



Mitigating Climate Change Through Bioclimatic Applications and Cultivation Techniques in Agriculture (Andalusia, Spain)

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Abstract

Bioclimatology is applied to agricultural and forestry ordinations, as farmlands and woodlands have a bioclimatic optimum for their development. It is essential to consider the thermo-climate and ombro-climate of the bioclimatic belts in the ordination of the territory to guarantee the maximum yield with minimum environmental costs. These bioclimatic parameters (thermo-climatic and ombro-climatic index, I_t/I_{tc} and I_o) are of particular interest in agriculture as a way of mitigating climate change. The main objective is to establish the climate trends and propose a phyto-bioclimatic model to mitigate sudden climate change in agriculture. The spatial pattern of temperature trends in southern Spain (Andalusia) between 1975 and 2007 was determined by analysing time series data from 48 climate stations distributed homogeneously throughout the study area on a monthly, seasonal and annual basis. The regression slopes were calculated with Sen's test, and the statistical significance of the trends was determined using the Mann-Kendall non-parametric test after pre-whitening the series with autocorrelation. The trends detected on the maps were spatially visualised by applying geo-statistical data interpolation techniques. The study found that positive trends have prevailed over negative trends in the last three decades, with increases of up to 4 °C in spring and summer clearly reflecting the highest percentages of stations with a significant positive trend (92% and 85%, respectively). The trends towards the greatest temperature increase were observed in May and June, with somewhat more moderate increases in April and July. Increases in the range of 0.15–0.4 °C/decade were found at the annual level with 87% of stations significant. The temperature increase reduces flowering and produces losses in agricultural yield as a consequence. It is demonstrated that the vegetation cover acts as a soil water reservoir and retains moisture during the summer months.

Keywords

Bioclimatology · Change · Climatology · Mitigation · Plant association · Trends

Abbreviations

Alt	Altitude
ETP	Potential evapotranspiration
I_o	Ombrothermic index
IPCC	Intergovernmental Panel on Climate Change
I_s	Summer ombrothermic indices
I_t/I_{tc}	Thermo-climatic index
P	Precipitation
PAV	Period of vegetative activity
RC	Soil water retention capacity
T_m	Mean temperature

1 Introduction

The fourth report by the Intergovernmental Panel on Climate Change (IPCC 2007) states: “Warming of the climate system is unequivocal”. The third assessment report highlighted an increase in temperature of approximately 0.6 °C [between 0.4 °C and 0.8 °C] (1901–2000) (IPCC 2001), affecting physical and biological systems in different parts of the globe. The fourth report contains clear evidence that climate change and global warming are now incontrovertible facts that affect us all. Global concentrations of carbon dioxide, methane and nitrous oxide in the atmosphere in recent years have increased considerably as a result of human activity since 1750. This linear trend over 100 years (1906–2005) is now calculated at 0.74 °C [between 0.56 °C and 0.92 °C] (IPCC 2007) and not the 0.6 °C cited in the third report. The increase in temperature is distributed over the entire planet but is more pronounced in higher northern latitudes. The IPCC has recently reported different scenarios with temperature oscillations between -1.0 and $+3.5$ °C depending on the territories.

Numerous studies at different climatic and regional scales on the Iberian Peninsula have revealed a general increase in temperature throughout history in the whole of the Spanish territory. These include the works of Del Rio et al. (2011), Ileana and Castro-Diez (2010), Brunet et al. (2009) and others such as Sáenz et al. (2001), Salat and Pascual (2006), Del Río et al. (2018) and Martínez et al. (2010) in northern Spain and Esteban-Parra et al. (1997), Castro-Diez et al. (2007) and Ordóñez (2008) in the south, specifically in Andalusia.

This accelerated rate of climate change is leading to a wide range of impacts with direct and indirect effects. Several studies have been carried out in Spain such as those by Rodríguez-Fonseca and Rodríguez-Puebla (2010), Brunet et al. (2009) and Moran Tejada (2011), among others, in addition to similar assessments at the continental (ACACIA project in Europe) and national level (ECCE project in Spain).

Due to its location and complex orography, the Iberian Peninsula has a highly variable climate (Font Tullot 2000) and is particularly vulnerable to climate change. It is subject to the influx of Atlantic depressions on one hand and to the influence of the Mediterranean cyclogenesis on the other; it is also under the influence of high pressure from the Siberian anticyclone and is an area of advection for the subtropical Atlantic winds and for dry winds from North Africa. Over many years, this variability in its climate has been the subject of many different types of studies on a wide range of topics (Capel 1998; Capel 2000; Sigro 2004; Almarza and Luna 2005; Martín-Vide et al. 2006; Beranova and Huth 2007; Dadhich et al. 2015).

According to the IPCC (2007), the Mediterranean area is one of the regions deserving special attention in terms of possible impacts from climate change. Climate change forecasts point to the likelihood of an increase in the frequency of heatwaves, maximum temperatures and a drop in precipitation, all of which may have important consequences on natural ecosystems and on society, health and the agricultural economy. Andalusia will be particularly affected, as climate change exacerbates desertification and erosion processes and leads to a scarcity of water resources due to deforestation, overexploitation of aquifers and a generalised loss of biodiversity in coastal and humid areas and woodlands. The loss of a vast carbon dioxide sink such

as forests due to cutting, fire or changes in land use has caused an increase in carbon dioxide concentrations, which further aggravates the situation (IPCC 2007).

Bioclimatology evidently has much to offer in these cases. The indices of Rivas Martínez and Loidí (1999) have established a close correlation between bioclimatic data and plant communities, so each territory can be characterised in these terms. This bioclimatic approach can be applied to a range of crops under a Mediterranean macro-bioclimate. The correlation between these indices and the distribution of olive (*Olea europaea*) cultivation clearly highlight the typically Mediterranean character of olive.

In Andalusia, agriculture plays a key role in the economic sustenance of the population, and most of the region is characterised by a predominance of farmlands. This sector can expect to see major changes, including a declining trend in yields in warmer regions due to heat and water stress. An increase in insect plagues, damage to crops, increased erosion rendering land unproductive due to an increase in heavy rainfall, salinization of irrigation waters, estuaries and freshwater systems due to rising sea levels will all have important social and economic repercussions. It is essential to analyse parameters such as temperature, rainfall and bioclimatic indices in combination with studies of agricultural yields (Cano et al. 1997; Meena et al. 2015) to determine how variations in these parameters will affect the territory and to what extent. This will allow us to create models for short- and medium-term adaptation that can alleviate the situation.

Bioclimatology as a science explores the close relationship between living beings and physical factors (climate) and thus has a strong association with agriculture, as the concepts of bioclimate and bioclimatic belt (thermotype and ombrotype) are essential for planning crops. It should be noted that the aim is to achieve the maximum yield in terms of quantity and quality with the lowest environmental and economic cost as societal demand. The only way to achieve this is to understand bioclimatology as a basic science in agricultural planning. The management of bioindicators and bioclimatic indices must therefore be incorporated into the management of olive cultivation, for which the essential framework is the bioclimatic interpretation of the territory. The treatment against pathogens and the costs incurred by the use and, in some cases, abuse of irrigation in areas of olive cultivation are not the same in different ombrotypes (semiarid, dry, subhumid), as the utilisation of water reserves and the type of crop must be adapted to the thermotype (It/Ict) and ombrotype. Olives are the predominant crop; they are cultivated over a broad area and are of exceptional socio-economic importance.

Biogeographical analyses and soil studies must therefore be conducted in potential sites for olive cultivation. Based on this information, Cano et al. (2003a) propose a model for agricultural management.

Environmental factors → Bioclimatology and biogeography → Vegetation series → Cultivation type

When applied to rainfed crops, this model will ensure a correct territorial ordination. In previous works (Cano et al. 1997), we established a close correlation

between kg/hectare yields of olive-growing areas and the values of the ombrothermic index (Io), continentality index (Ic) and thermicity index (It/Itc). This correlation established that the areas of maximum yield for the *Picual* (known as Martena or Loperena, is an Spain olive cultivar) variety are in the upper and upper-dry thermo-mediterranean and lower, upper-dry mesomediterranean bioclimates, and the values of the Io, Ic and It/Itc indices for maximum olive yields for the *Picual* variety are $I_o = 3.66$, $I_c = 18.5$ and $I_t/I_{tc} = 270/330$, coinciding with certain vegetation series. Some years later, we extended these studies to other olive varieties: *Hojiblanca*, *Lechín*, *Morisca*, *Manzanilla*, *Gordal* and *Verdiales* (Cano et al. 2004; Cano-Ortiz 2007; Cano and Cano-Ortiz 2013; Cano-Ortiz et al. 2014). The main objective of this work is to measure climatic and bioclimatic trends in order to establish models and cultivation techniques that serve to mitigate climate change in agriculture.

2 Material and Methods

2.1 Study Area

Our study area is Andalusia, which has an extension of 87,268 km² and is located in the south of the Iberian Peninsula. It serves as a bridge between Africa and Europe, and a meeting point between the Atlantic Ocean and the Mediterranean Sea.

Andalusia lies between parallels 36° and 38°44' N. It is the second largest region in Spain and occupies 17.3% of the Spanish territory and around 2% of the territory of the European Union. In total, it has 910 km of Atlantic and Mediterranean coastline and is divided into the eight provinces which are classified as western Andalusia, Seville, Huelva, Cadiz and Malaga, and eastern Andalusia, Jaen, Cordoba, Granada and Almería (Fig. 1).

Its relief (Fig. 2) is characterised by its altitudes (alt) and slopes. Three geographic areas can be distinguished from north to south: the Sierra Morena (the natural boundary with the southern sub-plateau), the Betic plain and the Betic mountain ranges (Subbética and Penibética), which are separated by a central depression. To the west is the Guadiana river which separates Andalusia from Portugal; to the south lies the Atlantic Ocean and the Mediterranean Sea, connected through the Strait of Gibraltar; and to the east, the Mediterranean Sea and the Sierra de Segura mountain range act as the natural boundary between Andalusia and the Levante, or eastern part of Spain.

The orographic complexity of Andalusia, with extreme physical contrasts between the high mountain ranges and formations such as the Sierra Nevada (with an alt of 3483 m on the Mulhacen peak), broad plains such as the Guadalquivir river plain, and coastal areas bathed by the Atlantic and Mediterranean, all play an important role in its climatic and bioclimatic diversification. These factors, combined with the pattern of atmospheric circulation in the specific sphere of the region, the alternation of seas and continents and the thermal contrast between the Atlantic and Mediterranean, make this an area of particular interest.

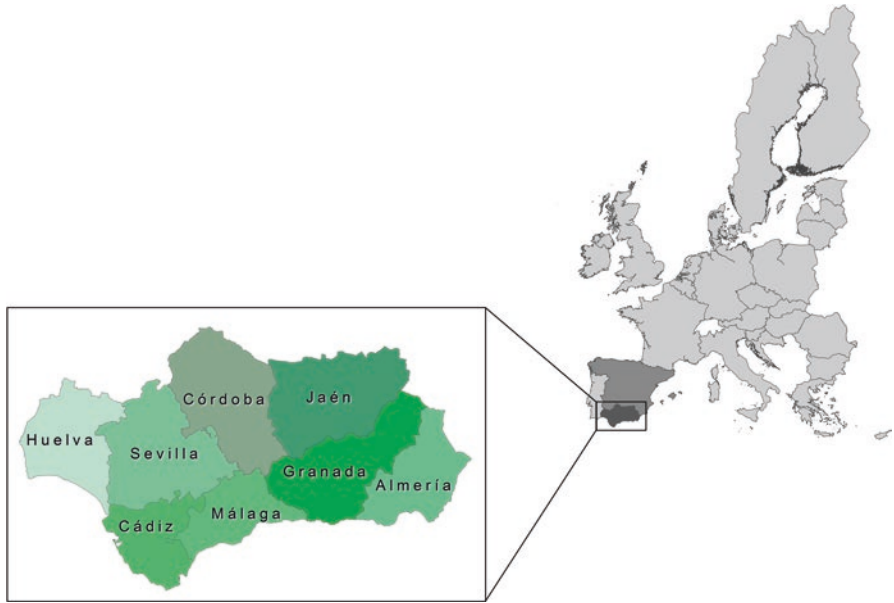


Fig. 1 Location of Andalusia



Fig. 2 Main mountain massifs in Andalusia

The study of the physical environment includes aspects of its geology and soil. The Guadalquivir valley is a sedimentary infill formed by soft materials which, with the exception of Quaternary materials, are all of marine origin. There is a particular predominance of loams and limestone loams from the Neogene-Quaternary era and

allochthonous materials from the Subbética mountain ranges. In the northernmost part of the valley, there is a predominance of Triassic materials, essentially sandstone, at the expense of loams and limestone loams (tabular coverage or cover of materials).

These geological materials give rise to the formation of different soil types. The northernmost area is characterised by chromic luvisols with a nearly neutral pH, which has a direct repercussion on the flora of this specific zone. The area occupying an intermediate position in the valley is rich in marls and limestone marls, originating calcic cambisols and clay-rich vertisols, which are characteristic of agricultural soils and used essentially for the cultivation of olives and cereals. Finally, in the southernmost zone, there is a predominance of orthic solonchaks, saline-type soils enriched with gypsum and sulphated salts, which have a direct influence on the flora.

2.2 Data Processing

The data series for average temperature used in our study cover a total of 33 years, from 1975 to 2007. A key aspect of this work was the collection and review of data from a total of 2450 climate stations provided by the Department of the Environment in the Andalusian Regional Government. Initially, all thermometric or thermopluviometric stations with complete data series for the aforementioned period were selected, resulting in a total of 157 stations. Finally, after a painstaking process of data purging, any stations that did not meet the criterion of containing below 3% of gaps in relation to the total data for each station in the study period were discarded. All gaps were replaced by the mean monthly value in each time series (Rodríguez-Puebla et al. 1998; Muñoz-Díaz and Rodrigo 2004; Del Rio et al. 2012). We focussed our study on the time series from 48 weather stations (Fig. 3).

After the series selection, the data was subjected to statistical analysis (Sneyers 1992). The Shapiro-Wilk test (Shapiro and Wilk 1965) was first applied to compare the normality of the time series. We obtained the non-normal distribution of the series, which ruled out the use of parametric analytical methods. The runs test (non-parametric test) was then applied to verify the homogeneity and randomness of the data.

The trends were analysed at several scales – monthly, seasonally and annually – as this combination afforded a greater level of information (Suppiah and Hennessy 1996; Rodrigo and Trigo 2007).

The magnitude of the trends and their statistical significance (to a 95% confidence level) was obtained using the Microsoft Excel application MAKENSES (Salmi et al. 2002), with the non-parametric method of the Mann-Kendall test (Del Río et al. 2012; Robert and James 1984), in addition to Sen's test (Gilbert 1987) to determine the slope associated with the time series. Prior to the Mann-Kendall test, a pre-whitening procedure was applied exclusively to all the time series with serial autocorrelation to avoid a higher or lower estimation than the actual statistical significance shown by the trend obtained in the Mann-Kendall test.

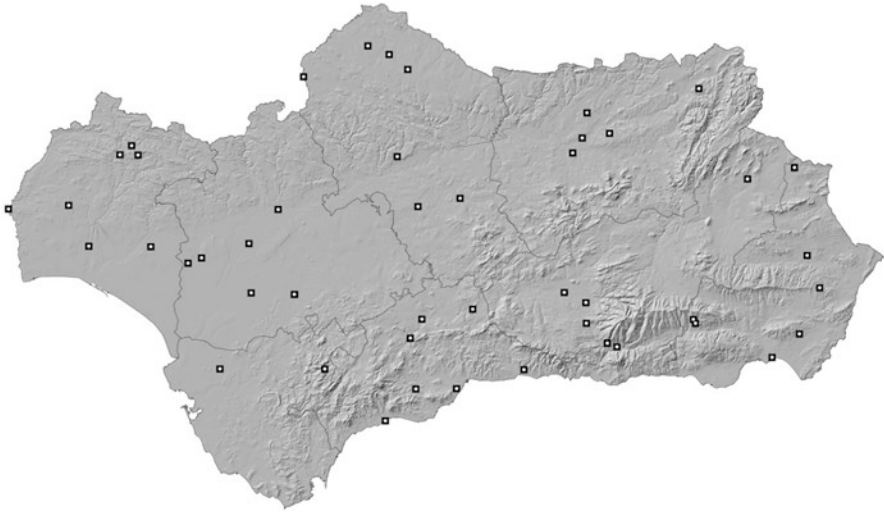


Fig. 3 Location of the weather stations in the study area

The trends were represented spatially and temporally by geo-statistical data interpolation techniques via kriging (Collins and Bolstad 1996; Johnston et al. 2001; Luna et al. 2006; Atorre et al. 2007; Cao et al. 2009; Del Río et al. 2012; Ram and Meena 2014), applied through the ArcGis© 10 programme. After several tests, it was observed that the best results were obtained from ordinary cokriging (Aznar et al. 2012) between the regression slopes (first variable) and the alt of each station (second variable), as both were spatially correlated. The exponential model had the best fit with the minimum error.

We identified the existing plant communities and important cultivation areas from the bioclimatic analysis, and particularly for olive, which is the predominant crop in Andalusia. We focussed on the farmlands in the Guadalquivir valley, an extension that is widely occupied by olive groves and to a lesser degree by almond (*Prunus dulcis*) orchards and plantations of cereal, cotton (*Gossypium* spp.) and sunflower (*Helianthus* spp.).

We followed Rivas-Martínez et al. (2002) for the description of the biogeographical units. The territory is included in the Betic, Western Iberian Mediterranean and Lusitanian-Andalusian coastal provinces, all of which have a high rate of endemism and diversity. The Betic province contains all the bioclimatic belts existing in the Mediterranean region of the Iberian Peninsula and owes its great diversity to its orology, geology and climatology. Our study covers the various biogeographical sectors, of which the Hispalense sector has the greatest territorial extension, and includes the great Guadalquivir valley, with a wide variety of materials.

Data from 48 meteorological stations were used to prepare the present bioclimatic study, selected either because they were in or near areas of olive cultivation or because they offered the greatest quantity of data. In rare cases, stations far from

cultivation areas were used. Formulas of Rivas-Martínez indices were applied (1996).

Ombrothermic indices are important to agronomy, as the greater the difference between I_{s2} and I_{s3} , the greater the compensation. To determine the territorial dominance of certain bioclimatic parameters such as I_o , I_c and I_t/I_{tc} and in order to establish the dominant thermotypes and ombrotypes, we have grouped the meteorological stations according to the number of months with vegetative activity, as the different varieties respond well to this criterion. We have divided the territory into three major areas, (a) territories with 12 months, (b) 10–11 months, and (c) 8–9 months of vegetative activity, by finding the means of these indices and obtaining the I_{om} , I_{cm} and $I_{t/I_{tc}m}$. We have also used crop yield data, and information on the agronomic characteristics of the varieties described by several authors such as Barranco et al. (1998) and Guerrero (1991), combining each variety with the value of the indices cited, and overlapping the crop type with each vegetation series (Rivas Martínez 1987; Cano et al. 2003b).

The various herbaceous plant associations were studied using the phytosociological methodology derived from the Braun-Blanquet (1979) Zürich-Montpellier school, subsequently modified by authors such as Géhu and Rivas-Martínez (1982). The syntaxonomical inclusion of the communities was done following Rivas-Martínez et al. (2001).

3 Results and Discussion

3.1 Analysis of Climate Trends

Figure 4 shows positive trends predominate over negative trends and are statistically more significant in the entire study territory between 1975 and 2007. This result confirms that the temperature in Andalusia has increased in the last three decades. Figure 5 shows the percentage of climate stations, obtained by the Mann-Kendall test with a confidence level of 95%.

Figure 6 shows the spatial-temporal distribution of seasonal temperature trends ($^{\circ}\text{C}/\text{year}$) in the study territory, thanks to the application of data interpolation techniques via cokriging (Aznar et al. 2012).

At the seasonal level, the four stations can be divided into two groups. The first is the main contributor to the general upward trend observed in temperatures and comprises spring (March, April and May) and summer (June, July and August), where the percentage of stations with a positive trend is very high – 100% and 92%, respectively – and the proportion of significant stations is 92% and 85% (with a confidence level of 95%). The second group includes autumn (September, October and November) and winter (December, January and February) and is characterised by representing a percentage of stations with a more moderate positive trend of 50% and 44%, respectively, together with a marked decline in stations with statistical significance at around 27% and 15%. Although there is a prevalence of stations with a negative trend in winter, and they are distributed homogeneously in autumn, in

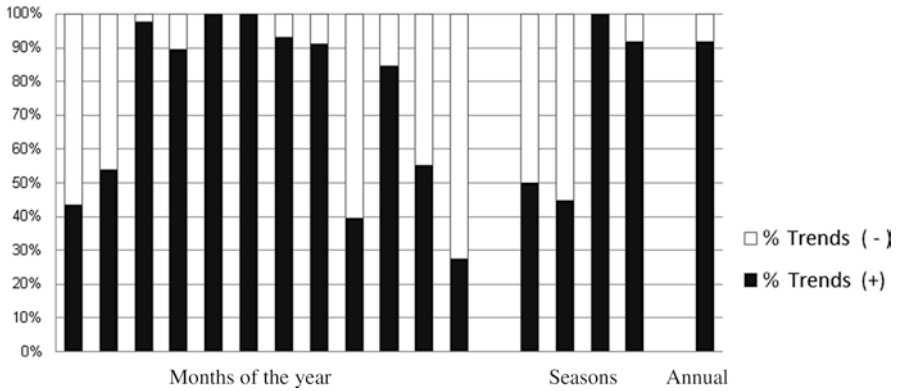


Fig. 4 Positive and negative trends in the whole of the study territory

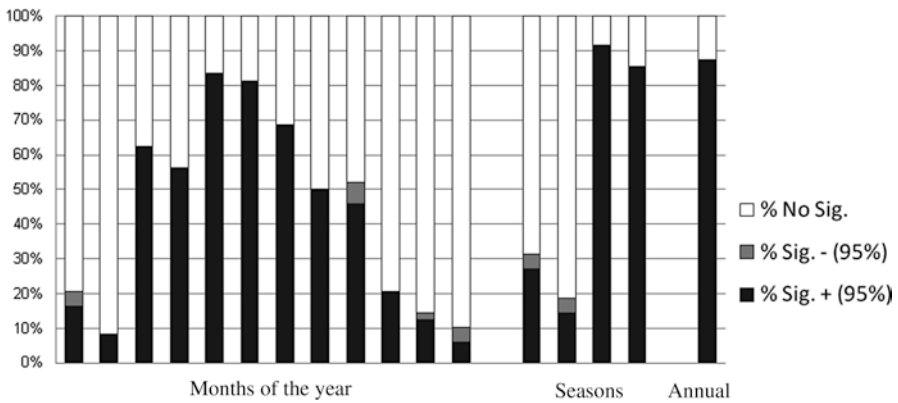


Fig. 5 Percentage of climate stations with positive and negative trends

statistical terms, and considering the total significant stations, there are more significant stations in both seasons with a positive than with a negative trend, with results of 87% compared to 13% (winter) and 78% compared to 22% (summer).

On a monthly basis, starting in winter, December has the highest percentage (86%) of stations with a significance level below 95% and the lowest percentage of significant stations with a positive trend (6%), compared to the other months in the same season and to all 12 months of the year. Most of Andalusia falls within the interval between $-0.15\text{ }^{\circ}\text{C}$ and $0.15\text{ }^{\circ}\text{C}/\text{decade}$ in the month of December. The western half of Andalusia has areas with more acute drops in temperature, between $0.45\text{ }^{\circ}\text{C}$ and $0.15\text{ }^{\circ}\text{C}/\text{decade}$ in some very specific areas of the mountains to the north of Cordoba and Malaga (Antequera depression), where the decline is as much as $0.6\text{ }^{\circ}\text{C}/\text{decade}$. In the eastern half of the territory, although the temperature distribution is somewhat more homogeneous, some declines can be seen in the central Jaen province (Guadalquivir Valley, in the Loma de Ubeda area), in the Almanzora

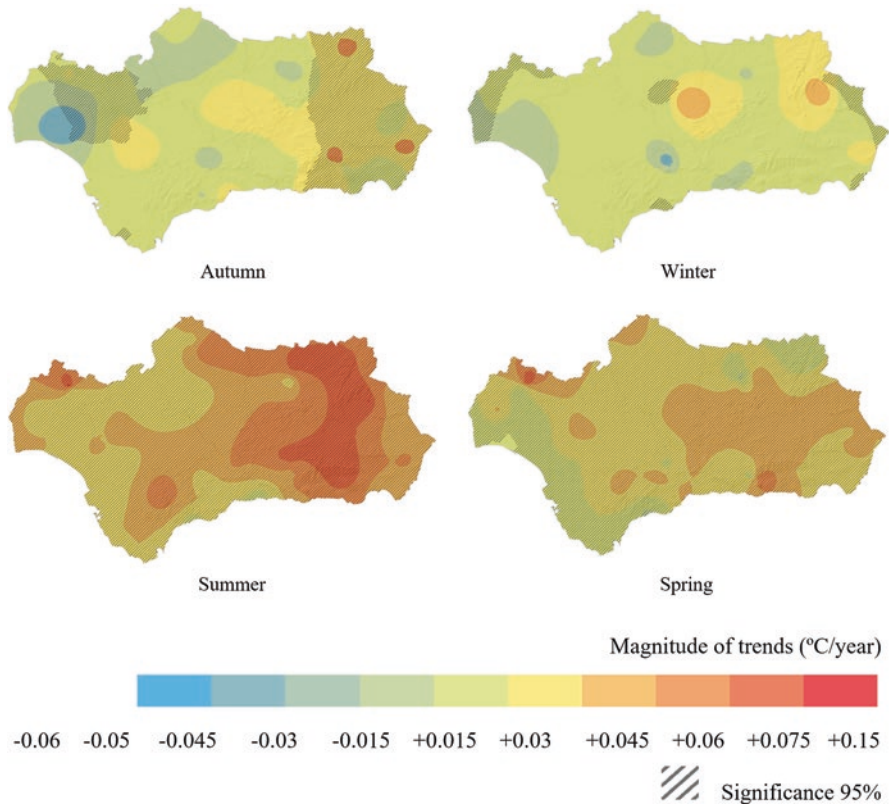


Fig. 6 Spatial distribution of seasonal temperature trends ($^{\circ}\text{C}/\text{year}$). Magnitude of the trends ($^{\circ}\text{C}/\text{year}$)

valley in Almería, and in Granada province, in the whole area between Sierra Nevada, the Lecrín Valley and the Sierra de Lújar mountains down to the coast. There is an increase of $0.45\text{--}0.6\text{ }^{\circ}\text{C}/\text{decade}$ in the easternmost part of Almería (Campo de Tabernas), north of Granada, in the north-eastern part of Jaén (Cazorla, Segura and Las Villas mountains) and in the Guadalquivir Valley in the agricultural area around Cordoba.

There is a variation of $-0.15\text{ }^{\circ}\text{C}$ and $0.15\text{ }^{\circ}\text{C}/\text{decade}$ in most of the territory in January, and some parts of the Guadalquivir Valley (central Jaén province, and the agricultural area around Huelva) have registered minimum decreases of approximately $0.47\text{ }^{\circ}\text{C}/\text{decade}$. The main temperature increases can be found in eastern Andalusia, with very similar magnitudes and situations to December, but covering a greater extension of territory. This expansion is particularly pronounced in the north-eastern part of Jaen (Cazorla, Segura and Las Villas mountains) and in the Guadalquivir Valley in the agricultural area around Cordoba, where the initial increase is $0.45\text{--}0.6\text{ }^{\circ}\text{C}/\text{decade}$, rising to $0.3\text{--}0.45\text{ }^{\circ}\text{C}/\text{decade}$ in the peripheral areas in the easternmost part of Almería (Campo de Tabernas) and in northeast Cadiz (Sierra de Grazalema).

In January, there are still a greater percentage of stations with a negative than a positive slope but to a lesser extent than December. Another finding is the continued high percentage of non-significant stations (79%) compared to the other winter months (December and February); January has a lower percentage of non-significant stations and a higher percentage of stations with a positive significance (17%).

February is the warmest of the winter months, with 52% of the stations showing a positive temperature trend. Although there is a generalised variation between -0.15 °C and 0.15 °C/decade in most of the study territory, the greatest temperature increases, with maximums of 0.6 °C/decade, are located in the following areas, from east to west: the easternmost zone of Almería (Campo de Tabernas); north-eastern zone of Jaen (Cazorla, Segura and Las Villas mountains); the Guadalquivir Valley in the farmlands around Cordoba, descending to the area between the Antequera depression (Malaga), the Sierra de Loja and the Granada depression; and finally, northern Huelva province (Sierra de Aracena). With regard to levels of significance for this month, it is worth noting the figure of 92% for non-significant stations (the highest all winter), compared to 8% of positive significant stations.

As observed when analysing the months of December, January and February, the general trend in winter is towards a slight increase in temperatures, with some specific areas of decline, and generally very temperate winters. After several studies, numerous researchers have indicated that the temporal evolution of these temperature trends may be largely due to the influence of the North Atlantic Oscillation (Beranova and Huth 2007; Rodriguez-Fonseca and Rodriguez-Puebla 2010; Lopez-Moreno et al. 2011; Sihag et al. 2015).

In early spring, there is a clear rise in temperatures in the whole territory and a notable absence of negative trends. 97% and 90% of stations in March and April and 100% in May have a positive slope, of which 63%, 56% and 83%, respectively, are statistically significant. May is the month with the highest number of significant stations in the whole year. However, Andalusia is not the only territory in Spain to show these significant positive trends (Ordóñez 2008; Brunet et al. 2009); this increase has also been registered in other studies such as those of Sigro (2004) in Catalonia; Morales et al. (2005) and Del Rio et al. (2009) in Castile-Leon; and Cruz and Lage (2006) in Galicia.

The general trend in March is a rise of 0.15 – 0.3 °C/decade, with a gradual increase in inland areas, mainly in eastern Andalusia (Sierra Morena, Guadalquivir Valley and the Subbética mountain ranges), at intervals of 0.3 – 0.45 °C/decade to a maximum of 0.98 °C/decade in the north-easternmost part of Jaen province (Cazorla, Segura and Las Villas mountains). Other maximums – although somewhat more moderate – of 0.76 °C/decade can be found in the Andarax Valley (Almería province) as it crosses the Sierra Nevada, and in the Sierra de Aracena (northern Huelva province). Nearer the coastal zones, this rise is increasingly moderated by the influence of the sea and is less than 0.15 °C/decade at some points of the coastline, mainly in the provinces of Huelva, Malaga and Granada.

April is characterised by a general rise in temperature, although as in March, the warmest areas are found in eastern Andalusia. The greatest increase occurs in areas of the interior (Sierra Morena, Guadalquivir Valley and the Subbética mountain

ranges), with intervals of $0.6\text{ }^{\circ}\text{C}$ – $0.75\text{ }^{\circ}\text{C}/\text{decade}$, reaching a maximum of $0.8\text{ }^{\circ}\text{C}$ and $1\text{ }^{\circ}\text{C}/\text{decade}$ in the north-easternmost part of Jaen province (Cazorla, Segura and Las Villas mountains) in the Guadalquivir Valley between Sierra Mágina and Sierra de Jabalcuz; in Malaga province in an area between the Antequera depression and the boundary with Granada province; and in the north of Huelva province (Sierra de Aracena). Areas with a coastal influence have registered increases that are more moderate than in inland areas but nonetheless higher than in March, revealing the smallest rises of $0.2\text{ }^{\circ}\text{C}/\text{decade}$, mainly in some points in the provinces of Huelva, Malaga and Granada.

May had the highest temperature increases in the whole year, with maximum values between $0.7\text{ }^{\circ}\text{C}$ and $0.95\text{ }^{\circ}\text{C}/\text{decade}$, which are particularly pronounced in the eastern half of Andalusia where most of the territory has values of $0.95\text{ }^{\circ}\text{C}/\text{decade}$. Geographically, the areas with the greatest increases are the Subbética and Penibética mountain ranges and part of the Guadalquivir Valley to the south of the provinces of Cordoba and Seville, and the north of Cadiz province. Lesser increases of $0.26\text{ }^{\circ}\text{C}/\text{decade}$ can be seen in the area to the northeast of Jaen province, in Seville province, between the Sierra Morena and the Guadalquivir Valley, and to the southeast of Huelva province. This downward trend is also evident in areas with a coastal influence, where the temperature gradient is between $0.4\text{ }^{\circ}\text{C}$ and $0.26\text{ }^{\circ}\text{C}/\text{decade}$ at some points of the coast of Almería, Granada and Malaga. May had the highest percentage of significant positive stations (83%), implying that the whole of Andalusia is undergoing a significant increase in temperature. This very high percentage is followed by June and July with 81% and 69% of significant positive stations, respectively.

Summer follows the same pattern as spring with a sustained rise in temperatures and a high percentage of significant stations with a positive trend. July and August have somewhat more instability, with some stations (6% and 8%, respectively) showing a negative trend, although not significant.

Although June is very similar to May, with 100% of stations again showing a positive trend –81% of which are statistically significant, the temperature increase is now lower and has a gradient of $0.3\text{ }^{\circ}\text{C}$ – $0.16\text{ }^{\circ}\text{C}/\text{decade}$ in areas with a coastal influence, and around $0.6\text{ }^{\circ}\text{C}/\text{decade}$ in areas in the interior, with maximums between $0.6\text{ }^{\circ}\text{C}$ and $0.8\text{ }^{\circ}\text{C}$. However, the temperature increase falls to $0.2\text{ }^{\circ}\text{C}/\text{decade}$ in some points in the interior such as the north-eastern zone of Jaen province (Segura, Cazorla and Las Villas mountains), and the Guadalquivir Valley as it passes through the westernmost part of Cordoba province.

In July and August, the upward temperature trend continues throughout practically the whole of the study territory, although this increase is now more moderate than in June, with values in July of around $0.15\text{ }^{\circ}\text{C}$ – $0.3\text{ }^{\circ}\text{C}/\text{decade}$. There are maximums of $0.5\text{ }^{\circ}\text{C}/\text{decade}$ in some isolated areas, namely, from east to west: north of Almería province (Almanzora Valley); Granada province in the area between the Sierra Nevada and the coastal zone (Alpujarras); and the Sierra de Aracena in the north of Huelva province. Although some stations already show a negative trend these months, the percentage of statistically significant positive stations continues to be high at around 69%.

In August, the percentage of stations showing a significant positive trend falls to 50%, lower than in the previous months of May, June and July. Although the temperature trends continue to follow a general upward pattern, the increases are now more moderate, at around 0.05–0.3 °C/decade, gradually decreasing nearer the coast. Some points on the coast of Malaga province and to the south of Huelva province have decreases of –0.3 °C/decade.

During the summer months, the Atlantic coast of Andalusia, and particularly the coast of Huelva, can be observed to undergo a smaller rise in temperature than the rest of the territory; this is compared to the sharp increase in the Guadalquivir Valley, which serves as a conduit for the Atlantic influence thereby amplifying the characteristics of continentality moving inland.

The autumn months are characterised by a decline in significant stations with a positive trend. In September, there are more stations with negative than positive trends, around 60% compared to 40%, although the percentage of positive significant stations (46%) is far higher than the 6% for negative significant stations. The temperature map highlights a division in western Andalusia, which has negative general trends and a rate of decline of between 0.15 °C and 0.4 °C/decade, and three isolated zones with positive trends: the Sierra de Aracena (to the north of Huelva province), the Guadalquivir Valley in Seville province and one zone on the coast of Malaga. Eastern Andalusia is warmer and shows an upward temperature trend with increases of around 0.15 °C/decade, reaching a maximum peak of 0.4 °C/decade on the coast of Almería province.

In comparison to the other autumn months, October has the highest percentage of stations with a positive trend, 81%, while 14% have a negative trend. However, only 20% of the positive stations are significant and tend to be distributed in the eastern half of Andalusia, mainly in the provinces of Jaen, Granada and Almería. This month is warmer than September and has a mainly positive temperature trend of between –0.15 °C and +0.3 °C/decade in most of the territory, with the sharpest increases observed in the Guadalquivir Valley, with maximums of between 0.3 °C and 0.48 °C/decade. The sharpest declines of –0.4 °C/decade can be seen in very specific areas like the central south-eastern quadrant of Huelva province and a small area in the north of Cordoba province.

In November, the temperatures once again begin to fall (44% of stations with a negative trend), although there is still a predominance of positive trends (54%), which have the highest percentage of significance: 12% compared to 2% for the total significant stations. Negative trends of 0.15–0.3 °C/decade can be seen at several points throughout Andalusia, which from east to west are north of Almería province; a small area in the centre of Jaen province; the Alhama, Tejada and Almijara mountains (boundary with the provinces of Granada and Malaga); north of the provinces of Cordoba and Seville; and all of Huelva province with the exception of the Sierra de Aracena to the north.

Finally, the spatial pattern of annual temperature trends shows that 92% of the stations are positive, 87% are statistically significant, and there are no significant negative stations (Fig. 7). A generalised rise in temperatures can therefore be seen throughout the territory, with values of 0.15–0.3 °C/decade in the entire coastal zone

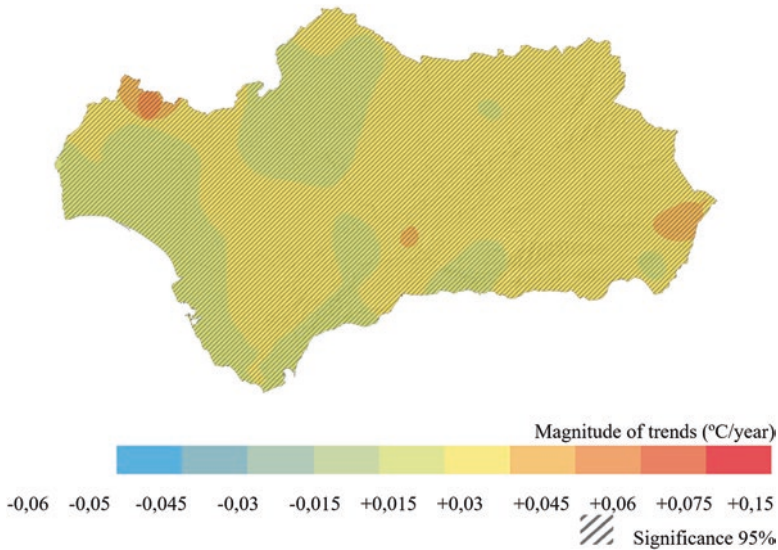


Fig. 7 Spatial distribution of temperature trends (°C/year) at the seasonal level. Magnitude of the trends (°C/year)

of western Andalusia (from Huelva to Malaga) and 0.3–0.45 °C/decade in practically all of eastern Andalusia and areas of the interior of the Guadalquivir Valley, in the area around Seville and Cadiz and in the Sierra de Aracena (Huelva). Some temperature peaks of over 0.45 °C/decade also occur in specific areas of Andalusia such as the south-easternmost part of Almería, northern Malaga and Sierra de Aracena (Huelva), which notably reaches a maximum of 0.8 °C/decade. Our results agree with numerous studies on the Iberian Peninsula which estimated an increase within the range of our values (Pausas 2004; Brunet et al. 2009 Brunet et al. 2010; Castro-Diez et al. 2007; Ileana and Castro-Diez 2010; Varma et al. 2017).

3.2 Bioclimatic Analysis

The analysis of the climatic and bioclimatic parameters reveals the following: 1) most of the territory sampled has a period of vegetative activity (PAV) of 12 months and thus undergoes no paralysis due to cold. Paralysis due to cold is understood as when the mean monthly temperature falls below 7.5 °C (Montero Burgos and Gonzalez Rebollar 1983), coinciding exactly with the territories more to the south and southwest of Jaen province, which is dominated by olive cultivation. This area has a predominantly thermo-mediterranean thermotype with an $I_t/I_{tcm} = 346$ and a dry ombrotpe with values of $I_{om} = 2.81$ and $I_{cm} = 19.36$. Places with a PAV of 8–9 months are dominant in the northwest of Jaen province and Granada, with the particularity that both territories have an upper mesomediterranean thermotype, with $I_t/I_{tcm} = 264.5$ and an I_{cm} (mean value of I_c) = 19.43. However, due to the

screening effect of the Segura, Las Villas and Cazorla mountains against storms, the value of I_{om} (mean value of I_o) = 4.42, so the stations tend to have a very high I_o .

The supramediterranean thermotype is highly under-represented as it contains very few areas of olive cultivation. These areas have 4–6 months of frost, so can be considered unproductive, and trees may even die due to extremely low temperatures. This occurred in 2005, when there were a very high number of days with temperatures below $-10\text{ }^{\circ}\text{C}$, so all the crops that were not at their bioclimatic optimum froze, as occurs in upper mesomediterranean and supramediterranean areas and even in enclosed valleys when the territory behaves as upper mesomediterranean or supramediterranean due to thermal inversion. Table 1 shows there are stations with 10–11 months of PAV in the lower mesomediterranean thermotype, which occupies a large part of Jaén and Cordoba provinces, with values of $I_{om} = 3.23$, $I_{cm} = 18.82$ and $I_t/I_{cm} = 304$.

The interpretation of I_{s2} is of particular interest in this analysis of the bioclimatic parameters that affect agriculture, and particularly olive cultivation. It has low values compared to I_{s3} , which can be explained by the rains in June, with compensation in stations where I_{s3} is very high compared to I_{s2} , thus reducing water stress. Evidently, the higher the I_{s3}/I_{s2} quotient, the greater the compensation, although this does not imply that the water stress disappears, as there may be abundant rains in winter and spring but very scarce in June, proving insufficient to offset the deficit in July and August. For example, the Santiago-Pontones station has rainfall of 1148, $I_{s2} = 0.27$ and $I_{s3} = 0.71$, and a I_{s3}/I_{s2} ratio = 2.62, compared to the Guadalmena Reservoir with $I_{s2} = 0.37$ and $I_{s3} = 0.55$ and a I_{s3}/I_{s2} ratio = 1.48. It is important in these situations to consider another parameter of vital importance for crop management: ETP (potential evapotranspiration) and RC (soil water retention capacity), which, as noted by Cano-Ortiz et al. (2014), essentially depends on the texture, structure, organic matter and vegetation cover of the soil. (Photograph 1)

3.3 Analysis of Vegetation Cover

Until 1970, olive cultivation in Spain followed traditional lines. However, the technology revolution has enabled the implementation of a “new olive cultivation” that has persisted until the present day and receives widespread economic and social approval. It has led to an excessive use of pesticides, herbicides and phytosanitary products and had a serious environmental impact that has occasionally produced treatment-resistant insects and plants, without bringing any substantial improvement in the local inhabitants’ standard of living. It has been demonstrated that the cost of using these chemical products equals or exceeds the economic advantage gained by this treatment, even before taking into account the added environmental cost, which is further aggravated by climate change. A bioclimatic treatment for territorial ordination is therefore necessary.

Sustainability can be understood as the capacity to endure over time without detriment to natural (soil, diversity, fauna) and cultural resources, applying management methods that enable constant yields and renewal. In fact, the aim of farmers is

Table 1 Bioclimatic analysis for meteorological stations with domain of olive cultivation

Station	Alt	Tm	Tmax	Tmin	P	Io	Is2	Is3	Is2/Is3	Ic	It/Itc	PAV
Andújar	212	18.1	28.3	9.2	463.9	2.13	0.17	0.28	1.66	19.1	371	12
Arjona	410	17.1	27.5	8.0	619.9	2.97	0.25	0.41	1.64	19.5	338	12
Torredonjimeno	591	16.6	27.5	7.8	648.9	3.25	0.33	0.55	1.66	19.7	329	12
Bailén	369	17.9	29.1	9.0	581.7	2.70	0.14	0.32	2.34	20.1	369	12
Jaén	510	16.9	27.4	8.6	578.3	2.85	0.20	0.40	2.00	18.8	345	12
Linares	419	17.1	26.7	8.4	642.2	3.12	0.21	0.52	2.48	18.3	339	12
La Rambla	200	15.6	25.5	7.6	527.4	2.81	0.30	0.41	1.37	17.9	308	12
Beas de Segura	577	17.1	28.3	8.3	658.0	3.20	0.30	0.58	1.93	19.7	322	12
Ubrique	332	16.3	23.8	10.2	1114.9	5.60	0.43	0.82	1.90	13.7	363	12
Jeréz de la Frontera –S. José	140	17.4	25.1	10.9	1018.2	4.87	0.20	0.41	2.05	14.2	392	12
El Campillo-Zumajo	340	16.5	26.2	9.1	802.0	4.05	0.22	0.52	2.36	17.1	347	12
Santa Barbara de la Casa	308	16.6	25.8	9.3	775.2	3.89	0.11	0.55	5.04	16.5	352	12
Posadas	88	17.7	27.4	9.0	686.9	3.23	0.30	0.50	1.66	18.4	359	12
Navas de la Concepción	434	14.3	22.6	7.1	719.7	4.19	0.26	0.63	2.42	15.5	284	12
Montoro	195	17.5	27.3	9.2	572.4	2.72	0.19	0.37	1.94	18.1	360	12
Pujerra	530	15.8	29.9	11.3	1094.7	5.77	0.60	0.63	1.05	16.1	331	12
Grazalema	823	15.3	25.2	7.5	1962.2	10.6	0.25	0.76	0.34	17.7	304	11
Baena	463	16.6	28.0	7.3	529.5	2.60	0.25	0.39	1.56	20.7	326	11
Úbeda	748	15.9	25.9	7.5	579.6	3.03	0.22	0.44	2.00	18.4	313	11
Hinojosa del Duque	549	14.8	25.1	6.7	476.9	2.68	0.42	0.68	1.61	18.4	284	11
Castro del Río	210	16.0	26.1	6.7	470.7	2.45	0.17	0.36	2.12	20.1	305	11
Granada-Aeropuerto	570	14.8	24.4	6.8	357.2	2.01	0.18	0.37	2.05	17.6	285	11
Cabra del Santo Cristo	938	14.3	24.3	6.6	449.9	2.62	0.35	0.65	1.86	17.7	275	10
Pantano Cubillas	630	15.3	25.3	7.2	525.5	2.86	0.19	0.47	2.47	18.1	297	10

(continued)

Table 1 (continued)

Station	Alt	Tm	Tmax	Tmin	P	Io	Is2	Is3	Is2/Is3	Ic	Iu/Iuc	PAV
Cazorla ICONA	885	14.1	25.5	5.5	792.4	4.68	0.32	0.74	2.31	19.2	257	9
Antequera-EI Torcal	1218	12.6	24.8	4.8	783.7	5.18	0.17	0.26	1.52	20.0	221	9
Guadix	915	14.1	24.4	6.1	320.8	1.89	0.32	0.54	1.68	18.3	264	9
Atarfe	598	13.5	24.8	5.4	401.8	2.48	0.10	0.36	2.00	19.4	243	9
Ronda-Los Quejigares	1180	10.8	22.1	3.9	1498.2	5.78	1.00	1.24	1.24	18.2	176	7
Siles-Acebeas	1320	10.7	22.2	3.4	1166.9	9.08	1.26	2.25	1.78	18.7	70.0	7

Note: *Alt* Altitude a.s.l., *Tm* Mean temperature, *Tmax* Maximum temperature, *Tmin* Minimum temperature, *P* Precipitation, *Bio* Bioclimatic indices: *Io* Ombrothermic index, *Is2* and *Is3* Summer ombrothermic indices, *Ic* Continentality index (annual thermal interval), *Iu/Iuc* Thermicity index/compensated thermicity index, *PAV* Period of Vegetative Activity.



Photograph 1 Image of the results of an agricultural plan that does not take bioclimatology into account

to abandon the criteria of maximum yield per hectare and improve the productivity of their business by managing the productive factors more effectively.

The practice of sustained olive cultivation triggers far-reaching changes, in many cases leading to a loss of biodiversity, which is now occurring on a massive scale. Until 1995, around 120 plant communities and almost 1000 plant species had been described in olive-growing areas, so olives cannot be viewed merely as another industrial crop (Cano et al. 2004; Meena et al. 2017). Olive groves are genuine ecosystems that are also home to a rich and profuse flora, some hundred or so vertebrates and a large number of invertebrate species. Another consequence of the loss of floristic biodiversity is a loss of fauna. Biological control mechanisms become affected, leading to outbreaks of insect plagues. The decline in floristic diversity is due among other causes to unsuitable tilling practices, loss of vegetation cover, lack of organic fertilisers, use of rollers (soil compaction), indiscriminate application of herbicides and, as a result, an increase in erosion and soil loss. It is therefore recommended to use agricultural practices that are not aggressive with the environment, including traditional and sustainable cultivation methods at least for marginal areas. For non-marginal high-yield areas, it is advisable to apply a mixed cultivation approach using both techniques, that is, planning the cultivation on an ecological/botanical basis while applying the “new olive cultivation” techniques which appeared in 1970, provided their administration is strictly controlled in order to minimise the environmental impact.

A crop is unproductive when the cost of production is equal to or higher than the income received by the farmer. This cost includes all the activities necessary for

production, plus the environmental cost, which in most cases is not quantifiable. A crop whose cost is higher than the income it generates is considered unproductive, and even apparently productive crops using modern technology should be considered unproductive if the environmental cost is too high. Excessively high costs must be understood as any situation in which cultivation causes irreversible losses to a certain resource. However, cases of “contamination” may be permitted where the system is itself capable of self-regenerating; hence, the expression “the polluter pays” is incorrect as there may be situations involving the loss of resources on which it is impossible to place a price due to their high ecological and natural value. Cultivation at the expense of irreversible losses to soil and biodiversity and the contamination of water and land is therefore not a valid option. These issues must be considered essential when considering the implantation of a crop. All the situations described in these previous cases should be subjected to a technical agricultural reform by implementing an agricultural plan that ensures the olive orchard is maintained according to the principles listed above and is productive to the extent that crop yields may even increase. The crop may also be of better quality, as quantity and quality are compatible. This implies considering the bioclimatic aspects of the territory.

Cultivation must be planned based on respect for the environment and the optimisation of the crop in question, as all crops have an ecological and bioclimatic optimum in which the potential impact on the environment is reduced. All this requires the creation of specific agricultural and nonstandardised models that will lead to maintaining certain crops in some cases and replacing them with other more productive and less contaminating alternatives in others.

This work is grounded in the knowledge of the climate, bioclimate and wild flora as bioindicators, based on their thorough study and comparison with numerous soil analyses carried out in the same location. We can apply important treatments that offer an indispensable tool for managing different types of vegetation cover so as to maximise their benefits and encourage their use by identifying and understanding the significance of these bioindicators.

We have therefore studied the plant associations present not only from the phytosociological point of view but giving importance to soil factors and observing the correlations with the floristic-phytosociological component. We have considered the climate factors prevailing in the study areas, as they play a key role in the presence of these associations.

Plant communities on cultivated land tend to be of two types: first the “matorral” or scrub, which acts as a focus for biodiversity and an element for controlling erosion, thereby reducing soil loss by forming part of boundaries or verges, whereas the purpose of the second type, the “herbazal” or grassland, is to reduce erosion. These grasslands may be of a very different nature depending on the soil and climate characteristics. However, all plant communities can be said to act as vegetation cover and play a role in controlling erosion.

Tilling has advantages and drawbacks. Tilling is totally eliminated in this non-tilling system, and the weeds are controlled exclusively by herbicides, which are normally applied in autumn before or immediately after the emergence of the weeds. This type of non-tilling cultivation is often poorly managed. There are greater water

losses due to run-off and seepage decreases, and erosion increases as there are no natural barriers to impede run-offs. It is therefore essential to manage the weeds to combat soil loss, which in turn requires soil management to mitigate some of the problems affecting the olive orchard, increase the yield and reduce the economic and environmental cost.

Other systems include mixed techniques such as semi-tilling and minimal tilling. This latter consists of tilling once or twice a year at a depth of around 5 cm in order to break the surface crust, then applying herbicides to the whole area following the non-tilling criteria. Bare soil management systems and herbicides can also be used. As we described earlier, the problem is erosion and water loss, along with loss of organic matter.

Living vegetation cover can thus be said to be beneficial. The use of vegetation cover is not new, as this technique was known to the Romans in the cultivation of vineyards and has been studied and applied since the early twentieth century. There are several types of vegetation cover: natural, artificial and seminatural. It can also be classified as inert or living cover.

Types of inert vegetation cover currently in use include shredded pruning and even straw for the purpose of increasing soil organic matter and nitrogen content which improves water retention capacity and soil structure. In general, the pruning should not be mixed with the tilled soil but left on the surface, as their continued presence on the soil ensures prolonged protection. In this case, weeds are usually controlled by herbicides. Stones are another type of inert vegetation cover that can be used, a practice that may be applied to soils with a high percentage of stoniness to protect from erosion, as the stones receive the impact of the raindrops and allow the water to seep through the soil. It is beneficial to place the stones in the lanes between the rows. Weeds must be controlled with herbicides when this technique is used.

Another category of living vegetation cover worth mentioning is spontaneous vegetation cover (natural cover), sown vegetation cover (artificial cover) and even mixed vegetation cover or a combination of spontaneous cover and sowing with gramineous or leguminous species. The difference must be observed between vegetation cover with herbaceous species and with woody and bulb species; these latter two types are undesirable as they compete strongly with the crop (Cano-Ortiz 2016). In the case of spontaneous vegetation cover, the weeds are left to emerge spontaneously (with no prior treatment) following two options: (1) allowing the vegetation cover to grow and then practising chemical or mechanical mowing; this latter is a promising technique that is not widely used except in organic crops and has advantages and drawbacks. The cover must be rigorously controlled and managed by expert staff to prevent it from becoming harmful rather than beneficial. (2) Weeds can be allowed to develop but selectively, that is, by directing or selecting the cover towards grasses, for example. This is achieved by using selective herbicides that eliminate broadleaved species (Dicotyledoneae), thus permitting the spontaneous entry of species from the genera *Lolium*, *Bromus* and *Hordeum*, and subsequently using chemical and mechanical mowing; in both cases, areas must be left that enable the seed bank to be maintained in the soil.

The alternative to natural or spontaneous vegetation is to sow one or several species of grasses such as oats, barley or rye at a dose of 50–60 kg/hectare, followed by surface raking. In cases where the slope does not allow, the best policy is to use natural cover with grasses, corrected by broadcast sowing of other grass species. Grass species are favoured because they correct erosion and contain a high quantity of lignin and humify slowly, gradually contributing small annual amounts of humus that are essential for the formation of the humus-clay complex. However, vegetation cover with Leguminosae can be achieved by sowing *Vicia*, *Trifolium*, *Lupinus* and *Medicago* which has both advantages and disadvantages. The main advantage is that the Leguminosae contribute nitrogen to the soil, leading to savings in nitrogen fertilisers; but they are rapidly absorbed into the soil, which becomes denuded in autumn and exposed to erosion. The most effective procedure is therefore to sow a mixture of leguminous and gramineous species and practice chemical or mechanical sowing before they begin to compete for water and nutrients. Small islands of terrain should be left and treated in order to ensure the maintenance of the seed bank in the soil.

Cultivation and erosion are closely related, as the extent of the erosion of the plot depends on the cultivation techniques used. Tilling is a traditional but aggressive technique, as experimentation has revealed soil losses of 20–40 tons per hectare per year, as opposed to 2.5 tons per hectare per year in plots with interspersed vegetation bands. Tilling is a long-established technique applied with the aim of increasing the availability of water by cultivating and controlling weeds. It often requires ploughing the plot several times, a practice that is counter-productive in olive orchards as it does not increase water availability but decreases the capacity of water to filter through the soil due to the presence of what are known as “*suelas de labor*”, or heavily compacted agricultural soils caused by the repeated transit of heavy machinery.

Tilling leads to disaggregation and loss of structure, gases and organic matter. It has been demonstrated that an olive grove tilled for 10 years suffers a 30% loss of organic matter, which requires the incorporation of high doses of fertilisers to achieve acceptable yield levels. (Photograph 2)

Other effects of tilling include increased water loss through transpiration, implying a greater loss of nutrients and particularly soil loss. Erosion is aggravated not only by tilling but by specific features of the plot such as the length and gradient of the hillside, making it inadvisable to cultivate this type of plot. Erosion can be reduced through the following measures: (1) improving the filtration of water in the soil, (2) reducing the length of the run-off, (3) implementing protection measures for the soil surface and (4) carrying out conservation work. Among other conservation measures, we propose the use of organic fertilisers and living vegetation cover and suggest maintaining the herbaceous plant associations currently existing in the cultivation area.

The chemical control of weeds has caused phytocoenoses or communities of herbaceous plants to modify their floristic combination, since the elimination of certain species encourages the spread of many other invasive species. This is often due to ignorance about the use of herbicides, as chemical compounds have been



Photograph 2 Image of sustainable agriculture: a woodland pasture with olive trees and a cover of leguminous plants and grasses (Finca Peña Flor)

applied that are unsuitable for the species in question. Care should be taken when stating that all flora growing in areas of olive cultivation is harmful and therefore our enemy. Evidently, this cannot be seen as a battle between humans and what are described as “weeds”, so the best policy is to identify these weeds and understand their botanical and technological behaviour in order to establish control mechanisms. (Photograph 3)

3.4 Phytosociological Analysis of Vegetation Cover in Southern Spain

The study of grassland plant communities in rainfed crops has revealed ten different types of floristic and ecological composition. These communities (plant associations) depend on the soil factor, ombrotype and thermotype, and act as an essential element in controlling erosion and water loss. They are therefore essential for combating the impacts of climate change on agriculture. These associations are *Linario spartea*-*Raphanetum raphanistri* (LR), *Carduo bourgeani*-*Silybetum mariani* (CS), *Bromo scoparii*-*Hordeetum leporine* (BH), *Anacyclus clavatus*-*Hordeetum leporini* (AcH), *Trifolio cherleri*-*Taeniantheretum capitis-medusae* (TT), *Urtico urentis*-*Malvetum neglectae* (UM), *Fedio cornucopiae*-*Sinapietum albae* (FS), *Resedo albae*-*Chrysanthemetum coronarii* (RChr), *Papaveri rhoeadis*-*Diplotaxietum virgatae* (PD) and *Trifolio cherleri*-*Plantaginetum bellardii* (TP) (Table 2).



Photograph 3 Ecological fertilisation with fertilisers from crop residues and manure

I to V are synthetic values (Braun-Blanquet 1979). Values I to V represent the lowest and highest presence of a species in the phytosociological analytical table.

The relation between soil and vegetation is very important for plant succession, which attains its climax through the vegetation dynamic; this in turn depends on the climate and soil where it is located. A regressive succession occurs if the soil is highly degraded or has suffered powerful erosion processes (Valle 1984) either due to a loss of vegetation cover or to unsuitable cultivation techniques. In the case of intense degradation, the final stage may even be different from the ancestral optimum. This results in high water losses, and in territories with a predominance of olive cultivation such as the vast Guadalquivir Valley, positive temperature trends lead to increased ETP which threatens the crop yield. Our study on the herbaceous associations in Spain covers the following vegetation series: *Pyro bourgaeanae-Quercus rotundifoliae sigmetum*, *Rhamnus oleoidis-Quercus rotundifoliae sigmetum*, *Myrica communis-Quercus rotundifoliae sigmetum*, *Paeonia coriacea-Quercus rotundifoliae sigmetum* and *Viburno tini-Quercus fagineae sigmetum*.

The association *Carduo bourgeani-Silybum mariani* was originally described for the central Spanish plateau and has an extensive distribution. Its optimum is located in the mesomediterranean thermotype and although it can be found in the thermo- and supramediterranean thermotype. It grows on dumps, in disturbed and nitrified soils, and may even withstand a degree of temporary waterlogging. It contacts with the nitrophilous therophytic grasslands of *Hordeion leporine* (hare barley) and *Malvenion neglectae* (mallow), and in cases of prolonged waterlogging is replaced by the highly nitrophilous grasslands of *Galio aparines-Conietum maculati*. This is tall dense grassland dominated by *Silybum marianum* (milk thistle),

Table 2 Synthetic phytosociological table for some of the associations studied

Characteristic species	AcH	BH	CS	FS	LR	PD	RC	UM	TP	TT
<i>Plantago lagopus</i> L.	II	II								III
<i>Bromus hordeaceus</i> L.	II	III								V
<i>Echium plantagineum</i> L.		II	II				II			II
<i>Bromus diandrus</i> Roth s.l.	III	II	II	IV	II	II	IV	III		
<i>Medicago polymorpha</i> L.	III	II		III	III	III	II	II		
<i>Calendula arvensis</i> L.	III	II		III	III	IV	II	II		
<i>Malva neglecta</i> Wallr.	II		II	III	II	II	II	IV		
<i>Erodium malacoides</i> (L.) L'HŪr.	III			III	II	III	III	II		
<i>Hordeum leporinum</i> Link	V	V	III		II			II		
<i>Sinapis alba</i> ssp. <i>mairei</i> (H. Lindb.) Mairei	IV		II	V			III	II		
<i>Carduus bourgaeanus</i> Boiss. and Reuter		II	II				II			
<i>Erodium moschatum</i> (L.) L'HŪr.		III			II			II		
<i>Diploaxis catholica</i> (L.) DC.			II			IV		III		
<i>Malva parviflora</i> L.			II				II	II		
<i>Silybum marianum</i> (L.) Gaertner			V	II			III			
<i>Raphanus raphanistrum</i> L.		II			V					
<i>Chrysanthemum coronarium</i> L.			II				V			
<i>Lactuca serriola</i> L.			II				III			
<i>Anacyclus clavatus</i> (Desf.) Pers.	III	II								
<i>Filago lutescens</i> Jordan	II									
<i>Avena barbata</i> Potter		II								
<i>Geranium molle</i> L.		III								
<i>Carduus pycnocephalus</i> L.			II							
<i>Carthamus lanatus</i> L.			II							
<i>Erodium ciconium</i> (L.) L'HŪr.			II							
<i>Onopordum nervosum</i> Boiss.			II							
<i>Orlaya daucooides</i> (L.) Greuter			II							
<i>Scolymus maculatus</i> L.			II							
<i>Sisymbrium officinale</i> (L.) Scop.			II							
<i>Avena sterilis</i> L.				II			III			
<i>Lamium amplexicaule</i> L.				II		II				
<i>Sonchus oleraceus</i> L.				II		II				
<i>Carduus tenuiflorus</i> Curtis				II						
<i>Galium verrucosum</i> Hudson				II						
<i>Geranium rotundifolium</i> L.				II						
<i>Bromus rigidus</i> Roth					II					II
<i>Lolium temulentum</i> L.					II	II				
<i>Anagallis coerulea</i> Schreber					II					
<i>Anthemis arvensis</i> L.					II					
<i>Chrysanthemum segetum</i> L.					II					
<i>Linaria spartea</i> (L.) Willd.					II					
<i>Stellaria media</i> (L.) Vill.						II				

(continued)

Table 2 (continued)

Characteristic species	AcH	BH	CS	FS	LR	PD	RC	UM	TP	TT
<i>Capsella bursa-pastoris</i> (L.) Medicus						II				
<i>Rapistrum rugosum</i> (L.) All.							II			
<i>Leontodon longirostris</i> (Finch & P.D. Sell) Talavera in Valdés & al.									III	IV
<i>Avena barbata</i> Pott ex Link ssp. <i>lusitanica</i> (Tab. Mor.) Romero Zarco									III	III
<i>Trifolium cherleri</i> L.									III	III
<i>Vulpia myuros</i> (L.) Gmelin									II	III
<i>Brachypodium distachyon</i> (L.) Beauv.									II	II
<i>Ornithopus compressus</i> L.									II	II
<i>Plantago coronopus</i> L.									II	II
<i>Plantago bellardii</i> All.									V	
<i>Xolantha guttata</i> (L.) Raf.									V	
<i>Hypochoeris achyrophorus</i> L.									III	
<i>Trifolium arvense</i> L.									II	
<i>Brassica barrelieri</i> (L.) Janka										II
<i>Bromus rubens</i> L.										II
<i>Taeniatherum caput-medusae</i> (L.) Nevski										III

**Photograph 4** The associations *Carduo bourgaeani-Silybetum mariani* and *Urtico urentis-Malvetum neglectae*

growing on dumps and in disturbed soils. It is found on soils with a mean pH of 8.189, CEC (meq/100 g) of 11.877, OOM (%) of 1.683 and a sandy texture. Some characteristic species are milk thistle, *Carduus bourgaeanus* (Italian plumeless thistle), *Carduus pycnocephalus* (Italian thistle), *Onopordum nervosum* (cotton thistle), *Scolymus maculatus* (spotted golden thistle) and *Orlaya daucoides* (flat-fruited *Orlaya*). (Photograph 4)

Mallow plant communities growing in olive groves are represented by the associations of *Urtico urentis-Malvetum neglectae*, with variable nitrophilous preferences, and presided by species such as *Malva neglecta* (dwarf mallow), *Malva parviflora* (cheeseweed) and *Urtica urens* (small nettle). It is found on manure heaps, abandoned cultivated land and land that has been overfertilised with

nitrogenated compounds. This association occurs in rings around the base of olive trees. It is widely distributed in the mid-European Atlantic Montane and Mediterranean areas in the mesomediterranean thermotype and may extend as far as the supramediterranean. This community is dominated by dwarf mallow or cheeseweed and sometimes by both, as the two species may coexist. There is a lesser presence of small nettle. Although the samples reveal a predominance of cheeseweed, which could be ascribed to *Sisymbrio-Malvetum parviflorae*, there are no ecological, floristic or biogeographical differences to support this syntaxon, so it could be synonymised to *Urtico urentis-Malvetum neglectae*, an association with a minimum area of 2 m² and a species richness of 7–16 species. The soil analysis reveals lower values for the soil parameters than for *Resedo-Chrysantemetum coronari*. However, the exchange capacity is 10.889 meq/100 g with a high value of assimilable phosphorus of 36.190 ppm, a sandy texture, 1.698 meq/100 g of exchangeable Mg, 1.266 meq/100 g of exchangeable K, an OOM of 1.904% and total nitrogen of 0.179%. The data identify communities of *Malva* as bioindicators of soil nitrogen content and of certain mineral ions such as K, Mg and P. Some characteristic species are small nettle, dwarf mallow, cheeseweed and *Diplotaxis catholica* (Table 3).

Galactito tomentosae-Vulpium membranaceae is a community with high cover and a subnitrophilous and thermophilous character. It develops in late spring and disappears in early summer and is dominated by the species *Galactites tomentosa*, *Vulpia geniculata*, *Andryala integrifolia*, *Leontodon taraxacoides* and *Echium plantagineum*. It tends to be present in soils with the following mean values: pH of 6.19; CEC (meq/100 g) of 11.109; OOM (%) of 1.293 and P (ppm) of 7.3. It has a sandy-silty texture and medium RC. Some characteristic species are *G. tomentosa*, *V. geniculata*, *A. integrifolia*, *L. taraxacoides*, *E. plantagineum*, *Gaudinia fragilis*, *Crepis vesicaria* and *Chamaemelum mixtum*.

The grasslands of *Trifolio cherleri-Taeniatherum capitis-medusae* are found on abandoned cultivated lands and the verges of paths and have a subnitrophilous character. They have their optimum in the meso- and supramediterranean belt in the Carpetan-Iberian-Leonese sector and are also very well represented in the Mariánico-Monchiquensian and Toledano-Tagano sectors of the Lusitanian-Extremaduran subprovince. Towards more nitrified environments, these grasslands contact with communities of *Hordeum leporinum*. They are located in soils with the following mean values: pH of 6.13; OOM (%) of 1.45; CEC (meq/100 g) of 9.63; P (ppm) of 5.11; they have a mainly sandy texture as a result of their low RC. These soil values are very similar to those of *Trifolio cherleri-Plantagnetum bellardii*, and there is a frequent presence of the companion species of this latter association, pointing to the strong dynamic between them. Some characteristic species are *Taeniatherum caput-medusae*, *Avena barbata* sp. *lusitanica*, *Trifolium cherleri*, *Plantago lagopus*, *E. plantagineum* and *Bromus rubens*.

Very similar to the subnitrophilous grasslands is the association *Plantagini bellardii-Aegilopetum geniculatae*, which is typical of less ruderal environments than *Hordeion leporini*. It is generally found in olive groves that have been fertilised for extended periods and in shrubland clearings with lower nitrogen content than the communities of *Hordeion leporini*. The substrates are decarbonated marmoreal

Table 3 Soil parameters of the herbaceous communities in the study

	AcH	ArH	BH	LR	PD	ArP	ArChr	RChr	UM	PA	TT
CEC	15.365	9.131	10.544	6.661	14.304	10.869	12.328	11.68	10.889	10.54	9.63
OOM	1.541	1.56	1.667	0.75	1.02	1.803	1.622	1.574	1.904	1.8	1.458
Nt	0.115	0.102	0.133	0.064	0.09	0.14	0.105	0.129	0.179	0.136	0.084
Pa	9.789	13.957	15.4	4.824	15.35	14.722	26.9	20.95	36.19	5.605	5.111
Mgc	1.683	1.856	1.068	0.835	2.351	1.864	2.131	2.716	1.698	1.713	1.097
Kc	0.79	0.256	0.375	0.259	1.002	0.412	0.698	1.476	1.266	0.206	0.156
pF 15 atm	15.322	8.613	8.203	7.366	19.117	13.001	11.975	14.24	13.197	11.82	6.673
Tx arc	17.758	19.78	14.503	17.28	40.015	25.394	19.763	24.24	21.293	25.83	13.59
Tx ar	20.448	62.411	54.254	64.238	19.986	45.694	55.826	37.85	46.001	44.98	64.93
Tx lim	61.794	17.803	31.245	18.51	40	28.906	24.413	37.94	32.712	29.2	21.49
CE	0.355	0.209	0.122	0.211	0.286	0.162	0.193	0.491	0.565	0.105	0.049
pH	8.275	7.43	7.475	6.616	8.085	7.633	7.77	7.943	7.776	7.581	6.13

Note: CEC cation exchange capacity in meq/100 g, OOM oxidisable organic matter in %, Nt total nitrogen in %, Pa assimilable phosphorous in ppm, Mgc exchangeable magnesium in meq/100 g, Kc exchangeable potassium in meq/100 g, pF 15 atm pressure at 15 atmospheres (water retention capacity) in %, Tx arc clayey texture in %, Tx ar sandy texture in %, Tx lim silty texture in %, pH

AcH *Anacyclo clavati-Hordeetum leporini*, ArH *Anacyclo radiati-Hordeetum leporini*, BH *Bromo scoparii-Hordeetum leporini*, LR *Linario sparteae-Raphanetum raphanistris*, PD *Papaveri rhoeadis-Diploxietum virgatae*, ArP *Anacyclo radiati-Papaveretum rhoeadis*, ArChr *Anacyclo radiati-Chrysanthemum coronarii*, RChr *Resedo albae-Chrysanthemum coronarii*, UM *Urtico urentis-Malvetum neglectae*, PA *Plantagini bellardii-Aegilopetum geniculatae*, TT *Trifolio cherleri-Taeniattheretum capitis-medusae* (Cano-Ortiz 2007)

limestones with a close to neutral pH. The subnitrophilous grassland of *Aegilops geniculata* is differentiated from *Trifolio cherleri-Taeniatheretum capitis-medusae*, with a siliceous character, due to the presence of basophilic elements such as *Medicago minima*, *Atractylis cancellata*, *Polygala monspeliaca*, *Velezia rigida* and others. It is differentiated from *Medicago rigidulae-Aegilopetum geniculatae* as it includes siliceous elements such as *Plantago bellardii* and *Trifolium subterraneum*. We therefore propose the association *Plantago bellardii-Aegilopetum geniculatae*, which grows on decarbonated substrates and substrates with little sun in mesomediterranean thermotypes and dry subhumid ombrotypes. In sunny and warmer exposures, this grassland gives way to the community of *Aegilopo neglectae-Stipetum capensis*. It grows in all Lusitanian-Extremaduran calcareous sites (Portugal and Spain) within the series *Lonicero implexae-Quercu rotundifoliae sigmetum*. It is characterised by growing on soils with the following mean values: pH of 7.581, OOM (%) of 1.8 and CEC (meq/100 g) of 10.53; it has a mainly sandy texture. Some characteristic species are *Aegilops geniculata*, *Trifolium stellatum*, *M. minima*, *A. triuncialis* and *T. scabrum*. In all cases, the characteristic species have their soil optimum in the soil values obtained for each plant community.

The association of herbaceous therophytes with a spring phenology is represented by *Fedio cornucopiae-Sinapietum albae* and is present in newly tilled loamy soils used mainly for olive cultivation. It is distributed in the Betic region in the thermo- and mesomediterranean thermotype and reaches its optimum in the olive groves on farmlands in the Guadalquivir area, where it forms monospecific communities of *Sinapis alba* subsp. *mairei*, on soils with a silty-clayey texture. It can grow to heights of 1.70 m and attain coverage of 100%. We have studied the soil factors that condition the presence of this association, although these are not the only influence on the location of *Fedio-Sinapietum mairei*, as *Sinapis alba* subsp. *mairei* also responds to temperature. This explains why it is located in the area of *Paeonio-Quercetum rotundifolia*, a thermophilous variation with *Pistacia lentiscus*, and *Rhamno-Quercetum rotundifoliae*, a grassland association included in the thermophilous alliance *Cerintho majoris-Fedion cornucopiae* (Rivas-Martínez et al. 2001). The grassland of *Fedio-Sinapietum* appears relatively frequently in olive groves on gypsum loams. The soil salinity test reveals a mean value of 0.690 mmhos/cm, with a minimum value of 0.24 and a maximum of 2.60, compared to the mean value of 0.27 mmhos/cm, minimum of 0.20 and maximum of 0.37 for *Papaveri-Diplotaxietum virgatae*. It can therefore be said that *Fedio-Sinapietum mairei* requires soils with a greater salt content than *Papaveri-Diplotaxietum virgatae*. Some characteristic species are *Sinapis alba* subspecies *mairei*, *B. diandrus*, *M. polymorpha*, *Erodium malacoides*, *Calendula arvensis*, dwarf mallow and *Fedia cornucopiae*. (Photograph 5)

The nitrophilous communities dominated by *Hordeum leporinum* have their optimum in the meso- and supramediterranean thermotypes. The association *Bromo scoparii-Hordeetum leporini* has a therophytic character and a spring phenology and has been described for continentalised environments in central Spain (Rivas-Martínez 1978; Datta et al. 2017). It has the following catenal contacts: towards less nitrified and drier soils, it contacts with grasslands of *Taeniathero-Aegilopion*



Photograph 5 The associations *Fedio cornucopiae-Sinapietum albae* and *Bromo scoparii-Hordeetum leporini*

geniculatae, where there is more moisture, with grasslands of *Agrostion salmanticae*, and towards more nitrified zones, with grasslands of mallow. It grows in soils with the following mean values: pH of 7.47; OOM (%) of 1.667; CEC (meq/100 g) of 10.544; P (ppm) of 15.40, with a mainly sandy texture and a medium RC. Some characteristic species are *H. leporinum*, *Geranium molle*, *B. hordeaceus*, *Erodium moschatum*, *Raphanus raphanistrum*, *M. polymorpha* and *Plantago lagopus*. However, *H. leporinum* is a grass that also becomes dominant in the thermomediterranean thermotype where it shares an ecological niche with other differential species. The following have therefore been described in these latter territories: the association *Anacyclo radiati-Hordeetum leporini*; a western

thermo-mediterranean association frequent in ruderalised environments, on verges of paths, roadsides and near old houses and dumps where there is a predominance of *Anacyclus radiatus* and *H. leporinum*. It has been described for the centre-south of Portugal and southeast Andalusia (Spain) and is dominated by *H. leporinum* and *A. radiatus*. This latter species prefers neutral-basic soils and thermophilous environments and thus does not extend to the upper Guadalquivir but is limited to the south-western Iberian Peninsula (Rivas-Martínez 1978). It occurs in soils with the following mean values, pH of 7.430, CEC (meq/100 g) of 9.13, OOM (%) of 1.56 and P (ppm) of 13.957, with a mainly sandy texture and a medium RC. Some characteristic species are *H. leporinum*, *A. radiatus*, *Plantago lagopus*, *Echium plantagineum*, *Avena fatua*, *Hedypnois cretica* and *B. rigidus*.

The Guadalquivir (Hispalense sector) and Subbética territories are home to grassland of *H. leporinum* that belongs to the association *Anacyclo clavati-Hordeetum leporini*, which occurs on basic substrates with a pH over 8. These grasslands frequently contain basophilic species such as *M. minima*, *Sinapis alba* subsp. *maireri*, *Moricandia arvensis*, *Centaurea pullata* and *Plantago albicans*, absent from *Bromo scoparii-Hordeetum leporini*, described for the continentalised zones of the plateau. There is a frequent presence of *A. clavatus*, which, although it is indifferent in soil terms, prefers basic substrates, and an absence of *A. radiatus*, a thermophilous element that does not extend as far as the upper Guadalquivir. This association is perfectly differentiated from *Bromo scoparii-Hordeetum leporini* and *Anacyclo radiati-Hordeetum leporini* in the statistical analysis. The syntaxon is distributed in dry subhumid mesomediterranean areas in Betic territories and grows in the area of the series *Paeonio-Quercu rotundifoliae sigmetum* and *Viburno tini-Quercu fagineae sigmetum*, occupying soils with a high value of CEC 15.3, pH of over 8, OOM of 1.54 and with a sandy-silty, clayey-silty texture and hence a medium RC.

The association *Anacyclo radiati-Chrysanthemetum coronarii* is characteristic of ruderalised environments such as the verges of paths and roadsides in the south-west of the Iberian Peninsula. There is a presence of *A. radiatus* and *Chrysanthemum coronarium* var. *concolor*, absent from the association *Resedo albae-Chrysanthemetum coronarii*, a community described for the Levantine and Balearic territories. The grassland proposed by Cano-Ortiz et al. (2009) grows in Lusitanian-Extremaduran territories on pH-neutral substrates with a high content in organic matter. Rivas-Martínez (1978) published the *Anacyclo radiati-Hordeetum leporini* subassociation *Chrysanthemetosum coronarii* for cases where the grassland of *H. leporinum* in the southwest of the peninsula presents *Chrysanthemum coronarium* (Cano et al. 2017; Yadav et al. 2017).

The differences in soil and structure, coupled with the frequent presence of *Chrysanthemum coronarium* var. *discolor* and var. *concolor*, led us in previous studies to propose a change in status and to raise the subassociation *Chrysanthemetosum coronarii* to the rank of association. It is dynamically derived from *Anacyclo radiati-Hordeetum leporini*, from which it is differentiated floristically and ecologically, as the soils conducive to *Anacyclo-Chrysanthemetum* have higher mean values of CEC, OOM, assimilable P, K, etc. than the soils of the association *Anacyclo radiati-Hordeetum leporini*. This association is found growing on soils with a mean pH of 7.77, OOM (%) of 1.6, and a mainly sandy texture. Some characteristic species are

A. radiatus, *H. leporinum*, *A. fatua*, *Lactuca serriola*, *Beta vulgaris* subsp. *maritima* and *Chrysanthemum coronarium* var. *discolor* and var. *concolor*.

The association *Resedo albae-Chrysanthemetum coronarii* grows under thermo- and mesomediterranean thermotypes in a subhumid climate. This community has nitrophilous preferences and is found on dumps. It is ruderal in nature and contacts towards more nitrified zones with formations of *Carduo-Silybetum mariani*. This grassland has a high degree of cover and a dominant species, *Chrysanthemum coronarium* that can grow to heights of 2 m, with a minimum area of 1 m². It has a floristic richness of 9–23 species per relevé. The presence of dwarf mallow, cheeseweed, milk thistle, *C. pycnocephalus*, *C. bourgaeanus* and cotton thistle points to a nitrophilous variant within the association. It is unsurprising that the soil study reveals high values of OOM of 1.574% and total nitrogen of 0.129% for this association, a CEC of 11.677 meq/100 g, and high values of exchangeable Mg with 2.716 meq/100 g and 1.476 meq/100 g of exchangeable K. It has a sandy-silty texture, so the RC decreases as these soils have pF15 atmospheres of 14.238%. The soil analysis shows there are insufficient differences to justify maintaining this association within the alliance *Hordeion leporini*, as its organic matter and total nitrogen values are closer to mallow; furthermore, the association has a physiognomy and structure that aligns it more closely with mallow, and there is a frequent presence of species in the genus *Malva* in the communities of *Chrysanthemum coronarium*. This may explain why the statistical study shows a combination of relevés of *Resedo-Chrysanthemetum* and *Urtico-Malventum*, possibly due to the fact that the mean values of the different soil parameters are very similar in both associations (Cano-Ortiz et al. 2014). Some characteristic species are *Chrysanthemum coronarium*, *B. diandrus*, *Erodium malacoides*, *A. sterilis*, *Lactuca serriola* and cheeseweed. (Photograph 6)

The grasslands of *Papaver* and *Diplotaxis* have been included in two associations. The first is a ruderal community in lower thermo-mesomediterranean territories with a dry subhumid ombrotype. The community of *Papaver rhoeas* and *Anacyclus radiatus* prefers more disturbed soils with lower organic matter content than the previous community. The presence of thermophilous elements differentiates this community from common poppy-*Diplotaxietum virgatae* which has a more



Photograph 6 The associations *Resedo-Chrysanthemetum coronarii* and common poppy-*Diplotaxietum virgatae*

continental character and has been described for the central Iberian Peninsula (Rivas-Martínez 1978). Cano-Ortiz et al. (2009) therefore proposed the association *Anacyclo radiati-Papaveretum rhoeadis*, which is dominated by *Papaver rhoeas* and *A. radiatus*, and located on soils with a pH of 7.6, OOM (%) of 1.8 and a mainly sandy-silty texture. The RC is medium. Some characteristic species are *P. rhoeas*, *P. dubium*, *Lolium rigidum*, *A. radiatus*, *P. hybridum* and *M. polymorpha*.

The second herbaceous community belongs to the association common poppy-*Diplotaxietum virgatae* and is a grassland distributed throughout the Manchegan, Lusitanian-Extremaduran and Betic mesomediterranean territories. This community has a spring character and is characteristic of disturbed nitrified soils, roadsides and verges of paths and grows in rainfed crops, olive groves, vineyards and areas of cereal cultivation, among others. Our samples were always taken on basic soils with a pH of 7.9–8.3; these grasslands are located on salt-poor soils and particularly on soils with higher clay content. From the floristic point of view, they may resemble the community of *Diplotaxis catholica* or *D. virgata*, which we interpret as the same community, as there are no synecological differences between the relevés dominated by either of the two species. This is more likely to be a fragmentation due to the indiscriminate use of herbicides. The minimum area obtained is 2 m², and the floristic richness is 8–18 species per relevé. These grasslands occur alongside those of *Sinapis alba* subsp. *mairei*, with which they contact catenally, and into which they transition as the salt concentration increases and the clay content and hence the CEC decreases. Further from thermophilous environments, there is a decline in *Sinapis alba* subsp. *mairei* and the grassland is enriched with species from the genus *Diplotaxis*, so *Papaveri-Diplotaxietum virgatae* occupies the areas of *Paeonio-Quercetum rotundifoliae typicum*, *Asparago acutifolii-Quercetum rotundifoliae* and *Pyro-Quercetum rotundifoliae*. These grasslands are included in the alliance *Hordeion leporini* (Rivas-Martínez et al. 2001; Meena et al. 2014). The statistical analyses conducted on the relevés collected in the Guadalquivir Valley and the originals show them as separated in the cluster (Cano-Ortiz et al. 2014), possibly due to the presence of thermophilous elements and to certain endemisms such as *Anchusa puechii* and *Arenaria hispanica* which are absent from the original table. This suggests the existence of a new syntaxon for loams in the Guadalquivir with a mesomediterranean thermotype and a dry ombrotype in the Hispalense sector, in the area of the series *Paeonio-Quercetum rotundifoliae sigmetum*. This association is characterised by growing on soils with a mean value of OOM of 1.02, CEC of 14.30 and pH of 8.08. It has a silty-clayey texture and therefore a high RC. Some characteristic species are *D. católica*, *M. polymorpha*, *C. arvensis*, *E. malacoides*, dwarf mallow, *Lamium amplexicaule* and *B. diandrus*.

In olive groves on Triassic materials with a neutral character, there is a grassland with a high degree of cover whose dominant species is *Raphanus raphanistrum*, which may ultimately reach a maximum height of 1.20 m. It has been described as a community of *Linaria spartea* and *R. raphanistrum* by Cano-Ortiz et al. (2013). This community has an early spring phenology and is found in the thermo- and lower mesomediterranean thermotype in the Hispalense, northern and Mariánico-Monchiquensian territories. This grassland is clearly differentiated from the rest of

the associations in the study due to its different floristic composition and synecology. It has a minimum area of 2 m² and a floristic richness of 10–17 species per relevé. The soil analysis reveals the existence of acid or base-poor soils. It occurs throughout the entire length of the Guadalquivir Valley, which contacts with the siliceous materials of the Sierra Morena. The neutral-basophilic community of *Raphanus raphanistrum* should therefore be included within the acid-neutrophilous faciation of the series *Rhamno-Quercro rotundifoliae sigmetum* and the acid-neutrophilous faciation of *Paeonio-Quercro rotundifoliae*. Its ecological and floristic characteristics mean we can establish the new association toadflax-*Raphanetum raphanistri* Cano-Ortiz, del Río, Pinto Gomes ass. nova hoc loco within the alliance *Hordeion leporini* (Table 2 rel. 1–24, typus rel. 1 in Cano-Ortiz et al. 2013). This association was not typified according to the stipulations of the international code of phytosociological nomenclature and is therefore typified here. The plant community name is typified considering the code of phytosociological nomenclature, since Cano Ortiz et al. (2013) provide a table of plant communities without specifying the name of the plant association, making it necessary to propose a type relevé.

Some characteristic species are *M. polymorpha*, *H. leporinum*, *B. diandrus*, *L. amethystea*, *L. spartea*, *Brassica barrelieri* and *R. raphanistrum*. (Photograph 7)

Finally, the non-nitrified grassland of *Trifolio cherleri-Plantaginetum bellardii* grows in spring on thin soils that are not very intensively grazed. It has its optimum in the Lusitanian-Extremaduran sector. This association has an early phenology and scarce biomass and grows in dry subhumid environments in Lusitanian-Extremaduran territories. It is characterised by low-growing therophytic species with a low degree of cover. This association is characterised by soils with the following mean values, pH of 6.04, CEC (meq/100 g) of 5.21, OOM (%) of 1.569 and P (ppm) of 5.26, with a sandy texture and low RC. Some characteristic species are *Xolantha guttata* (European frostweed), *Plantago bellardii* (hairy plantain),



Photograph 7 *Linaria spartea-Raphanetum raphanistri*

Hypochaeris achyrophorus (Mediterranean catsear), *Ornithopus compressus* (yellow serradella) and *Filago pyramidata* (broadleaf cottonrose).

4 Conclusions

Positive trends have clearly prevailed over negative ones in recent decades. Spring shows the highest significant positive trend, and there is a certain decline in winter, which is not the season that contributes most to the generally observed warming trend. Temperatures have undergone a significant increase in Andalusia. The greatest rise can be seen in May and June, with slightly more moderate rises in April and July. The trend with the highest magnitude was found in May (0.7–0.95 °C/decade). The areas in Andalusia that have seen the sharpest rise in temperature are the zone between the Guadalquivir Valley and the Subbética mountain ranges (mainly in the provinces of Córdoba and Jaén), the Aracena range to the north of Huelva province and the easternmost area of Almería province. Annual temperatures have raised 0.15–0.45 °C/decade, with 87% stations significant. Spring and summer are the seasons that contribute most to these annual trends. Our findings point to positive and negative temperature trends in Andalusia. Positive trends prevail in the Guadalquivir Valley, an area dominated by agricultural production and particularly areas of olive cultivation.

The consequences of climate change for agriculture – specifically in Andalusia – are becoming catastrophic, as the irregular temperatures and rainfall affect crops and cause losses in yields, a situation that is further aggravated by intensive cultivation practices using misguided agricultural techniques. The bioclimatic location of the crops and the use of an appropriate vegetation cover for olive groves are two important techniques for mitigating climate change. It is therefore essential to implement an agricultural ordination based on the knowledge of the climate in a territory and to use vegetation cover to mitigate the sharp rises in temperature and reduce evapotranspiration as part of a policy of sustainable development.

5 Future Prospectus

Demonstrated the positive trends of temperature in Europe, and in particular in the Guadalquivir valley, together with an irregular distribution of rainfall, and an increase in evapotranspiration and drought (Skarbit et al. 2018; García Barrón et al. 2018; Spinoni et al. 2018; Kumar et al. 2018). Based on the bioclimatic classification of Rivas-Martínez and Loidi (1999), as in that classification the temperature parameter intervenes, there is a bioclimatic tendency parallel to the climatic tendency, in which the mesomediterranean thermocline tends to the thermomediterranean, with the consequent entry of thermophilic species, some of which can be used to create vegetation cover

We are currently resampling the plant associations sampled in previous years in order to determine their state of conservation and propose regeneration models,

since plant cover mitigates climate change. In the future, we expect to obtain a set of species that are more or less favoured by climate change and which can be used for plant cover to mitigate climate disasters.

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