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The organic mulches in vineyards exerted an influence on spontaneous weed cover and plant biodiversity

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ABSTRACT

The current trend toward sustainable agricultural practices creates a demand for alternatives to conventional soil management. One of the main problems for farmers is the competition for water and nutrients of weeds with the crop and the complicated management that this entails. Conventional practices such as tillage and the use of herbicides are commonly used and imply high environmental impacts while organic mulches could be an attractive sustainable alternative for soil management. Therefore, the 3-year effect of different soil management practices with organic mulches on the control of spontaneous weeds in the vine row has been studied. Three types of organic mulches [grapevine pruning debris (GPD), straw (SM) and spent mushroom compost (SMC)] and two conventional soil management methods [in-row tillage (TILL) and herbicide (HERB)] were compared on a vineyard in North Spain. For this purpose, the percentage of soil covered by weeds (PWC), the presence of each species and its effect on the vine development, and the weed community formations were analysed in each soil management. In addition, soil nutrition, soil temperature and soil water content were measured. On the one hand, SM and GPD mulches limited the presence of weeds (<30%), reducing the need for tillage maintenance and improving soil integrity. On the other hand, SMC produced excessive weed growth (>85%) that could be a problem for the farmer. Of the conventional practices, the TILL treatment was strongly affected by the timing of agricultural work and environmental conditions, with large variability between years. The results indicated that the application of organic mulches reduced the percentage of species with a harmful effect on optimal vine growth and increased plant diversity and its benefits for the ecosystem. Organic mulches are an effective alternative for soil management due to the improvement of the chemical and physical properties of the soil, the increase in the water content of the soil, the reduction of heat stress and the percentage of noxious species for optimum vine growth.

1. Introduction

Grapevine is one of the oldest crops in the Mediterranean area, and is very important in the economy, society and culture (Limier et al., 2018). Spain, France and Italy are the countries that contribute most to the world's vineyard surface, accounting for 33.9% of the world's wine-growing area (OIV, International Organisation of Vine And Wine, 2021). Vine management is currently changing due to the social demand for more sustainable management of agroecosystems (Harvey and Pilgrim, 2011) supported by the European Green Deal policy initiative (EU Farm to Fork Strategy). In Spain, in the last four years, the area under organic management has increased by 33%, with a total area of more than 142,000 ha (MAPA, 2022). Hence, one of the challenges is finding alternative management methods to control excessive weed coverage, a limiting factor in grape production (Kazakou et al., 2016) due to the allelopathic effect (Kara and Ata, 2021) and the competition for water, nutrients and light (Hembree and Lanini, 2006).

Traditionally, weed control has been performed by using herbicides and tillage, causing soil erosion problems (Prosdocimi et al., 2016), pollution and the emergence of herbicide-resistant species (Heap and Duke, 2018). In Spain, conventional viticulture tried to keep the soil bare, favouring the emergence of species that can grow and reproduce quickly (Damour et al., 2018; Gaba et al., 2014; Garnier and Navas, 2012; Kazakou et al., 2016). For this reason, tillage and the use of

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herbicides assist the profile of ruderal species: small plants of a high specific area and big seeds (Grime, 2006; Kazakou et al., 2016). However, the selection and emergence of fast-cycling species often favour competitive species that restrict optimal vine development due to the rapid sequestration and uptake of resources (Reich, 2014; Storkey et al., 2012). Furthermore, agricultural intensification has led to the stripping of biodiversity, simplifying the plant community and worsening ecosystem stability (Báez and Collins, 2008; Guerra et al., 2022a; Tilman et al., 2014). That is why, this study aimed to search for more ecological soil management alternatives to guarantee adequate crop production, reduce the input of agrochemicals to the environment, increase biodiversity and, thus, increase ecosystem services.

It is important to consider the balance between the benefits of increased weed presence and the competition they provide to vines to maintain good grape production and quality (MacLaren et al., 2019). A stable weed community brings numerous benefits to the ecosystem, such as providing niches for pollinators and natural enemies of grapevine pests (Gaba et al., 2015; Kubota et al., 2015), reducing soil erosion (Novara et al., 2011), and improving water infiltration (Celette and Gary, 2013). In addition, a diverse herbaceous community provides essential ecosystem services that increase functional richness with different niche formations leading to less competition with the vineyard (Báez and Collins, 2008; Kazakou et al., 2016; Tilman et al., 2014).

The composition of species present in the vineyard can be very variable. Previous reports, such as that by Guerra et al. (2022b), classified the species according to their impact on the vineyard. For this purpose, noxious grapevine weed species (NGWS) and therophyte grassland species (TGS) were defined. TGS species were characteristic of the Natura 2000 habitat "6220 Pseudo-steppe with grasses and annuals" (Thero-Brachypodietea) and could be classified as species of interest (Guerra et al., 2022b; Ríos and Salvador, 2009). This habitat is regulated by the European Law Council Directive 92/43/EEC, which promotes the conservation of interesting habitats. It is well known that further intensification of soil management through herbicide or in-row tillage (conventional management) leads to an increased presence of highly competitive NGWS species, resulting in low biodiversity and a poor herbaceous community (Hall et al., 2020; Kazakou et al., 2016; Sanguankeo and León, 2011). Organic mulches at the vine row could be a more sustainable alternative to control the presence of excessive weed cover (Najul and Anzalone, 2006). The addition of organic amendments brings many benefits to soil characteristics such as reduced bulk density and compaction, increased porosity, aggregate stability and nutrient content (Asai et al., 2009; Celik et al., 2010; Hati et al., 2006; Manna et al., 2007) by increasing the availability of nitrogen, potassium and phosphorus (Oladele et al., 2019). In addition, the use of organic mulches can stimulate the activities of microbial soil communities, thus enhancing the soil's organic matter and nutrient content (Scavo et al., 2022). The effects on vineyards are widely attributed to the changes produced by the organic mulches on the physical, chemical and biological characteristics of the soil (Mundy and Agnew, 2002; Xu et al., 2015). We hypothesize that organic mulches in the vine row lead to increased species richness with a greater presence of TGS species, improving the quality of the agroecosystem.

Moreover, in a climate change scenario where the negative effects on agricultural productivity have been drastically accentuated (Santillán et al., 2019), the use of organic mulches increases the soil water content, reduces soil evaporation and increases water storage and infiltration capacity (Novak and Watts, 2013). In addition, organic mulch reduces extreme soil temperature fluctuations (Pou et al., 2021), an interesting feature to mitigate the effects of heat waves, which will be increasingly frequent in the Mediterranean area (Drobinski et al., 2020; Molina et al., 2020).

In this sense, a field experiment has been carried out over three years (2019, 2021 and 2022) in a plot located in Logroño (north-eastern Spain), where five soil management treatments on the vine row have been compared. Three treatments had organic mulches: (i) shredded grapevine pruning debris from previous years (GPD), (ii) spent mushroom compost (SMC), mainly composed of straw, poultry manure and urea, and (iii) straw (SM). These treatments were compared with two traditional management: (iv) herbicide (HERB) on the vine row and (v) in-row tillage (TILL). The main objectives of this work were (1) to evaluate the capacity of each practice to control the emergence of problematic weeds, (2) to identify the plant species communities present in each treatment and, (3) to analyse the effect they could have on the vine row soil.

2. Materials and methods

2.1. Experimental design and treatments

The field experiment was located in north-eastern Spain (Logroño, La Rioja), in the Rioja origin appellation. The study was conducted over three years (2019, 2021 and 2022) in a commercial vineyard (3 m x 1.2 m and 2778 vines ha-1) of the Tempranillo variety planted in 1985 grafted on R-110 rootstock and spur-pruned on a bilateral Royat Cordon system. The soil was classified as haplocalcid semi-arid soil according to the Soil Resource base (Soil Survey Staff, 2014), with average percentages of 34% sand, 43% silt, 23% clay and 28% carbonates. The vineyard was managed under the European Union and Spanish regulations for organic cultivation (EU, 2018; RD, 2014).

All soil management treatments were initially established in February 2019 (day of the year (DOY) 37) and replaced annually between March and April (see Appendix, Table A.1). As detailed in the work of Blanco-Pérez et al. (2022), treatments were performed on the vine row up to 50 cm on each side of the vine. The three treatments with organic covers were substrates of grapevine pruning debris (GPD) from previous years, straw mulch (SM) from the Government of La Rioja, and spent mushroom compost (SMC) of mushroom (Agaricus bisporus) rich in animal manure and urea provided by "Sustratos de La Rioja SL". Organic matter was applied to a thickness of about 25 cm. In comparison, the two most commonly used conventional soil management practices in the region have been performed: in-row tillage (TILL) and the application of herbicide (HERB). The herbicide used was Terafit (25% p:p Flazasulfuron) and Atila (36% p:v Glyphosate) at 100 l ha-1 (Fernández Alcázar, 2011). The experimental design was a strip-split plot. Each soil treatment featured three plots, each with 40–50 vines.

The physical composition of the three organic mulches was very different among them (Table A.2). On the one hand, the percentage of humidity and ash in the SMC was higher, representing 52% and 48%, respectively, compared to 25% and 4% in the GPD and 14% and 6% in the SM. On the other hand, concentrations of essential elements such as phosphorus (P), magnesium (Mg), nitrogen (N) and calcium (Ca) were observed in the SMC mulch, up to 3 times higher than those measured in the cover with GPD and SM.

2.2. Climate, soil water content and soil composition

The region's climate was classified as Mediterranean with Atlantic influence with warm and dry summers (see Appendix, Table A.3). Climatic conditions were recorded by an agrometeorological weather station (SIAR, 2022) located at 5 km from the experiment field. In addition, the temperature (°C) and soil water content (SWC) were recorded in each replication with Sentek equipment (Sentek Pty Ltd., Stepney, Australia) and "Drill & Drop" probes (Sentek Drill and Drop, 2020). These sensors automatically collect and send data every 30 min at three depths (5, 15 and 25 cm). The probes were installed in October 2020 and recorded data for two years continuously in the soil under the vine row soil management.

Soil nutritional composition was measured in all blocks before the establishment of the treatments (December 2018) and at the end of the experiment (October 2022). In each plot, soil samples (0–30 cm) were a mixture collected at 10 points along the row, discarding the organic cover. Then, the samples were dried at 40 °C for one week. The Regional Laboratory of the Government of La Rioja (Logroño, Spain) analysed the following parameters for each plot before (2018) and at the end of the field experiment (2022): pH, electrical conductivity, organic matter (Walkley and Black, 1934), macro-nutrients (NPK), oligo-nutrients (Mg, Ca, SO4), iron (Fe), and sodium (Na) (Mehlich, 1984, 1978).

2.3. Weed emergence and plant community data collection

During the three years of study (2019, 2021 and 2022), the percentage of area covered by weeds (PWC) was monitored every 15 days in a total interval of 100–120 days per year as already described in Andújar et al. (2010), Guerra et al. (2022b) and Pereira and Gregorini (2022), coinciding with their vegetative cycle (from emergence to withering). Data collection consisted of photographing a 0.5 × 0.5 m quadrant at the same three sites within each plot. This methodology was a non-destructive analysis, which allowed the monitoring of weeds throughout their entire cycle. Subsequently, the percentage of weed soil coverage was calculated with computational processing of the photographs (ImageJ version 1.52a).

In addition, in 2021 and 2022, all spontaneous weeds present in the soil management treatments were identified through the use of a dichotomous key and the assistance of subject matter experts (Castroviejo, 2020). The relative percentage of species (Guerra et al., 2022b; Mueller-Dombois and Ellenberg, 1974) was calculated as the percentage between the number of individuals of each species and the total number of individuals in the plot. The tracking has been carried out throughout the vegetative cycle of the spontaneous plants, with a special interest in the period of maximum presence due to their greater impact on the vine. Subsequently, the real abundance of each species (RAS) was calculated based on the relative percentage and the estimated percentage of coverage in each block:

$$Real \quad abundance \quad (RAS) = \frac{Relative \quad percentage \times Coverage \quad percentage}{100}$$

Afterwards, therophytic grassland species (TGS) characteristics of the protected habitat Natura 2000 "6220 Pseudo-steppe with grasses and annuals" (Ríos and Salvador, 2009) and species harmful to the optimal growth of vine (NGWS) (Guerra et al., 2022b) were classified.

2.4. Statistical analysis

The effect of soil management on the herbaceous cover and the presence of plant communities was analysed separately. In addition, each year was analysed independently due to the differences in environmental conditions, the time application of agricultural practices, the evolution of the herbaceous cover and the composition of species identified. Treatment differences in the percentage of vegetation cover, soil composition and soil water content were analysed by multiple comparisons of means with Duncan's test (parametric data) and Dunnett's test (non-parametric data) using SPSS 22.0 (IBM Corp., Armonk, NY, USA). The normality and homoscedasticity were explored using the Shapiro-Wilk test and Levene's tests, respectively. In the soil water content (SWC) analysis, normality was verified by the Kolmogorov-Smirnov test ($n > 50$). The variation of soil parameters at the beginning and end of the experiment was analysed using a T-test. Principal component analysis (PCA) graphs were performed to visualize the clusters of soil management treatments based on species richness using the FactoMinR package with RStudio software, version 4.2.2. The differences in plant community composition between soil management treatments were identified using Wald statistics (Basu et al., 2017). To make this, a multivariate general linear model (GLM) has been made using the mvabund R package. We assumed a Poisson distribution for species richness and diversity and used a log link function (Jowett et al., 2019; Wang et al., 2012). Statistical significance was considered when p-value < 0.05.

3. Results

3.1. Climate, soil water content and soil composition

During the data acquisition period, cumulative rainfall was 175.2 mm, 164.7 mm and 87.4 mm in 2019, 2021 and 2022, respectively (annexe Table A.3). The mean temperatures throughout the vegetative cycles were 16.7 °C, 17.6 °C and 20.4 ºC in 2019, 2021 and 2022, respectively. Thus, 2019 and 2021 registered similar climatic conditions, with lower spring temperatures and higher rainfalls. Contrarily, 2022 was drier and warmer, with an average of 2.8 °C higher in all measurement intervals compared to 2019 and 2021. The rainfall was equally distributed throughout the growing season in 2019, while cumulative rainfall was concentrated up to DOY 173 in 2021 and occurred mainly at the beginning of the cycle in 2022, resulting in a dry summer.

For this reason, soil water content (SWC) measured at 5 cm (Fig. 1. A) was slightly lower in 2022 in almost all treatments during the study months (1 April to 31 August). Focusing on the upper part of the profile (0–15 cm) where the effect of the soil treatment was higher and the main differences in SWC were evident, the HERB treatment stored the lowest SWC, followed by the GPD mulch. The TILL treatment had the highest SWC at 5 cm, but this decreased with increasing depth obtaining the lowest soil water content at 25 cm.

The soil temperatures show more clearly the climatological difference between years (Fig. 1. B). In 2022, the treatments have an average soil temperature of 1–2 °C higher than in 2021. However, in both years, the same pattern of treatments was observed. At 5 cm, the HERB treatment had an average temperature of 3–5 °C higher than the other soil treatments. This difference decreased with increasing depth, although it was still the soil with the highest average temperature. TILL and SMC treatments had the second warmer soils with similar behaviour between them. The SM soil was the coldest, with − 2 °C between TLL and SMC and − 1 °C with the GPD soil.

Soil management affected soil fertility (annexe Table A.4). In 2018, the soil field was homogeneous, with no differences between study site locations. Four years after the establishment of the treatments, in 2022, 8 of the 11 parameters showed differences between soil treatments, although this was mainly noticeable for the treatment with SMC, differing from the rest, in 6 out of the 11 parameters measured. In this treatment, higher amounts of organic matter content (OM), soil pH, electrical conductivity (EC) and P, K, Na, Mg and SO4 were observed after 4 years. In addition, P and K concentrations were higher in the mulch-cover soils than in the conventionally managed soils (bare soils).

3.2. Soil management treatment impact on weed cover

The percentages of weed cover (PWC) are presented in Fig. 2. As expected, the HERB treatment had the lowest PWC, reaching values of up to 8% coverage. In contrast, TILL, the other conventional soil management practice, showed a maximum PWC of 48% and 82% in 2019 and 2021, respectively. However, the same treatment in 2022 reached values of up to 10% of weed coverage. As for the mulched plots, the SM and GPD treatments had a similar trend, reaching peaks of PWC of up to 10–30% and then a steady decline once the weeds finished their growing cycle. In this way, both GPD and SM managed to reduce the appearance of weeds to values close to those achieved with the use of the herbicide. On the contrary, the SMC mulch treatment obtained the highest PWC values, reaching maximum percentages of weed coverage of 91% and 85% in 2021 and 2022, respectively. However, a lower growth rate was obtained in 2019, reaching a maximum of 47% in this treatment. Mowing of the biggest weeds, marked by the intermittent lines, mainly affected treatments with a weed cover above 30% in 2021 and 2022. In 2021, this action temporarily reduced weed cover in the TILL treatment

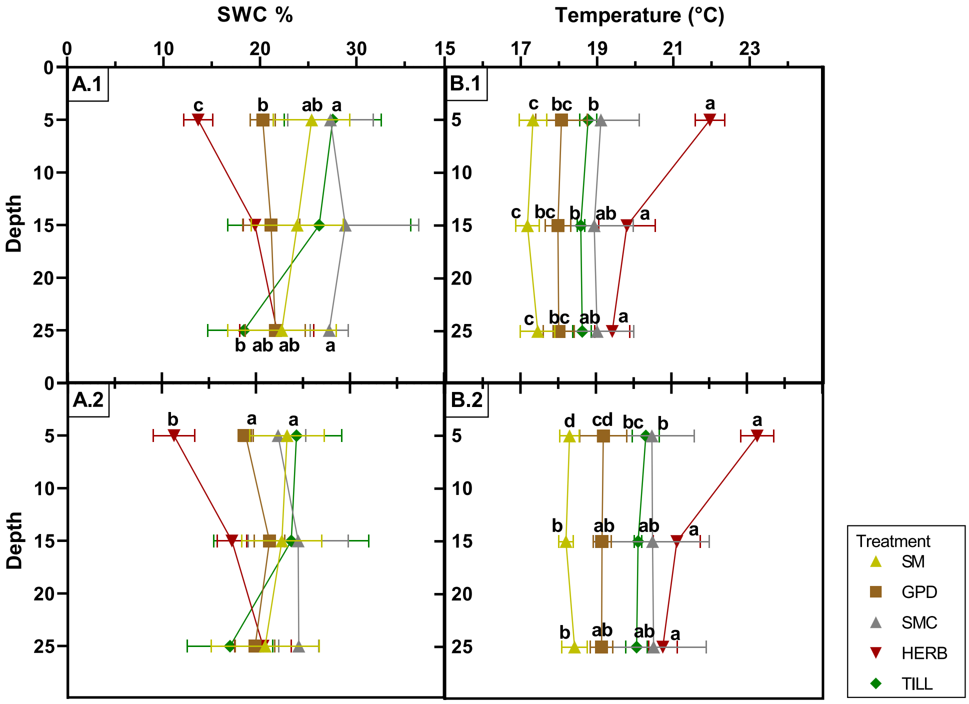


Fig. 1. Average of the percentage soil water content (SWC%, A) and daily soil temperature (°C, B) in 2021 (1) and 2022 (2) with standard deviations during the vegetative cycle of spontaneous plants (April 1 to August 31) at 3 soil depths (5, 15 and 25 cm) in the five treatments analysed: grapevine pruning debris (GPD), spent mushroom compost (SMC), straw (SM), under-row tillage (TILL) and herbicide (HERB). Statistical differences (*p-value* < 0.05) between treatments on each day were measured by Duncan's test (parametric data) and Dunnett's test (non-parametric data).

but did not affect the SMC mulch treatment.

3.3. Effect on plant community formation

The analyses on the proportion of real abundance of plant species (RAS) for the different treatments carried out in 2021 and 2022 are summarised in Table 1. Taking into account the two years analysed, a total of 49 herbaceous plant species were identified, of which 29 had relatively low abundance (<1%). Of the total species found, 11 could be classified as NGWS and 17 as TGS species (Guerra et al., 2022b; Ríos and Salvador, 2009). Interestingly, SM had the highest diversity of herbaceous species with 39 different plant species, followed by SMC and GPD mulches with 32 and 30 species identified, respectively. However, in conventional treatments this herbaceous diversity was lower, being 22 in TILL treatment and 17 in HERB.

To represent the effect of different soil treatments on the RAS during the growing season, principal component analysis (PCA) was performed for each year (Fig. 3). Wald statistic was used to find treatment dependence of real abundance species in both years. In 2021, the conventional HERB soil management treatment did not have species composition differentiated from the other treatments and was placed in a highly clustered position due to the lack of presence and diversity of plant species (Fig. 3A). In addition, GPD and SM were grouped, thus showing similar RAS values. In this year, most of the differences between the soil management treatments were observed by PC2. SM segregation was due to the differential RAS of Bromus madritensis, Hordeum vulgare, Galium verrucosum, Galium aparine, Convolvulus arvensis, Triticum aestivum and two species of the Sonchus genus. Two other data sets in the upper part, formed by the TILL and SMC treatments, were in this case influenced by the species Amaranthus blitoides, Chenopodium album, Salsola kali, Cirsium arvense, Malva sylvestris, Erigeron bonariensis, Moricandia arvensis, Diplotaxis erucoides and Medicago lupulina.

A similar trend was observed in 2022 compared to the 2021 year (Fig. 3B). The HERB and SMC treatments showed no differences from the other treatments, except HERB with GPD. Conventional treatments (HERB and TILL) were grouped in a central area without statistical differences. The SM and GPD mulch treatments were clustered on top of the PCA differentiated by PC2. Furthermore, these two soil treatments were differentiated by PC1 due to key species such as Malva neglecta, Triticum aestivum and Rubia tinctorum in SM mulch, and Galium parisiense, Micropyrum tenellum, Catapodium rigidum, Picris hieracioides, Hordeum murinum, Convolvulus arvensis and Bromus madritensis in GPD mulch. The SMC mulch diverged from the other treatments with a large dispersion of measurements without significant differences. Despite the lack of significance, the trend of the SMC mulch was different from that of GPD and SM due to Moricandia arvensis, Papaver rhoeas, Cirsium arvense, Crepis vesicaria subsp. taraxacifolia and Fallopia convolvulus.

3.4. Effect on the presence of harmful weed species

Of the 49 species found, 51% of them had a residual presence (less than 1%), among which *Diplotaxis erucoides, Rubia tinctorum, Solanum nigrum subsp. nigrum* and *Stellaria media* were classified as NGWS (Table 1). Of the most abundant species, some were found in almost all the treatments, but others were specific to one treatment. For example, *Chenopodium album, Convolvulus arvensis* and *Cirsium arvense* were abundant in all the treatments except for the herbicide treatment. Anyway, *Amaranthus retroflexus, Amaranthus blitoides* and *Salsola kali*, were only present in the SMC mulch and *Malva sylvestris* and *Salsola kali*, were specific to the TILL treatment.

There were differences between treatments in the accumulated abundance of noxious weed species (Fig. 4). SMC stands out for its high abundance (57.15%) of these species, followed by TILL (38.73%), SM (19.5%) and GPD (16.9%). Finally, HERB stands out for its low percentage of these species (1.4%). The species composition of NGWS changed between treatments. In the three mulching treatments *Chenopodium album, Cirsium arvense* and especially *Convolvulus arvensis* constituted between 75.5% and 90.1% of the NGWS species present. Especially in the SMC mulch treatment, the distribution of species was

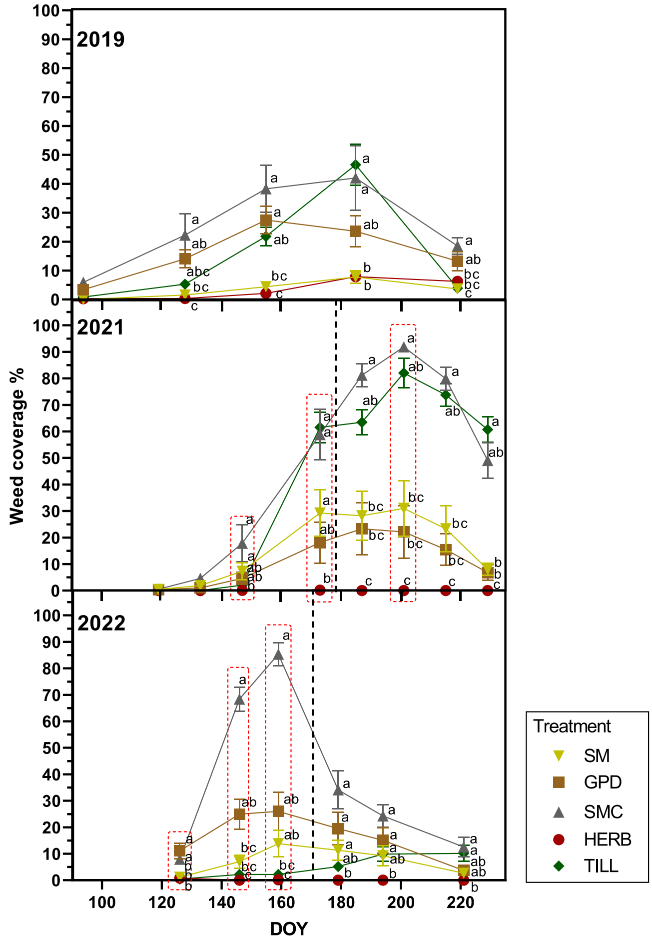


Fig. 2. Percentage of weed cover (PWC) with its standard error on the vine row during the vegetative cycle in the three study years (2019, 2021 and 2022) of three soil mulching treatments (grapevine pruning debris (GPD), spent mushroom compost (SMC) and straw (SM)) and two conventional managements (in-row tillage (TILL) and herbicide (HERB)). Weed species composition and abundance were measured on days marked with a flashing red square. Statistical differences (p-$value < 0.05$) between treatments on each day were measured by Duncan's test (parametric data) and Dunnett's test (non-parametric data).

more homogeneous, with a significant weight of *Salsola kali.* On the other hand, in conventional soil management treatments, the presence of *Convolvulus arvensis* was almost residual, with *Cirsium arvense* being the most abundant species in the TILL treatment.

4. Discussion

Our results show significant differences in the PWC and RAS, the appearance of weed communities and their effect on the vine on the different soil managements analysed. Specifically, we can confirm that the use of GPD and SM are two effective alternatives to reduce weed cover by up to 70–95% without the use of chemical inputs and tillage in the vine row area.

4.1. Effect of under-vine mulches on weed emergence and soil parameters

Soil water conservation is essential in arid and semi-arid regions (Flexas et al., 2010; Morison et al., 2008) and mulching could address this. As documented in the work of Novak and Watts (2013), organic mulches reduce evaporation and increase the water content in the soil. Mulching has been described as the most sustainable agricultural practice in arid and semi-arid regions as it retains water in the upper soil layers reducing the need for irrigation (Pou et al., 2021).

The variability in the PWC observed between years could be partly due to the different start/replenishment dates of treatments (Fig. 2). In the year 2019, the treatments were established at the beginning of February, while in the years 2021 and 2022 the replacement of the treatments occurred at the beginning of spring (annexe Table A.1), therefore significantly influencing the emergence of weeds and their growth. As in the work of Pou et al. (2021), an attenuation of soil temperature by mulching was observed, mainly in more superficial areas of the soil (Fig. 1. B). However, this effect had no significant impact on the initial emergence of weeds (Fig. 2). Moreover, other studies reported that the colour of the mulch was important in the soil temperature (Dabney et al., 2001; Sharratt and Flerchinger, 1995). Dark-coloured mulches (i.e. grazing vetch) allowed more soil warming than light-coloured ones (i.e. oat straw). In our study, the SMC (dark colour) had more soil temperature than SM and GPD (light colour) without differences in weed emergence. In the second year of data collection (2021), weed growth was slower at the beginning of its vegetative cycle, mainly due to the temperatures attenuation of this year, and then, it accelerated due to the high temperatures and rainfall registered in May (annexe Table A.3). However, in the third year of sampling (2022), the weed growth cycle was accelerated, starting at the beginning of May, when high temperatures were recorded, and high water reserves were present in the soil. However, in this same year, the withering of the weeds occurred earlier than the previous year. This fact could be due to the high temperatures recorded during the months of June and July (up to 2 °C higher than in 2021) with low rainfall accumulated (annexe Table A.3). Regarding the effect of the different treatments on the PWC, our results revealed that the most effective mulches were SM and GPD with weed covers lower than 30%. Among the organic mulches, SM and GPD showed the highest weed suppression because they provide a physical barrier to the sun and completely inhibit the incidence of light (Teasdale and Mohler, 1993). In addition, these mulches provide a protective layer to the soil surface that is extremely effective in preventing soil erosion and improving soil ecology (Erenstein, 2002).

Slow decomposing mulch, such as SM and GDP, with a high C/N ratio, can smooth weed growth for a longer period (Table A.2). However, slowly decomposing mulch may not provide nutrients quickly to the follow-up crop (Sainju et al., 2005). This could be the reason why SMC cover recorded the highest PWC, reaching values above 85% (Fig. 2). In this case, the composition of the SMC mulch based on fine material rich in N, P, K and other essential elements such as Ca, Mg and SO_4 stimulates the growth of weeds on it (Table A.2).

In our study, the high percentage of weed cover on SMC organic mulch was expected to reach higher water consumption. In this sense, Lopes et al. (2004) described that for PWC of 50–80%, the transpiration (E) values per unit of the soil of the herbaceous cover can reach water consumption close to the vines (Lopes et al., 2004). However, contrary to what was expected, the high PWC on SMC organic mulch did not translate into a reduction of available SWC in the vine row (Fig. 1. A).

The contribution of SMC increased ash content and soil elements (annexe Table A.2 and Table A.4). Therefore, this leads to an increase in soil aggregation, a reduction in bulk density and the appearance of larger pore spaces, increasing water retention (Busscher et al., 2011) and compensating the increased water demand caused by spontaneous weeds. Although Na values increased in the SMC mulch soil (+198%), the ratio between Mg, K and Ca was very low and it was not a limiting factor in the uptake of essential elements such as N, K and P. The increase of EC in this soil was mainly due to the higher SWC content (Fig. 1) and the higher concentration of P and Mg, increasing the cation exchange capacity and, consequently, enhancing soil fertility (Hedley et al., 2004; Rodríguez-Pérez et al., 2011). In addition, the SMC mulch reduced the soil pH (7.8) due to the decomposition of organic matter and urea input (Xiao et al., 2022), increasing the solubilisation and uptake of certain elements such as K, Fe, Ca and Mg (Kowalenko and Ihnat, 2010). For this reason, the elements that were not supplied by the SMC mulch

Table 1
Average maximum relative abundance (%) in 2021 and 2022 of the species identified in the different soil management treatments: grapevine pruning debris (GPD), spent mushroom compost (SMC), straw (SM), under-row tillage (TILL) and herbicide (HERB). Species with noxious effects on the optimal growth of grapevine (NGWS) and therophytic grassland species (TGS) have been identified. The - and + signs indicate the non-presence of the species in the treatment (-) and those with a relative abundance of less than 1% (+).

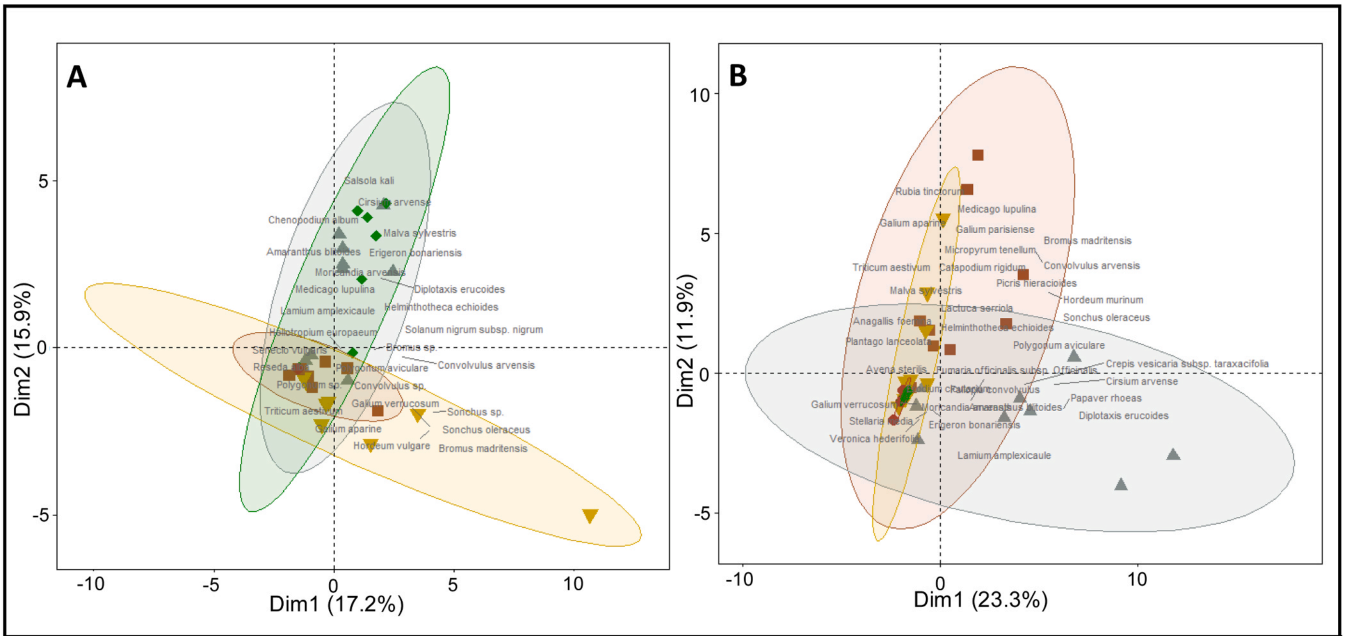
Family	EPPO Code	Species	Noxious	SM	GPD	SMC	HERB	TILL
Amaranthaceae	AMABL	*Amaranthus blitoides* Watson		-	+	5.93	-	+
Amaranthaceae	AMARE	*Amaranthus retroflexus* L.		-	-	15.46	-	-
Primulaceae	ANGCO	*Anagallis foemina* Miller		+	-	-	-	-
Poaceae	AVEST	*Avena sterilis* L.	TGS	+	-	-	-	-
Poaceae	BROMA	*Bromus madritensis* L.	TGS	+	2.10	1.60	+	+
Poaceae		*Bromus* sp.		+	+	+	-	+
Poaceae	SCCRI	*Catapodium rigidum* (L.) C.E.Hubb.	TGS	-	+	-	-	+
Caryophyllaceae	CERGL	*Cerastium glomeratum* Thuillier	TGS	+	-	+	-	-
Amaranthaceae	CHEAL	*Chenopodium album* L.	NGWS	2.05	1.83	17.10	1.20	3.00
Amaranthaceae	CHEVU	*Chenopodium vulvaria* L.		-	-	1.54	-	-
Asteraceae	CIRAR	*Cirsium arvense* (L.) Scopoli	NGWS	1.56	2.35	10.44	-	17.27
Convolvulaceae	CONAR	*Convolvulus arvensis* L.	NGWS	13.98	9.90	15.61	+	4.63
Convolvulaceae		*Convolvulus* sp.		+	+	-	-	-
Asteraceae	CVPVT	*Crepis vesicaria* L. subsp. *taraxacifolia* (Thuill.) Thell. ex. Schinz & Keller	TGS	+	+	+	-	-
Brassicaceae	DIPER	*Diplotaxis erucoides* (L.) de Candolle	NGWS	+	+	+	-	+
Asteraceae	ERIBO	*Erigeron bonariensis* L.		+	+	3.00	-	+
Asteraceae	ERISU	*Erigeron sumatrensis* Retzius		-	-	+	-	-
Geraniaceae	EROCI	*Erodium cicutarium* (L.) L'Héritier	TGS	+	-	-	-	-
Polygonaceae	POLCO	*Fallopia convolvulus* (L.) Löve		+	-	3.72	-	-
Papaveraceae	FUMOF	*Fumaria officinalis* L. subsp. *officinalis*	TGS	-	+	-	-	-
Rubiaceae	GALAP	*Galium aparine* L. subsp. *aparine*		+	+	+	+	-
Rubiaceae	GALPR	*Galium parisiense* L.	TGS	+	2.31	+	+	+
Rubiaceae	GALVR	*Galium verrucosum* Hudson		+	+	-	+	-
Boraginaceae	HEOEU	*Heliotropium europaeum* L.	TGS	-	-	-	-	+
Asteraceae	PICEC	*Helminthotheca echioides* (L.) Holub		+	1.43	1.38	-	+
Poaceae	HORMU	*Hordeum murinum* L.	TGS	+	+	1.80	+	+
Poaceae	HORVX	*Hordeum vulgare* L.		1.36	-	+	-	+
Asteraceae	LACSE	*Lactuca serriola* L.	NGWS	+	+	1.06	-	+
Lamiaceae	LAMAM	*Lamium amplexicaule* L.	TGS	+	1.15	1.31	-	+
Malvaceae	MALSI	*Malva sylvestris L.*	NGWS	+	+	+	-	6.29
Lamiaceae	MAQVU	*Marrubium vulgare* L.		-	-	+	-	-
Fabaceae	MEDLU	*Medicago lupulina* L.		+	+	+	-	+
Poaceae	MJPTE	*Micropyrum tenellum* (L.) Link.	TGS	+	+	-	-	-
Brassicaceae	MOCAR	*Moricandia arvensis* (L.) de Candolle		-	+	+	-	+
Papaveraceae	PAPRH	*Papaver rhoeas* L.	TGS	+	+	+	-	-
Asteraceae	PICHI	*Picris hieracioides* L.		+	1.35	+	-	+
Plantaginaceae	PLALA	*Plantago lanceolata* L.	TGS	+	-	-	-	-
Polygonaceae	POLAV	*Polygonum aviculare* L.	TGS	3.72	2.64	1.42	+	+
Polygonaceae		*Polygonum* sp.		+	+	-	-	-
Resedaceae	RESAL	*Reseda alba* L.		-	+	-	-	-
Rubiaceae	RBITI	*Rubia tinctorum* L.	NGWS	+	+	-	+	-
Amaranthaceae	SASKA	*Salsola kali* L.	NGWS	+	+	10.01	-	6.44
Asteraceae	SENVU	*Senecio vulgaris* L.	TGS	+	+	+	-	-
Solanaceae	SOLNI	*Solanum nigrum* subsp. *nigrum* L.	NGWS	+	-	+	-	+
Asteraceae	SONOL	*Sonchus oleraceus* L.	NGWS	+	+	1.32	+	+
Asteraceae		*Sonchus* sp.		+	+	-	-	+
Caryophyllaceae	STEME	*Stellaria media* (L.) Villars	NGWS	+	+	+	-	-
Poaceae	TRZAX	*Triticum aestivum* L.		+	+	-	-	-
Plantaginaceae	VERHE	*Veronica hederifolia* L.	TGS	+	+	+	+	-
Total species identified				39	30	32	17	22

reduced their soil quantity composition (Fe and Ca) because they were more easily absorbed by the weeds and vines. The incorporation of organic mulches on a long-term basis resulted in reduced soil loss, improved soil structure (Blaise et al., 2021) and fertility reducing the input of inorganic fertilisers that cause environmental damage as the eutrophication of freshwaters (Dupas et al., 2015).

4.2. Species richness and plant community formation

The relationship between agriculture, biodiversity and weed control in vineyards has become very important (Tscharntke et al., 2005). In this sense, different soil management techniques affected species richness and their distribution. In agreement with Hall et al. (2020), conventional soil management treatments showed a lower species richness compared to alternative soil management (Table 1). HERB treatment had almost no herbaceous composition, only differing in 2022 with the GPD mulch. The SM differed from the rest of the treatments, above all due to the greater presence of the species Hordeum vulgare and Triticum aestivum, which could have been introduced with the mulch in the vineyard. Moreover, the SMC substrate is made up of animal waste and urea, which favours soil nitrification. Thus, the nitrophilic species such as Amaranthus retroflexus and Chenopodium album were found in greater abundance in the treatment with SMC cover (Cabrera-Pérez et al., 2022; Teasdale and Mohler, 2000). In addition, the high concentration of nitrates provided by this substrate could also have favoured the germination of other species such as Amaranthus retroflexus. Cirsium arvense was the most abundant species in TILL management because this type of soil management favours geophytic spreading species (Wilmanns, 1993).

Treatments with organic mulches, especially with SM and GPD covers, had a high abundance (+20–30%) of TGS incorporated into the agroecosystem from close habitats such as Polygonum aviculare, Lamium amplexicaule, Galium parisiense and Bromus madritensis. As observed in the works of Hall et al. (2020) and Kazakou et al. (2016), as



	2021					2022				
Treatment	SM	GPD	SMC	HERB	TILL	SM	GPD	SMC	HERB	TILL
▼ SM										
■ GPD	4.529^{ns}					7.816^{***}				
▲ SMC	13.291^{**}	13.166^{***}				6.904^{ns}	6.357^{ns}			
● HERB	3.735^{ns}	3.5^{ns}	3.636^{ns}			4.082^{ns}	5.243^{*}	4.774^{ns}		
◆ TILL	14.492^{***}	13.371^{***}	13.738^{***}	2.751^{ns}		4.783^{*}	7.282^{**}	8.437^{ns}	2.315^{ns}	

Fig. 3. Principal component analysis (PCA) bi-plots of the relative abundances of species identified in (A) 2021 and (B) 2022 in the different soil management treatments: grapevine pruning debris (GPD), spent mushroom compost (SMC), straw (SM), under-row tillage (TILL) and herbicide (HERB). A table with Wald values and significance coefficients between treatments is attached: ^{ns}, no significance; *, *p-value* ≤ 0.05; **, *p-value* ≤ 0.01; ***, *p-value* ≤ 0.001.

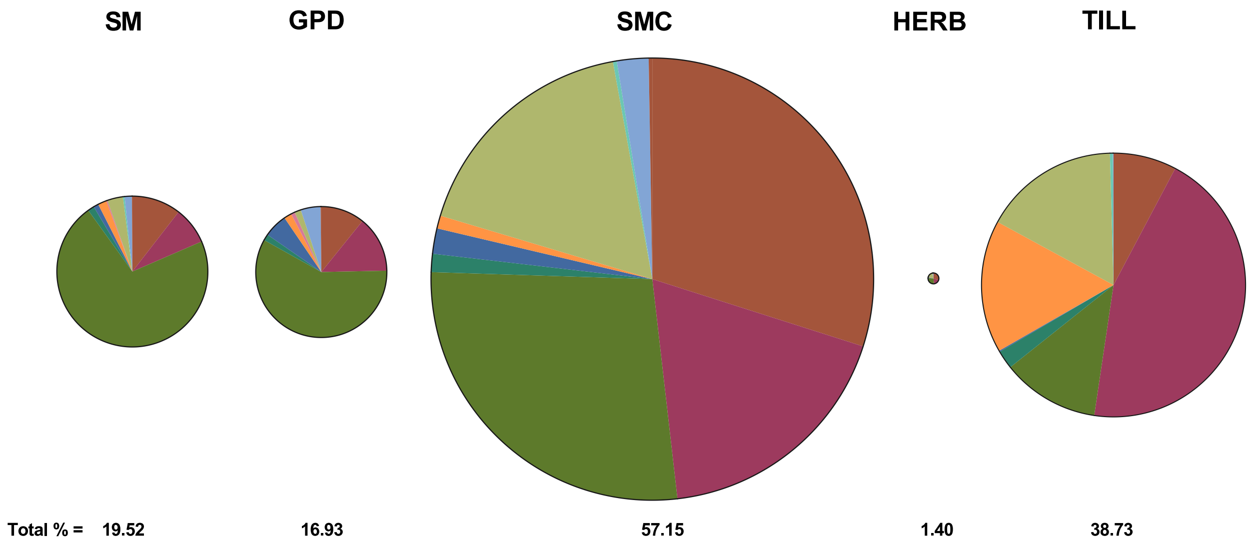
the intensity of soil disturbance decreases, functional richness increases, forming more complete niches and reducing the competition to the vineyard. The stabilisation of herbaceous communities makes the plant community more resilient to disturbance and able to provide essential ecosystem services (Báez and Collins, 2008; Morecroft et al., 2016; Tilman et al., 2014). In this sense, our results suggest that organic mulches induced changes in weed species and promoted the introduction of uncommon TGS species in agroecosystems being less harmful to the vineyard.

4.3. Impact of the distribution of noxious species on the vine

The different soil management directly affected the presence and composition of NGWS (Fig. 4). On the one hand, the presence of these species was notable in all treatments, although they only represented 22% of the total number of species identified. On the other hand, the proportion between noxious weeds and the other species found (not harmful) was highly variable between treatments. In this sense, in organic mulch treatments, this percentage ranged between 54% and 65%. In contrast, for conventional treatments, it was 84% for the HERB treatment and 92% for the TILL management.

Chenopodium album, Cirsium arvense, Convolvulus arvensis and Salsola kali were the most abundant species in the NGWS species group, representing more than 80% of the abundance in all treatments. Chenopodium album and Cirsium arvense were also reported in other studies as the most abundant herbaceous species (Konstantinovic et al., 2014; Lopes et al., 2004; Porčová and Smutný, 2018). Convolvulus arvensis was the most abundant species in SM and GPD mulches due to its ability to crawl and perforate, avoiding the physical barrier created by the organic covers of these treatments. In addition, it was also observed how the TILL treatment more efficiently controlled the excessive presence of Convolvulus arvensis. This species is problematic due to its difficult control by chemical compounds (Pfirter et al., 1997) and its high adaptation to different soil management (Tebeau et al., 2017). A serious problem is the increase in resistance to herbicides, for example, that described for Solanum nigrum and Cirsium arvense in orchards of fruit trees in New Zealand (Sims et al., 1994).

In addition to direct competition with grapevine for water and nutrients, the low biodiversity and high incidence of NGWS species could reduce the ecosystem stability and facilitate the incidence of grapevine pathogens and diseases. It is also interesting to consider the possible effect these species may have on the vineyard. Certain species such as Chenopodium album and Solanum nigrum can act as a reservoir for grapevine infectious nematodes (e.g. Meloidogyne spp.) that can be spread by agricultural practices (Castillo et al., 2008; Maixner et al., 1995). Moreover, some species can also act as a reservoir for grapevine diseases such as viruses and fungi. Some examples were the susceptibility of Chenopodium album to Grapevine Pinot Gris Virus (GPGV) and Convolvulus arvensis and Sonchus oleraceus to the pathogen of Petri's disease (Agustí-Brisach et al., 2011; Demian et al., 2022; Gualandri et al., 2017). Other studies associated some weeds, such as Chenopodium album, Convolvulus arvensis, Solanum nigrum and Malva



	Species	SM	GPD	SMC	HERB	TILL
🟧	*Chenopodium album*	2.05	1.83	17.1	1.2	3.00
🟪	*Cirsium arvense*	1.56	2.35	10.44	0	17.27
🟩	*Convolvulus arvensis*	13.98	9.9	15.61	0.17	4.63
🟦	*Diplotaxis erucoides*	0.27	0.26	0.76	0	0.88
🟦	*Lactuca serriola*	0.21	0.99	1.06	0	0.05
🟧	*Malva sylvestris*	0.36	0.32	0.54	0	6.29
🟥	*Rubia tinctorum*	0.05	0.16	0	0.02	0
🟨	*Salsola kali*	0.66	0.27	10.01	0	6.44
🟩	*Solanum nigrum* subsp. *nigrum*	0.07	0	0.16	0	0.14
🟦	*Sonchus oleraceus*	0.3	0.83	1.32	0.02	0.03
🟫	*Stellaria media*	0.02	0.03	0.15	0	0

Fig. 4. Average maximum relative abundance in 2021 and 2022 of the noxious grapevine weeds species (NGWS) in three soil mulching treatments (grapevine pruning debris (GPD), spent mushroom compost (SMC) and straw (SM)) and two conventional managements (under-row tillage (TILL) and herbicide (HERB)).

sylvestris, with vines and/or insects infected by 'Bois Noir' epidemiology (Johannesen et al., 2012; Mori et al., 2015; Quaglino et al., 2021; Tolu et al., 2006).

5. Conclusions

The use of organic mulches such as SM and GPD were the best management alternatives due to their effective control over the excessive presence of weeds in the vine line, the high number of introduced TGS species, the low percentage of NGWS species identified and the non-requirement of chemical compounds. In addition, the SMC mulch treatment, although it had great coverage of weeds, positively affected the composition of the soil, making it more porous and improving surface water retention. This soil management increased the concentration of essential elements, allowing the emergence of a characteristic and specialised herbaceous community. These changes in SMC soils resulted in a more spontaneous weed cover, reaching higher percentages of herbaceous cover (>80%). The use of organic mulches resulted in a reduction (more than 20%) of NGWS species compared to conventional soil management (HERB and TILL treatments). In conclusion, organic mulches improved the physicochemical properties of the soil, reduced chemical input and improved surface water holding capacity and attenuated extreme temperature peaks.

CRediT authorship contribution statement

Andreu Mairata: Conceptualization, Investigation, Data curation, Formal analysis, Writing. **David Labarga:** Investigation, Writing – review & editing. **Miguel Puelles:** Investigation, Writing – review & editing. **Joaquín Hute:** Data curation, Software, Investigation, Writing – review & editing. **Javier Portu:** Writing – review & editing. **Luis Rivacoba:** Writing – review & editing. **Alicia Pou:** Funding acquisition, Conceptualization, Supervision, Writing – review & editing.

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.

Data Availability

Data will be made available on request.

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Appendix

Table A.1
Day of year (DOY) when soil management treatments (grapevine pruning debris (GPD), spent mushroom compost (SMC), straw (SM), under-row tillage (TILL) and herbicide (HERB)) and other general agronomic practices have been carried out in the three study years (2019, 2021 and 2022).

Treatment	2019	2021	2022
SM	37	89	88
GPD	37	89	90
SMC	37	98	114
HERB	37	89	114
TILL	37	105	122
Weeding machine (all treatments)		174	171

Table A.2
Physical and chemical properties of the organic mulches based on grapevine pruning debris (GPD), straw (SM), and spent mushroom compost (SMC) analysed by the Regional Laboratory of the Government of La Rioja (Logroño, Spain).

	SM	GPD	SMC
Humidity (%)	13.7	25.4	52.0
Ashes (%)	5.7	3.7	48.1
Organic matter (%)	94.3	96.3	51.9
N (%)	0.77	0.88	2.38
C/N	71.3	63.6	12.6
Al (ppm)	46	182	3921
Cd (ppm)	0.04	0.07	0.25
Ca (ppm)	5163	11941	109814
Cu (ppm)	2	40	62
Cr (ppm)	7	3	9
P (ppm)	1110	881	7516
Fe (ppm)	154	182	3577
Mg (ppm)	373	2899	9724
Mn (ppm)	20	31	450
Hg (ppm)	0.010	0.017	0.029
Ni (ppm)	3	7	11
Pb (ppm)	1	1	4
K (ppm)	11943	7864	24668
Na (ppm)	202	1059	3519
SO_4	2856	1762	106932
Zn (ppm)	9	44	301

Table A.3
Summary of climatic conditions (temperature, precipitation, vapour pressure deficit and vegetative activity) before and between measurement days registered by SIAR station (SIAR, 2022).

Year	From DOY	To DOY	Mean temperature (°C)	Total rainfall (mm)
2019	73	94	9.8	5.0
	94	128	12.0	63.4
	128	155	16.0	30.3
	155	185	20.6	45.8
	185	219	23.1	30.7
			16.7	175.2
2021	98	119	10.8	40.7
	119	133	13.3	22.6
	133	147	14.5	18.8
	147	173	19.5	123
	173	187	20.0	1.8
	187	201	20.4	1.4
	201	215	21.6	0.8
	215	229	22.5	3.2
			17.6	164.7
2022	105	126	12.4	64.6
	126	146	18.8	7.2
	146	159	20.4	0.8
	159	179	22.7	1.8
	179	194	21.9	1.8
	194	221	25.3	11.2
			20.4	87.4

Table A.4
Oxidable organic matter (OM), pH, soil electrical conductivity (EC) and nutrient concentrations in 2018 and 2022 and their percentage variation between years. Letters show statistical differences (p-value ≤ 0.05) between soil management treatments (GPD: grapevine pruning debris, HERB: herbicide, TILL: under-row tillage, SM: straw, SMC: spent mushroom compost). Asterisks show differences between years (*, p-value ≤ 0.05; **, p-value ≤ 0.01; ***, p-value ≤ 0.001).

Year	2018					2022					Variation				
Treatment	SM	GPD	SMC	HERB	TILL	SM	GPD	SMC	HERB	TILL	GPD	HERB	TILL	SM	SMC
OM %	2.4 ± 0.3	2.4 ± 0.1	2.6 ± 0.4	2.3 ± 0.2	2.5 ± 0.5	2.3 ± 0.2^{b}	2.3 ± 0.1^{b}	3.2 ± 0.4^{a}	2.2 ± 0.1^{b}	2.3 ± 0.1^{b}	-4.2%	-4.2%	-10.3%	-3.4%	24.4%
pH	8.2 ± 0	8.2 ± 0	8.2 ± 0	8.2 ± 0	8.2 ± 0.1	8.2 ± 0^{b}	8.2 ± 0.1^{b}	7.8 ± 0^{a}	8.2 ± 0^{b}	8.2 ± 0^{b}	0%	0%	0.6%	0%	-4.9%***
EC (dS m^{-1})	0.2 ± 0	0.2 ± 0	0.2 ± 0	0.2 ± 0	0.2 ± 0	0.2 ± 0^{b}	0.2 ± 0^{b}	0.8 ± 0^{a}	0.2 ± 0^{b}	0.2 ± 0^{b}	-1.7%	-3.8%	-17.4%*	0.4%	345.8%***
N (ppmil)	1.7 ± 0.3	1.9 ± 0	2 ± 0.3	1.8 ± 0.1	1.9 ± 0.2	1.6 ± 0.1	1.6 ± 0.1	2.2 ± 0.3	1.6 ± 0.1	1.6 ± 0.1	-14.1%**	-10.2%	-17.5%	-9%	12.4%
P (ppm)	66.2 ± 18.1	70.7 ± 18.2	50.4 ± 1.4	62.6 ± 4	57.8 ± 12.8	36 ± 5.4^{bc}	36.2 ± 0.4^{bc}	74.4 ± 15.2^{a}	47 ± 9.8^{b}	29.1 ± 5.2^{c}	-48.7%*	-25%	-49.7%*	-45.6%	47.6%
K (meq 100 g^{-1})	1,1 ± 0,3	1,2 ± 0,3	0,9 ± 0,1	1 ± 0,1	0,9 ± 0,1	0,9 ± 0,2^{bc}	1,1 ± 0,1^{a}	3,4 ± 0,2^{a}	0,8 ± 0,1 ^{cd}	0,6 ± 0^{d}	-5%	-16,6%	-38,2%*	-18%	282%***
Na (meq 100 g^{-1})	0,1 ± 0,03	0,12 ± 0,04	0,15 ± 0,02	0,09 ± 0,04	0,09 ± 0,04	0,16 ± 0,02^{b}	0,2 ± 0,02^{b}	0,45 ± 0,07^{a}	0,15 ± 0,02^{b}	0,16 ± 0,01^{b}	56,8%	56,5%	79,8%	61,1%*	198%**
Mg (meq 100 g^{-1})	2,3 ± 0,2	2,1 ± 0,1	2,1 ± 0,1	2,1 ± 0,2	2,2 ± 0,1	2,1 ± 0,1^{b}	2,1 ± 0,2^{b}	3,5 ± 0,1^{a}	2 ± 0,1^{b}	1,8 ± 0,1^{b}	0,3%	-5%	-19%**	-10,8%	66%***
Ca (meq 100 g^{-1})	134,7 ± 32,5	126,2 ± 22	157,6 ± 24,3	123,3 ± 31,1	133,3 ± 41,9	125,3 ± 7,3	112,3 ± 1,7	123,7 ± 9,3	108,8 ± 7,4	127,3 ± 22,7	-11%	-11,7%	-4,5%	-7%	-21,5%
Fe (ppm)	59.4 ± 10.3	65.1 ± 15.6	63 ± 29.5	64.7 ± 17.9	53.1 ± 6.7	55 ± 4.4	54.4 ± 4.5	40.1 ± 6.4	62.1 ± 23.3	40 ± 6.4	-16.5%	-3.9%	-24.5%	-7.5%	-36.4%
SO_4 (ppm)	15.1 ± 4.4	18.2 ± 6.8	26.5 ± 17.3	13.9 ± 8.1	14.6 ± 8.2	42.3 ± 10.9^{b}	20.8 ± 5.5^{b}	2310.1 ± 115.9^{a}	34.5 ± 8.2^{b}	27.5 ± 1^{b}	14.4%	148.6%*	88.7%	179.5%*	8610.2%***

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