VEGETATIVE GROWTH AND EARLY PRODUCTION OF SIX OLIVE CULTIVARS, IN SOUTHERN ATACAMA DESERT, CHILE

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ABSTRACT

Tree survival, early fruit production, vegetative growth and alternate bearing were examined in six different olive cultivars (Barnea, Biancolilla, Coratina, Empeltre, Koroneiki and Leccino) under intensive agronomic conditions in southern Atacama Desert, in the Coquimbo Region of Chile. The cultivars were evaluated over four successive years and had a high survival rate (93%) confirming their potential for these dry-lands. Fruit production (recorded over the growing seasons 2002-2003), vegetative growth (2000-2003) and alternate bearing differed significantly among cultivars. Olive selection in intensively managed planting at the southern part of the Atacama Desert depends on matching specific cultivars to sites on which they perform the best.

KEY WORDS: Olea europaea, survival, alternate bearing, fruit production, longitudinal analysis.

INTRODUCTION

The Mediterranean climate has environmental conditions which are regarded advantageous for the establishment of olive (Olea europaea L.) plantations. The Mediterranean Basis area produces over 90% of the total olive production. The Olive is one of the most widely cultivated and economically important fruit crop for several subtropical Mediterranean countries, mainly for Croatia, Greece, Italy, Spain, Portugal and Turkey [2].

This crop is having an increasing economic interest beyond subtropical Mediterranean Basis countries, such as Argentina, Australia, Brazil, Chile, South Africa and USA. The olive tree has been naturalized in several regions of America, where it is used for the olive industry.

Cultivars such as Barnea, Biancolilla, Coratina, Empeltre, Koroneiki and Leccino have many practical applications for the virgin oil industry, but their performance is relatively not documented in the southern part of the Atacama Desert, in the administrative region of Coquimbo, Northern Chile. This dry-land has a Mediterranean climate and in the last decade several projects (supported by Chilean government programs) were undertaken for providing the farming technical solutions.

Olive trees can be grown under environmental conditions that present prolonged periods without any precipitations; a common environmental condition of the Mediterranean climate with arid or semiarid tendency [11]. The arid zone of Northern Chile has a relative agronomic potential for cultivation and agro-industrial exploration of improved olive cultivars. Therefore, farmers are beginning to establish intensively managed olive orchard, and research institutions are conducting productivity improvement programs for this crop. Regional research institutions have been implementing a strategy which include the assessment of olive cultivars in several environmental conditions (trough time) in order to estimate differentiable genotypic response and to improve the productivity of olive plantations. The precocity of the production (leading to a more rapid return on investment), absence of alternate bearing and high fruit production per tree are some of the characteristics searched in an olive cultivar under these arid conditions.

Repeated measures data applied to the same experimental unit are frequently unbalanced and strongly correlated [15]. Alternate bearing of olive trees may be an adequate example of correlated response data. This trait is related when some cultivars have a tendency to produce higher yields in a year followed by lower yields the following year [18]. So, the alternate bearing may be one of the main limiting factors for olive production.

Researchers are habitually interested in analyzing data that arise from a longitudinal study (repeated measures or clustered design) in which exists correlation among observations on a given subject [10]. An example of longitudinal analysis is when the olive production and vegetative growth are measured over the same tree (subject) through time.

In this article we aimed at examining vegetative growth and fruit production over four and two growing seasons, respectively, in six different olive cultivars: Barnea, Biancolilla, Coratina, Empeltre, Koroneiki and Leccino. Tree survival (monitored after four growing seasons) and alternate bearing index (using the fruit production data sets) were also examined. The understanding about the early performance of these olive cultivars will be crucial to maximize the olive productivity under intensive agronomic conditions in southern Atacama Desert.

MATERIALS AND METHODS

Study locations

Six different olive cultivars (Barnea, Biancolilla, Coratina, Empeltre, Koroneiki and Leccino) were hand-planted on three sites in Coquimbo administrative Region of Chile: Illapel, Ovalle and Monte Patria (Table 1). This region has an arid Mediterranean climate, in which the precipitations are concentrated mainly during the winter months (June to September), with average annual precipitation varying from 132 mm to 208 mm (Table 2). In Ovalle (localized in the rural area of Cerrillos) there is a relatively lower mean temperature because of the influence of sea fogs which are directly associated to the cold Humboldt Current in the Pacific Ocean [17]. Illapel has a relatively lower average temperature than Monte Patria due to its higher latitude.

The trials were established in spring 1999. In each field experiment a drip irrigation system was implemented, in which the crop water requirements were estimated according to Orgaz and Fereres [16] and Doorenbos and Pruitt [5] based on pan evaporation reposition.

Study design and trait measurements

The treatments (cultivars) were restricted in a randomized complete experimental design in each location, with six trees per plot, and 8 x 4 m of density.

Total tree survival was recorded in spring 2003 (after four growing seasons). This trait was measured as a binary response. Absolute growth rate of the stem perimeter and fruit production were recorded over the growing seasons 2000-2003 and 2002-2003, respectively. The fruit production data sets were used to examine the alternate bearing index which was calculated using the following formula [18]:

Table 1: Sites of Mediterranean semiarid region of Chile considered in the assessment of the six olive cultivars.

Sites	Province	Latitude (S)	Longitude (W)	Altitude (m)
Ovalle	Limarí	30° 35’	71° 28’	200
Illapel	Choapa	31° 50’	70° 51’	580
Monte Patria	Limarí	30° 45’	70° 44’	820

Table 2: Climatic data of the three localities studied in the Mediterranean semiarid region of Chile.

Localities	Cold-hours (0-12.5°C)	Relative Humidity (%)	Pan evaporation (mm year^{-1})	Precipitation (mm year^{-1})	Mean Temperature (°C)
Ovalle	2194	69.92	1702	132	14.61
Illapel	2029	59.70	1807	208	15.40
Monte Patria	1918	53.11	2050	152	15.99

$$ABI = \left(\frac{1}{(n-1)}\right)\left\{\frac{|(a_2 - a_1)|}{a_1 + a_2} + \frac{|(a_3 - a_2)|}{a_2 + a_3} \cdots + \frac{|(a_n - a_{n-1})|}{a_{n-1} + a_n}\right\}$$

Where n is the number of years of evaluation; $a_1, a_2, a_3, \ldots, a_{n-1}, a_n$ are the fruit productions per tree (kg tree^{-1}) which were measured in the respective period of analysis (the growing seasons 2002-2003).

Statistical analysis

Total tree survival was analyzed using a generalized linear modeling approach (GLM) [14] because the variable response was considered binary, i.e. Bernoulli distribution. This analysis was carried out using GENMOD procedure of SAS software [21]. Mean separations were performed using contrasts (α=0.05).

Early fruit production was also assessed using generalized linear models due to the presence of problems with the normality assumption. As two growing seasons were jointly evaluated (longitudinal analysis), the agronomic data analysis was conducted using Generalized Estimating Equations [13], an extension of GLM to fit a generalized linear model to clustered data [24]. The previous assumptions of normality for fruit production data were checked by visually inspecting a normal-plot and by using the following statistics: Shapiro-Wilk, Chi-square and Lilliefors [6]. The Normal probability plot and statistic tests were performed using the SAS-INSIGHT and UNIVARIATE procedures of SAS [21]. The approximate distribution of this variable was judged by visually inspecting a plot of the outcome using the R program according to [6]. The model adequacy checking was also conducted using the GENMOD procedure [21]. The comparison between independence and dependence working correlation matrixes (WCM) was done according to Myers et al. [15] and Liang and Zeger [13].

Absolute growth rate of the stem perimeter (measured from 2000 to 2003) was analyzed using MIXED procedure of SAS [21] regarding a longitudinal study. Seven different correlation structures were fitted for the residual (co) variance matrix: Variance Components (VC), Banded Toeplitz (TOEP2 and TOEP3), Autoregressive (AR1), Compound Symmetry (CS), Huynh-Feldt (HF) and Unstructured (UN), which were tested using the Schwarz’s Bayesian information criteria (BIC) and the Akaike’s information criteria (AIC).

Alternate bearing index was analyzed using GLM procedure of SAS [21] and mean separations were performed using Tukey’s t-test (α=0.05).

RESULTS AND DISCUSSION

The survival did not differ significantly among olive cultivars after four growing seasons ($p>0.05$; Table 3) and achieved an average value of 93%, confirming the potential of these cultivars for intensively managed olive production in Southern Atacama Desert. The cultivar-site interaction and site effects were also not significant ($p>0.05$).

Fruit production differed significantly among cultivars ($p<0.01$; Table 3). The site and cultivar-site interaction effects were also significant ($p<0.01$). The statistical analysis carried out in R program has confirmed lack of symmetry for the data distribution of this trait. The Kernel Density Estimation method was used for estimating the mode value (using SAS-Insight), which was 3 kg tree^{-1}, and it was much lower than the mean (14 kg tree^{-1}). Therefore, a generalized linear model was used with Gamma distribution [8] and log link function. The Gamma distribution has many applications in regression analysis, in which the response variable is continuous and the variance is not constant but rather is proportional to the square of the mean [15]. In the present study the square of the mean was proportional to the variance (σ^2=189.4).

In the Generalized Estimating Equation approach, the working correlation matrix (WCM) has showed a correlation over 0.3 (the rho-value of the WCM was -0.3216), which is regarded an appropriated correlation for a non-independent structure [15, 13].

Due to the cultivar-site interaction effect was significant for fruit production an analysis site-to-site was carried out. This analysis is given in Table 4. The WCM showed different structures in each of the sites, which evidenced a high correlation in Ovalle (ρ=-0.88), moderate in Illapel (ρ=-0.45) and null correlation in Monte Patria (working independent correlation matrix).

The model parameters (estimated using a generalized estimating equations approach) are also given in Table 4. The equations for fruit production are the following:

$$P_{Illapel} = EXP(2.4653 + 0.5641\,KO + 0.649\,LE + 0.9359\,BA + 1.038\,CO - 2.1652\,BI)$$

$$P_{Ovalle} = EXP(2.3918 + 0.3295\,KO + 0.8177\,LE + 0.5752\,BA + 0.4276\,CO)$$

$$P_{Monte\ Patria} = EXP(1.0761 + 1.7027\,KO + 1.4032\,BA + 0.9186\,CO)$$

where P is the mean fruit production (kg tree^{-1}) in each site; KO, LE, BA, CO and BI are the cultivars Koroneiki, Leccino, Barnea, Coratina and Biancolilla, respectively. The models have exponential form due to the logarithmic link function.

In this case, the generalized estimated equations models represent the contribution of each parameter (or cultivar) over mean fruit production. Parameters with positive signs indicate that a specific cultivar increases the mean fruit production and negative signs indicate that such cultivar contribute to reduce the mean fruit production in a specific site. For example, in Illapel site, Koroneiki, Leccino, Barnea and Coratina cultivars have a positive and significant effect over fruit production, based on generalized estimating equation analysis. On the other hand, Biancolilla has a significant but negative effect (reducing) over mean fruit production in the same site. The same analysis may be done for each site.

The cultivar-site interaction effect may also be checked in the generalized estimating equations models fitted site-to-site. Leccino performed relatively well in Ovalle site, but in Illapel and Monte Patria sites, Coratina and Koroneiki, respectively, were the cultivars that performed the best, and Leccino was not significant over mean production in Monte Patria.

Despite Koroneiki is a cultivar that may evidence a greater yield, such as in Monte Patria site, Stefanoudaki et al. [22] affirmed that the oil quality of this cultivar may be influenced by the water availability. However, the dependence of the water availability on quality oil is not a particular feature of Koroneiki; Proietti and Antognozzi [19] whose worked with Ascolana cultivar, affirmed that a adequate soil water is also important for obtaining a satisfactory fruit size, which is strongly correlated with its commercial value. In Mediterranean climate conditions, where summer precipitations are modest, such as arid or semiarid regions, the irrigation can improve the commercial value of olive fruit.

Significant growth differences occurred among olive cultivars ($p<0.01$; Table 3). Growth was also significantly influenced by environment and cultivar-site interaction ($p<0.01$). The uncorrelated covariance structure performed the best according to both statistical information criteria (Akaike and Schwarz's Bayesian information criteria).

Koroneiki showed low values of growth rates in all sites (Table 5), which appear to be inversely correlated with the fruit production. Coratina evidenced a positive effect over mean fruit production in all sites, and performed well for growth rate in the three sites. Coratina cultivar is widely grown in southern Italy where it has showed excellent yield. Antioxidant properties have also been reported by Aldini et al. [1], although Coratina could be more sensitive to low temperatures when it is compared with other olive cultivars [7].

Leccino showed a poor performance for the mean stem perimeter in all sites, but in Ovalle, Leccino showed the major effect over mean fruit production. Leccino is considered a promissory cultivar for arid environments due to its agronomic characteristics [3], oil quality [9], and its relatively high tolerance to salinity [4]. These facts are very important for intensively managed olive production in southern Atacama Desert.

Alternate bearing recorded over the growing seasons 2002-2003 differed significantly among olive cultivars ($p<0.01$; Table 3). The cultivar-site interaction was significant ($p<0.01$) but site effect was not ($p>0.05$). Mean alternate bearing index varied from 0.17 to 1 (Table 6). Alternate bearing is still a serious problem in the cultivation of several fruit tree species, including olive trees [12]. Due to significant cultivar-site interaction effect, it was regarded an analysis for each individual site (Table 6). Coratina, Leccino and Koroneike had the lowest alternate bearing index in Illapel, Ovalle and Monte Patria, respectively. The estimates of alternate bearing index were 0.18, 0.17 and 0.23 for Coratina,

Table 3: Statistical significance of each source of variation for all agronomic traits under analysis in six different olive cultivars evaluated at southern Atacama Desert, in Coquimbo administrative region of Chile.

Source	DF	S	FP	AGP	AB
		χ^2-value	χ^2-value	F-value	F-value
Cultivar	5	3.36	44.40 **	7.74 **	16.58 **
Site	2	0.31	40.70 **	64.70 **	2.74
Cultivar x Site	10	6.60	37.35 **	3.23 **	7.00 **

** Significant at p<0.01. DF: degrees of freedom. S: tree survival after four growing seasons. FP: fruit production (growing seasons 2002-2003). AGP: absolute growth rate of the stem perimeter (2000-2003). AB: alternate bearing (2002-2003). χ^2: chi-Square.

Table 4: Generalized estimating equations analysis for fruit production (measured over growing seasons 2002-2003) in six olive cultivars (Barnea, Biancolilla, Coratina, Empeltre, Koroneiki and Leccino) evaluated on three sites in Northern Chile.

Site	Parameter	Estimate	95% Confidence Limits		Z	Pr > |Z|
			Lower	Upper		
Illapel	Intercept	2.4653	2.0828	2.8478	12.63	< 0.0001
	Koroneiki	0.5641	0.1201	1.008	2.49	0.0128
	Leccino	0.649	0.1693	1.1287	2.65	0.008
	Barnea	0.9359	0.5081	1.3638	4.29	< 0.0001
	Coratina	1.038	0.6262	1.4499	4.94	< 0.0001
	Biancolilla	-2.1652	-3.1882	-1.1422	-4.15	< 0.0001
	Empeltre	0	0	0	.	.
	ρ	-0.45				
Ovalle	Intercept	2.3918	2.3273	2.4564	72.63	< 0.0001
	Koroneiki	0.3295	0.0849	0.5741	2.64	0.0083
	Leccino	0.8177	0.6484	0.987	9.47	< 0.0001
	Barnea	0.5752	0.4756	0.6747	11.32	< 0.0001
	Coratina	0.4276	0.2972	0.558	6.43	< 0.0001
	Biancolilla	-0.0031	-0.3995	0.3934	-0.02	0.988
	Empeltre	0	0	0	.	.
	ρ	-0.88				
Monte Patria	Intercept	1.0761	0.4049	1.7474	3.14	0.0017
	Koroneiki	1.7027	1.0212	2.3841	4.9	< 0.0001
	Leccino	-0.461	-1.8661	0.9442	-0.64	0.5202
	Barnea	1.4032	0.6425	2.1638	3.62	0.0003
	Coratina	0.9186	0.0712	1.7659	2.12	0.0336
	Biancolilla	-0.0288	-1.0325	0.9748	-0.06	0.9551
	Empeltre	0	0	0	.	.
	ρ	0				

ρ: Rho-values of the working correlation matrix.

Table 5. Mean absolute growth rate of the stem perimeter for the olive cultivars (Barnea, Biancolilla, Coratina, Empeltre, Koroneiki and Leccino) evaluated under the arid Mediterranean conditions of Northern Chile in the growing seasons 2000-2003.

	Sites		
Cultivar	**Illapel**	**Ovalle**	**Monte Patria**
Koroneiki	11.53 bc	9.13 bc	9.09 c
Leccino	12.31 bc	9.36 b	10.34 bc
Barnea	11.35 c	9.28 bc	11.24 ab
Coratina	13.13 ab	10.92 a	12.11 a
Biancolilla	14.03 a	8.79 c	10.59 ab
Empeltre	13.03 ab	10.21 b	11.07 ab

Means followed by the same letters are not significantly different at p=0.05, according to test.

Table 6: Mean alternate bearing index for the six olive cultivars (Barnea, Biancolilla, Coratina, Empeltre, Koroneiki and Leccino) evaluated on three sites in southern Atacama Desert, in the Coquimbo administrative region of Chile.

	Mean alternate bearing index[1]		
Cultivar	**Illapel**	**Ovalle**	**Monte Patria**
Barnea	0.48 bc	0.45 bc	0.62 b
Biancoli	1.00 a	1.00 a	0.81 ab
Coratina	0.18 c	0.47 b	1.00 a
Empeltre	1.00 a	1.00 a	1.00 a
Koroneike	0.51 bc	0.70 a	0.23 c
Leccino	0.56 ab	0.17 c	0.79 ab
Overall mean	0.62	0.63	0.74

[1]Means followed by different letters in the same row are different, P<0.05.

Leccino and Koroneike, respectively. It was found a strong association between fruit production and alternate bearing index. The three cultivars with lower alternate bearing index also evidenced greater effects in fruit production. In other words, if we chosen those cultivars that minimize alternate bearing we would select indirectly those cultivars that maximize mean fruit production in each site. Rallo et al. [20] affirmed that several olive cultivars, or individual olive trees, may have different degrees of alternate bearing, mainly due to an inhibition of floral induction. This alternate bearing necessarily does not occur simultaneously in all cultivars and sometimes individual trees within a cultivar [23].

CONCLUSIONS

Tree mortality was not a problem for olive production in southern Atacama Desert. The total survival rate (over 90%) confirms the potential of this crop for intensively managed olive production in Northern Chile.

Alternate bearing is crucial for maximizing productivity in olive trees, but it is also important to identify the olive cultivars that performed well for fruit production and alternate bearing jointly. Coratina, Leccino and Koroneike were the cultivars that minimized alternate bearing and maximized mean fruit production, in Illapel, Ovalle and Monte Patria sites, respectively.

Olive selection in intensively managed planting at the southern part of the Atacama Desert, in the Coquimbo Region of Chile, depends on optimizing economical traits by selecting cultivars that perform well on a particular site.

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