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Bioclimatic Applications and Soil Indicators for Olive Cultivation (South of the Iberian Peninsula)

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Scientific advances in bioclimatology have brought a greater understanding of the functioning of plant individuals, populations and communities, and the study and interpretation of bioclimatic indices reveals the close relationship between the values of these indices and crop yields. In cases where insufficient meteorological data are available to allow the various formulas to be applied, thermoclimatic and ombroclimatic bioindicators must be used, some of which have been collected by us in previous works. This paper contains a bioclimatic study of the southern Iberian Peninsula in relation to the main olive varieties grown in these territories. We establish the values of some key indices for cultivation: continentality index (Ic), which determines the annual thermal range and allows us to establish the period of vegetative activity (PAV); the ombrothermic index (Io), which measures the ombrotype in the different sites; and the thermicity and compensated thermicity index, which denote the thermotype in the territory (It/Itc). We also study soil nutrient indicators. All these elements allow a sustainable agricultural ordination aimed at increasing product yield and quality, and minimizing environmental cost.

Keywords: Bioclimatology, bioindicators, olive cultivation, yield, sustainable.

INTRODUCTION

Advances in bioclimatic research have brought a greater understanding of the functioning of plant individuals, populations and communities. By applying bioclimatic indices, Rivas-Martínez and Loidi (1999) were able to establish a close relationship between bioclimatic data and plant communities, thus enabling the characterisation of each territory. However, these bioclimatic approaches are also applicable to different crops. The correlation between the indices for the Mediterranean macrobioclimate and the distribution of olive plantations clearly highlights the typically Mediterranean character of *Olea europaea* L. In the southern Iberian Peninsula, olive cultivation covers vast areas and has major socio-economic importance. The main varieties are Picual, Cornicabra, Hojiblanca, Lechin, Morisca, Manzanilla, Gordal and Verdial.

Under this climate classification, almost all the olive plantations are located in areas with a Mediterranean pluviseasonal oceanic (Ic< or =21, Io>2.0), Mediterranean pluviseasonal continental (Ic>21, Io>2.2) or Mediterranean continental xeric (Ic>21, 1.0<Io<2.2) bioclimate: there are very few olive plantations under the Mediterranean oceanic xeric bioclimate (Ic< ó =21, 1.0<Io<2.2).

Practically all the olive plantations are located in bioclimatic belts with a thermomediterranean (Itc 350-450)

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or mesomediterranean (Itc 210-350) thermotype, and a semiarid (Io 1.0-2.0), dry (Io 2.0-3.6) or subhumid (Io 3.6-7.0) ombroclimate. Only in isolated cases do we find non-extensive cultivations in the supramediterranean (Itc 80-210), and exceptionally in the humid mesomediterranean.

Although various factors have conditioned the cultivation of the different olive varieties in each zone, they are not always located in their ecological optimum from the bioclimatic point of view. Recent studies (Cano et al., 2001a; Ighbareyeh et al., 2014a,b,c) have highlighted the influence of bioclimatology on olive yields; however this is the first time the bioclimatic characterization of the different varieties has been undertaken. One of the aims of the present study is to relate the distribution of the different olive varieties with various bioclimatic indices, and characterize each one according to its bioclimatic requirements. The goal is to contribute new criteria for the agricultural planning of olive cultivation. This also requires biogeographical and soil studies of potential sites for olive cultivation. All this information can be used to propose models for agricultural management, according to Cano et al. (2003). The influence of climate change on agriculture (Peters et al. 2014) is mitigated by the application of agricultural management bioclimatology.

MATERIALS AND METHODS

We first identified the communities, their localisation and their relationship with the most widespread olive plantations in the southern Iberian Peninsula, with particular emphasis on the rural areas of the Guadalquivir valley, an extension occupied predominantly by olive plantations along with some cereal, cotton, and sunflower cultivation. Although this area was our primary focus, we also made botanical and soil studies and compiled bioclimatic indices for nearby territories in the centre-south of Spain (Albacete, C. Real, Granada, Malaga, Seville, Huelva, Badajoz).

The present work is based on data from 57 meteorological stations, selected due to their location either in or near areas of olive cultivation, or –in a few cases– far from olive plantations. We used the following formulas to calculate the values of the various index Rivas Martínez (1996): ombrothermic index, Io = Pp/Tp; bi-monthly summer ombrothermic index, Is2 = PJuly+August/TJuly+August; tri-monthly summer ombrothermic index, Is3 = PJune+July+August/TJune+July+August; and continentality index, Ic = Tmax-Tmin; thermicity index, or –where applicable– compensated thermicity index, It/Itc = (T+M+m)10. Pp = positive precipitation and Tp = positive temperature (in this case equivalent to annual precipitation and average annual temperature divided by 12, as all the months have an average temperature above 0°); P = precipitation of the months indicated; T = average temperature of the months indicated; Tmax = maximum temperature of the averages of the warmest month of the year; Tmin = minimum temperature of the averages of the coldest month of the year; T = average annual temperature; M = average of the maximum temperature of the coldest month of the year; and m = average of the minimum temperature of the coldest month of the year.

The Itc is applied only to stations with Ic >18, and is obtained by adding a correction factor C to the It, thus establishing the PAV = period of vegetative activity for each station. The Io reveals the ombrotype and determines how much rain falls in a territory and its vegetation response; whereas the Ic shows its continentality, and the It/Itc its thermicity. Summer ombrothermic indices are important in agriculture, as the greater the difference between Is2 and Is3, the greater the compensation. In order to determine the predominance of particular bioclimatic parameters such as Io, Ic and It/Itc in a territory and establish the dominant thermotypes and ombrotypes, we grouped the meteorological stations according to the number of months with vegetative activity, as all the varieties respond well to this criterion. We defined three major areas throughout the whole territory: those where vegetative activity occurs for a) 12 months, b) 10-11 months, and c) 8-9 months. We calculated the averages of the indices mentioned and obtained the Iom, Icm and It/Itcm. We also used previous data on yields collected in Cano et al. (1997), as well as the agricultural characteristics of varieties described by authors such as Barranco et al. (1998) and Guerrero (1991). We compared each variety with the value of the indices expressed, and contrasted the cultivation with each vegetation series (Rivas Martínez, 1987).

For the soil study we followed Aguilar et al. (1987), who describe the Guadalquivir valley as having a predominance of materials from the Triassic era and a widespread presence of elements such as loam, limestone and gypsum, which produce chromic cambisols, calcic cambisols, calcaric fluvisols, calcaric lithosols, calcic luvisols, chromic luvisols, calcaric regosols, orthic solonchaks, and vertisols. We took soil samples by extracting 1 kg of material from a range of depths depending on the root system of the dominant species; these soils were identified with the same code as the phytosociological inventories produced by this UTM. The samples were analysed in the food and agricultural laboratory in Granada (Atarfe) to determine the values of the following parameters: exchangeable calcium, cation exchange capacity, carbonates, assimilable phosphorous, exchangeable magnesium, oxidisable organic material, total nitrogen, pH 1/2.5, exchangeable potassium, pF 1/3 atmospheres, pF 15 atmospheres, prior salinity test, clay texture, silt texture, sand texture, and sieve 2mm.

For the floristic study obtained the characteristic species and companions in each association. We studied four associations in one community, which we named: *Papaveri*

Table 1. Average values of certain soil parameters. *F-S=Fedio-Sinapietum, P-D= Papaveri-Diplotaxietum, R-S= Resedo-Chrysanthemetum, U-M= Urtico-Malvetum, L-R=* Community of *Linaria spartea* and *Raphanus raphanistrum*. CEC = Cation Exchange Capacity. OOM = Oxidisable Organic Material N_t = Total nitrogen. P_a = Assimilable phosphorous. Mg_c = Exchangeable magnesium. K_c = Exchangeable potassium. L-A = Limy-clayey. A-L = Sandy-silty. A = Sandy. CR = Retention capacity (A, high, M, medium, B, low). Sa = Salinity.

	C.I.C	M.O.O	N_t	P_a	Mg_c	K_c	P^F15atmósferas	Textura	CR	Sa	P^H
F-S	12.242	1.039	0.086	13.10	2.828	0.841	18.788	L-A	A	0.689	8.06
P-D	14.073	1.029	0.090	16.05	2.343	0.991	18.547	L-A	A	0.277	8.08
R-C	11.326	1.611	0.131	21.80	2.726	1.488	13.453	A-L	M	0.494	7.94
U-M	8.944	1.056	0.098	22.14	1.637	0.902	11.030	A-L	M	0.783	7.50
L-R	6.739	0.725	0.063	4.618	0.915	0.270	7.695	A	B	0.233	6.78

rhoeadis-Diplotaxietum virgatae, Fedio cornucopiae-Sinapietum mairei. Urtico urentis-Malvetum neglectae, Resedo albae-Chrysanthemetum corronarii, community of *Rhaphanus raphanistrum.* We compiled phytosociological inventories taking into account the minimum calculated areas where the association occurs; these phytosociological inventories include abundance-dominance indices of Braun-Blanquet (1979).

The interpretation of vegetation based on climate domains (sigmetum) is very important for the subsequent treatment of the vegetation. In order to implement agricultural or any other types of actions, it is essential to have a thorough knowledge of the vegetation series, the catenal contacts between the different landscape units, and the vegetation dynamic. Vegetation dynamic is understood as the successions that occur in the plant cover with the appearance of the initial, intermediate, transitional and final stages. The final stage is reached at the point of the stable biological maximum in harmony with itself and with the ecological factors in the environment. Braun-Blanquet (1979) distinguishes between progressive successions directed towards the climax, and regressive successions which move away from the climax. Regressive successions are normally caused by human and animal intervention, and also by environmental factors. Climatophilous series depend on the general characteristics of the environment –particularly the territorial microclimate–, and the location of the olive plantation.

RESULTS AND DISCUSSION

Soil indicators

1.- *As. Fedio-Sinapietum mairei* and *Papaveri-Diplotaxietum virgatae*.

Both associations have a high average value of CEC (12.241-14.073), as a result of an OOM with an average value of 1.039-1.029. The texture is limy-clayey, causing a high CR as these soils have pF 15 atmospheres (18.788-18.547), and high values of exchangeable Mg (2.828-2.343), exchangeable K (0.841-0.991), and very high assimilable P (13.10-16.05). Based on these values, places where either of these two associations are present can be characterised as optimum for olive cultivation, provided the ombrothermic index Io is the same or a somewhat above 3.6 (Cano et al., 1997), and thus any possible nutritional deficiencies will be minimum.

2.- *As. Resedo-Chrysanthemetum coronarii* and *Urtico-Malvetum neglectae*.

The two associations are obtained from *Fedio-Sinapietum mairei* and *Papaveri-Diplotaxietum virgatae*, but present a slightly lower CEC (11.326-8.944) and a higher OOM (1.611-1.056) and total nitrogen (0.131-0.098). However they still have high exchangeable bases, exchangeable Mg (2.726-1.637), exchangeable K (1.488-0.902), and an greater quantity of assimilable P (21.800-22.143). The main soil difference with *Fedio-Sinapietum mairei* and *Resedo – Chrysanthemetum coronarii* lies in its markedly sandy texture, causing it to have lower CR. The value of the pF 15 atmosphere ranges between 13.453 and 11.030. These data allow us to consider these as nitrophilous soils, with a high CEC and exchangeable bases. These are rich soils that with an Io of equal to or higher than 3.6 do not require any fertilisation to ensure successful cultivation.

3.- *Community of Raphanus raphanistrum*

A predominance of *Raphanus raphanistrum* indicates the presence of base-poor soils with low CEC and very low CR, which will cause a water deficit under cultivation. As the pH is acid, acid-neutral, neutral-basic or slightly basic, the quantity of assimilable P is low and is also trapped, making it necessary to turn the soil. The low content in OOM and total nitrogen requires the content of these elements to be increased. This herbaceous plant community therefore acts as an indicator of low levels of N-P-K.

Table 1 shows the average values for a range of parameters, and reveals the high values for these parameters in the first four associations in the previous table. The exception is salinity –which is low in *Papaveri-Diplotaxietum virgatae*– and CR –average in *Resedo-Chrysanthemetum coronarii* and *Urtico-Malvetum neglectae*– as a consequence of the greater content in sand than silt. It is particularly worth noting the high levels of assimilable P, and exchangeable K and Mg. However the community of *Linaria spartea and Raphanus raphanistrum* represents the opposite extreme, as the average values of all the parameters are very low. This is an oligotrophic community that grows on nutrient-poor soils (Cano-Ortiz et al., 2013), and thus olive plantations require these nutrients to be added externally, or otherwise to be grown under different cultivation techniques than at present.

Bioclimatic study

Obtain the values of values for T, P, Io, Ic, It/Itc, Tmax , Tmin, Alt (altitude), Is2, Is3 and PAV (period of vegetative activity) for each one. The analysis of the climate and bioclimatic parameters revealed that most of the territory in the study has 12 months of PAV, with no interruption due to cold –considered as occurring when the average monthly T falls below 7.5 ºC (Montero Burgos and González Rebollar, 1983). This precisely coincides with the territories lying more to the south and south-west of the province, which have mainly a thermomediterranean thermotype with It/Itcm =346, and a dry ombrotype with values of Iom = 2.81 and Icm =19.36. The sites with a PAV of 8-9 months are located predominantly in the northwest of the province of Jaén, with the particularity that both territories have a upper mesomediterranean thermotype with It/Itcm = 264.5, and an Icm (average value of the Ic) of 19.43. However the value for Iom (average value of Io) is 4.42, due to the fact that the mountain ranges of Segura, Las Villas and Cazorla –among others– act as a screen against low pressure areas, causing the stations to have a high Io. There is scarce representation of the supramediterranean thermotype due to the relatively low presence of olive plantations in this thermotype. These sites have between 4 to 6 months of frost and can therefore be regarded as unproductive, even causing trees to die due to excessively low temperatures, as occurred in 2005. This year had a very high number of days with temperatures below -10 ºC, and thus any plantations that were not in their bioclimatic optimum were affected by frost. This occurs in upper mesomediterranean and supramediterranean areas, and even in enclosed valleys where thermal inversion causes the territory to behave as upper meso- or supramediterranean. However there are stations 10 to 11 months of PAV and a lower mesomediterranean thermotype occupying a large part of the province of Jaén and Cordoba, with values of Iom = 3.23 Icm =18.82 and It/Itcm =304.

Floristic and phytosociological study

The interpretation of vegetation based on climate domains (sigmetum) is very important for the subsequent treatment of the vegetation. In order to implement agricultural or any other types of actions, it is essential to have a thorough knowledge of the vegetation series, the catenal contacts between the different landscape units, and the vegetation dynamic. Climatophilous series depend on general features of the environment and act as precise indicators for the optimisation of agricultural cultivation. In this study we propose a set of series that are suitable for olive cultivation, and others that are not. * Series where olive cultivation can occur.
** Series where olive cultivation is optimum.

Vegetation series

1.- Mesomediterranean luso-extremadurense silicicolous holm oak series (*Quercus rotundifolia*): *Pyro bourgeanae-Querco rotundifoliae S.***
2.- Thermomediterranean mariánico-monchiquense and bético dry-subhumid silicicolous holm oak series (*Quercus rotundifolia*): *Myrto communis-Querco rotundifoliae S.***
3.- Mesomediterranean luso-extremadurense subhumid-humid silicicolous cork oak series (*Quercus suber*): *Sanguisorbo agrimonioidis-Querco suberis S.**
4.- Mesomediterranean luso-extremadurense humid silicicolous Pyrenean oak series (*Quercus pyrenaica*): *Arbuto unedonis-Querco pyrenaicae S.**
5.- Supramediterranean luso-extremadurense silicicolous Pyrenean oak series (*Quercus pyrenaica*): *Sorbo torminalis-Querco pyrenaicae s.*
6.- Thermomediterranean bético and algarviense dry-subhumid basophilous holm oak or holly oak series (*Quercus rotundifolia*): *Rhamno oleoidis-Querco rotundifoliae S.***
7.- Mesomediterranean bético dry-subhumid basophilous holm oak series (*Quercus rotundifoliae*): *Paeonio coriaceae-Querco rotundifoliae S.***
8.- Supramediterranean bético basophilous dry-subhumid holm oak series (*Quercus rotundifolia*): *Berberido hispanicae-Querco rotundifoliae S.**
9.- Supra-mesomediterranean bético basophilous subhumid-humid Portuguese oak series (*Quercus faginea*): *Daphno latifoliae-Acero granatensis S.**
10.- Mesomediterranean western almeriense and guadiciano-bastetana semi-arid mastic series (*Pistacia lentiscus*): *Bupleuro gibraltarici-Pistacio lentisci S.**
11.- Mesomediterranean manchega and aragonesa basophilous holm oak series (*Quercus rotundifolia*): *Querco rotundifoliae S.***
12.- Meso-supramediterranean filábrica and nevadense silicicolous holm oak series (*Quercus rotundifolia*): *Adenocarpo decorticantis-Querco rotundifoliae S.**

13.- Mesomediterranean bético basophilous subhumid Portuguese oak series (*Quercus faginea*): *Viburno tini-Querco alpestris S.***

VARIETIES

Based on the studies conducted by Cano et al. (2007), olive varieties respond to different values in the various bioclimatic indices, and are located in the area of a particular vegetation series. Cano et al. (2003) thus propose a specific model for agricultural and forestry management.

PICUAL

The Picual variety has its optimum in the upper thermomediterranean and lower mesomediterranean belt with values of Io = 3.6-4.6, Ic =18-20 and It/Itc = 280/400. This variety is widespread in the provinces of Jaén, Cordoba and Granada. To achieve its ecological optimum it should be sited in areas occupied by the following series *1) Pyro bourgaeanae-Querco rotundifoliae s. thermophilous faciation with Myrtus communis. 2) Paeonio coriaceae-Querco rotundifoliae s. thermophilous faciation with Pistacia lentiscus. 3) Viburno tini-Queco fagineae s.) Myrto communis-Querco rotundifoliae s. 5) Rhamno-Querco rotundifoliae s.*

CORNICABRA

This variety has its optimum in the upper mesomediterranean belt extending into the lower supramediterranean, with values of Io =2.6-3.6, Ic = 20-22 and It/Itc = 210/280. This variety is widely grown in Ciudad Real, Toledo and parts of Albacete. Its optimum is in the series *1) Pyro-Querco rotundifoliae s.) Querco rotundifoliae s.*

HOJIBLANCA

This variety has its optimum in the upper thermomediterranean with a dry ombrotype, and with Io =2.6-3.6, Ic = 17-18 and It/Itc = 350/400. Its optimum is in the series *1) Rhamno-Querco rotundifolaie s.) Myrto communis-Querco rotundifoliae s*, and also in *Paeonio-Querco rotundifoliae s. thermophilous faciation with Pistacia lentiscus*.

LECHIN

This variety is widespread throughout the provinces of Seville, Cordoba and Cadiz, and has its optimum in the dry-subhumid thermomediterranean with Io = 4-6, Ic = 15-17 and It/Itc = 350/450. It should be located in the thermomediterranean cork oak and Portuguese oak series of *1) Myrto communis-Querco suberis s.) Oleo-Querco broteroi s.3) Rhamno-Querco rotundifoliae s.) Myrto-Querco rotundifoliae s* and in mesophytic faciations of holm oak.

MORISCA

This variety has its optimum in the dry ombrotype and upper thermomediterranean thermotype, and may extend to the lower mesomediterranean. It cannot withstand extreme cold, but can resist a maximum of one month's frost when located in places with values of Io = 2.6-3.6, Ic = 16-18, and It/Itc = 280/400. This plant tolerates drought and limy soils, and therefore grows well in the region of Tierra de Barros (BA), where there is a degree of basicity, and a pH of nearly 7 (neutral). It should be located in the holm oak series of *Pyro-Querco rotundifoliae s. basophilous faciation and thermophilous faciation*. This variety can also be grown in the area occupied by the series of *Myrto-Querco rotundifoliae s.*

MANZANILLA

This is an eating variety that grows in areas of Seville and Badajoz, extending towards territories in Cáceres, where it is known by the name of "manzanilla cacereña". It is sensitive to frost, and has a thermomediterranean optimum which may extend to the lower mesomediterranean. This plant is sensitive to peacock spot, tuberculosis and verticilosis, and should therefore be located in areas with a dry ombrotype, in this case with values of Io = 2.6-3.6, Ic = 15-17 and It/Itc = 280/450. It can occupy the area of the Morisca variety and is therefore located in the same series.

GORDAL

Unlike the Manzanilla, this variety is resistant to cold and also requires a certain number of hours of frost to flower; its optimum is therefore mesomediterranean. It is resistant to peacock spot and can therefore be grown in the dry-subhumid ombrotype, where it requires sites with values of Io = 3.6-4.6, Ic = 18-20 and It/Itc =210/350. It should be grown in the area occupied by the same series as the Picual and Hojiblanca varieties. This suggests the need to reconsider the cultivation of the Gordal variety in thermomediterranean areas, as this variety is not currently located in its ecological optimum, which –among other causes– may lead to alternate fruiting.

VERDIAL

The Verdial variety is located in lower thermo- and mesomediterranean areas in territories in Huelva, Seville, Badajoz, Malaga and Portugal, as reported by Barranco et al. (1998) and Guerrero (1991), where –according to the first author– different varieties of Verdial occur. They all share the fact that their fruits do not turn totally black, except in the case of the Verdial from Vélez-Málaga, whose high olive oil yield may make it attractive to cultivate. In general terms it can be said to have its optimum in places with Io = 2.6-3.6, Ic =12-15 and It/Itc =280-450, and is present in practically the same series as the Morisca and Manzanilla varieties. As it is sensitive to frost and peacock spot, its cultivation should be planned in thermomediterranean sites with a dry ombrotype.

ARBEQUINA

This cultivar has a mesomediterranean optimum with values of It/Itc = 210-350, Ic = or > 21, and Io = or > 3.6 (dry/subhumid). It is resistant to cold, has relatively underdeveloped trees, and its fruit is small and tightly attached. This is a variety that does not grow well in very limy soils, as this may cause the occurrence of iron chlorosis. It is tolerant of peacock spot and verticilosis, and therefore grows well in zones with Io = or > 3.6.

FARGA

Typical of the provinces of Castellón and Valencia, this plant has its optimum in the upper thermomediterranean to lower mesomediterranean, with It/Itc = 350, Ic = 16-17 and Io < 3.6. It is not frost resistant, although it can withstand cold weather.

CONCLUSIONS

The research carried out so far allows points to the need for national and European policies to establish scientific and technological criteria when planning olive cultivation, in order to enable sustainable development and minimize economic and environmental cost. We have therefore carried out a general bioclimatic study of areas of olive cultivation to serve as a model for sustainable development in which each variety occupies its own bioclimatic niche. This calls for the territorial ordination of traditional crops and new known botanical resources. In the case of olive cultivation, we establish the limits of bioclimatic tolerance for each of the main varieties, in addition to some soil indicators that can be used for the ordination of ecological olive plantations.

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