Characterization of pedological parameters that influence almond productivity

Caracterização dos parâmetros pedológicos que influenciam a produtividade da amendoeira

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ABSTRACT

Several almond orchards have been studied in south-eastern Spain to characterize and evaluate the soils dedicated to the cultivation of different cultivars in order to identify the parameters that most affect yield. The percentage of gravels, high in several of the soils studied, correlated negatively with the clay content and Water Holding Capacity (WHC) as did the percentage of $CaCO_3$ with available potassium. The greatest yield corresponded to soils with higher surface porosity and lower subsurface porosity, enaulic or gefuric related distribution in the surface horizons and porphyric related distribution in the subsurface horizons. Both for the Fertility Capability Classification as well as for the Agricultural Productivity Evaluation (FAO), the soils with the best characteristics for the crop did not coincide with those in which the greatest yield was found (Ferragnès registering the highest yield), due to the flowering period of the rest of the cultivars selected, which was more influenced by the climatic characteristics of the zone, especially temperature.

Key -words: Almond tree; soil characteristic and micromorphology; systems of land evaluation

RESUMO

Estudaram-se vários pomares de amendoeira situados no Sudeste de Espanha com o objectivo de caracterizar e avaliar os solos dedicados à cultura de diferentes cultivares de forma a identificar os parâmetros que mais afectam a produtividade. A percentagem de cascalho, presente em quantidades elevadas, em alguns dos solos estudados, está negativamente correlacionada com o teor de argila e a capacidade máxima de retenção de água, bem como a percentagem de $CaCO_3$ com o teor de potássio disponível no solo. As maiores produções corresponderam aos solos que apresentaram uma maior porosidade superficial e uma menor porosidade sub superficial, com uma distribuição

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enáulica ou gefúrica nos horizontes superficiais e uma distribuição porfírica nos horizontes sub superficiais. Os solos que melhores características apresentam para este tipo de cultura, quer no que se refere à sua fertilidade (Fertility Capability Classification), quer em termos da sua aptidão agrícola (FAO), não foram os que permitiram obter as maiores produções (tendo-se registado a maior produção para a cultivar Ferragnès), uma vez que o período de floração das restantes cultivares seleccionadas foi mais influenciado pelas condições climáticas da zona, nomeadamente pela temperatura, do que pelas características do solo.

Palavras-chave: amendoeira, características do solo e micromorfologia, sistemas de avaliação do solo.

INTRODUCTION

Spain, Italy, and the USA are the leading countries in almond cultivation. In Spain, this crop occupies some 700,000 ha (FAO, 2003) of which more than 195,000 are found in Andalusia, and 75,500 in the province of Granada (Junta de Andalucía, 2003). About 92% of the orchards are rainfed due fundamentally to the drought resistance of the tree, which constitutes a good crop even in situations of severe water deficit. Some works have considered irrigation as counterproductive in fine-textured soils, as the almond is prone to root rot and very sensitive to soil inundation (Barbera & Monastra, 1989).

Traditionally, the almond in Spain has been considered a rustic crop well adapted to most soil types, although Ibar (1985) pointed out that the best soils for this tree are light textured, loamy or slightly sandy, as they encourage water infiltration.

The low annual yields and their fluctuation have generally been associated with climatic conditions, such as frost and temperature. The almond is very sensitive to frost during flowering and fruit development. In temperate zones of the Mediterranean, the winter can be mild and favourable to early flowering, which is often interrupted by late frosts (Ibar, 1985). The breaking of dormancy and the onset flowering require mean temperatures higher than 7ºC during a variable time period, depending on the cultivar (Tabuenca *et al.*, 1972;Ibar, 1985).

Egea *et al.* (2003) have studied the temperature requirements for several almond cultivars grown in Spain according to Richardson *et al.* (1974). The days of cold accumulation needed to break the dormancy period varied for the cultivar Desmayo (27 days), Marcona (34 days) and Ferragnès (41 days), and therefore the flowering data (when 50% of the flowers were open) fluctuated from 28 January for Desmayo to 8 and 15 February for Marcona and Ferragnès, respectively.

Due to the economic importance of this crop and its involvement in environmental processes in arid as well as semiarid zones, it has drawn the attention of numerous researchers in recent years (Valverde, *et al.*, 2006; Van Wesemael *et al.*, 2006; Gomes-Laranjo, *et al.*, 2006; Romero & Botía, 2006). However, most of these works are oriented towards the use of water resources and their influence on yield, while few works are available on the pedological characteristics that determine the crop, despite the influence that these parameters can have on the development of the crop.

The rise in the number of orchards in the Mediterranean region and their repercussion in the protection of poorly productive land, vulnerable to strong erosion processes on being abandoned, makes studies necessary in order to identify the most suitable cultivar and soils.

The aim of the present paper is to characterize and evaluate the soils dedicated to the cultivation of different cultivars of almond in order to determine the parameters that most affect yield.

MATERIALS AND METHODS

The study took place at six almond orchards in the Valle de Lecrín (Granada province, SE Spain), very close to each other and under the same system of management. These orchards include all the varieties of almond present in the region and the number of plots sampled was proportional to the surface area occupied in the region. Also the different soil types existing in the region were represented (Sierra *et al.*, 1992). The mean annual precipitation is roughly 430 mm, with the absolute rainfall maximum in winter and two secondary peaks in spring and autumn. The mean annual temperature is about 16ºC, with the zone being protected from cold northern winds thanks to various mountain chains but being exposed to cold, wet winds from the west. Even so, the mean temperatures of December and January do not exceed 10ºC, and in both months frost is frequent and that is registered even in February (Table 1).

The soils were classified according to FAO (1998) as thapto-luvic petric Calcisol (P-1), hypercalcic Cambisol (P-2), calcic Luvisol (P-3), thapto-luvic calcic Regosol (P-4), haplic Calcisol (P-5) and humic Regosol (P-6).

For the analysis of the pedological parameters, samples were collected from each horizon, air dried, and screened (<2 mm). The textural analysis was made by the pipette method of Robinson (Soil Conservation Service, 1972). The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were extracted with NH_4OAc 1M and the cation exchange capacity was determined by saturation in sodium and, after to washing with alcohol, extraction of adsorbed sodium with NH_4OAc 1M (Soil Conservation Service, 1972). The pH was measured in a soil suspension in distilled water (1: 2.5) using a Crison 2002 pH meter.

For the determination of the organic carbon, nitrogen, phosphorus, and $CaCO_3$ equivalent, the sample was ground and screened again (0.125 mm pore size). The

Table 1 - Climatic characteristics of the zone

Year	Precipitation (mm)	minimum Temp December (ºC)	minimum Temp January (ºC)	minimum Temp February (ºC)
1995	135	-1.2	-1.4	-0.8
1996	676	-1.6	1.2	-3.2
1997	767	-0.8	0.6	2.6
1998	531	-0.6	0.8	1.4
1999	165	-0.8	-1.6	-2.8
2000	442	-0.4	-1.2	2.8
2001	379	-0.6	-1.0	1.2
2002	409	-0.0	0.4	1.0
2003	545	-0.5	-3.0	-3.0
2004	491	-1.8	-1.2	0.0
2005	134	-3.2	-6.4	-2.6

content of the organic carbon was determined using the method of Walkey & Black (1934) modified by Tyurin (1951); for the total nitrogen, the Kjeldahl method was used (Bremner, 1965); the available P was measured by the classical Olsen method (Olsen *et al.*, 1954); and the $CaCO_3$ equivalent was determined by a manometric method (Williams, 1948).

The WHCwas calculated using the following expression:

WHC (mm) = (FC – PWP) x DAHF x Cm x Depth (dm), where FC is the moisture content at field capacity extracted in a pressure plate at 33 kPa and PWP the moisture at the withering point, measured at 1500 kPa (Casel & Nielsen, 1986). DAHF is the bulk density of the fine earth. Cm (percentage of fine earth) was calculated using the fallowing expression:

Cm = (Dg (1-G/100)) / ((Dg (1-G/100) + DAHf x G/100), where G is the percentage of gravels and Dg the density (Soil Conservation Service, 1972).

The soils were micro morphologically characterized in thin sections prepared according to the method of Page & Richard (1990) and described in accordance with Bullock *et al.* (1985) and Brewer (1964). The porosity was quantified by an Ibas 2000 image analyser, examining 30 microscopic fields in each thin layer.

The cultivated varieties were Ferragnès (P-1; P-4; P-5), Desmayo largueta (P-2) and Marcona (P-3; P-6). The capacity of potential use of each soil was evaluated by the Fertility Capability Classification (FCC) proposed by Buol *et al.* (1975) and modified by Sánchez *et al.* (2003), as well as by the Agricultural Productivity Evaluation system FAO (Riquier, Bramao & Cornet 1970).

Yield was monitored for the period 1995-2005, although sometimes yield was null, especially in the varieties Desmayo and Marcona.

The statistical analysis was performed using the computer program SPSS 11.0.

RESULTS AND DISCUSSION

Morphological and physico-chemical characteristics of the soils

The soils studied were more than 80 cm deep, except for soil P-2, which presented a calcareous crust at 25 cm that might be a physical limitation for root growth. The characteristics of these soils are presented in Table 2, which shows gravels to be abundant in all the profiles, although in some horizons, discontinuous with the rest of the profile, the gravels are scarcer, as in horizons Ap and 2Bt of profile P-1, and in horizon 3Btk of profile P-4. Their composition was quartzitic and schistose in most cases, and the degree of alteration varied in the different soils, being generally medium to high for the schists and lower (affecting exclusively the borders) in the quartzites.

The textures varied in the different horizons, with the heavy-textured clays or loamy clays predominating, although some horizons, such as the profile P-6, have loamy textures. The content in calcium carbonate was very high in all the profiles, and generally increased in depth, frequently exceeding 40%. Despite these fine textures and the profile depth, the Water Holding Capacity was low due to the abundant gravels.

The organic-carbon content was low in all the horizons, conditioned by the crop traditional tillage without adding any organic debris, as was the phosphorus and potassium contents. Nitrogen was higher on the surface, being supplied by the fertilizer.

To establish the influence of the pedological parameters in the productivity of

Table 2- Main characteristics of the soils studied

Hor	Depth (cm)	OC (%)	N (%)	P (mg kg^{-1})	K (cmol$_c$ kg^{-1})	CIC (cmol$_c$ kg^{-1})	$CaCO_3$ (%)	pH	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	ρ_b (Mg m^{-3})	WHC (mm)
P-1														
Ap	0-21	1.01	0.11	9.80	0.92	17.88	66.79	7.8	2.5	26.6	29.8	43.6	1.37	25.2
Ck	21-53	0.39	0.39	9.70	0.40	10.67	17.68	8.1	23.9	29.3	33.5	37.2	1.46	49.2
2Bt	63-68	0.30	0.30	6.90	0.46	12.60	24.55	8.5	6.6	31.7	27.0	41.3	1.47	19.4
P-2														
Ap	0-13	1.26	0.15	5.44	0.40	11.65	60.28	8.2	27.7	45.0	29.0	26.0	1.40	13.6
Bw	13-25	0.93	0.19	1.03	0.20	11.65	46.97	8.3	25.8	42.4	28.0	29.6	1.43	11.4
Ck	>25	0.69	0.10	0.95	0.12	18.60	81.43	8.1	48.4	48.9	28.8	22.3	1.49	21.7
P-3														
Ap	0-28	1.07	0.13	4.96	0.92	5.40	1.61	7.9	35.2	56.9	29.4	13.6	1.47	25.5
Bt1	28-51	0.40	0.09	0.63	0.40	5.79	9.07	8.1	30.7	49.9	24.4	25.7	1.52	20.0
Bt2	51-80	0.29	0.09	0.83	0.46	13.72	10.16	8.0	26.0	37.0	27.8	35.2	1.49	24.9
P-4														
Ap	0-15	1.00	0.15	10.6	0.58	10.42	0.63	8.0	37.9	51.2	21.2	27.5	1.44	12.2
2C	15-42	0.51	0.10	4.73	0.40	8.23	26.86	7.6	26.5	52.9	20.4	26.5	1.50	24.9
3Btk	42-68	0.33	0.08	0.82	0.20	10.93	6.67	7.5	3.6	27.3	19.0	53.7	1.43	37.3
P-5														
Ap	0-18	0.95	0.09	3.35	0.14	3.49	87.29	8.3	67.4	37.4	52.0	10.6	1.46	4.0
2C	18-72	0.42	0.08	0.84	0.09	2.33	95.50	8.6	76.8	33.4	55.4	11.2	1.52	10.1
3C	>72	0.12	0.03	0.70	0.06	1.16	95.80	8.8	69.5	66.8	28.9	4.3	1.62	3.5
P-6														
Ap	0-30	2.23	0.23	2.06	0.40	9.65	77.42	8.1	59.3	43.8	41.7	14.5	1.31	19.8
C1	30-52	0.77	0.12	0.55	0.12	4.89	77.24	8.0	75.4	40.6	45.3	14.1	1.48	10.5
2Ck	52-68	0.20	0.06	0.62	0.12	1.85	93.06	8.2	55.0	43.3	41.7	15.0	1.55	11.5

the crop, we used a weighted mean of the pedological variables studied in the three uppermost horizons (Table 3).

With the Pearson correlation coefficient (Table 4), the correlations between the percentage of gravels, clay, and Water Holding Capacity were bilateral, negative, and significant at the level of 0.01. There was a notable correlation, also negative, between the calcium carbonate content and available potassium. One of the causes for the lower yield in the soils with high $CaCO_3$ contents was presumably the low availability of potassium, although we cannot affirm this only with the data gathered in the present work, and further studies will be needed to verify this assumption.

The mean productivity was correlated with the clay content, the WHC and available P. These correlations however,

Table 3 – Weighted mean of the parameters studied

profiles	OC_{wm}	N_{wm}	P_{wm}	K_{wm}	CEC_{wm}	$CaCO_{3wm}$	pH_{wm}	$Gravel_{wm}$	$Sand_{wm}$	$Clay_{wm}$	$Silt_{wm}$
P-1	0.53	0.09	19.31	0.54	13.0	31.1	8.1	14.4	29.2	39.8	31.0
P-2	0.92	0.14	2.27	0.22	13.7	66.1	8.2	36.4	46.0	25.3	28.7
P-3	0.59	0.10	2.22	0.60	8.5	6.9	8.0	30.6	47.7	24.9	27.4
P-4	0.55	0.10	4.53	0.36	9.8	15.5	7.7	20.3	42.7	37.1	20.1
P-5	0.46	0.07	1.30	0.09	2.3	96.0	8.6	72.8	41.5	9.6	49.0
P-6	1.28	0.15	1.23	0.24	6.3	81.0	8.1	63.5	42.7	14.5	42.9

Table 4 - Pearson's correlation coefficient for the parameters studied.

	Gravel	Sand	Silt	Clay	WHC	OC	N	P	K	CEC	$CaCO_3$	pH	porosity
Gravel													
Sand	0.319												
Silt	0.897	-0.095											
Clay	-0.974**	-0.461	0.897*										
WHC	-0.936**	-0.570	-0.712	0.946**									
OC	0.357	0.280	0.225	-0.352	-0.355								
N	0.089	0.357	-0.089	-0.112	-0.180	0.940**							
P	-0.640	-0.918**	-0.244	0.718	0.820*	-0.356	-0.313						
K	-0.778	-0.231	-0.623	0.682	0.838*	-0.288	-0.145	0.541					
CEC	-0.822*	-0.236	-0.741	0.790	0.700	0.05	0.333	0.533	0.492				
$CaCO_3$	0.888*	0.204	0.777	-0.804	-0.888*	0.412	0.212	-0.538	-0.966**	-0.572			
pH	0.711	-0.112	0.858*	-0.704	-0.619	-0.038	-0.247	-0.118	-0.559	-0.483	0.660		
porosity	-0.717	-0.201	-0.728	0.759	0.713	0.247	0.416	0.383	0.537	0.636	-0.586	-0.896*	
Yield	-0.586	-0.519	-0.478	0.708	0.646	-0.615	-0.544	0.543	0.316	0.168	-0.469	-0.520	0.507

*. Correlation significant at 0.05 (bilateral)
**. Correlation significant at 0.01 (bilateral)

Table 5 - Yield values for the years 1995 to 2005.

	Profiles					
	P-1	P-2	P-3	P-4	P-5	P-6
Year	Production (kg ha^{-1})					
1995	9.1	25.8	20.0	9.6	8.7	28.7
1996	189.7	49.9	101.8	225.8	108.2	64.8
1997	298.9	124.8	206.2	416.3	238.0	184.2
1998	361.3	73.6	137.0	406.7	233.7	113.6
1999	29.9	36.8	16.6	28.8	26.8	10.6
2000	322.3	82.4	187.6	421.1	212.9	119.4
2001	314.5	109.9	123.1	406.7	206.9	109.9
2002	348.3	159.4	178.9	433.9	220.7	114.1
2003	114.4	86.3	69.2	105.7	64.9	76.4
2004	130.0	81.0	131.0	144.1	77.9	115.2
2005	2.6	21.9	12.0	14.4	13.9	7.4
	Mean yield (kg ha^{-1})					
	192.8	77.5	107.6	237.6	128.4	85.9

did not reach statistical significance. This lack of statistical correlation would be expected if we consider jointly all the varieties present in zone, and, as stated above, the climate exerts an extraordinary effect on the flowering date, depending on the cultivar. Thus, Desmayo and Marcona had years of null or practically null yield (Table 4 and Table 5).

The principal-components analysis reveals three components that explain 91.8% of the variance (Table 6). Almost 60% of the variance was explained by the first component, in which the variables with greater weight were WHC and clay (negative), and calcium carbonate and the percentage of gravels (with a positive relation). In the second component nitrogen and organic carbon had the greatest weight.

If instead of pooling all the samples, we grouped them by varieties we would find that the most productive cultivar was Ferragnès (clearly due to its late flowering period), followed by Marcona, and finally Desmayo. Within these, the preponderant role of clay and the negative correlation with $CaCO_3$ becomes more apparent.

Table 6 - Principal-components analysis of the soils studied.

	Component		
	1	2	3
WHC_{wm}	-0.980	-0.102	0.124
OC_{wm}	0.383	0.715	0.533
K_{wm}	-0.836	0.012	-0.152
N_{wm}	0.155	0.873	0.455
P_{wm}	-0.721	-0.489	0.490
CEC_{wm}	-0.758	0.348	0.340
$CaCO_{3wm}$	0.919	-0.023	0.251
$Sand_{wm}$	0.423	0.643	-0.607
$Clay_{wm}$	-0.970	0.023	0.076
$Silt_{wm}$	0.829	-0.419	0.288
$Gravel_{wm}$	0.985	-0.099	0.035
pH_{wm}	0.685	-0.541	0.230
% accum. variance	58.47	79.60	91.77

Micromorphological characteristics

A complete micro morphological study was made though only the most important aspects are pointed out (Table 7).

The study of the micromorphological characteristics of the soils served to establish the influence of the physical parameters on yield. The microstructure was not developed in some profiles, such as P-1 and P-3, while the rest had granular or crumbly structure on the surface to subangular blocks in the B horizons (Table 7). The c/f-related distribution was primarily enaulic or porphyric, though in some soils were gefuric or even monic.

The basal mass of the soil was abundant and carbonated, coinciding with the relatively high quantities of carbonates detected in the chemical analyses. The pores and nodules frequently appeared surrounded by a clayey or humus-clayey matrix, with lighter zones for the elimination of the matrix. The carbonate nodules constituted the most common micromorphological feature.

Diverse forms of the pedological features of calcite appeared, the most frequent were recrystallizations, needle-like crystals and coatings, occasionally associated with clay cutans. In the P-3 profile, there were also small ferruginous needle-like nodules. Clay cutans appear only in this profile. Presumably, in other soils these had disappeared due to agricultural practices. In agreement with Mack (1992), carbonates are retained in the soils when rainfall is less than 600 mm, as in the studied zone, where the analyses indicate a certain leaching of the carbonates from the upper horizons, although it is not sufficient to cause the mobilization of the clay. This mobilization and accumulation in the B horizons occurred in the profile with the lowest calcium carbonate content (Table 2). Nevertheless, the presence of calcium carbonate and crystallizations in the soil matrix could be due to subsequent recarbonation processes, so that numerous clay cutans were transformed into calcite deposits. Similar processes in decarbonated soils have been described by several authors (Aguilar *et al.*, 1983; Delgado *et al.*, 1994, Khormali *et al.*, 2003).

The pores varied markedly in size and shape (Table 7), although those of simple and compound packing voids predominated, with occasional equidimensional and elongated vughs and relatively frequent planar voids. Also, the size varied widely, although macropores and mesopores predominated, with micropores being present in lesser quantities. The distribution was random in most of the horizons, although they also appeared horizontally and vertically. This abundant porosity allowed adequate circulation of water and gases in the soil, impeding hydromorphic processes, which, as mentioned above, are harmful to the crop. In fact, no signs of current hydromorphy appeared in any of the studied profiles.

The micromorphological study corroborated the data of the chemical analysis and provided another relationship—i.e. the highest productivity corresponded to the greatest surface porosity and lowest subsurface porosity. Also, the soils with the highest yield presented a porphyric-related distribution in the subsurface. Thus, we first need to consider the cultivar and on this basis we can state that the most favourable distribution with respect to yield is enaulic and then gefuric aboveground while the most favourable underground is porphyric. With respect to porosity, when we take into account the cultivar, we find that the greater the surface porosity and the lower the subsurface porosity, the greater the yield.

Table 7 - Main morphological characteristics of the soils studied.

Ho riz.	Components						Porosity (>30 µ)				
	Skeleton grains		Fine material		Organic matter	Micro-struc-ture	Description	Abundance (%)	Orientation	Relation c/f limit c/f	Related distribution
	Size	Shape	Mineralogy/ orientation/ degree of altera-tion	Transparency (light paral-lel)							
P-1											
Ap	Abundant coarse sand; lesser amounts of fine sand and silts	Surface ir-regular, subangular and rough	Quartz and mus-covite, random, medium –high.	Spotted	Fossil re-mains very refringent, scattered	Not aggre-gated	Simple and com-pound packing voids, some vughs and channels	51.34	Horizontal	70/30 5 µ	enaulic
Ck	Abundant coarse sand	Irregular, slightly rounded	Quartz and very rare muscovite and biotite. Slightly altered	Spotted		Not aggre-gated	Irregular, non-rounded, vughs	27.04	Not ori-ented	50/50 5 µ	porphyric open
2Bt	Very abundant fine sand	Polyhedral	Quartz, musco-vite and rare bio-tite	Spotted		Suban gular blocks	Irregular vughs, ser-rated walls and less frequent smooth walls and slightly serrated; some fissures.	17.26		40/60 5 µ	porphyric closed
P-2											
Ap	Variables very fine silt and sand	Needle-like angular and sub-rounded.	Quartz and quartzite; ran-dom, hardly al-tered	Nebulous or spotted in some zones	Anisotropic organic re-mains not recogniz-able	Crum-bly crys-talline aggre-gates	Elongated vughs and simple packing voids	33.32	Not ori-ented	75/25 5 µ	gefuric
Bw	Very abundant coarse sand	Irregular. Polyhedral or needle-like	Quartz. musco-vite and biotite	Dusty		Granu-lar ag-gre-gates	Simple packing voids. Elongated vughs	26.14	Not ori-ented	80/20 5 µ	Porphyric open
C	Abundant fine sand, the rest silt	Tabular or ovoid, subangular	Polycrystalline quartz with in-clusions of mus-covite with ran-dom, isolated crystals	Spotted		Not devel-oped	Simple packing voids	24.18	Vertical tendency	10/90	Porphyric open

Table 7 - Main morphological characteristics of the soils studied (continuation).

P-3											
Ap	Fragments of coarse sand rounded	Tabular, moderately rough surface		Nebulous, crystal-lamorph	Very scarce vegetal remains; tissues lignified and pigments.	Free grains	Simple and compound packing voids	40.04	Not oriented; not related	95/5	Enaulic
Bt_1	Abundant very fine sand or silt; some very coarse sand		Crystals from quartz and biotite	Spotted.	Absent	Not aggregated with vughs	Simple and compound packing voids	20.12	Not oriented	99/1	Porphyric
Bt_2	Very fine sand		Quartz	Nebulous crystallomorph		Not aggregated	More vughs than packing voids, some fissures.	20.86		80/20	Porphyric
P-4											
Ap	Very abundant of all sizes; fine and very fine sand	Rectangular and more or less square	Quartz and schists	Spotted	Do not appear	Granular aggregate	Equidimensional and elongated vughs	58.36		70/30	Enaulic
2C	Coarse sand	Irregular; some square; the smallest ovoid	Quartz at random	Spotted		Not developed	Few simple packing voids; abundant vughs; very scarce planar voids	38.64	Random	99/1	Enaulic
3Btk	Very fine sand	Needle-like	Muscovite, linear and concentric around pores and skeleton grains	Crystallomorph	Scarce, undifferentiated and anisotropic tissue remains; scarce pigments	Subangular blocks	Compound packing voids, some planar voids	15.20		75/25	Enaulic and porphyric
P-5											
Ap	Abundant silts, with a smaller quantity of fine sand	Irregular, polyhedral and subangular	Calcite, hardly altered	Nebulous		Granular	Packing voids and vughs	44.67		95/5	Gefuric with some domains of monic

Table 7 - Main morphological characteristics of the soils studied (continuation).

P-6

Ap	All sizes and most included in the aggregates			Nebulous, spotted	Frequent residues of tissues in which cell walls are recognized; pigments	Crumbly aggregates	Packing voids and channels	36.12		99/1	Gefuric
C1	Frequent of fine and very fine sand and silts	Not spherical; angular and of moderately rough surface	Carbonates hardly altered	Spotted; crystallomorph		Rock fragments, polyhedral	Packing voids	24.86	Random	90/10	Gefuric
2Ck	Dominant fine sand and silts	Irregular, angular, with rough surface	Calcite, random, hardly altered	Occasional, nebulous and crystallomorphic		Not aggregated	Simple packing voids and vughs	26.14		90/10	Gefuric; in some zones enaulic with diffuse limits

Yield and evaluation systems by the FAO and FCC

To study the possible relationship of yield with some of the existing evaluation method, the systems of Riquier, Bramao & Cornet (1970) and Sanchez *et al.* (2003) were used.

The mean yield for the period 1995-2005 is shown in Table 5. The orchards varied to a greater or lesser degree, following the order: P-4>P-1>P-5>P-3>P-6>P-2. The most productive variety was Ferragnès, followed by Marcona and, finally, Desmayo largueta. The Agricultural Productivity Evaluation System of the FAO (Riquier, Bramao, & Cornet, 1970) enabled us to calculate the productivity and potentiality index, considering some management practices optimal and some conditions outside the disease-free soil environment and with excellent varieties.

Table 8 - Evaluation systems of productivity FCC =Fertility Capability classification (2003)
Riquier = Riquier, Bramao & Cornet method (1970)

Profiles	FCC	Riquier
P-1	$Cdr^{+}b$	25.9
P-2	$Ldr^{++}b$	19.6
P-3	Sdr^{+}	31.1
P-4	$Ldr^{+}b$	28.0
P-5	$Ldr^{++}b$	18.8
P-6	$Ldr^{++}b$	28.0

The values of the productivity index are listed in Table 8. As can be seen, in accordance with the evaluation system, there were marginal soils for nonforest tree crops, and even in profiles P-2 and P-5 the value of the index was even lower than the recommended for recreation, pasture, or special crops. The main limitations according to this classification system were the low organic-matter content, the low cation-exchange capacity, the high calcium carbonate content (except in profiles P-4 and P-3), and shallowness (in the case of profile P-2).

The order of suitability of the soil to the crop, according to this classification, was: P-3>P-4=P-6>P-1>P-2>P-5. These results do not coincide with the relationships established if we regard the average yield. The low value of the productivity index of profile P-5 is striking, as it does not coincide with the real yield obtained. This low value was the result primarily of the high calcium carbonate content in the profile, from the decomposition of parent material (dolomite). However, the cultivar used adapts well to the local climate and counteracts the negative effect of the carbonate, although with lower yield in the three soils in which the same cultivar is grown.

Something similar could be argued for profile P-3, with the highest productivity index according to this classification system but with low real yield, in this case the cultivar is Marcona. Probably, the flowering period in the first days of February (Egea *et al.*, 2003) caused the low productivity, even lower than that in the most unfavourable soil, from the standpoint of the productivity index, for its shallowness, P-2.

The results of applying the Fertility Capability Classification are presented in Table 8. The soils P-2, P-5, and P-6 fit into this system in the same category, on presenting a loamy surface texture (L), a very dry season (d), more than 35% gravels in the upper 50 cm of the soil (r^{++}), and high carbonate content (b). These soils are differentiated from P-4 only in gravel content, which in this soil did not surpass 35% (r^+). The soil P-1 can be distinguished from P-4 by the clayey surface texture (C). Finally, soil P-3 stands out from the rest by the sandy-loamy surface texture (S) and by the lower calcium carbonate content.

Again, the soil P-3, as observed above on applying the FAO evaluation system, presented the lowest limitations for the crop, although the low real yield appears to be related to the poor adaptation of the cultivar chosen.

CONCLUSIONS

The main limiting factor on productivity in the almond tree in the study area is climate, which can be corrected for by using late-flowering varieties. These varieties can counteract the negative properties of the soils, such as the high calcium-carbonate content in the profile.

The differences observed between the FAO evaluation index and real yield is due to the greater suitability of the cultivar Ferragnès to the climate of the zone.

The presence of high clay contents are not advantageous on the surface, but it is a very important parameter in the subsurface, especially for the location of this crop primarily in arid zones, which gives rise to porosity above and greater Water Holding Capacity belowground.

In summary, the main parameters for almond production are: the cultivar, which determines the flowering period; the clay content, which governs porosity and water retention, especially in the subsurface, due to the existence of a porphyric related distribution; good surface porosity, which is due to the existence of a enaulic or gefuric related distribution; and finally the great quantities of $CaCO_3$.

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