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An approach to zoning in the wine growing regions of "Jerez-Xérès-Sherry" and "Manzanilla-Sanlúcar de Barrameda" (Cádiz, Spain)

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Abstract

The Appellations of Origin "Jerez-Xérès-Sherry" and "Manzanilla-Sanlúcar de Barrameda" occupy one of the oldest and most world renowned viticultural areas in the peninsula, but it is not exempt from the serious problems that are to be found throughout the sector. In order to try to adapt to the present situation, zoning plans are being promoted whereby priority is given to the quality of the product, sustainable development and the economic interests. This work undertakes an approach to the viticultural zoning. The nutritional state of the grapevines is studied by means of foliage analysis at veraison. The quality of production was measured by means of the berry weight and the analysis of the most usual variables of the must at the time of harvest (°Baumé, pH and titratable acidity) over five seasons, in the 21 plots where the soil profiles were opened for analysis. As a result of applying statistical analysis, the plots are grouped into five classes, two of which are subdivided. The most significant differences were established between the plots of class CL1, on Miocene limestone, and those of class CL5, on Pliocene-Quaternary sands and clays. Class CL1 presented the highest content of ash (mean ± sd CL1; CL5) (15.36 ± 1.73; 12.36 ± 1.77) and calcium (3.42 ± 0.90; 2.65 ± 0.72), the lowest berry weight (2.10 ± 0.30; 2.47 ± 0.50) and a greater Baumé degree (10.55 ± 0.86; 9.63 ± 0.98) than the CL5. This new approach takes other essential factors for the quality of the production into account such as the climate and the geomorphology (altitude, slope, and physiography).

Additional key words: climate; plant; soil; viticultural zoning.

Resumen

Una aproximación a la zonificación de la región vitícola "Jerez-Xérès-Sherry" y "Manzanilla-Sanlúcar de Barrameda" (Cádiz, España)

Las Denominaciones de Origen Jerez-Xérès-Sherry y Manzanilla-Sanlúcar de Barrameda ocupan una de las zonas de producción más antiguas de la península y de mayor reconocimiento a nivel mundial, aunque no están exentas de la grave problemática por la que atraviesa el sector. Para intentar adaptarse a la situación actual se están promoviendo planes de zonificación en donde prima la calidad del producto, el desarrollo sostenible y los intereses económicos. En este trabajo se realiza una aproximación a la zonificación vitícola. Para ello, se estudia el estado nutricional de las vides mediante el análisis foliar en el envero, la calidad de producción mediante el peso de los granos de uva y el análisis de las variables más usuales del mosto en la época de vendimia (°Baumé, pH y acidez total) durante 5 campañas, en 21 parcelas coincidentes con la apertura de los perfiles. Como resultado de aplicar el análisis estadístico, se han agrupado las parcelas en cinco clases, dos de ellas a su vez subdivididas. Las principales diferencias significativas se encontraron en las parcelas de las clases CL1, sobre albarizas del Mioceno, y las de la clase CL5, sobre arenas y arcillas del Plioceno-Cuaternario. La clase CL1 presenta el contenido más elevado de cenizas (mean ± sd CL1; CL5) (15,36 ± 1,73; 12,36 ± 1,77) y calcio (3,42 ± 0,90; 2,65 ± 0,72), el menor peso de grano de uva (2,10 ± 0,30; 2,47 ± 0,50) y un mayor grado Baumé (10,55 ± 0,86; 9,63 ± 0,98) que la CL5. Esta nueva aproximación tiene en cuenta otros factores esenciales para la calidad de la producción como son el clima y la geomorfología (altitud, pendiente, fisiografía).

Palabras clave: clima; planta; suelo; zonificación vitícola.

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Introduction

The wine sector is of great importance to Spain, not only for the large areas dedicated to grapevine cultivation, but also for the world renowned wines that are produced, as well as for its repercussion in the economy of the country. The wine-producing zone (approximately 10,000 ha) protected by the Appellations of Origin (AO's) "Jerez-Xérès-Sherry", "Manzanilla-Sanlúcar de Barrameda" and "Vinagre de Jerez", commonly called the Sherry Triangle, is located in the south of the Iberian Peninsula (Fig. 1), within Andalusia, extending throughout eight municipal districts (MD's), in the north-western quadrant of the province of Cadiz: Jerez de la Frontera, El Puerto de Santa María, Sanlúcar de Barrameda, Chipiona, Trebujena, Rota, Puerto Real, and Chiclana de la Frontera and certain estates in the municipal district of Lebrija, in the province of Seville.

This area is an exceptional enclave since it is bordered to the north by the Guadalquivir River and to the west by the Atlantic Ocean, in addition to its proximity to the Mediterranean, which from the beginning has favoured maritime commerce and the spread of its wines throughout the world. Its origin goes back to around 1,100 BC when the Phoenicians introduced the vines and the art of wine making into this region, from the Lebanon.

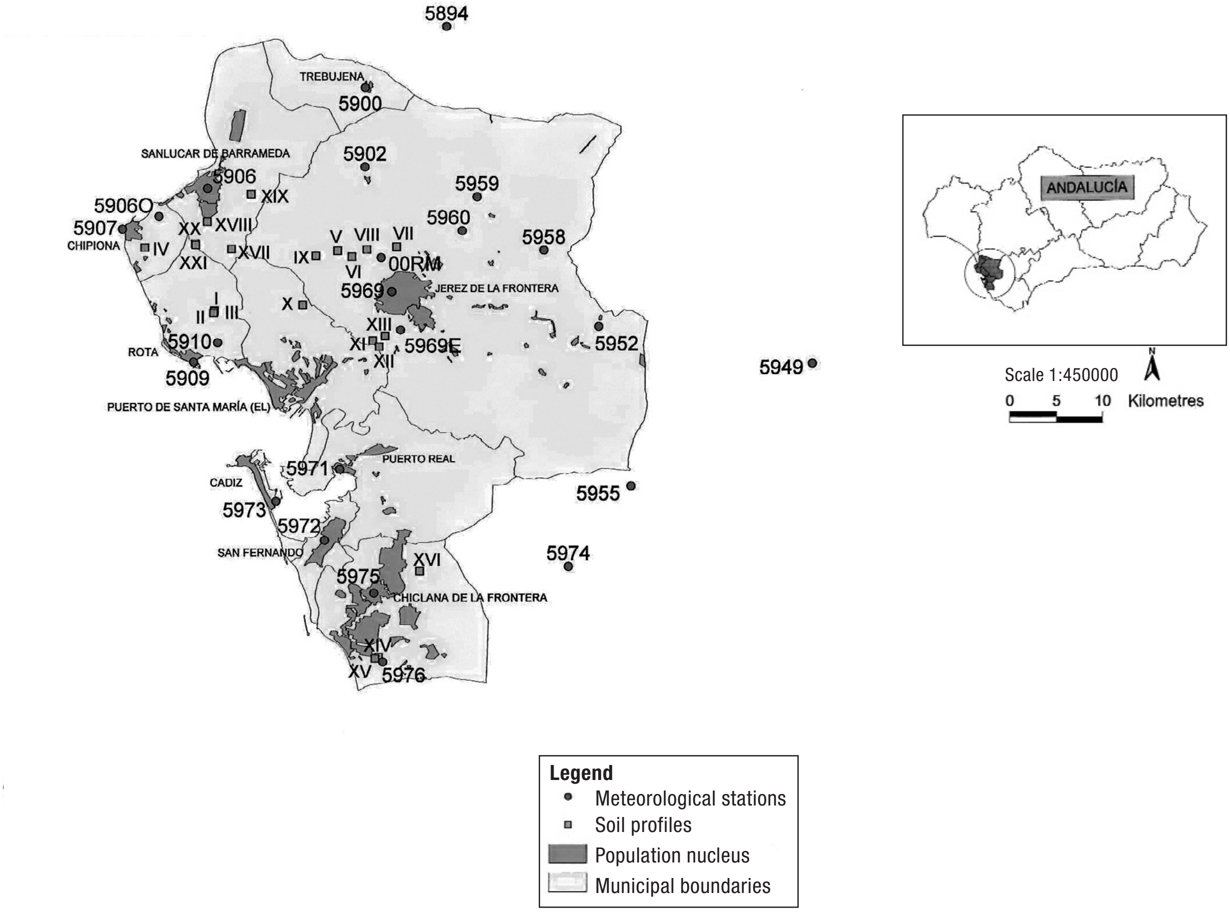

Figure 1. Geographical location of the soil profiles and meteorological stations that served as a basis for the study of the zoning approach.

Abbreviations used: AECOVI Jerez (Sociedad de Cooperativas Andaluzas Vitícolas); AO (Appellations of Origin); CEBAC (Centro de Edafología y Biología Aplicada del Cuarto); CIITDF (Inter-Institute Committee for the Study of Analytical Techniques of Foliage Diagnosis); ESRI (Environmental Systems Research Institute); GIS (Geographic Information System); ICA (Cartographic Institute of Andalusia); IGME (Spanish Geological and Mining Institute); MAPA (Ministerio de Agricultura, Pesca y Alimentación); MD (municipal districts); NMI (National Meteorological Institute); RADO (Regulating Council of the Appellation of Origin); WRBSR (World Reference Base for Soil Resources).

These AO's are considered zones of maximum interest within Andalusian vitiviniculture and are amongst the oldest of Spain (Sáez, 1995). The importance of these lands is linked to the unquestionable fact of their relationship with the quality of their famous wines (*fino, manzanilla, oloroso, amontillado*, etc.), produced with musts of the cultivated grape (*Vitis vinifera*) variety Palomino Fino and submitted to characteristic processes of vinification and ageing in oak that form their singularity. Vine growing and enology mark the history of this region, they define not only the socio-economic development of the area, but also shape the landscape, the cultural identity of the society and, in parallel with history, they comprise the quality and typicity of its wines. The fact that the production of grapes and wines of great quality has been maintained in the area for more than two millennia ratifies its suitability for the cultivation of the grapevine.

The problems of the wine sector, especially that of decreased consumption, and therefore surplus production, increasing competition in global markets and the increased demand for wines of quality and typicity, have led technicians and organizations of different AO's to promote zoning plans. These are being carried out not only in Spain (Gómez Sánchez, 1995; Paneque Macías, 2000; Pérez *et al*., 2000; Paneque *et al.,* 1998, 2002; Osta *et al.*, 2005), but also in vine-growing areas world-wide including France, Italy, Switzerland, Chile, Argentina and South Africa (Dutt *et al.*, 1981; Falcetti and Scienza, 1991; Morlat and Asselin, 1992; Costantini *et al*., 1996; Tonietto and Carbonneau, 2004; Vaudour and Shaw, 2005; Zufferey *et al.*, 2008; Carey *et al.*, 2009).

Zoning is a step prior to the planning of the territory and is fundamental for strategic studies of vitiviniculture and the market (Falcetti and Lacono, 1996; Costantini, 1999; Montesinos and Quintanilla, 2006). Vitiviniculture zoning is shown as a valid tool to delimit those wine-producing zones with greater potentiality or a particular potential for a certain type of wine, and can help to identify, characterize, organize and maintain the great diversity found in wine production (Vaudour, 2002; Tesic, 2004).

Traditionally the Regulating Council of the Appellation of Origen (RCAO) distinguished two zones. One is called *Jerez Superior* and is composed of the estates of white, calcareous marl soils *(albarizas)* of the MD's of Jerez de la Frontera, El Puerto de Santa María, Sanlúcar de Barrameda and those of Rota, Chipiona and Trebujena, bordering with that of Sanlúcar. These areas are suitable for the production of superior quality wines due to the physical-chemical composition of their soil, their situation and climatologic characteristics (García del Barrio, 1979; García de Luján, 1997). The other zone is called *Jerez Zona* and is composed of the estates of silty clay and sandy soils, mainly in the MD's of Chipiona, Trebujena, Rota, Puerto Real, Chiclana de la Frontera, and Lebrija.

Our study attempts to approach the zoning where a methodology is shown prior to mapping of the vine-growing areas of the AO's Jerez-Xérès-Sherry and Manzanilla-Sanlúcar de Barrameda for the Palomino Fino variety. This methodology combines criteria of classical studies and innovative ones that are considered essential for the quality of the production such us geologic, geomorphologic, edaphic, climatic and biological factors (Paneque *et al.,* 2000). Our results are verified to adjust to previous studies and to the traditional knowledge of the zone.

Material and methods

In order to formulate the methodology of the zoning proposal in the AO's of Jerez-Xérès-Sherry and Manzanilla-Sanlúcar de Barrameda, studies were made in a representative group of vineyard plots of the Palomino Fino variety in the "Marco de Jerez" region. These studies were made on the morphological, chemical and physical characteristics and hydrologic properties of the edaphic materials and their geology; the climatic characteristics, the nutritional state of the grapevine and the quality of the production. The results from all these studies were subjected to the corresponding statistical methodology.

The location of the vineyards in the AO zone was made from the digitized map of uses and coverage of soils of the Junta de Andalucía (1999) on a 1:10,000 scale. The available and produced information was codified and integrated in a geographic information system (GIS) for later treatment with the program ArcGIS 9.1 (ESRI, 2005).

Geology, geomorphology, climate and soil

Data was used that was provided by the Geological and Mining Institute of Spain (IGME) on the maps at a scale of 1:50,000 and their corresponding reports. In addition, the digitized information of the maps from the Lithologic and Physiographic Units of the Junta de Andalucía; the soils map at a 1:50,000 scale of Bellinfante

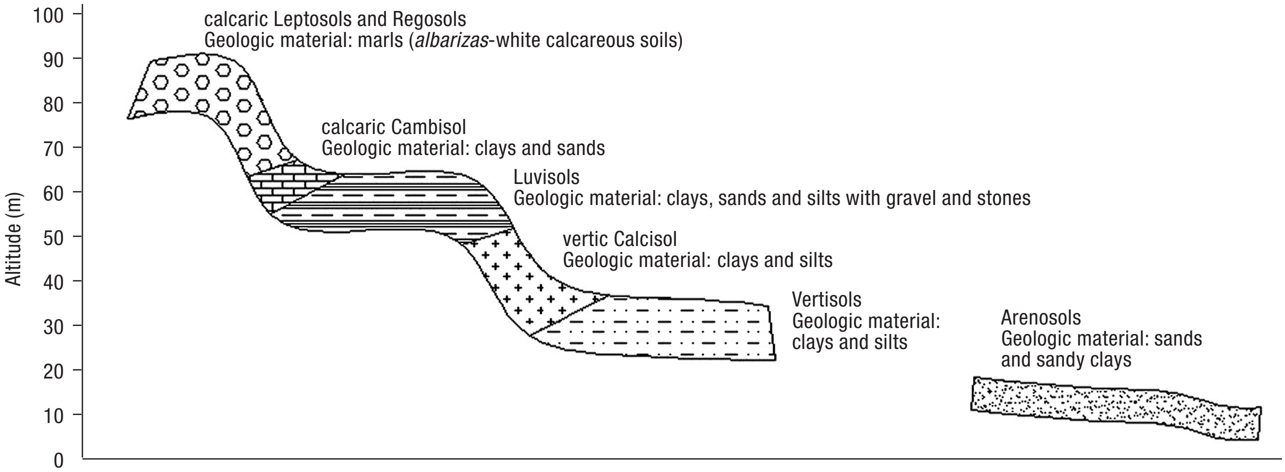

Figure 2. Toposequence of soils and geologic material.

(2004); the corresponding digitized and geo-referenced topographic maps at a 1:10,000 scale provided by the Cartographic Institute of Andalusia (ICA, 1998), were also used.

The study of the climate of the zone was made by means of data provided by the National Meteorological Institute (NMI), the Institute of Agricultural and Fisheries Research and Training and of the Ecological Production of the Rancho de La Merced Centre. Twenty-four stations were selected following the spatio-temporal criteria recommended by the World Meteorological Organization.

Regarding the soil, the materials subject to research corresponded to soils of the AO's Jerez-Xérès-Sherry and Manzanilla Sanlúcar de Barrameda, from vineyard plots of the Palomino Fino variety, of AECOVI, in the MD's of Jerez de la Frontera, Sanlúcar de Barrameda, Chipiona, Rota, Puerto de Santa María, and Chiclana de la Frontera (Cadiz). The selection was carried out after the bibliographical review of the edaphologic studies of the zone was completed (CEBAC, 1963, 1971; García del Barrio *et al.*, 1971; García del Barrio, 1972, 1988; García de Luján, 1997; Paneque *et al.*, 2000). After detailed on-site reconnaissance and expert advice, 21 representative vineyard soil profiles were opened in the stated municipal districts (Fig. 1).

In the 21 profiles studied, 80 horizons were differentiated, where complete studies were carried out on the morphology and chemical and physical properties. A description of the profiles was made in the field and completed in the laboratory in accordance with the "Guide for the description of soil profiles" (FAO, 1977) and the adaptation made by the Andalusian Regional Department of Environment (Junta de Andalucía, 1999) based on the aforementioned guide. These, together with the chemical and physical analyses, enabled the classification of the soils according to the FAO-ISRIC-SICS (WRBSR, 1998). A toposequence of the distribution of the soils and geologic material is given in Figure 2.

Triplicate disturbed samples were taken from the different horizons for the chemical analyses of pH, the carbonate content, active lime, total nitrogen, phosphorus, assimilable macronutrients (Ca, Mg, Na and K), cation exchange capacity (CEC), exchange cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}), sum of exchangeable basic cations (S) and of base saturation percentage (% V). All these were measured according to the Official Methods of Soil Analysis of the Ministry of Agriculture, Fisheries and Food (MAPA, 1994). The determination of assimilable micronutrients (Fe, Cu, Mn and Zn) was carried out according to Pinta (1973), the organic matter (OM) in the soil as per Guitián and Carballas (1976), and the chlorotic power index (CPI), defined by Juste and Pouget (1972).

Triplicate disturbed samples were taken for the analyses of the physical properties including granulometry, determination of the texture and real density (MAPA, 1994). Non-disturbed samples were used to determine the bulk density, total porosity, water content in the soil (maximum water capacity, aeration capacity, field capacity, available water retention capacity, usable water, permanent wilting point and the water non-usable by the roots) and the saturated hydraulic conductivity (K) (MAPA, 1994).

The climatic data (average, maximum and minimum temperatures, hours of cold, precipitations, relative humidity, winds, evapotranspiration and the different climatic indices) as well as the physiographic and geomorphological data and those corresponding to the description and the analyses of soils are referred to in Pardo Calle (2007).

The most significant data of the studied profiles, which served as the basis to make the proposal of the zoning approach, are shown in Table 1.

Nutritional state and quality of production of Palomino Fino

The nutritional state of the Palomino Fino grapevines was determined by means of the analysis of foliage at veraison. For this analysis, about 100 g of leaves were taken and determinations were made for ash content, nitrogen, phosphorus, potassium, calcium, magnesium and for the micronutrients iron, copper, manganese and zinc. The samples were mineralized by means of the techniques recommended by the Inter-Institute Committee for the Study of Analytical Techniques of Foliage Diagnosis (CIITDF, 1969). The ash content was weighed and the determination of K was made by flame spectrophotometry, whereas Ca, Mg, Fe, Cu, Mn and Zn were determined by atomic absorption spectrophotometry (Pinta, 1973). The phosphorus determination was made according to Guitián and Carballas (1976), and the determination of nitrogen was made by the Kjeldahl method. The study was carried out over five seasons, from 1999 to 2004, in the 21 plots where the soil profiles were opened.

For the determination of the quality of the production, samples were taken from clusters of grapes (Sabir *et al*., 2010) at the time of harvest at each one of the 21 plots sampled for the analysis of the mineral nutrition, during the same five seasons. The berry weight was determined, and the titratable acidity (g L^{-1}, expressed as tartaric acid, TH_2), pH and Baumé degree of the extracted must were analysed.

Statistical analysis

During the five seasons of study, various statistical analyses were made to evaluate the mineral nutrition and the production characteristics of the Palomino Fino variety in the 'Marco de Jerez', and to verify the soil-climate-plant interrelationship.

A preliminary attempt at classification was made by grouping soil types (Leptosols, Regosols, Cambisols, Calcisols, Luvisols, Vertisols and Arenosols) for the statistical treatment and later discussion of the results. If there were no significant differences in the variables studied in the foliage analysis and the production in the different types of soil, a new classification was made that included altitudinal, physiographic, geolithologic, geographic and edaphologic criteria. In this way the soil profiles of the 21 plots under study were grouped into five classes (CL1, CL2, CL3, CL4 and CL5), represented by one or two reference soil groups, according to the FAO-ISRIC-SICS (WRBSR, 1998). Some characteristics of each class are summarized in Table 2.

Class CL1 is located in non-dissected stable plains, located at more than 60 m of altitude, on Miocene marls (*albarizas*) and Leptosol and Calcic Regosol type soils. Classes CL2 and CL4, are located in dissected unstable plains, of 45 to 60 m of altitude and composed of Quaternary materials. The CL2 are mostly clays and sands and the CL4 mainly clays, sands and silts with gravel and stones, they are mainly different types of Luvisols. Class CL5 is composed of units of transition to marsh on sands and clays and Pliocene and Quaternary sands. Class CL3 is located on non-dissected fluvial terrace at between 20 and 45 m of altitude and the material is composed of clays and silts, giving rise to mainly Vertisol soils.

After the descriptive analysis of the data, a comparison of averages was made with graphical and analytical methods to verify whether significant differences existed between each one of the study variables and the factor of variation considered (previously defined classes). Parametric (Analysis of Variance, ANOVA) or non-parametric (Kruskal-Wallis) tests were used, according to whether the applicable hypothesis was verified or not (normal distribution was verified with Shapiro-Wilk's test and homoscedasticity with Levene's test). Where differences existed in a variable, Scheffé's (parametric treatment) or Dunn's (non-parametric treatment) tests for multiple comparisons were used to determine between which categories or classes these differences existed. All the described analyses were made using the statistical program SPSS v.14 (2005).

Results

Soil-climate-plant interaction: foliage analysis and quality of production

A first step in the treatment of results is a descriptive statistic of the studied variables of the foliage analysis and of production (Table 3).

Table 1. Characterization of the soil profiles: altitude (m), slope (%), orientation, physiographic units, parent geologic material, soil classification according to the FAO (1998), municipal district and location

Profile	Altitude (m)	Slope (%)	Orientation	Physiography	Geologic material	Soil group (FAO, 1998)	Municipal district	UTM (HUSO 30)
I	49	<2	E	Dissected unstable plains	Terraced calcareous sediments of the Quaternary	calcic-chromic Luvisol	Rota	X: 201808 Y: 4063260
II	45	3-4	S	Dissected unstable plains	Terraced calcareous sediments of the Quaternary	calcaric Cambisol	Rota	X: 201782 Y: 4063173
III	40	2	E	Non- dissected fluvial terrace	Fluvial argillaceous and calcareous sediments of the Quaternary	pelic Vertisol	Rota	X: 201707 Y: 4063006
IV	8	1	S	Units of transition to marsh	Upper Pleistocene Sands (Quaternary)	haplic Arenosol	Chipiona	X: 194855 Y: 4069507
V	77	4-6	N	Non- dissected stable plains	Calcareous marl of the Miocene (Tertiary)	calcaric Regosol	Jerez de la Frontera	X: 214066 Y: 4069148
VI	37	6	W	Dissected unstable plains	Terraced calcareous sediments of the Quaternary	calcic-chromic Luvisol	Jerez de la Frontera	X: 215506 Y: 4068567
VII	71	4-6	NW	Non- dissected stable plains	Calcareous marl of the Miocene (Tertiary)	calcaric Regosol	Jerez de la Frontera	X: 219961 Y: 4069552
VIII	45	4	S	Non- dissected fluvial terrace	Calcareous marl of the Miocene (Tertiary)	vertic Calcisol	Jerez de la Frontera	X: 216984 Y: 4069281
IX	60	4-6	W	Non- dissected stable plains	Calcareous marl of the Miocene (Tertiary)	calcaric Leptosol	Jerez de la Frontera	X: 211918 Y: 4068664
X	63	2-3	SW	Dissected unstable plains	Terraced calcareous sediments of the Pleistocene (Quaternary)	haplic chromicl Luvisol	Puerto de Santa María	X: 210600 Y: 4063800
XI	20	7-8	NE	Units of transition to marsh	Sandy marls of the Miocene (Tertiary)	calcaric Regosol	Jerez de la Frontera	X: 217596 Y: 4060221
XII	50	13	NE	Non- dissected stable plains	Calcareous marl of the Miocene (Tertiary)	calcaric Regosol	Jerez de la Frontera	X: 218242 Y: 4059625
XIII	45	2-3	SW	Dissected unstable plains	Terraced calcareous sediments over Quaternary sandstones	calcic-chromic Luvisol	Jerez de la Frontera	X: 218842 Y: 4060687
XIV	20	<2	NW	Units of transition to marsh	Calcareous sandstones of the Quaternary	arenic Luvisol	Chiclana de la Fra.	X: 218237 Y: 4028821
XV	23	<2	NW	Units of transition to marsh	Sands on hydromorphic basement (Quaternary)	gleyc Arenosol	Chiclana de la Fra.	X: 217883 Y: 4028665
XVI	65	<2	W	Non- dissected stable plains	Calcareous marl of the Miocene (Tertiary)	calcaric Leptosol	Chiclana de la Fra.	X: 222338 Y: 4037336
XVII	30	<2	SE	Non- dissected fluvial terrace	Calcareous marl sediments of the Miocene (Tertiary)	calcic Vertisol	Sanlúcar de Bda.	X: 203485 Y: 4069349
XVIII	45	2	NE	Non- dissected table plains	Calcareous marl of the Miocene (Tertiary)	calcaric Leptosol	Sanlúcar de Bda.	X: 201069 Y: 4072068
XIX	50	6-8	W	Non- dissected stable plains	Calcareous marl of the Miocene (Tertiary)	calcaric Leptosol	Sanlúcar de Bda.	X: 205438 Y: 4074803
XX	49	<2	NW	Dissected unstable plains	Altered marl sediment over Quaternary sandstones	calcic Luvisol	Sanlúcar de Bda.	X: 199868 Y: 4069917
XXI	54	2	NW	Dissected unstable plains	Terraced calcareous sediments of the Quaternary	calcic Luvisol	Sanlúcar de Bda.	X: 199934 Y: 4069770

Table 2. Characteristics of the classes of plots CL1, CL2, CL3, CL4 and CL5

Class	Physiography	Altitude (m)	Geological material	Period	Local[1]	Soil[2]	Plot
CL1	Stable plains (non-dissected)	>60	Marls ('albarizas' -white, calcareous soils)	Miocene	NW Centre S	caLP caLP caRG caRG caLP caRG caLP	XVIII XIX V VII IX XII XVI
CL2	Dissected unstable plains	45-60	Clays and sands	Quaternary	W Centre	caCm cc-crLV	II XIII
CL3	Non-dissected fluvial terrace	20-45	Clays and silts	Quaternary	W NW Centre	peVR ccVR vrCL	III XVII VIII
CL4	Dissected unstable plains	45-60	Clays, sands and silts with gravel and stones	Quaternary	NW W Centre	ccLV ccLV cc-crLV cr-haLV cc-crLV	XX XXI I X VI
CL5	Units of transition to marsh	<20	Sands and sandy clays	Pliocene; Quaternary	W Centre S	haAR caRG arLV glAR	IV XI XIV XV

[1] Local: Location in the AO. [2] caLP: calcaric Leptosol; caRG: calcaric Regosol; caCm: calcaric Cambisol; vrCL: vertic Calcisol; ccVR: calcic Vertisol; peVR: pelic Vertisol; cc-crLV: chromic calcic Luvisol; ccLV: calcic Luvisol; cr-haLV: haplic chromic Luvisol; arLV: arenic Luvisol; haAR: haplic Arenosol; glAR: gleyic Arenosol.

In order to establish possible differences in relation to the variables studied (foliage analysis and production) between the five classes of established plots, a study of comparison of averages was carried out. The ANOVA parametric comparison was applied to the variables: the ash, Ca, Mg and Mn content in leaves, the Baumé degree, the titratable acidity and pH of the must and berry weight when they fulfilled the normality hypothesis (Shapiro-Wilk's test) and homoscedasticity (Levene's test). Significant differences were found in the content of ash ($p < 0.005$) and calcium ($p = 0.048$) in leaves, the Baumé degree of the must ($p = 0.004$) and in the berry weight ($p = 0.019$). Scheffé's multiple comparisons test was then made to determine which classes of plots had differences between them.

The most elevated ash content corresponded to the vineyard of class CL1, although without significant differences from that of the class CL2 plots. The lowest ash content was that of the class CL5 plots, without any difference from those of classes CL3, CL2 and CL4. Significant differences were found between class CL1 and the classes CL3 ($p = 0.007$), CL4 (0.011) and CL5 ($p = 0.005$), with the ash content being greater in class CL1. The Ca content was greater in CL1 compared to CL5. Therefore, the main differences were established between classes CL1 and CL5 ($p = 0.041$).

The CL5 plots presented the lowest Baumé degree, with statistically significant differences between this class and the classes CL1 ($p = 0.036$) and CL3 ($p = 0.025$). There was also a difference in the berry weight between classes CL1 and CL5, it being less in class CL1 than in class CL5 ($p = 0.033$), unlike that observed with the Baumé degree.

The Kruskal-Wallis test was applied to the rest of the variables (content of N, P, K, Fe, Cu and Zn in leaves) to determine possible differences between the classes of plots. This test only demonstrated differences in the Cu content of the leaves ($p = 0.018$), which mainly depends on the agronomic management. The application of Dunn's test for this variable found neither

Table 3. Results of the foliage analysis: ash, macro and micronutrients, berry weight, Baumé degree, pH and titratable acidity of Palomino Fino in the AO's during the seasons from 2000 to 2004

	n	Average (standard dev.)	Median (interquartile range)	Minimum	Maximum
Ashes and macronutrients (g/100 g dm)					
Ash	105	14.06 (1.86)	13.85 (2.28)	9.2	19.2
N	105	1.87 (0.29)	1.82 (0.33)	1.15	2.84
P	105	0.31 (0.21)	0.25 (0.13)	0.02	1.18
K	105	0.49 (0.19)	0.45 (0.23)	0.07	1.18
Ca	105	3.21 (0.88)	3.20 (1.31)	1.66	5.72
Mg	105	0.25 (0.07)	0.25 (0.10)	0.10	0.45
Micro-nutrients (mg kg^{-1} dm)					
Fe	105	298.71 (153.18)	267.02 (145.09)	5.4	1,113.6
Cu	105	239.55 (196.16)	187.39 (194.81)	0.0	908.2
Mn	105	121.61 (51.51)	109.89 (62.32)	36.5	284.1
Zn	105	71.88 (69.77)	49.26 (62.32)	0.2	391.4
Production (harvest)					
Berry weight (g)	105	2.25 (0.39)	2.10 (0.49)	1.5	3.4
°Baumé	105	10.31 (1.00)	10.20 (1.42)	8.2	13.2
pH	105	3.89 (0.31)	3.9 (0.43)	3.40	4.70
Titratable acidity (TH_2 g L^{-1})	105	3.03 (0.61)	3.09 (0.81)	1.80	4.92

differences between the plots of classes CL4, CL1 and CL5, which gave the highest values for leaf Cu, nor between the plots of classes CL2 and CL3. Significant differences were found between class CL4 and the classes CL2 ($p = 0.029$) and CL3 ($p = 0.007$), with the highest values in class CL4. Also significant differences were found between class CL3 and the classes CL1 ($p = 0.019$) and CL5 ($p = 0.027$), with the lowest values in class CL3.

In short, the statistical analysis showed differences between the five classes of vine plots regarding the ash, Ca and Cu content in leaves, and the Baumé degree and the berry weight (Table 4).

Table 5 shows the significant results of the descriptive analysis of the variables of the foliage analysis of Palomino Fino at veraison, and of production in the harvest for each of the plots pertaining to the five established classes, based on physico-environmental criteria.

For the zoning proposal, apart from the classification made and corroborated with the statistical analysis, other physical variables were introduced for the demarcation and characterisation of the five main classes and the subclasses (1.1, 1.2, 5.1, and 5.2). These variables were the ranges of slope, geographic location in the AO, average annual precipitation (AAP), average maximum annual temperature (AMAT), average minimum annual temperature (AmAT), active heat summation indices (AHSI), effective heat summation indices (EHSI) and the heliothermic, hydrothermic and bioclimatic indices (Table 6).

The most significant characteristics of the seven proposed zones of the most important areas in the AO occupied by the present vineyards are:

— Class 1 includes all the calcaric Leptosols and most of the calcaric Regosols. They are vine growing soils on parent Miocene calcareous marls (white *albarizas*) in non-dissected stable plains, occupying the highest positions (in general, over 60 m of altitude), with slopes between 2 and 13%. There are average annual precipitations of 575 to 695 mm. It is divided into two subclasses based on temperatures: CL 1.1 has greater thermal range, whereas CL 1.2 has a maximum average annual temperature (Table 6). In spite of this, the two have the same range of active heat summation indices and the same range of effective heat summation indices. This variation in temperatures marks the differences in the relevant climatic indices [hydrothermal product, heliothermic product (HP), Huglin index, Hidalgo bioclimatic index and the Gorszinsky continentality coefficient].

— Class 2 includes a calcaric Cambisol and a calcic-chromic Luvisol. They are vine-growing soils on parent

Table 4. Comparison of foliage analysis and the production of Palomino Fino in the different, pre-established classes

	Class	Shapiro-Wilk test *p*-value	Levene test *p*-value	ANOVA test *p*-value	Scheffe test difference (*p*-value)
Ash	CL1	0.128	0.135	< 0.005**	$\mu_{CL1} > \mu_{CL3}$ (0.007)**
	CL2	0.057			$\mu_{CL1} > \mu_{CL4}$ (0.011)*
	CL3	0.568			$\mu_{CL1} > \mu_{CL5}$ (0.005)**
	CL4	0.334			
	CL5	0.253			
Ca	CL1	0.401	0.632	0.048*	$\mu_{CL1} > \mu_{CL5}$ (0.041)*
	CL2	0.644			
	CL3	0.368			
	CL4	0.151			
	CL5	0.366			
Berry weight (g)	CL1	0.113	0.170	0.019*	$\mu_{CL5} > \mu_{CL1}$ (0.033)*
	CL2	0.728			
	CL3	0.642			
	CL4	0.379			
	CL5	0.721			
°Baumé	CL1	0.151	0.236	0.004**	$\mu_{CL1} > \mu_{CL5}$ (0.036)*
	CL2	0.597			$\mu_{CL3} > \mu_{CL5}$ (0.025)*
	CL3	0.356			
	CL4	0.547			
	CL5	0.304			
Cu	CL1	0.003**	0.201	0.018*	$\mu_{CL1} > \mu_{CL3}$ (0.019)*
	CL2	0.04*			$\mu_{CL4} > \mu_{CL2}$ (0.029)*
	CL3	0.002**			$\mu_{CL4} > \mu_{CL3}$ (0.007)**
	CL4	0.001**			$\mu_{CL5} > \mu_{CL3}$ (0.027)*
	CL5	0.07			

*,**: significant at the 0.05 and 0.01 level, respectively.

Quaternary clays and sands, in dissected unstable plains, with altitudes of 45-60 m and slopes of 2-13%. Average annual precipitations reach 540 to 575 mm.

— Class 3 includes pelic Vertisol, calcic Vertisol and vertic Calcisol. They are vine-growing soils on parent Quaternary clays and silts in non-dissected fluvial terraces, with altitudes of 20-45 m and slopes of 2-13%. It has average annual precipitations of 500 to 540 mm.

— Class 4 mainly includes the Luvisols, as much calcic-chromic Luvisols, chromic-haplic Luvisols, as calcic Luvisols. They are vine-growing soils on parent Quaternary clays, sands and silts with rounded stones in dissected unstable plains, with altitudes of 45-60 m and slopes of 2-13%. It has average annual precipitations of 540 to 575 mm.

— Class 5 includes a haplic Arenosol, a gleyic Arenosol and some soils with a high sand content (arenic Luvisol and a calcaric Regosol). They are vine-growing soils that are located in units of transition to marsh, with altitudes of < 20 m and slopes < 2%. The sub-classes CL5.1 and CL 5.2 are differentiated by their parent, or underlying, geologic material and the climatic values that they show. Thus CL5.1 has parent clays and sands and CL5.2 has parent sands. In addition, CL5.1 reaches average annual precipitations of 500 to 540 mm and CL 5.2 of 575 to 695 mm. CL5.1 has greater values for climatic indices than CL5.2, except for the Hydrothermal Product and the Gorszinsky continentality coefficient which are similar.

Discussion

Studies carried out by other authors on the mineral nutrition of Palomino Fino in the phenologic state of veraison in plots of the municipal district of Jerez de la Frontera over six years, show average values of macronutrients very similar to those found in this study, except for the P content, which is lower, and that

Table 5. Foliage analysis and production data for Palomino Fino at harvest for the 5 classes of plots (CL1 to CL5)

	Class	n	Average (standard dev.)	Median (interquartile range)	Minimum	Maximum
Foliage analysis (Veraison)						
Ash	CL1	35	15.36 (1.73)	14.86 (2.81)	12.6	19.2
	CL2	13	13.84 (1.24)	14.20 (1.55)	11.3	15.6
	CL3	15	13.50 (1.32)	13.71 (2.08)	11.3	15.7
	CL4	24	13.82 (1.37)	13.52 (2.08)	11.9	16.9
	CL5	18	12.36 (1.77)	12.62 (1.70)	9.2	15.8
Ca	CL1	35	3.42 (0.90)	3.51 (1.49)	1.88	5.72
	CL2	13	3.39 (0.85)	3.27 (1.23)	2.30	5.03
	CL3	15	3.18 (0.91)	2.95 (1.37)	1.99	5.22
	CL4	24	3.32 (0.84)	3.33 (1.31)	1.89	4.72
	CL5	18	2.65 (0.72)	2.48 (1.18)	1.66	4.12
Cu	CL1	35	257.80 (214.39)	181.08 (190.44)	36.6	899.1
	CL2	13	171.03 (158.19)	118.93 (208.69)	0.0	534.5
	CL3	15	157.48 (188.25)	98.95 (211.49)	0.0	581.1
	CL4	24	305.39 (228.06)	245.19 (202.73)	28.7	908.2
	CL5	18	223.90 (84.92)	224.68 (173.77)	116.8	356.3
Production (Harvest)						
°Baumé	CL1	35	10.55 (0.86)	10.50 (1.18)	9.2	13.2
	CL2	13	10.71 (1.13)	10.80 (1.50)	8.5	12.2
	CL3	15	10.72 (1.17)	10.60 (2.20)	9.0	12.5
	CL4	24	10.03 (0.76)	10.00 (1.01)	8.2	11.2
	CL5	18	9.63 (0.98)	9.50 (1.11)	8.2	11.4
Berry weight (g)	CL1	35	2.10 (0.30)	2.10 (0.24)	1.6	3.0
	CL2	13	2.22 (0.25)	2.15 (0.38)	1.9	2.7
	CL3	15	2.20 (0.31)	2.25 (0.37)	1.6	2.8
	CL4	24	2.33 (0.43)	2.40 (0.69)	1.5	3.1
	CL5	18	2.47 (0.50)	2.47 (0.68)	1.5	3.4

of K which is greater in Sarmiento *et al*. (1992 a). In relation to the micronutrients, the contents of Fe, Mn and Cu are practically of the same order in both studies, with the exception of the Zn content, which is far below that of Sarmiento *et al*. (1992 b).

In relation to the production data, the average results obtained, close to 2 g per grape, define the berry weight as low; and the average values of Baumé degree (10.3) and titratable acidity (3.0 TH_2 g L^{-1}) are less than those described by García de Luján *et al.* (1990) for Palomino Fino in the IFAPA-Rancho de La Merced (Jerez de la Frontera), of 11.0 and 3.7 TH_2 g L^{-1}, respectively.

In this study, five classes (CL1, CL2, CL3, CL4 and CL5) of vine-growing lands were established, in addition to studying altitudinal, physiographic, geolithologic, geographic and edaphologic criteria, in the main vineyard areas of the Region with the Appellations of Origin Jerez-Xérès-Sherry and Manzanilla-Sanlúcar de Barrameda. For various reasons, classes 1 and 5 include two partially different subclasses. The subdivision of CL1 was due to climatic differences and the subdivision of CL5 was due mainly to geographic, climatic and edaphologic differences.

This geo-edaphologic and climatic zoning is validated to a great extent by the foliage analysis at veraison, the quality of the must and the berry weight of the cultivated grape variety Palomino Fino. Specifically, the zoning is validated by the statistical differences found in the contents in ash and Ca in the leaves, the Baumé degree of the must, and the berry weight. The most significant differences were established between the plots of class CL1, on Miocene limestone, and those of class CL5, on Pliocene-Quaternary sands and clays. Class CL1 presented the highest content of ash and calcium, the lowest berry weight and a greater Baumé degree than the CL5, although the highest value for this variable was reached in CL2. There were also differences in the Cu content, but it is not indicative

Table 6. Zoning proposal in seven cartographic zones of the most important areas occupied by vineyards

	CL1		**CL2**	**CL3**	**CL4**	**CL5**	
	1.1	**1.2**				**5.1**	**5.2**
Soil profiles	V, VII, IX, XII, XVIII, XIX	XVI	II, XIII	III, XVII, VIII	XX, XXI, I, X, VI	IV, XI	XIV, XV
Geomorphology data							
Altitude	>60	>60	45-60	20-45	45-60	<20	<20
Physiography	Non-dissected stable plains	Non-dissected stable plains	Dissected unstable plains	Non-dissected fluvial terraces	Dissected unstable plains	Units of transition to marsh	Units of transition to marsh
Geologic material	Limestone soils	Limestone soils	Clays and Sands	Clays and Silts	Clays, Sands and Silts with rounded stones	Clays and Sands	Sands
Slope	2-13%	2-13%	2-13%	2-13%	2-13%	<2%	<2%
Precipitations							
AAP[1]	575-695	575-695	540-575	500-540	540-575	500-540	575-695
Temperature[2]							
AMAT	22.8-23.2	22.4-22.8	22.8-23.2	22.4-22.8	22.8-23.2	22.4-22.8	22.4-22.8
AmAT	10.3-11.6	11.6-13.0	11.6-13.0	10.3-11.6	11.6-13.0	10.3-11.6	10.3-11.6
AHSI	6,300-6,400	6,300-6,400	6,400-6,500	6,300-6,400	6,400-6,500	6,400-6,500	6,200-6,300
EHSI	2,700-2,800	2,700-2,800	>2,800	2,700-2,800	2,600-2,700	2,700-2,800	2,600-2,700
Precipitations and temperature[3]							
HTP	1,400-1,580	1,580-1,670	1,580-1,670	1,580-1,670	1,400-1,580	1,580-1,670	1,580-1,670
HP	<8	8.0-8.3	8.0-8.3	8.0-8.3	8.0-8.3	>8.3	<8
HI	>2,600	2,600-2,500	2,600-2,500	2,600-2,500	2,600-2,500	2,600-2,500	<2,500
Bioclimatic index[4]							
CBI	8.0-9.0	8.0-9.0	9.0-9.3	9.0-9.3	9.0-9.3	9.0-9.3	<8.0
HBI	13-14	12-13	12-13	14-15	12-13	14-15	12-13
G	22-24	18-20	20-22	20-22	20-22	20-22	20-22
Soil group	caLP; caRG	caLP; caRG	caCM; cc-crLV	peVR; ccVR; vrCL	ccLV; ccLV; cc-crLV; cr-haLV; cc-crLV	haAR;caRG	arLV;glAR
Soils	Leptosols-Regosols	Leptosols-Regosols	Cambisols-Luvisols	Vertisols	Luvisols	Arenosols	Arenosols

[1] AAP: average annual precipitation. [2] AMAT: average maximum annual temperature; AmAT: average minimum annual temperature; AHSI: active heat summation index; EHSI: effective heat summation index. [3] HTP: hydrothermal product; HP: heliothermic product; HI: huglin index. [4] CBI: Constantinescu bioclimatic index; HBI: Hidalgo bioclimatic index; G: Gorszinsky continentality coefficient.

since it is very variable and depends to a large extent on the agricultural management.

This new focus represents an important advance beyond the criterion followed by the Regulating Council of the mentioned AO's which considers two zones or classes of vine-growing land (García de Luján, 1997), 1) *Jerez Superior* on white, marl soils and 2) sherry production on other soils and lithologic materials (*Jerez Zona*). The new approach takes other factors essential for the quality of the production into account such as the climate and the geomorphology (altitude, slope, and physiography).

Regarding the study's limitations, it should be pointed out that 21 soil profiles were used and it would be interesting to expand this number in subsequent work. However, every effort was made to ensure that each soil type represented reality as closely as possible, with advice from a group of soil experts knowledgeable about the area. One of the difficulties is the availability of study plots. Frequently vineyard owners are reluctant to participate in this type of field work, mainly about the opening of the soil profiles. To this must be added the economic determinant. In practice, taking cultivation techniques, soil preparation and soil management practices into account is very complex and this information is very difficult to obtain rigorously. All the vineyards are not the same age, although efforts were made to choose those vineyards that were as homogeneous as possible regarding this variable. Nor was rootstock taken into account, they were adjusted to the most frequently used in the zone.

Conclusions

We established five classes of vine-growing land in which are distributed the main vineyard areas of the Region with the Appellations of Origin Jerez-Xérès-Sherry and Manzanilla Sanlúcar de Barrameda. Classes 1 and 5 are divided into two partially different subclasses for various reasons, mainly geographical, climatic and soil conditions.

This geoedaphic and climatic zoning is largely validated by analyzing foliage at veraison, must quality and grape berry weight of the Vitis vinifera Palomino Fino variety, specifically, by differences in the ash and Ca content of the leaf, the Baume degree of the must and grape berry weight. The most significant differences are between the plots of class CL1 on Miocene albarizas and class CL5 on Pliocene-Quaternary sands and clays.

In further research it would be very useful to extend this study to other vine-growing areas of Andalusia with AO's and resolve, as far as possible, some of the limitations of this work.

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