Full Length Research Papers

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

Ana Cano Ortiz¹. Jehad M.H. Ighbareyeh². Eusebio Cano²*

¹Department of Interra Sustainability, Resources Engineering SL, Plaza de España, Salamanca, Spain.
²Department of Animal Biology, Plant and Ecology, Botany, University of Jaén, Jaén, Spain.

Accepted 06 December, 2014

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 Verdal.

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< ñ=21, 1.0<Io<2.2).

Practically all the olive plantations are located in bioclimatic belts with a thermomediterranean (ltc 350-450)
or mesomediterranean (ltc 210-350) thermotype, and a
semiarid (lo 1.0-2.0), dry (lo 2.0-3.6) or subhumid (lo 3.6-
7.0) ombroclimate. Only in isolated cases do we find non-
extensive cultivations in the supramediterranean (ltc 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 localization 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
continuity 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°C); P =
prefi pitation 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 lc >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 lc shows its continentality, and the
It/ltc 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 lo, lc and It/ltc 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 lom, lcm and
It/ltc. 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, calcic Luvisols, calcic Lithosols, calcic
Luvisols, chromic Luvisols, calcic 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 phosphorus,
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
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

<table>
<thead>
<tr>
<th></th>
<th>C.I.C</th>
<th>M.O.O</th>
<th>N_t</th>
<th>P_s</th>
<th>Mg_c</th>
<th>K_c</th>
<th>PR 15 atmósferas</th>
<th>Textura</th>
<th>CR</th>
<th>Sa</th>
<th>PH</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-S</td>
<td>12.242</td>
<td>1.039</td>
<td>0.086</td>
<td>13.10</td>
<td>2.828</td>
<td>0.841</td>
<td>18.788</td>
<td>L-A</td>
<td>A</td>
<td>0.689</td>
<td>8.06</td>
</tr>
<tr>
<td>P-D</td>
<td>14.073</td>
<td>1.029</td>
<td>0.090</td>
<td>16.05</td>
<td>2.343</td>
<td>0.991</td>
<td>18.547</td>
<td>L-A</td>
<td>A</td>
<td>0.277</td>
<td>7.49</td>
</tr>
<tr>
<td>R-C</td>
<td>11.326</td>
<td>1.611</td>
<td>0.131</td>
<td>21.80</td>
<td>2.726</td>
<td>1.488</td>
<td>13.453</td>
<td>A-L</td>
<td>M</td>
<td>0.494</td>
<td>7.50</td>
</tr>
<tr>
<td>U-M</td>
<td>8.944</td>
<td>1.056</td>
<td>0.098</td>
<td>22.14</td>
<td>1.637</td>
<td>0.902</td>
<td>11.030</td>
<td>A-L</td>
<td>M</td>
<td>0.783</td>
<td>7.50</td>
</tr>
<tr>
<td>L-R</td>
<td>6.739</td>
<td>0.725</td>
<td>0.063</td>
<td>4.618</td>
<td>0.915</td>
<td>0.270</td>
<td>7.695</td>
<td>A</td>
<td>B</td>
<td>0.233</td>
<td>6.78</td>
</tr>
</tbody>
</table>
parameters in the first four associations in the previous table. The exception is salinity—which is low in *Papaver-Diplotaxietum virgatae*– and CR –average in *Resedochrysanthemetum coronani* 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 °C (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 ombrotypes with values of Iom = 2.81 and lcm =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 lcm (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 °C, 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 lcm =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 agrimonioidei-Querco suberis S.*
4. **Mesomediterranean luso-extremadurense humid holm oak series** (*Quercus pyrenaica*): *Arbuto unedonis-Querco pyrenaicae S.*
5. **Supramediterranean luso-extremadurense silicicolous Pyrenean oak series** (*Quercus pyrenaica*): *Arbuto torninalis-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 rotundifolia*): *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*): *Daphnio latifoliae-Acero granatensis S.*
10. **Mesomediterranean western almeriense and guadiano-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-Querco 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 = 350/450. Its optimum is in the series 1) Rhamno-Querco rotundifoliae 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 \( I_0 = 2.6-3.6, I_c = 12-15 \) and \( I_t/I_c = 280-450 \), 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 ombotype.

**ARBEQUINA**

This cultivar has a mesomediterranean optimum with values of \( I_t/I_c = 210-350, I_c = \) or \( > 21 \), and \( I_0 = \) 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 \( I_0 = \) 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 \( I_t/I_c = 350, I_c = 16-17 \) and \( I_0 < 3.6 \). 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.

**REFERENCES**


