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Early performance of *Olea europaea* cv. Arbequina, Picual and Frantoio in the southern Atacama Desert

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ABSTRACT - *The cultivars Arbequina, Picual and Frantoio of* Olea europaea *are cultivated in several Mediterranean countries. In 1999, these cultivars were planted at three locations in the region of Coquimbo, an arid, Mediterranean-like area in Chile. A generalized linear modeling approach was used in view of the non-normal distribution of the agronomic data sets. Fruit yield (harvests of 2002-2003), precocity (2002) and tree survival (after four growing seasons) differed significantly between the cultivars. Arbequina and Picual had a positive effect on the yield. Picual was the earliest cultivar at two sites. The survival rate of Frantoio was high at the three sites (90-100%), as opposed to Picual (56-83%). The approach of Generalized Linear Models was particularly useful where the assumption of normality was not satisfied. The selection of cultivars is promising in this arid region of Chile, while the success will depend on the selection of well-adapted genotypes to a particular location.*

Key words: arid zones, generalized models, olive tree, quasi-likelihood.

INTRODUCTION

Olea europaea cv. Arbequina, Picual and Frantoio have many practical applications and are very important olive cultivars for virgin or extra-virgin oil production. Picual and Arbequina are preferred in several Mediterranean regions of Spain due to their early production, high oil yield and several other agronomic advantages (Tous et al. 1998). Of the total global olive oil production of ~2.0 million tons, Picual olive oils represent 25% (Brenes et al. 2002). Spain, Italy and Greece together produce 75%, while Spain accounts for nearly half of the world's olive harvest. Arbequina, also known as Alberquina is, according to the FAO olive germplasm database, one of the most widely used Spanish cultivars for oil production (Lopes et al. 2004).

In the Mediterranean basin, there are many varieties of olive trees. This region alone produces 99% and consumes 87% of the world's olive oil (Loumou and Giourga 2003). Consequently, olive oil production and olive cultivation are often related to Mediterranean climatic conditions where hundreds of olive tree cultivars were selected over the centuries and adapted to various microclimates and soil types. The central region of Chile has a Mediterranean-like climate. In the past decade the Chilean government supported several projects (Mora et al. 2007) concerning the evaluation of plant material including Arbequina, Picual and Frantoio.

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The productivity of extensive regions in Chile is critically marginal due to climatic and/or soil conditions; the deserts, the arid, and the semi-arid zones cover about 30 million ha, i.e., 40% of the country's area (Ormazábal 1991). Although these areas are extremely poor in productive lands, from the agricultural perspective, there is an agronomic potential for intensive olive cultivation. The olive crop has become one of the most important alternatives for cost-effective farming systems under intensive agronomic conditions. As a result, research stations of the Instituto de Investigaciones Agropecuarias (INIA), located in the administrative regions of Atacama and Coquimbo in the southern Atacama Desert, have been actively collecting and maintaining olive germplasm under continuous evaluation to meet the farmers' needs for planting material.

When olive cultivars are evaluated at an early age aiming to obtain early genotypes, i.e., the ability of a cultivar to start bearing at an early age, it is common to find trees without fruits, and on the other hand, trees with a higher production. Moreover, in olive cultivars or olive trees, the so-called alternate bearing may be observed, due mainly to an inhibition of floral induction (Rallo et al. 1994). Alternate bearing does not necessarily occur simultaneously in all cultivars, or even in all trees within a same cultivar (Tous et al. 1998). As a possible consequence, the assumption of normality of the response variable may be completely unrealistic. Another example is a binary response for tree survival which is recorded as 0 or 1. Earliness in fruit crops can also be treated as a binary response. A farmer may want to predict whether or not an olive cultivar produces early under specific environmental conditions.

Nelder and Wedderbun (1972) proposed the theory of Generalized Linear Models (GLMs) as an alternative method for the statistical data analysis where the assumption of normality is not satisfied. The GLM is a natural extension of classic linear models and provides a theory of unified conceptual structure for several frequently used statistical methods (Dobson 2001). The use of GLM is interesting for biological experiments where the response variable follows a very general distribution called the exponential family (Demetrio 2001, Soares et al. 2005).

GLM is based on the assumption of independent observations with no correlation between the outcomes. In many situations the measures of the repeated response are based on the same experimental unit. This requires the use of special statistical techniques because the responses of a same individual tend to be strongly correlated (Myers et al. 2002). Alternate bearing in olive trees is clearly a very good example of this still unsolved problem in the cultivation of a series of fruit tree species, including olive trees (Goldschmidt 2005, Levin and Lavee 2005). A typical example of correlated responses are longitudinal studies, where each subject is observed over a period of time, and repeated observations of the response variable and relevant covariates are recorded. Since the repeated observations are related to the same unit, responses are generally correlated (Pan and Connett 2002).

Liang and Zeger (1986) proposed the Generalized Estimating Equations (GEEs) procedure as an application of quasi-likelihood (Wedderburn 1974) to overcome the problem of fitting a generalized linear model to clustered data. The GEE methodology is considered an intuitive extension of the Generalized Linear Model.

This study was undertaken to investigate the early performance of *Olea europaea* cv. Arbequina, Picual and Frantoio under the arid conditions of northern Chile. First results of a series of studies conducted with these cultivars in the region of Coquimbo are presented. Due to problems with the assumption of normality in the data sets, a generalized linear modeling approach was used. The understanding of this scientific inference could lead to the optimization of agronomic studies with olive cultivars where the normality assumption is not satisfied.

MATERIAL AND METHODS

Field trials

The evaluation of the experiment was conducted at three locations in the arid zone of northern Chile: two sites in the Province of Limarí (Limarí-1: 30° 35' S, 71° 28' W, 200 m asl, and Limarí-2: 30° 45' S, 70° 44' W, 820 m asl) and one site in the Province of Choapa (Choapa: 31° 50' S, 70° 51' W, 580 m asl). These sites are located in a transitional dry-land area between the Atacama Desert and the semi-arid areas of central Chile (Ormazábal 1991, Squeo et al. 2006).

Treatments (olive cultivars: Arbequina, Picual and Frantoio) were arranged in a completely randomized block design, in a factorial scheme with two factors: cultivar and site (factorial 3x3), and variable number of replications (58 in Limarí-1; 52 in Limarí-2; 48 in Choapa). The trees were planted in 8 x 4 m spacing. Crop management protocols and specific characterization of the sites have already been presented in previous reports (Astorga and Mora 2005), where a series of contiguous experiments considering several olive cultivars was examined.

Trait measurements

The trees were hand-planted on 1999. The total fruits per tree (kg tree^{-1}) were harvested and quantified in the growing seasons 2002 and 2003. With this data collection, two quantitative traits were considered:

1. Olive fruit yield (kg tree^{-1}) in a longitudinal study (both growing seasons).

2. Earliness measured as presence/absence of a determined yield level at age 3, growing season 2002. This binary response was based on the following assumption (Tous et al. 1998): 0 for any tree that did not produce fruits from an economical point of view (i.e., yield lower than 5 kg tree^{-1}) and 1 for individual yield of over (or equal to) 5 kg tree^{-1}.

Additionally, the tree survival was measured four years after plantation, in the 2003 growing season. This response variable has a Binomial distribution, and was coded 1 for survival and 0 for death otherwise.

Statistical analyses of fruit yield

The linear model associated to the fruit yield data (assuming normality) for the fruit yield measured in a particular growing season is:

$$y_{ijk}=\mu+c_i+s_j+cxs_{ij}+\varepsilon_{ijk} \quad (1)$$

Where y_{ijk} is the k^{th} observation value (k=1, 2,..., 48); μ is the intercept or overall mean; c_i is the fixed effect of the i^{th} cultivar (i=1,2,3); s_j is the fixed effect of the j^{th} site (j=1,2,3); $c \times s_{ij}$ is the fixed effect of the interaction and ε_{ijk} is the residual random effect.

The previous assumptions of normality for olive fruit yield were checked by visually inspecting a normal plot, using the following statistics: Shapiro-Wilk, Chi-square and Lilliefors (Silva et al. 2006). The Normal probability plot and Shapiro-Wilk statistic were applied using the UNIVARIATE and SAS-INSIGHT procedures (SAS-Institute 1996). Chi-square and Lilliefors tests were run using software Genes (Cruz 1998).

Due to problems with the normality assumption a generalized linear modeling approach was used for the experimental evaluation (Nelder and Wedderbun 1972). Since the two growing seasons were jointly evaluated (longitudinal analysis), the agronomic data were analyzed using Generalized Estimating Equations (Liang and Zeger 1986), an extension of GLM to fit a generalized linear model to grouped data.

GEE and GLM assume that the probability density functions for an observed trait can be expressed as a very general distribution called the exponential family (Demetrio 2001, Dobson 2001, Myers et al. 2002).

Individual olive trees measured repeatedly over two growing seasons were referred to as the subject, and observations in the same subject were considered correlated, which gave the problem the nature of multivariate analysis (Myers et al. 2002). For a specific subject (j), we have the linear model:

$$y_j = X_j\beta + \varepsilon_j \quad (2)$$

Where y_j is the vector containing response values on the j^{th} subject, X_j is the design matrix defining the contributions to the model of the cultivar, site and interaction effects, β is a vector of the regression coefficients or model parameters, and ε_j is a vector of random errors. The basic marginal distribution of olive fruit yield *per se* is unknown. Subsequently, the approximate distribution of the variable response was judged by visually inspecting a diagram of the results using the **R** program according to Dos Santos and Mora (2007). The model was also tested using the GENMOD procedure of SAS (SAS-Institute 1996).

The GEE approach estimates â by solving the following estimation equations (Liang and Zeger 1986):

$$\sum_{j=1}^{n} D_j' V_j^{-1}(y_j - \mu_j) = 0 \quad (3)$$

Where D is the matrix of partial derivatives $\partial\mu_i / \partial\beta_j$; V is the variance-covariance matrix of observations of the j^{th} subject. Expression (3) is often also called quasi-score function since it involves quasi-likelihood. Quasi-likelihood estimations were taken into consideration by the use of generalized least squares.

The generalized estimating equations approach was conducted using GENMOD procedure, with the command REPEATED (SAS-Institute 1996). The command TYPE was used to choose an appropriate correlation structure for GEE parameter estimates (Horton and Lipsitz 1999, Myers et al. 2002).

Statistical analyses of earlyness and survival

Earlyness of cultivars and tree survival (binary responses) was analyzed using Generalized Linear Models (GLM). In this analysis, it was assumed that the response variable has a binomial distribution with parameter n and P, with the following probability density function:

$$f(y;P;\theta) = \exp\left\{ y\ln(P/1-P) - n\ln(1+e^{\theta}) + \ln\left(\frac{n}{y}\right)\right\} \quad (4)$$

where θ denotes a natural location parameter. The Binomial distribution is member of the exponential family of distribution that can be expressed as:

$$f(y;\theta,\phi) = \exp\left\{\frac{y\theta - b(\theta)}{a(\phi)} + c(y,\phi)\right\} \quad (5)$$

where $a(\phi)=1$, $b(\theta)=n\ln(1+e^{\theta})$, $\theta=\ln(P/1-P)$, and $c(\bullet)=\ln(n/y)$. The logit link function was employed using GENMOD procedure (SAS-Institute 1996), which fits GLMs to the data by maximum likelihood estimation of the parameter vector β, with the following maximum likelihood score equation:

$$X'(y-\mu)=0 \quad (6)$$

RESULTS AND DISCUSSION

Fruit yield

The normal probability plot and the statistics used to check the normality assumption confirmed problems with normality ($P<0.01$). The analyses performed in R and GENES programs indicated lack of symmetry in the data distribution. The mode (1.63 kg $tree^{-1}$, estimated using the Kernel Density Estimation method) was lower than the mean (13.24 kg $tree^{-1}$) confirming asymmetry. A generalized linear model with Gamma distribution (Freund 1992) and log link was therefore used as alternative analysis. Gamma distribution can be applied in studies where the response is continuous and the variance not constant but rather proportional to the mean square (Myers et al. 2002), as in the case of this study.

In our study, 29% of all trees were unproductive in both growing seasons. These observations are considered invalid response values for Gamma distribution (Freund 1992). Here, this problem was overcome by adding an arbitrary value (i.e. 0.5) to the observations. Previous studies (Myers et al. 2002) indicated that this kind of approach does not affect data distribution; a fact confirmed in our study.

The analysis of GEEs is given in Table 1, admitting a satisfactory combination between the response variable distribution (Gamma) and the Log link function (Demetrio 2001). Technically the Log link is not the canonical link, but previous studies (Myers et al. 2002) recommend it to overcome certain mathematical problems by using the reciprocal link (canonical link). Since only two growing seasons were analyzed, the same correlation values are estimated for any non-independent correlation structures included in the GENMOD procedure (Myers et al. 2002). Consequently, the comparisons were only carried out between independent and non-independent models according to Myers et al. (2002) and Liang and Zeger (1986). The correlation was so small (r = -0.20) that the use of the independent correlation structure was indicated as more adequate. Consequently, the independence model was used, i.e. the identity matrix, for GEE parameter estimates. Liang and Zeger (1986) discussed this issue and affirmed that when the magnitude of all correlations is lower than about 0.3, the use of an independent correlation structure often appears to be satisfactory. The GENMOD procedure computes both model-based and empirical standard errors of the regression coefficients. Estimates of the empirical standard error are usually preferred for allowing more robust estimators (Myers et al. 2002).

Arbequina and Picual were significant and the positive sign in the GEE parameter estimates suggests a positive (increasing) effect on the fruit yield. Limarí-1 site was also significant and had a positive effect, whereas Limarí-2 site was significant but had a negative (reduction) effect on the overall mean production.

The components of the interaction effect were significant for AxL2, PxL1 and PxL2, and indicated that an analysis by site should be conducted. This result was confirmed by the quasi-score statistics for Type III GEE analysis, using the GENMOD procedure, in which the cultivar, site and cultivar-site interaction effects were significant ($P<0.01$).

The Generalized Estimating Equations (GEE) within sites are given in Table 2. In this context, the analyses of contrasts are also useful for determining differences between the cultivars. Depending on the locations, the olive cultivars performed differently (Table

Table 1. General analysis of Generalized Estimating Equations (GEE) for fruit yield in olive cultivars (Arbequina, Picual and Frantoio) evaluated under the arid Mediterranean conditions of northern Chile, in the growing seasons 2002-2003; an independence matrix was used

Parameter	Estimate	SE	95% Confidence Limits		Z	Pr > |Z|
			Lower Limits	Upper Limits		
Intercept	2.3802	0.0565	2.2695	2.4908	42.16	<0.0001
Arbequina (A)	0.3191	0.076	0.1702	0.468	4.2	<0.0001
Picual (P)	0.3039	0.0898	0.1278	0.4799	3.38	0.0007
Frantoio (F)	0	0	0	0	.	.
Limarí-1 (L1)	0.4306	0.073	0.2874	0.5737	5.9	<0.0001
Limarí-2 (L2)	-2.6903	0.2033	-3.0888	-2.2919	-13.24	<0.0001
Choapa (C)	0	0	0	0	.	.
AxL1	-0.0137	0.0968	-0.2033	0.176	-0.14	0.8876
AxL2	1.9803	0.2336	1.5224	2.4381	8.48	<0.0001
AxC	0	0	0	0	.	.
PxL1	-0.3344	0.1171	-0.564	-0.1048	-2.85	0.0043
PxL2	2.5549	0.2327	2.0989	3.011	10.98	<0.0001
PxC	0	0	0	0	.	.
FxL1	0	0	0	0	.	.
FxL2	0	0	0	0	.	.
FxC	0	0	0	0	.	.
GEE	$y = e^{2.3082 + 0.3191A + 0.3039P + 0.4306L1 - 2.6903L2 + 1.9803AxL2 - 0.3344PxL1 + 2.5549PxL2}$					

SE: empirical standard error

Table 2. Analyses of contrasts and Generalized Estimating Equations (GEE) within sites for fruit yield of olive cultivars (Arbequina, Picual and Frantoio) evaluated under the arid Mediterranean conditions of northern Chile, in the growing seasons 2002-2003

Contrast	df	Limarí-1**		Limarí-2**		Choapa**	
		χ^2	$p > \chi^2$	χ^2	$p > \chi^2$	χ^2	$p > \chi^2$
Contrast							
Arbequina - Picual	1	19.58	<0.0001	12.01	0.0005	0.03	0.8600
Arbequina - Frantoio	1	20.83	<0.0001	27.1	<0.0001	14.58	0.0001
Picual - Frantoio	1	0.13	0.7227	41.15	<0.0001	9.14	0.0025
Means fruit yield (kg tree^{-1})							
Arbequina (A)		22.06 a		6.81 b		14.37 a	
Picual (P)		15.46 b		12.29 a		14.14 a	
Frantoio (F)		16.12 b		0.23 c		10.31 b	
GEE		$y=e^{2.8108+0.3054A}$		$y=e^{0.3102+2.2993A+2.8588P}$		$y=e^{2.3802+0.3191A+0.3039P}$	
WCM		$\begin{bmatrix} 1 & -0.43 \\ -0.43 & 1 \end{bmatrix}$		$\begin{bmatrix} 1 & 0.00 \\ 0.00 & 1 \end{bmatrix}$		$\begin{bmatrix} 1 & -0.74 \\ -0.74 & 1 \end{bmatrix}$	

Chi-square; p: probability; ** Cultivars evidenced significant differences within sites according to quasi-score statistics (P<0.01). WCM: Working correlation matrix

2). Arbequina and Picual performed well in Choapa, but not as well in Limarí. Tous et al. (1998) verified significant differences for olive yield in a group of five varieties in Spain where Arbequina and Picual had similar responses. Picual did not perform well in Limarí-2 and Choapa, and produced less in Limarí-1 than in Arbequina.

Ben-Rouina et al. (2002) stated that growth and productivity of olive-trees are mainly determined by a number of factors related to climatic conditions, soil availability and nutrient status. Astorga and Mora (2005) evidenced significant differences between six oil cultivars in productivity and accumulated fruit yield, considering analogous environments. León et al. (2004)

studied the genetic variability of seedlings from crosses among the olive cultivars Arbequina, Frantoio and Picual over three years, and observed a broad range of variability in some yield traits. Based on the study of the relation coefficients, these authors further concluded a high year-to-year correlation which could be a reliable indicator of the values obtained in the following years.

Working correlation matrices were site-dependent; the correlation was highest in Choapa, moderate in Limarí-1 and lowest in Limarí-2 (zero). Pan and Connett (2002) discussed the importance of the choice of the working correlation matrix, which could influence the estimation efficiency. In general, a correlation matrix that is closer to the true correlation is most efficient. Myers et al. (2002) pointed out that an unfortunate choice of the correlation structure results in a large discrepancy between the model-based and the empirical variance-covariance structures.

Earlyness

The earlyness of the cultivars differed significantly among cultivars (P<0.05; Table 3). Earlyness (measured as the presence/absence of a determined yield level at age 3; a binary trait) was also significantly influenced by environment and cultivar x site interaction (P<0.01). Picual was earlier than Arbequina and Frantoio in the Province of Limarí (Limarí-1 and Limarí-2), but was not early in the Province of Choapa (Table 4). Arbequina and Frantoio performed identically at the three sites and were not early in Limarí-2. Precocity can be defined as the ability of a particular cultivar to start bearing at an early age, which is a highly desirable in olive trees (Pritsa et al. 2003). It is important to remember that olive trees are generally cultivated in areas of high economic value. In view of the high cost of establishment of an orchard, the unproductive period of the implanted cultivar should be very long (Pritsa et al. 2003, Tous et al. 1998).

For a small farmer, who needs to recover the implementation costs as soon as possible, cultivar Picual is recommended in the Province of Limarí. But if Picual is chosen for planting in Limarí-1 there will be a loss of yield per tree, since Arbequina evidenced a higher mean yield. Page (2004) affirmed that improving precocity in commercial cultivars would benefit olive fruit producers, because it would lead to a faster return on investment and, over a fixed period, accumulate higher yields than less precocious cultivars with a similar yield. Obviously, an economic analysis should also be carried out in order to validate an appropriate decision.

Survival

Survival after four growing seasons differed significantly among cultivars (P<0.01; Table 3). The cultivar x site interaction, and site effect were significant (P<0.01). Mean survival ranged from 53.8 to 100%, 55.8 to 82.8% and 89.6 to 100% for Arbequina Picual and Frantoio, respectively. Frantoio had very high survival rate at three sites, but low yields, as discussed in the above analysis. The survival of Arbequina was also very high in Limarí-1 and Choapa indicating the possibility of obtaining a cultivar with both characteristics, although the cultivar x site interaction could be a limiting factor for this goal. Survival is important for intensively managed olive production. Early survival has not been included as a trait in olive tree selection programs (e. g. Tous et al. 1998), although its impact on productivity can be large. Tree survival is an important characteristic for agroforestry systems under water stress (Abdelkdair and Schultz 2005, Abebe 1994). Previous studies (Rawat and Banerjee 1998) mentioned that semiarid and coastal regions are affected by salinization; a fact that can affect plantation productivity and/or overall survival rates.

Table 3. Deviance and Chi-square values for survival and earlyness in olive cultivars (Arbequina, Picual and Frantoio) evaluated under the arid Mediterranean conditions of northern Chile, in the growing season 2002

Source of Variation	df	Survival		Earlyness	
		Deviance	Chi-Square	Deviance	Chi-Square
Intercept		389.3	-	473.0	-
Cultivar	2	354.4	34.85 **	465.4	7.59 *
Site	2	323.3	31.10 **	335.5	129.82 **
Cultivar x Site	4	297.0	26.31 **	299.4	36.16 **

df: Degrees of freedom from experimental design. ** P<0.01. * P<0.05

Table 4. Mean precocity of the olive cultivars (Arbequina, Picual and Frantoio) evaluated under the arid Mediterranean conditions of northern Chile in the growing season 2002, and analysis of contrasts within sites for cultivar effect

Contrast	df	Limarí-1**		Limarí-2**		Choapa**	
		χ^2	$p > \chi^2$	χ^2	$p > \chi^2$	χ^2	$p > \chi^2$
Arbequina – Picual	1	7.43	0.0064	9.48	0.0021	10.1	0.0015
Arbequina – Frantoio	1	0.11	0.7365	2.13	0.1443	0.03	0.8517
Picual – Frantoio	1	6.16	0.0131	23.38	<0.0001	9.08	0.0026
Mean survival (%)							
Arbequina		0.609 b		0.048 b		0.178 a	
Picual		0.854 a		0.400 a		0.000 b	
Frantoio		0.642 b		0.000 b		0.163 a	

Chi-square; p: probability; ** Cultivars evidenced significant differences within sites according to score statistics (P<0.01)

Table 5. Mean survival for the olive cultivars (Arbequina, Picual and Frantoio) after four growing seasons and analysis of contrasts within sites for cultivar effect

Contrast	df	Limarí-1**		Limarí-2**		Choapa**	
		χ^2	$p > \chi^2$	χ^2	$p > \chi^2$	χ^2	$p > \chi^2$
Arbequina – Picual	1	12.52	0.0004	0.03	0.8552	6.78	0.0092
Arbequina – Frantoio	1	1.24	0.2653	30.44	< 0.0001	0.55	0.4580
Picual – Frantoio	1	8.65	0.0033	31.5	< 0.0001	3.59	0.0581
Mean survival (%)							
Arbequina		100.0 a		53.8 b		93.8 a	
Picual		82.8 b		55.8 b		75.0 b	
Frantoio		98.1 a		100.0 a		89.6 a	

Chi-square; p: probability; ** Cultivars evidenced significant differences within sites according to score statistics (P<0.01)

CONCLUSIONS

Olive cultivar selections are promising for intensively managed agricultural systems in this arid zone of northern Chile. The success will depend on optimizing yields by selecting genotypes that perform well at particular sites.

The results demonstrated the effectiveness of the Generalized Linear modeling approach, including its extension to longitudinal analysis: the Generalized Estimating Equations method, for attending the early evaluation of olive cultivars in a situation where the assumption of normality was not satisfied.

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Avaliação de *Olea europaea* cv. Arbequina, Picual e Frantoio no sul do deserto de Atacama

RESUMO - Olea europaea cv. *Arbequina, Picual e Frantoio são cultivados em vários países Mediterrâneos. Em 1999, estes cultivares foram plantados em três locais da Região de Coquimbo; uma zona árida Mediterrânea do Chile. Uma abordagem de modelação linear generalizada foi conduzida porque o conjunto de dados agronômicos não teve distribuição Normal. Produção de frutos (medida nas safras 2002-2003), precocidade (2002) e a sobrevivência das árvores (quatro anos após a plantação) diferiram significativamente entre os cultivares. Arbequina e Picual tiveram um positivo efeito sobre a produção. Picual teve alta precocidade em dois locais. Frantoio teve alta sobrevivência nos três locais (90-100%) ao contrario de Picual (56-83%). Os Modelos Lineares Generalizados foram úteis em uma situação onde o pressuposto de normalidade não foi atendido. A seleção de cultivares tem importante potencial na região árida do Chile, mas sua efetividade dependerá da seleção de genótipos que respondem bem sobre um determinado local.*

Palavras-chave: modelos generalizados, oliveira, quase-verossimilhança, zonas áridas.

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