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RESEARCH ARTICLE

Natural vegetation management to conserve biodiversity and soil water in olive orchards

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Abstract

The combined impact of soil tillage intensification and expansion of olive farming is resulting in soil degradation and biodiversity decline. We hypothesized that, instead of tilling, mowing to control the natural vegetation in spring can increase biodiversity and improve soil quality. We compared the effects of natural vegetation mowing (NVM) with those of tillage (NVT) on plant community composition and cover, soil water content and resistance to penetration, and olive yield over an 8-year period, in a Mediterranean rainfed olive orchard. NVM had an average of 28 more species and showed a strong positive correlation with Poaceae and Fabaceae, and also with geophytes and hemicryptophytes. In contrast, NVT was negatively correlated with species richness and diversity, with perennial life forms, and positively correlated with Convolvulaceae. Proportions of grass and straw cover in spring were higher in NVM from the beginning of the study (average difference was about 20%). In autumn, grass cover became higher in NVM than in NVT from year five (13% more) and straw cover from year two (30% more). Olive production did not differ between treatments in any of the years. Soil water was higher in NVM, at both soil depths, particularly in mid-summer and after the first autumn rains (1 to 2%). Soil resistance to penetration was 1 Mpa higher in NVM than in NVT. As compared to conventional tillage, natural vegetation cover mowed in spring seems to be an effective management practice to improve the overall rainfed olive orchard biodiversity and soil quality, without affecting production.

Additional key words: mowing; *Olea europaea;* productivity; tillage; vegetation cover.

Introduction

Olive (*Olea europaea* L.) is one of the main Mediterranean crops, playing an important role in the socio-economic life of the region since ancient times (Fernández-Zamudio & De Miguel, 2006). By enduring the summer water stress and high temperatures characteristic of this region, olive trees can be established in the less valuable soils – less fertile, rugged or steeper soils (Rühl *et al*., 2011), which enhances the landscape value of olive orchards. Traditional olive production is based on low tree densities (about 100 trees ha^{-1}) and weed control via soil tillage, to ensure the productivity in the Mediterranean limited rainfall environment (Gómez *et al*., 2009b). However, besides reducing biodiversity, this practice has had serious impact on runoff and erosion patterns (Francia-Martínez *et al*., 2006; Mas *et al*., 2007; Zuazo *et al*., 2009). Since the advent of residual herbicides, no-tillage systems using herbicides to control weeds have been tested as alternative to conventional tillage (Gómez *et al*., 1999), but herbicide application also causes severe problems regarding biodiversity and soil and water quality (Mas *et al*., 2007; Gómez *et al*., 2009b; Alcántara *et al*., 2011). To overcome the aforementioned problems the use of cover crops was recognized as a simple and feasible practice in olive orchards (Francia-Martínez *et al*., 2006; Gómez *et al*., 2009a,b; Zuazo *et al*., 2009;

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This work has 1 supplementary table that does not appear in the printed article but that accompanies the paper online.

Abbreviations used: ANOSIM (Analysis of Similarity); HCA (Hierarchical Cluster Analysis); IS (Initial Situation); IV (Species Importance Value); NMDS (Non-Metric Multidimensional Scaling); NVM (Natural Vegetation Mowing); NVT (Natural Vegetation Tillage); S (Species Richness); TDR (Time-Domain Reflectometry).

Ramos *et al*., 2010). Yet, although consistent with soil and water conservation, this method still reduces plant diversity and is somehow difficult to implement due to technical problems, namely the choice of the cover crop and the correct killing date to avoid water competition (Gómez *et al*., 2009a).

Olive cropping is nowadays a profit-increasing activity and the area occupied by olive orchards is expanding to meet the growing olive oil demand. Moreover, profit maximization in the short-run dictates too often the management system choice, like the intensive and super-intensive production, where competition between trees and weeds for water uptake is reduced through intensive tillage (Francia-Martínez *et al*., 2006; Metzidakis *et al*., 2008). These land-use practices worsen soil degradation and water scarcity, the most limiting factor for crop production in the Mediterranean region (Zuazo *et al*., 2009; Ramos *et al*., 2010). Intensification also results in decline of agroecosystems plant diversity that is detrimental to the overall ecosystem equilibrium (Storkey *et al*., 2012). Plant diversity enhances wildlife food and shelter availability (Potts *et al*., 2006; Nekhay & Arriaza, 2009) and maintains pest natural predator populations, hence diminishing the need for pesticides (Solomou & Sfougaris, 2011; Paredes *et al*., 2013). It is also one of the most relevant factors to enhance soil stability (Pohl *et al*., 2009), foster microbial and fungal community richness and functional diversity, and thus N mineralization rates (Zak *et al*., 2003; Lamb *et al*., 2011). Therefore, promoting plant diversity should be regarded as an important issue in the development of sustainable agriculture.

Although to crop with the appropriate soil, water, and biodiversity conservation techniques is imperative, regarding olive orchards, neither the old nor the more recent farming systems paid enough attention to biodiversity conservation (Calatrava-Leyva *et al*., 2007). Even research efforts have been mostly focused on the effects of management techniques on soil properties and quality, overlooking the need to preserve biodiversity. We hypothesized that, instead of tilling, mowing to control the natural vegetation of olive orchard in spring can increase biodiversity and improve soil quality, without negative effects in production. In this context, we compared the effects of tillage with those of mowing on plant diversity and cover, soil water content and resistance to penetration, and olive production, over an 8-year period, in a Mediterranean rainfed olive orchard.

Material and methods

Study site

The study was conducted between 2000 and 2007 in an experimental 5-ha rainfed olive orchard (cv. Cobrançosa) planted in 1991 and located at the Herdade dos Lameirões (38° 6' 16" N, 7° 13' 40" W; 178 m a.s.l.; Moura, Southeast Portugal).

The area has the typical winter wet, summer dry pattern of the Mediterranean-type climate. Average annual precipitation recorded during the study period was 486 mm and average annual air temperature was 16.6°C (for 1951-80 annual rainfall was 664.6 mm and annual temperature was 15.4°C; INMG, 1991). Sum of precipitation from June to September (the period between fruit setting and fruit maturation) was 8.6, 81.7, 52.7, 40.9, 33.8, 7.2, and 76.7 mm in 2000, 2001, 2002, 2003, 2004, 2005, and 2007, respectively (56.4 mm for 1951-80; INMG, 1991). These measures were recorded in a meteorological station (Estação Meteorológica da Herdade dos Lameirões) located in the study area, ca. 1 km away from the study plots. The soil is a Calcaric-Vertic Cambisol (Chromic), *i.e.,* a red soil with incipient soil formation, with carbonates and a high clay content that causes soil cracking under lowering soil water content (WRB, 2006), with a fairly even slope (around 6%).

Experimental design

In the study orchard a two-treatment, completely randomized design, was used to evaluate the effects of the soil management system. Although the development of natural herbaceous cover was allowed in all plots until spring, two different soil management systems (treatments) were applied by then to control ground flora. Plots hereafter named natural vegetation tillage, NVT, were tilled with a harrow at 20 cm depth and plots hereafter named natural vegetation mowing, NVM, were mowed to the ground, except for a central strip to ensure soil seed bank restoration. Plant chopped residues were left on soil surface. Among experimental units assigned to each treatment, eight plots of 70 × 21 m^2 were randomly selected for each soil management system evaluation. Tree spacing within and between rows was of 3.5 and 7 m, respectively, and thus each plot had two rows of 20 trees, with three 7 m wide inter-rows.

In mid-winter of the fourth study year (2003), ground flora of both treatments was sprayed with Bi-Hedonal (MCPA and 2,4 D with 275 g a.i. ha^{-1} each) to control forbs and promote grasses.

Sampling procedures

Vegetation sampling

To evaluate the influence of soil management systems on floristic diversity, three 1 m^2 randomized quadrats were conducted in each plot (24 per treatment). This quadrat size was used because it represents a compromise between data reliability and time consumption. Before treatments were first accomplished (spring 2000) and every spring thereafter (from 2001 to 2007, excepting 2006), each plot was surveyed for plant species composition and abundance. Abundance of each species was visually estimated from the vertical projection of plant canopies onto the ground expressed as a percentage of quadrat area (Mueller-Dombois & Ellenberg, 1974). Plant nomenclature follows Flora Iberica (Castroviejo *et al*., 1986-2012) and Nova Flora de Portugal (Franco, 1971, 1984; Franco & Rocha Afonso, 1994-2003). The functional diversity of vegetation under the two soil management systems was evaluated using Raunkiaer (1934) life form (therophytes, geophytes, hemicryptophytes, and protohemicryptophytes), morphotype (grasses and forbs), family, and ecological value (ruderals or characteristic of ecologically high natural valued communities after Rivas-Martínez *et al*., 2002). Additionally, total green and straw cover was estimated. In autumn, vegetation was in the initial stage of development, and thus a broader approach was adopted and surveys were done to family level only. Besides, green and straw cover and bare soil were also evaluated.

Olive yield was yearly assessed for each treatment by evaluating the production (t ha^{-1}) of the 40 trees in each experimental plot (320 trees per treatment).

Soil sampling

Soil water content was evaluated fortnightly in both soil management systems at 20 and 40 cm depth. Soil water measurements were taken inside two PVC access tubes per plot (16 per treatment), permanently installed in the inter-row at 0.6 m from the tree trunk, with a time-domain reflectometry (TDR) probe (Delta-T Devices PR1/4d-02).

Taking into account that olive cropping is made in autumn, a rainy period, equipment trafficability can be improved by increasing soil resistance. Thus, to assess the cumulated effect of treatments on trafficability, soil resistance to penetration was evaluated in autumn 2004, after the first continuous rain period (about 70 mm) to ensure homogeneity in soil water content. Measurements were carried out with an Eijkelkamp Penetrologger SN68010022 cone penetrometer, every centimeter down to a depth of 80 cm, in one sampling point per plot located in the middle of the inter-row, summing up eight measurement sets in each soil treatment.

Data analysis

Data from each set of three quadrats per plot were pooled into a single sample per plot (summing up eight samples per treatment) for further analysis. The structure of vegetation assemblages was analyzed with Primer v.6 (Primer-E Ltd. Plymouth, UK). Data on plant species abundance was organized into a species × surveys matrix and species richness (S = number of species) and the Simpson diversity index expressed as its transformed form 1-λ, *i.e.,* the Gini-Simpson diversity index, was calculated. The Gini-Simpson index varies between 0 and 1, being 0 when the community is dominated by a single species and approaching 1 as diversity increases. The species abundance matrix was then transformed into a resemblance matrix by calculating the Bray-Curtis similarity index between all survey-pairs. From this resemblance matrix, a Hierarchical Cluster Analysis (HCA) and a Non-Metric Multidimensional Scaling (NMDS) were generated to detect similarity between plant assemblages. Statistical significance of differences in species assemblages between soil management systems and also among the formed clusters were assessed with Similarity Analysis (ANOSIM) for 1-way layout (Clarke & Warwick, 2001) (999 permutations, at the significance level of 0.1%). The test value (R) varies between 1, when samples are completely separated and 0 if there is no separation on the averages between and among samples. To assess the degree of association between treatments and functional diversity, descriptive vegetation attributes (main plant families, Raunkiaer life forms, species richness and Gini-Simpson index) were projected on the NMDS ordination diagram, based on significant Pearson correlations ($p < 0.05$) between each attribute and the NMDS axes. Data were arcsin [sqrt (x)] transformed before calculating Bray-Curtis similarities and performing NMDS and HCA.

Additionally to analyses of species assemblages in Primer, the degree of association between individual species and soil management systems was calculated using Indicator-Species Analysis in PC-ORD (McCune & Mefford, 1999). Resulting importance values (IV) combine information on relative abundance and frequency of species, attaining a maximum (IV = 100) when all individuals of a given species are restricted to a class, and all samples from a certain class contain an occurrence of that species.

Differences in olive production and in green, grass, and straw percentage cover, species richness, and Gini-Simpson diversity index between soil management systems by year were performed with non-parametric Mann-Whitney tests, using SPSS 18.0 for Windows (Statistical Package for the Social Sciences). Non-parametric Mann-Whitney tests were also performed to compare mean values of soil water content and resistance to penetration.

Results

Plant cover and olive production

Different soil management systems resulted in differences in herbaceous community cover and diversity. In spring (Fig. 1a), similar proportion of green cover was observed in both management systems across the study years, but in the extremely dry year of 2005. In this year, with a total precipitation of 251 mm (annual average of 486 mm during the study

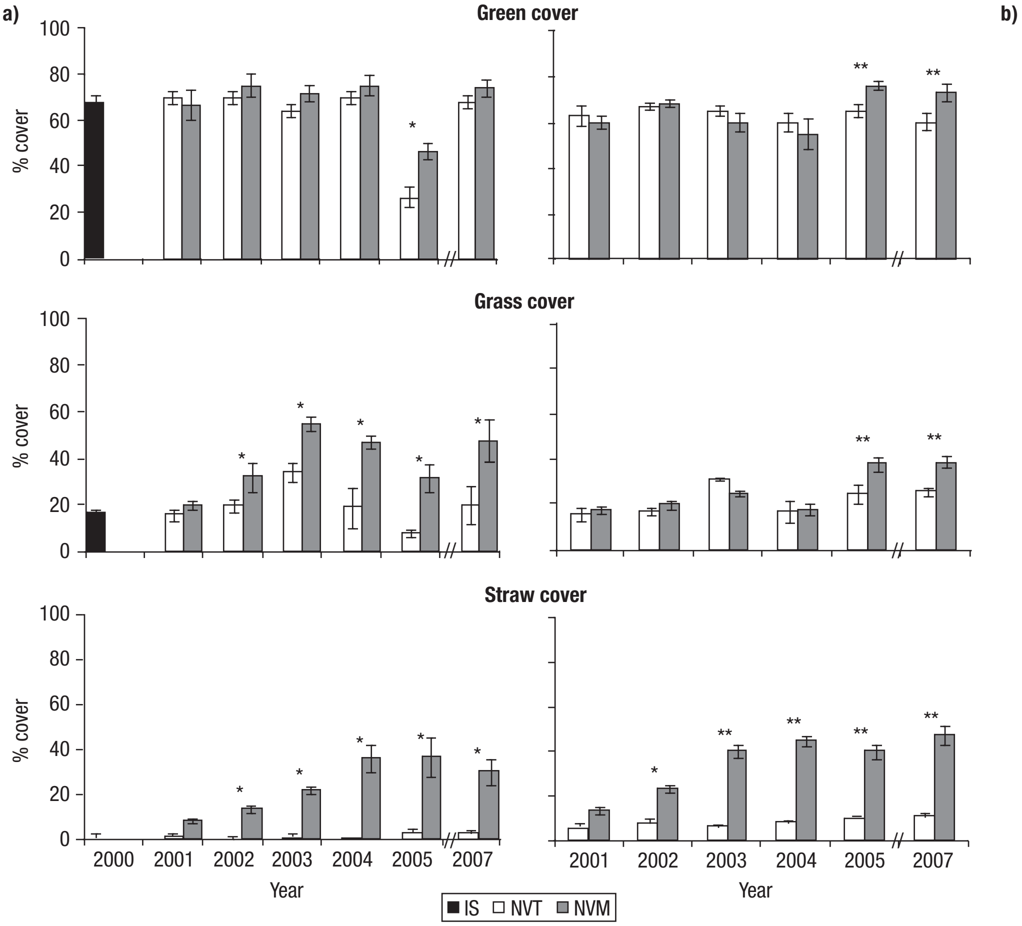

Figure 1. Mean proportion (%) of green, grass, and straw cover in spring (a) and autumn (b), for the initial situation (IS), natural vegetation tillage (NVT), and natural vegetation mowing (NVM), from 2000 to 2007. Bars represent the standard error of the mean (n = 16 for IS and n = 8 for NVT and NVM). Asterisks indicate significant differences between soil management systems at $p < 0.05$ (*) and at $p < 0.01$ (**).

period), green cover suffered a pronounced decline in both management systems, but the values observed in NVM were significantly higher than in NVT. Grass cover was higher in NVM from 2002, two years after the onset of treatments, until the end of the study period. The proportion of soil covered by straw was higher in NVM than in NVT in all study years, increasing progressively until a pronounced maximum was attained five years after treatments beginning, one year after grass cover peak. In autumn (Fig. 1b), the proportions of both green and grass cover became significantly higher in NVM than in NVT from year five. At the end of the study period, grass cover was increased by 1.6 and 2.2-fold in NVT and NVM, respectively. Cover by straw was higher in NVM, increasing gradually until the third year, while in NVT almost no variation was observed.

Considering spring weed community of the whole olive orchard, both mowing and tillage plots included, there were more dicotyledonous species (77 spp.) than monocotyledons (25). In terms of Raunkiaer life form, therophytes were the most numerous life form (72 spp.), followed by hemicryptophytes (19), protohemicryptophytes (7), and geophytes (4). Beyond grasses (21 spp.), the most abundant families were Asteraceae (24) and Fabaceae (9). Nevertheless, while Asteraceae attained ca. 20% in either of treatments, Poaceae and Fabaceae abundance in NVM (14 and 35%, respectively) were more than twofold those of NVT (5 and 11%). Additionally, both species richness (S) and diversity (Gini-Simpson index) were higher in NVM across all the study years (Fig. 2).

The Indicator-Species Analysis also provided differences between treatments. In NVT only four species ranked an IV > 50 (*Polygonum aviculare* L., *Anagallis arvensis* L., *Lactuca serriola* L., and *Sonchus oleraceus* L.), while in NVM the same abundance rank was shared by 25 species (Suppl. Table S1 [pdf online]). Furthermore, geophytes (like *Ornithogalum narbonense* L., *Arisarum vulgare* Targ.-Tozz., and *Arum italicum* Mill. ssp. *italicum*) and hemicryptophytes (like *Rumex pulcher* L., *Andryala integrifolia* L., *Foeniculum vulgare* Miller, *Crepis vesicaria* L., and *Leontodon taraxacoides* (Vill.) Mérat) were clearly associated with NVM, which also supported protohemicryptophytes (like *Holcus lanatus* L.). In contrast, the more important NVT species did not include perennial life forms.

The two-dimensional NMDS distribution (Fig. 3) of sampled plots according to plant species composition shows a clear separation between treatments (three-dimensional NMDS scatterplot, with a stress value of 0.09, is not shown for lack of clarity). This separation is corroborated by ANOSIM (global $R = 0.791$, number of used permutations = 999, significance level = 0.1%). The HCA generated four significantly different clusters (ANOSIM global $R = 0.917$, significance level = 0.1%) at a similarity level of 46%. The superimposition of the four clusters on the NMDS ordination diagram shows that all NVM plots and the initial situation (IS-00) are assembled together in the same group. In turn, NVT plots are divided into three clusters: one formed by NVT-01, NVT-02, and NVT-07, another by NVT-03 and NVT-04, and the third by

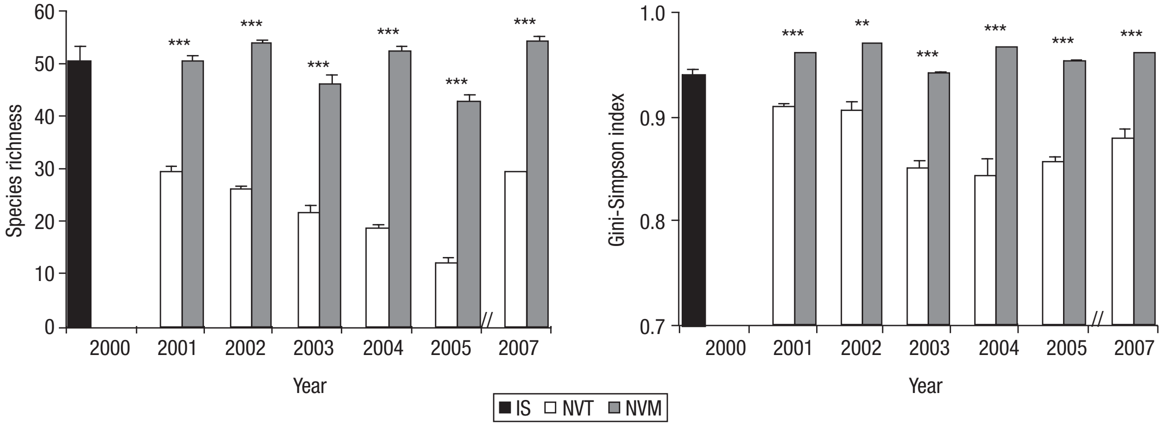

Figure 2. Mean species richness and Gini-Simpson diversity index in spring, for the initial situation (IS), natural vegetation tillage (NVT), and natural vegetation mowing (NVM), from 2000 to 2007. Bars represent the standard error of the mean (n = 16 for IS and n = 8 for NVT and NVM). Asterisks indicate significant differences between soil management systems at $p < 0.01$ (**) and at $p < 0.001$ (***).

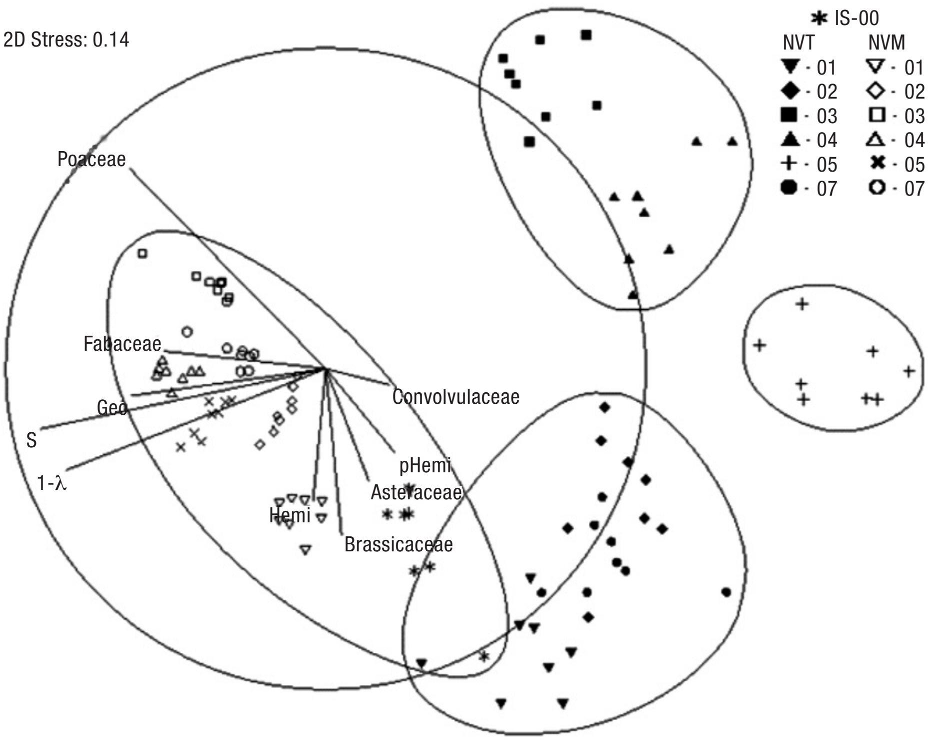

Figure 3. Non-metric multidimensional scaling (NMDS) ordination of Bray-Curtis similarities, based on species composition and abundance, among sampled plots. Symbols refer to the initial situation (IS, year 2000) and the soil management system (NVT: natural vegetation tillage; NVM: natural vegetation mowing), according to sampling date (2000-2007). Superimposed circles represent clusters of samples at 46% similarity and vectors represent significant ($p < 0.05$) descriptive attributes (S: species richness; 1-λ: Gini-Simpson index; Geo: geophytes; Hemi: hemicryptophytes; pHemi: protohemicryptophytes). The *stress value* indicates the ease with which all data points were fitted into two dimensions.

NVT-05. By projecting samples attributes on the NMDS ordination diagram (Fig. 3) significant correlations ($p < 0.05$) were found between treatments and descriptive attributes. NVM showed a strong positive correlation with species richness (S) and diversity (1-λ), Poaceae and Fabaceae, and also with geophytes and hemicryptophytes. In contrast, NVT was negatively correlated with S and diversity and with the overall perennial life forms, and positively correlated with Convolvulaceae and also with Asteraceae and Brassicaceae in the initial study years.

The annual olive production generally increased throughout the study period, in spite of year-to-year alternation in production observed in both soil managements, but production was not significantly affected by treatment (Fig. 4).

Soil physical properties

In the overall, soil water content was higher at 40 cm than at 20 cm depth, in both management systems. On the other hand, soil water was higher in NVM than in NVT, at both soil depths, particularly in mid-summer and after the first autumn rains (Table 1). Additionally, autumn values were in average 1.1 to 1.5

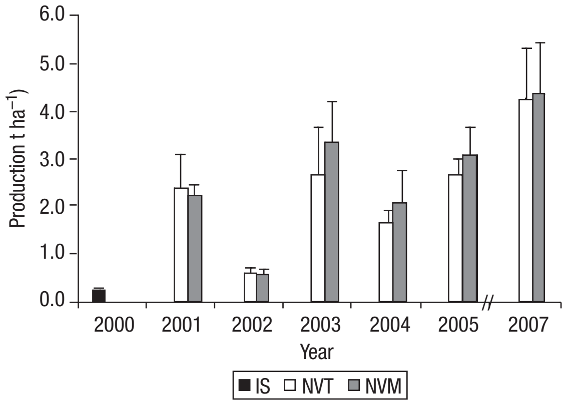

Figure 4. Olive production (t ha^{-1}) in the initial situation (IS), natural vegetation tillage (NVT) and natural vegetation mowing (NVM), from 2000 to 2007. Bars represent the standard error of the mean (n = 640 for IS and n = 320 trees for NVT and NVM). Means did not differ significantly ($p > 0.462$) among treatments.

Table 1. Mean soil water content (%) in natural vegetation tillage (NVT) and in natural vegetation mowing (NVM), from 2000 to 2007, at mid-summer (end of July) after a drought period ranging from 44 to 87 days and in early-autumn after the first rains (R) ranging from 41 to 164 mm. Standard errors of the means are indicated in parenthesis (n = 8 – 16)

Soil depth	2000		2001		2002		2003		2004		2005		2006	2007	
	NVT	NVM	NVT	NVM	NVT	NVM	NVT	NVM	NVT	NVM	NVT	NVM	NVT/ NVM	NVT	NVM
Dry days	Dry season														
	68		52		76		87		53		60		na	44	
20 cm	8.1 (0.4)	8.6 (0.4)	10.8 (2.4)	11.0 (1.2)	10.4^{a} (0.8)	11.6^{b} (0.5)	9.5^{a} (0.9)	10.4^{b} (0.5)	10.5 (0.5)	11.3 (0.4)	9.12 (0.6)	9.8^{b} (0.7)	na	10.5^{a} (0.5)	13.4^{b} (0.7)
40 cm	13.8 (0.6)	15.0 (0.6)	15.7 (1.9)	16.8 (2.6)	15.2 (1.0)	15.1 (0.9)	13.0^{a} (0.9)	13.9^{b} (0.6)	17.1^{a} (0.6)	22.5^{b} (1.1)	13.6^{a} (1.1)	14.8^{b} (1.6)	na	17.3^{a} (0.8)	19.2^{b} (1.1)
R	Early-autumn														
	41		164		58		67		84		72		na	na	
20 cm	12.5 (0.8)	12.6 (0.8)	23.3^{a} (1.2)	24.9^{b} (1.2)	13.1^{a} (1.4)	15.4^{b} (1.6)	12.7^{a} (1.7)	15.8^{b} (1.3)	18.7^{a} (1.8)	19.6^{b} (1.7)	20.2^{a} (1.6)	22.5^{b} (1.6)	na	na	na
40 cm	13.6 (0.8)	14.2 (0.8)	26.2 (1.3)	26.9 (1.1)	13.7^{a} (1.3)	16.6^{b} (1.7)	15.3^{a} (2.0)	17.6^{b} (1.4)	25.1 (2.0)	25.7 (2.6)	14.9^{a} (1.4)	17.5^{b} (2.0)	na	na	na

Means for the same year and depth with different letters are significantly different ($p < 0.05$). na: non-available.

times higher than summer values in both treatments and depths, excepting at 20 cm depth in NVM, which doubled from the dry season value.

Soil resistance to penetration increased from 1 down to 18 cm depth in both management systems, but was significantly higher (significance ranged from $p = 0.001$ to $p = 0.03$) in NVM than in NVT (Fig. 5). From 19 cm to 80 cm depth (some data not shown), values decreased in NVM and no further significant differences ($p > 0.05$) were obtained between management systems.

Discussion

According to our hypothesis, mowing natural vegetation in spring improved the orchard plant diversity and soil water conservation, without affecting olive production.

The families Poaceae, Asteraceae, and Fabaceae, which are among the richest families of the Mediterranean flora and the most common in olive orchards (*e.g.,* Solomou & Sfougaris, 2011), were the predominant families in both mowing and tillage management systems. However, a clear effect of soil management on plant species diversity was observed almost from the first year of treatment application. A more diverse flora was promoted by mowing (NVM) and by the maintenance of a central vegetation strip for reseeding,

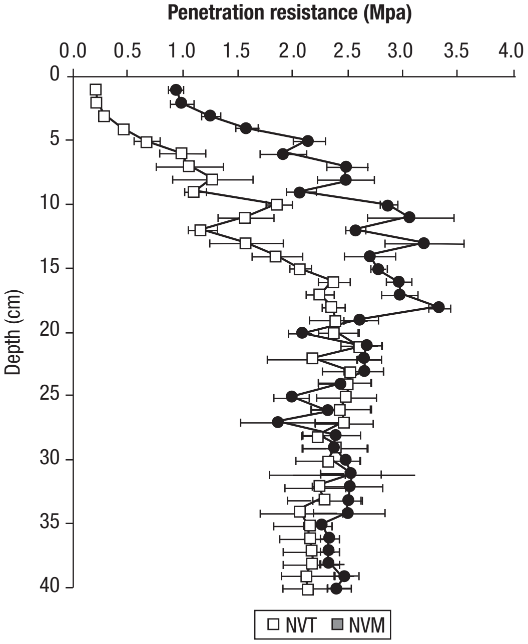

Figure 5. Soil resistance to penetration in natural vegetation tillage (NVT) and in natural vegetation mowing (NVM), in autumn 2004. Bars represent the standard error of the mean (n = 8).

as shown by the placement and dimension of species richness (S) and diversity (1-λ) vectors. In contrast, tillage (NVT) seems to have a detrimental effect on S and 1-λ in NMDS analysis, particularly in dry years as suggested by the pronounced decrease observed under tillage in 2005 and also by the separation of this community (NVT-05) in a single cluster. Results of cluster allocation in NMDS graph also shows a more similar and consistent plant species composition in-between mowed plots (NVM), compared to the three disperse clusters of tilled plots. Higher biodiversity in less intensive olive farming and, in contrast, a strong detrimental effect of tillage were also reported in other studies (Duarte *et al*., 2008; Zuazo *et al*., 2009). Furthermore, the four species that ranked higher IV in NVT (above 50), were previously reported in association with tillage (Verdú & Mas, 2004; Plaza *et al*., 2011). On the other hand, some of the more important species within NVM assemblage (*Hordeum murinum* L.*, Torilis nodosa* (L.) Gaertner*, Calendula arvensis* L.*, Lamarckia aurea* (L.) Moench*, Campanula erinus* L., and *Poa annua* L.) were reported in association with mowing (Mas *et al*., 2007) and other (*Lolium rigidum* Gaudin, *Aegilops triuncialis* L., *Medicago* spp., *Galium tricornutum* Dandy, and *Hordeum murinum*) with less intense tillage farming systems (Saavedra & Pastor, 1995; Plaza *et al*., 2011; Solomou & Sfougaris, 2011). Moreover, *Galium tricornutum* and *Anthemis arvensis* L., associated only with NVM, are arable species threatened in other European countries (Storkey *et al*., 2012). The primary reason for the absence of perennial life forms among NVT species might be the destruction of the herbaceous layer by tillage, including renewal buds near the ground surface. By allowing perennials to resume growth with the fall rains, in contrast, mowing can promote functional diversity, as suggested by the clear association observed between geophytes, hemicryptophytes, and protohemicryptophytes and NVM. Additionally, in accordance with other studies (Potts *et al*., 2006), all NVT indicator species were ruderals, whilst NVM also favored species that, following Rivas-Martínez *et al*. (2002), are characteristic of ecologically diverse communities with a high natural value. Among these, we may emphasize characteristic species of meadows (*Phalaris minor* Retz, *Holcus lanatus*, and *Leontodon taraxacoides*), natural perennial grasslands (*Gaudinia fragilis* (L.) Beauv., *Ornithogalum narbonense*, and *Andryala integrifolia*), therophytic grasslands (*Vicia lutea* L. and *Briza minor* L.), riparian wet deciduous woodlands (*Arum italicum* subsp. *italicum*), woods and shrub semi-shaded fringes (*Torilis nodosa* and *Galium minutulum* Jord.), and from evergreen oak forests (*Arisarum vulgare*). The species rich NVM natural vegetation potentially provides an array of benefits concerning food and shelter resources to associated fauna and thereby enhances fauna diversity (Potts *et al*., 2006). Increased plant diversity can also boost fundamental ecosystem functions like litter decomposition, due to the higher diversity of soil decomposers and herbivores, which in turn promote the diversity of other components of the soil food web (Zak *et al*., 2003).

The overall higher NVM diversity was not reflected in higher total green cover, which would affect orchards productivity through competition for water with the olive trees (*e.g.,* Ramos *et al*., 2010). In fact, as compared to spring tillage, mowing did not negatively affect soil water retention during the dry season of most study years. This is most probably because mowing before the water balance starts to be negative minimizes soil water use by the vegetation cover (Alcántara *et al*., 2011; Ferreira *et al*., 2013). The trend to improved soil water conservation observed under vegetation mowing might be ascribed to the mulch effect of plant residues left on the soil surface, which lowers soil water evaporation under drought (Taguas *et al*., 2010; Alcántara *et al*., 2011). This effect is of utmost importance in the semi-arid rainfed Mediterranean oliviculture (Zuazo *et al*., 2009), particularly during fruit development. The persistence of plant residues after mowing also had a positive effect on soil water content in autumn, particularly during the first rains from the second year. The higher soil resistance to penetration observed in the upper soil layers under NVM after the first autumn rains can also be ascribed to grass and straw increment, as reported by other authors (Sainju *et al*., 2003; Pohl *et al*., 2009). Improved resistance to penetration enhances soil trafficability during olive harvesting period when the weather is usually wet (*e.g.,* Pardini *et al*., 2002). Increment of plant diversity and grass abundance results not only in higher straw cover, but also in higher root abundance and diversity (Gómez *et al*., 2009a; Taguas *et al*., 2010; Alcántara *et al*., 2011), also enhancing soil stability and water infiltration and holding capacity (Pohl *et al*., 2009) reducing thus soil erosion (García-Fayos & Bochet, 2009; Ramos *et al*., 2010; Gucci *et al*., 2012). Under tillage management, on the other hand, the higher proportion of bare ground might have affected soil moisture by reducing water infiltration, as observed in other olive orchards (Gómez *et al*., 2009a; Alcántara *et al*., 2011). Reduction in the infiltration of rainfall to be used by olive trees can be associated with sediment and runoff losses that are a significant source of nutrients loss, thus increasing the risk of eutrophication (Gómez *et al*., 2009a). In contrast, the increased flow resistance provided by the vegetation cover dissipates the energy of the surface water, and both live plants and straw intercept part of the sediment particles carried by the water (Gómez *et al*., 2009a). The higher organic matter input to the soil from plant debris also improves soil quality and C storage, reducing runoff, soil erosion, and N leaching from the soil profile to the surface and groundwater as compared with conventional tillage (Francia-Martínez *et al*., 2006; Gucci *et al*., 2012; Ferreira *et al*., 2013). Ground cover vegetation can thus improve ecosystem services provided by olive orchards, including soil development and carbon sequestration, mitigating climate change (Nieto *et al*., 2013; Rodríguez-Entrena & Arriaza, 2013; Parras-Alcántara *et al*., 2013; Soriano *et al*., 2014). Strong correlations between plant diversity and soil fertility have been reported by other authors (García-Fayos & Bochet, 2009). Thus, rather than drought, the association of mowing with increased plant diversity, and also with Fabaceae abundance, which should have enhanced soil fertility, might explain the trend to higher production under mowing, in spite of the observed alternate bearing pattern, characteristic of the olive tree (Fernandes-Silva *et al*., 2010). In fact, although yield of cv. Cobrançosa can be affected by severe drought, high water use efficiency enables this cultivar to cope with moderate water stress with an acceptable production (Bacelar *et al*., 2007; Fernandes-Silva *et al*., 2010).

This paper contributes to link biodiversity conservation with sustainable agriculture, preserving ecosystem services like soil and water conservation. Maintaining natural vegetation cover controlled in spring by mowing before water shortage is an environment-friendly management system that should replace conventional tillage in Mediterranean rainfed olive orchards. According to our results, this practice can improve the overall orchard biodiversity and soil water conservation without negatively affecting olive yield. Furthermore, by providing an effective autumn straw cover, improved trafficability for harvesting is also expected under natural vegetation mowing. From an environmentally sustainable perspective, the proposed management option should thus be rewarded for conserving agro-ecosystems and preserving landscape.

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