapevine density was 4000/ha. Fungicides were regularly applied from April to early August in order to control powdery and downy mildew.

Vineyards were irrigated using one aerial dripper per grapevine plant and a flow rate of 1.6 L/h dripper. Irrigation, in place for at least 5 year, was only allowed between 1st May and 15th August and usually started in June. None of the vineyards were irrigated before 2006. Irrigation frequency was two to four times during summer with a total duration ranging from 50 to 216 hours. In the region, the average total irrigation time is 90 hours equivalent to 60 mm of precipitation and an irrigated session lasted between one to three days. The control vineyards were never irrigated. Irrigated vineyards usually received one additional herbicide treatment (June/July) due to higher vegetation regrowth.

2.2. Soil moisture and chemistry

In order to evaluate the movement of irrigation water, we measured soil moisture in August 2022 eight hours after irrigation at different distances from the drippers using ML3 ThetaProbe soil moisture sensors. The duration of irrigation was one to three days and measurements were taken in the afternoon. One measurement at a depth of 10 cm was taken directly under the dripper, a second at a distance of 0.6 m from the dripper in the direction of an inter-row and the third in the middle of the inter-row (1.25 m from the dripper). The measurements were repeated twelve times in each vineyard.

Soil samples were collected inside the rows, under grapevine plants at four sampling points per vineyard in April 2022. Two vineyard rows were sampled. For each row, the first and the second sampling point were located at 15 m and 25 m from the border of the vineyard, respectively. We excluded the outermost rows. At each sampling point, we collected a composite sample of five sub-samples. Organic matter content, cation exchange capacity, pH and texture were analysed using standard protocols.

2.3. Vegetation surveys

The vegetation was analysed within grapevine rows in April, before irrigation, and in August, at the end of the irrigation period, and at least one month after the last weed control. The cover of all vascular plant species and total plant cover were estimated in 50x50 cm^2 plots close to soil sampling points at the same time as mesofauna sampling. Cover values are the vertical projection of all aboveground plant organs and the cover sum may exceed 100 % due to the potential overlap of leaf cover.

2.4. Soil mesofauna sampling

We sampled soil mesofauna in April before irrigation started and in August at the end of the irrigation period. For each period, four soil samples were collected under the grapevine plants at soil sampling points close to the dripper, using cylinders of 5 cm in diameter and 5 cm in height. Samples were kept separately resulting in a total of 20 samples per treatment for mesofauna analyses. For each sample, mites and springtails were extracted using a moisture gradient according to the Berlèse-Tullgren method (González et al., 2021). Mites were identified according to diet (decomposers and predators) and at taxonomic level (suborders: Astigmata, Mesostigmata, Oribatida, Prostigmata). Due to various diet strategies of Prostigmata mites (Potapov et al., 2022), we decided to separate this group into predator Prostigmata and non-predator Prostigmata. Springtails were identified at the order level (Entomobryomorpha, Neelipleona, Poduromorpha, Symphypleona) and additionally at the ecological guild level (Epiedaphic, Hemiedaphic, Euedaphic) (Hedde et al., 2022).

2.5. Organic matter decomposition

Organic matter decomposition by decomposer microfauna, bacteria and fungi was analysed using the tea bag method following the tea bag index protocol (TBI: Keuskamp et al., 2013). Two types of tea were used, Rooibos red tea (EAN: 87 22700 18843 8) that is characterized by a slow decomposition, and green tea (EAN: 87 22700 05552 5) with a fast decomposition. The mesh size of tea bags was 0.25 mm, which allowed microorganisms involved in soil organic matter decomposition to penetrate (Keuskamp et al., 2013).

We weighed tea bags and buried a pair of green and red tea under-vine, at each of the four soil and mesofauna sampling points to 8 cm depth from 24 January 2023 to 20 April 2023. According to Keuskamp et al., (2013), a burying period of 90 days was chosen. After burying, tea bags were dried for 48 h at 70°C and weighted afterwards. The weight loss during burying period corresponds to organic matter decomposition. We calculated the stabilisation factor S and the decomposition rate k. These two statistics are based on a two-phased model of decomposition: fast during the initial phase (Green tea) and slow during the second phase (Red tea). Thus, S and k calculation includes the decomposition speed of labile and recalcitrant litter. S and k are important estimators for litter decay (S) and carbon turnover (k) (von Oppen et al., 2024). We calculated S and k following the tea bag index protocol of Keuskamp et al. (2013).

2.6. Grapevine yield and performance

In September 2022, during the harvest period, eight grapevine plants closest to the soil and mesofauna sampling points were randomly selected in each vineyard, and the number of grapes counted. We further cut and weighted one grape per grapevine plant to calculate yield as the mean number of grapes per grapevine multiplied by the mean grape weight per grapevine. We also analysed the sugar content of 20 grapevine berries from eight different grapevine plants per vineyard. Grapevine berry sugar content was analysed using refractometry. Grapevine nutritional state was measured using SPAD 502 chlorophyll index (Konica Minolta®). Measurements were taken randomly on ten leaves per plant and eight plants per vineyard.

2.7. Data analysis

All data were analysed using R software (R version 4.2.2, R Core Team, 2022). Data on mesofauna abundances were scaled to 1 m^2. The effects of irrigation on mites, vegetation cover, annual/perennial plant cover ratio, species richness, organic matter decomposition, chlorophyll index and grapevine yield were analysed using generalized linear mixed models (GLMM, packages Lme4 or glmmTMB). Springtails were not included in the univariate analyses since their abundance was too low in August. Irrigation and period (April / August) were fitted as fixed factors and the vineyard pair ID as a random factor. Mite and springtail abundances were analysed using GLMMs with Poisson distribution and log-link function. In the case of overdispersion, a negative binomial model was fitted. Groups occurring less than one time per vineyard were not considered in our analyses. Vegetation cover, plant species richness, annual/perennial plant cover ratio, tea bag decomposition, chlorophyll index and grapevine yield were analysed using GLMMs with gaussian error distribution. Data analysed with Gaussian error distribution were transformed using bestNormalize package when residuals were not normally distributed or variances were not homogeneous (Peterson, 2021). A Tukey post-hoc analysis (lsmeans package) was applied when the interaction between the period and irrigation was significant.

In order to evaluate irrigation effects on mesofauna communities, a Between Class Analysis (BCA) was run using ade4 package (Dray and Dufour, 2007) based on Hellinger transformation. Non-metric multidimensional scaling (NMDS) was used to compare plant communities (vegan package, Oksanen et al., 2022) based on the Bray–Curtis dissimilarity index. Effects of irrigation on vegetation and mesofauna communities were tested by permutational multivariate analysis (PERMANOVA) using the Adonis function (Oksanen et al., 2022).

3. Results

3.1. Soil moisture and chemistry

No difference in soil moisture was recorded between irrigated and non-irrigated vineyards in April. In August, soil moisture differed between the two treatments but only under grapevine plants (Appendix B Fig. 2). No differences in soil texture, organic matter content, cation exchange capacity or pH were found (Appendix C Table 1).

3.2. Responses of vegetation to irrigation

A total of 39 species belonging to 17 families was recorded. Regardless of irrigation, total vegetation cover was significantly higher in April (40 %) than in August (17 %) (Appendix D Table 2). A difference between irrigation treatments occurred in April with vegetation cover being higher in non-irrigated vineyards, but no effect of irrigation on vegetation cover was found in August (Appendix D Table 2). Plant species richness was also higher in April than in August (Appendix D Table 2), but no effect of treatment was found (Appendix D Table 2, Fig. 1). Annual/perennial plant cover ratio was affected by the period but not by treatment (Table 1, Appendix D Table 2). Perennial plant cover was not affected by treatment or period, whereas annual plant cover was significantly higher in April (35 %) than in August (<5 %). In April, higher annual plant cover was found in non-irrigated vineyards (50 %) than in irrigated vineyards (25 %) (Appendix D Table 2). Plant community composition was not significantly different between treatments (Fig. 2).

3.3. Responses of mesofauna to irrigation

We identified a total of 255 springtails and 1548 mites. Mites were

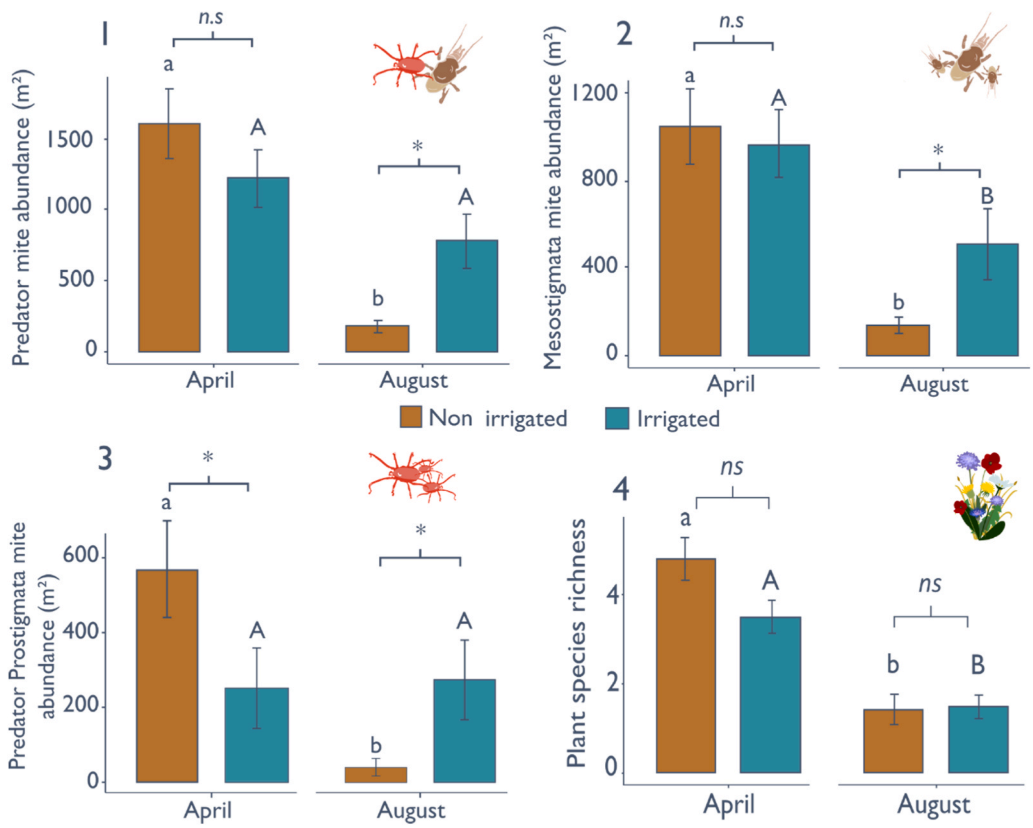

Fig. 1. Effect of irrigation on the abundance (± SE) of mesofauna (1: predator mites; 2: Mesostigmata mites; 3: predator Prostigmata mites) and plant species richness (4) in April and August. Different lower case letters indicate significant differences (p < 0.05) between months for non-irrigated vineyards and capital letters indicate significant differences between months for irrigated vineyards. Braces show significant differences between the two irrigation treatments in the same month.

Table 1
Effect of irrigation on vegetation cover, plant species richness, and mesofauna abundance in April (before irrigation) and August (irrigation period). Chisq represents Chi squared of generalized linear mixed models. Values in bold indicate significant differences between irrigated and non-irrigated vineyards at P< 0.05, values in italics marginally significant differences at P< 0.1 – P> 0.05 and NS non-significant differences.

	Irrigation		Period		Irrigation x Period	
	Chisq	P-value	Chisq	P-value	Chisq	P-value
Vegetation cover	**17.261**	**<0.001**	**22.343**	**<0.001**	*3.376*	*0.066*
Plant species richness		NS	**89.039**	**<0.001**	**7.374**	**0.007**
Annual/Perennial plant cover ratio		NS	**31.914**	**<0.001**	**4.602**	**0.032**
Annual plant cover		NS	**113.512**	**<0.001**	**19.694**	**<0.001**
Total mites		NS	**11.796**	**<0.001**	*3.519*	*0.061*
Oribatida		NS	*2.818*	*0.093*		NS
Mesostigmata		NS	**65.172**	**<0.001**	**4.262**	**0.039**
Prostigmata		NS	**7.888**	**0.005**	**21.985**	**<0.001**
Decomposer mites		NS	**13.599**	**<0.001**		**NS**
Predator mites		NS	**25.416**	**<0.001**	**13.990**	**<0.001**
Predator prostigmata		NS		NS	**14.510**	**<0.001**

represented by Oribatida (1064), Mesostigamta (228), Astigmata (132) and Prostigmata (100 Predators and 25 Non-Predators). We sampled 61 epi-edaphic, 78 hemi-edaphic and 116 eu-edaphic springtails. The most abundant sub-order was Poduromorpha (180), followed by Entomobriomorpha (61) and Symphypleona (14). Few springtails were found in August (17), with no occurrence in non-irrigated vineyard.

We only found small differences between irrigated and non-irrigated vineyards in April. Prostigmata predators were significantly more abundant in non-irrigated vineyards than in irrigated ones (Appendix D Table 2, Fig. 2). The irrigation effect was not significant for other mesofauna groups (Table 1, Appendix D Table 2, Appendix E Table 3, Appendix F Fig. 3).

In August, both predatory mite groups (Mesostigmata and Prostigmata predators) were significantly more abundant in irrigated vineyards (Appendix D Table 2). We did not find significant differences for decomposer mites, Oribatida and total mite abundance (Table 1).

We found more mites in April than in August for almost all sampled groups (Table 1). However, for both Prostigmata and predator Prostigmata the differences were only significant for non-irrigated vineyards (Appendix D Table 2). The structure of the mesofauna community differed significantly between periods and in August also between treatments (Fig. 3).

3.4. *Effect of irrigation on organic matter decomposition*

Green tea bags lost 42 % of organic matter mass and red tea bags 22 %. The stabilisation factor (S) and the decomposition rate (k) did not differ between treatments (irrigated: $S = 0.482$, $k = 0.023$; non-

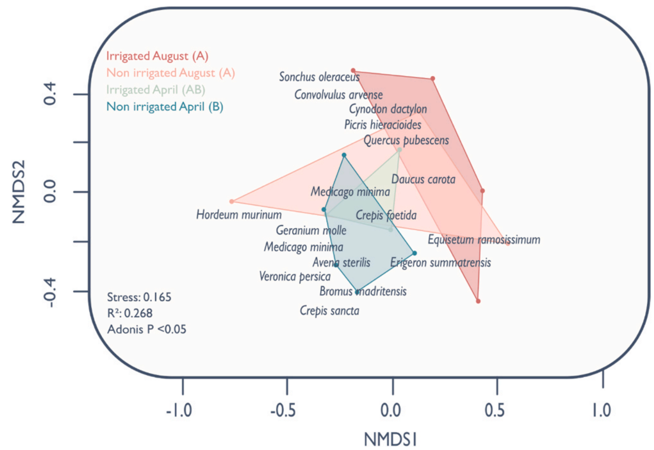

Fig. 2. Effects of irrigation and sampling date on plant community composition (occurrence > 2) of under-vine vegetation using Non-Metric Multidimensional Scaling (NMDS). Different capital letters next to the treatment legend indicate a significant difference (Pairwise Adonis $p < 0.05$).

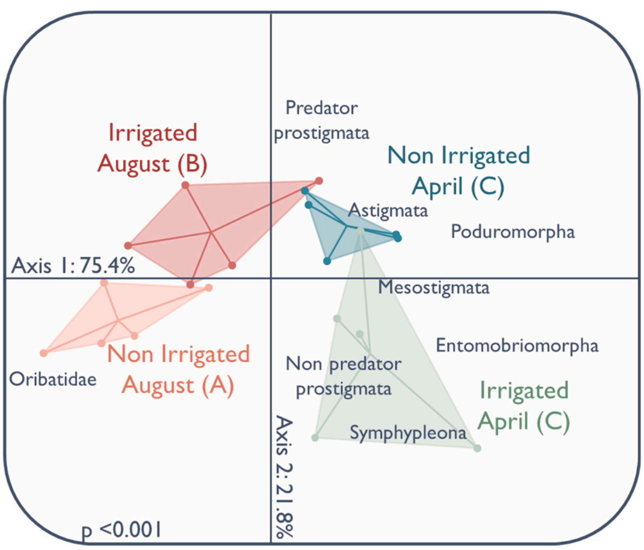

Fig. 3. Effect of irrigation and sampling date on mesofauna community structure at order level for mites and sub-order level for springtails using a Between Class Analysis (BCA, Monte-Carlo test: $p < 0.05$, Adonis $p < 0.05$). Different capital letters in brackets indicate significant differences between the mesofauna communities (Pairwise Adonis $p < 0.05$).

irrigated: $S = 0.483$, $k = 0.020$) (Fig. 4).

3.5. Effect of irrigation on grapevine yield and vine health

Grapevine yield was significantly higher (12t/ha) in irrigated than in non-irrigated (8t/ha) vineyards (Fig. 5). The concentration of fruit sugar (glucose, fructose) was lower in irrigated vineyards (Fig. 5) with 231 g/L for irrigated and 238 g/L for non-irrigated vineyards. Irrigation did not significantly affect the chlorophyll index (Fig. 5).

4. Discussion

In this study, we analysed the effect of irrigation on vineyard vegetation, soil mesofauna and related functions. We found that irrigation limits the decrease of mite abundance from the suitable season in April to the summer drought period in August, resulting in a significantly higher mite abundance in irrigated plots. In contrast, springtails were not significantly affected by irrigation. Organic matter decomposition also remained unaffected by irrigation and effects on vegetation were only apparent in April before irrigation started. As expected, irrigation increased grapevine yield and reduced sugar content of grapevine berries.

4.1. Irrigation effects on vegetation

During summer, aboveground parts of most plant species are drying out resulting in lower vegetation cover and lower aboveground plant species richness. Contrary to our expectations, irrigation did not affect vegetation cover or plant species richness. Thus, the amount of added water may not have been sufficient to prevent drying or summer senescence is part of phenology driven by other factors than humidity (Müller, 2017). During the growing season in April, vegetation cover was higher in the non-irrigated vineyards mainly due to higher cover of annuals. Under-vine vegetation is chemically or mechanically controlled to avoid competition with grapevine plants (Kazakou et al., 2016; Peruzzi et al., 2023), and contamination during mechanical harvesting (Florentine et al., 2021). Stronger control measures in irrigated vineyards may have resulted in an overcompensation and lower plant cover than in non-irrigated vineyards. In particular, annual species do not resprout after chemical weed control explaining their reduced abundance in irrigated vineyards. However, no changes in functional groups or plant species composition were detected.

4.2. Irrigation benefits mites but not springtails

Mesofauna abundances decreased from April to August due to the Mediterranean summer drought largely limiting water availability in the upper soil layers. Apart from direct effects of drought, the decrease in mesofauna abundance may also result from drought-related plant senescence, leading to lower availability of food resources. This decrease in mesofauna abundance was buffered by irrigation resulting in higher abundances of mites in irrigated vineyards, and confirming our hypothesis that irrigation increases mesofauna abundances (Ferreira et al., 2015; Guidi et al., 2022; Lindberg et al., 2002; Rahman et al., 2017). Since no such irrigation effect was found for plant cover, arthropods were most likely directly affected by irrigation. Astigmata (Behan-Pelletier, 1999) and Prostigmata mites (Alatalo et al., 2017; Convey et al., 2003) are particularly sensitive to drought, whereas Oribatida are more resistant (Crossley et al., 1992; Lindberg and Bengtsson, 2005). For Mesostigmata, several studies found evidence for a negative effect of drought (Lindberg et al., 2002; Meyer et al., 2021), whereas others did not find any effect (Holmstrup et al., 2013; Lindberg and Bengtsson, 2006). Mesostigmata are more resistant to drought but depend on food resources that are strongly affected by drought such as springtails (Crossley et al., 1992) or secondary decomposers (Klarner et al., 2013). As Mesostigmata mites can move from ground vegetation to grapevine leaves (Tixier et al., 2000), the effect of irrigation may reduce damage to grapevine leaves by increasing the predation of predatory mites (e.g., Mesostigmata) on phytophagous grapevine mites (e.g., Prostigmata) that are present during the drought period (Barnes et al., 2024) and damage grapevine leaves and buds.

Unlike mites, springtails hardly responded to irrigation in August. Springtails were only found in irrigated vineyards, but their abundances were very low, complicating statistical testing. Springtails are known to be more sensitive to drought than mites (Convey et al., 2003; Vestergård et al., 2015). Irrigation may not have been sufficiently high to compensate for water loss during the hottest and driest months. The arthropod resistance to desiccation is directly linked to their cuticle morphology (Teets and Denlinger, 2014). Arthropods with permeable cuticles may only persist as drought-resistant eggs during this stressful period (Alvarez et al., 1999; Hopkin, 1997). Furthermore, springtails may respond to drought by moving deeper into the soil where soil moisture levels are higher. In these ecomorphic stage, springtails stop

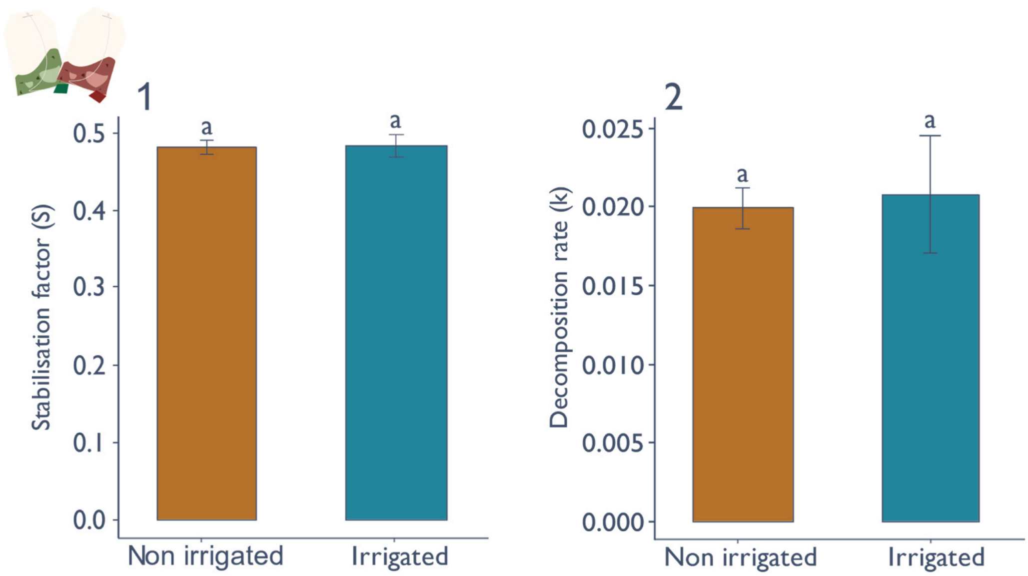

Fig. 4. Effect of irrigation on tea bag decomposition (± SE) after 90 days. Stabilisation factor (1) and decomposition rate (2). Different letters indicate significant differences ($p < 0.05$).

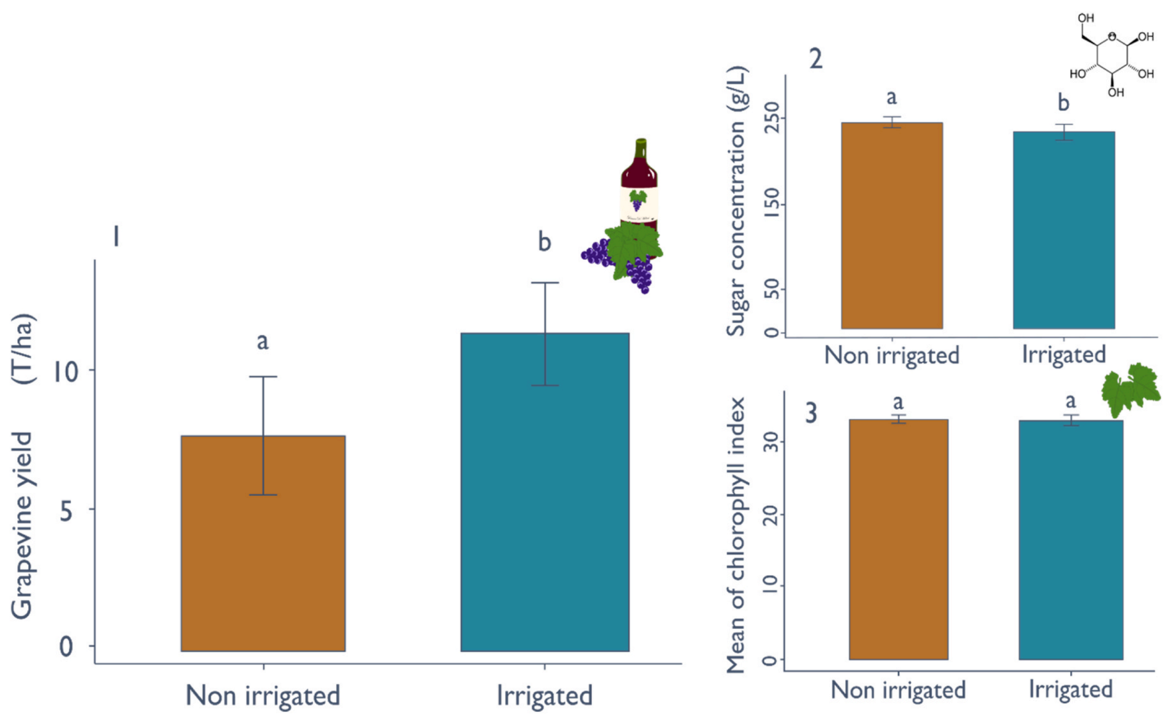

Fig. 5. Effect of irrigation on grapevine yield (1), sugar concentration (glucose, fructose) (2), and chlorophyll index (3), (± SE). Different letters indicate significant differences ($p < 0.05$).

feeding and just these stages are often found in deeper layers of soil (Cassagnau, 1986). Many springtail species change to an ecomorphic stage under drought and increasing temperature (Bonfanti et al., 2023).

We found few significant differences between irrigated and non-irrigated vineyards in April suggesting that irrigation effects of the previous summer do not persist until the next growing season. Only the April abundance of predator Prostigmata was significantly affected by summer irrigation.

4.3. No effect on organic matter decomposition

Contrary to our hypothesis, no significant differences in the stabilization factor (S) and the decomposition rate (k) were observed, suggesting that irrigation had no effect on organic matter decomposition. In semi-arid regions, irrigation typically enhances decomposition in agricultural soils (Arroita et al., 2013) as decomposition processes are generally water-dependent (Sierra et al., 2015). We initially expected lower S values in irrigated vineyards, as S tends to decrease with increased mean annual precipitation, and higher k values, since k is known to rise with greater soil moisture (Keuskamp et al., 2013).

However, these expected trends were not observed, most likely due to the tea bag incubation period. Tea bags were buried from January to May corresponding to peak microbial activity but several months after irrigation. Microorganisms, the primary agents of tea bag decomposition (Aponte et al., 2010), may have driven these patterns. Our findings suggest that the influence of irrigation on decomposer microorganisms does not persist until the subsequent growing season, corresponding to the observed dynamics in mesofauna community composition and abundance.

4.4. Responses of yield and grapevine performance to irrigation

In Mediterranean vineyards, irrigation is used to mitigate the negative effects of drought on grapevine production and sugar content. Accordingly, we found a higher yield in irrigated vineyards and a lower sugar content. Irrigation is known to increase grapevine yield and to reduce sugar content in grapevine fruits (Acevedo-Opazo et al., 2010; Ion et al., 2020; Irvin et al., 2016; Winter et al., 2018).

We did not find significant differences in the chlorophyll index, which does not confirm performance differences between irrigated and non-irrigated vineyards. The high sensitivity of the chlorophyll index to other environmental factors (Madison and Andersen, 1963; Mirás-Avalos et al., 2017) may have resulted in high unexplained variation masking irrigation effects.

5. Conclusions

Vineyard irrigation aims to compensate for increasing Mediterranean summer drought according to climate change projections and will likely increase in future. We demonstrated a buffering mechanism of irrigation limiting negative effects of summer drought on soil organisms. This effect was strong for mites with higher summer abundance in irrigated vineyards but weak for springtails. These irrigation effects do not persist from the irrigation period in summer to the following spring. Our multi-taxon approach highlights the complexity of agroecosystem responses to irrigation, that depend on taxa and vary over time. While no persistent effects on plant community composition were observed, long-term changes may occur in mesofauna communities. To better understand effects of irrigation on the mesofauna, a higher frequency of sampling over longer periods is needed including more detailed analysis of species and functional community composition.

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CRediT authorship contribution statement

Melloul Emile: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Rocher Léo:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Conceptualization. **Bischoff Armin:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Gros Raphaël:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Blight Olivier:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agee.2025.109592.

Data Availability

Data will be made available on request.

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