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Stability analysis of fruit yield of some olive cultivars in semi-arid environmental condition

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Abstract: This study was conducted to evaluate yield stability of 12 Iranian and foreign olive cultivars in Dalaho Olive Research Station during 2006-2008. According to the variance analysis, significant variation ($p<0.01$) was observed between cultivars and years. Classification based on Duncan ($p<0.05$) showed that Konservolia was superior variety and Sevillano, Koroneiki and Zard were placed in the second group. Cultivars were divided into 3 groups based on cluster analysis using Ward method. The first principal component of the interaction between olive cultivars and the year's show 69.25% of the variance and was statistically significant at 1% level based on AMMI analysis. According to regression coefficient (*bi*) deviation from regression (S^2_{di}), Wricke's ecovalence (W_i), coefficient of determination (Ri^2) and Shukla's stability variance (δ_i^2) methods 'Mission' and 'Zard' had the higher stability. According to the AMMI stability (ASV) ranking, the following cultivars were the most stable, Mission, Amigdalolia and Koroneiki, while the most unstable were 'Konservolia', 'Sevillano', 'Roghani', 'Arbequina' and 'Abou-Satal'. 'Konservolia' even showed the lowest stability but its stability in all parameters was significant different in terms of performance. Generally 'Konservolia', 'Sevillano', 'Koroneiki' and 'Zard' were appropriate for fruit yield and will be introduced for breeding programs in semi-warm climate.

1. Introduction

Olive (*Olea europaea* L.) tree is an evergreen native to the Mediterranean region. Some olive wild genotypes are present in different region of Iran like Kermanshah province in the west of Iran. There are more than 40 native olive genotypes in subtropical regions of Kermanshah province like Sarpool-e-Zahab, Gilan-e-Gharb and Paveh. Marone and Fiorino (2012) reported that olive (*Olea europaea* L.) distributed across three continents from South Africa to the central part of the Africa and Horn Africa, from Egypt and Red Sea to the Mediterranean areas and Asia from Palestine, Syria, Mesopotamia and western and eastern areas of Himalaya Chain to the Southwestern of China. This report revealed that there are some olive genotypes in three continents. In recent years, due to higher olive oil demand, the cultivation of olive has been expanded in various regions of Iran. However, the cultivation of olive tree is limited because of harsh environmental conditions and water scarcity in most of the new olive plantation areas (Arji and Arzani, 2008). The limitation of water as well as long hot summers in the regions lead to poor fruit and oil quality (Saadati *et al.,* 2013; Khaleghi *et al.,* 2015). Cheng *et al.* (2017) stated that low temperatures would be improved olive oil quality by increasing unsaturated fatty acid amounts in the fruit. Temime *et al.* (2006) reported that more unsaturated fatty acid of Chetoui olive variety was recorded in cooler regions than dry and warm regions. Despite of good vegetative growth, some of the olive varieties do not show good performance as production in warm regions. This is due to lack of adapted and stable cultivars in such environmental conditions. Check-adapted varieties and optimal stability are essential for the fruit yield. It is assumed that the stability of a genotype is very important over time in each region (Finlay and Wilkinson, 1963).

Homeostatic and agronomic are two genotypic stabilities. In homeostatic stability a certain genotype shows constant response under different conditions. But in agronomic stability, genotype yield is linked to productivity potential (Hayward *et al.,* 1993). Generally, the stability is defined as the actual performance of a genotype under changing environmental conditions. Reliable stability of production efficiency under environment changing is very important (Kan *et al.,* 2010). Stability analysis methods are categorized in two parametric and non-parametric groups (Sabaghnia *et al.,* 2006). Several methods such as regression coefficient (Finlay and Wilkinson, 1963), sum of squared deviations from regression (Eberhart and Russel, 1966), stability variance (Shukla, 1972) and additive main effects and multiplicative interaction (AMMI) (Gauch and Zobel, 1988) have been commonly used to parametric stability analysis.

Environmental sustainability of individual genotypes can also be estimated by regression analysis and cultivar will be stable when the deviation of regression was zero or at least (Hayward *et al.,* 1993). It is mentioned that regression analysis in bilinear models and analysis of variance in biadditive models have limitations in genotype and environment interaction. This restriction reduced by multiplicative components for interactions in generalized linear models (GLM) such as additive effects and multiplicative interaction (AMMI) (Gauch, 1992). In this model the main additive effects was calculated by variance analysis and then genotypes and environment interaction, which is known as multiplicative interaction, are analyzed by principal components analysis (Romagosa and Fox, 1993).

Olive is one of the fruit trees with alternate bearing tendency in which it not bear regularly (Lavee, 2007). This phenomenon is affected by different factors like genetic and physiological traits (Goldschmidt, 2005). The degree of alternate bearing in olive is highly dependent on environmental conditions (Lavee, 2007). Fruit production in olive is more irregular by climate change where adverse environmental conditions are frequent (Lodolini and Neri, 2012). For this purposes stability of olive production is very important in new olive growing region like Sarpool-e-Zehab environmental conditions. AMMI analysis was used to evaluate the stability of different crops (Esmaeilzadeh-Moghaddam *et al*., 2011), but there is lack of research in horticultural crops. Weather conditions are variable during different years in new olive cultivation regions so that we need to find out more stable olive cultivars. In the present work, the year was considered as environmental variable. Generally, the main goal of this study was the evaluation of yield stability of different olive cultivars in warm condition of Kermanshah province.

2. Materials and Methods

Material, site characterization and experimental design

This experiment was conducted in Dalahv Olive Research Station of Sarpool-e-Zahab (longitude: 45° 51´ E, latitude: 34° 30´ N, altitude: 570 m asl) to verify the yield stability of 12 Iranian and foreign olive cultivars (Table 1). Two years old self-rooting plantlets were planted in the year 2000, with 6x6 m spacing

Table 1 - Name and codes of genotypes

Genotype	Name
1	Amphisis
2	Konservolia
3	Zard
4	Amigdalolia
5	Koroneiki
6	Roghani
7	Manzanillo
8	Abou-Satal
9	Mission
10	Arbequina
11	Sevillano
12	Shenge

distance in a randomized complete block design with three replications. Each experimental unit consisted of 5 trees so that 15 trees of each cultivar were evaluated. Trees were pruned as vase shape and irrigated each three days with drip irrigation system. Climate of Sarpool-e-Zahab is warm with relatively low humidity during summer as shown in figure 1. Also soil and water analysis were reported (Tables 2 and 3).

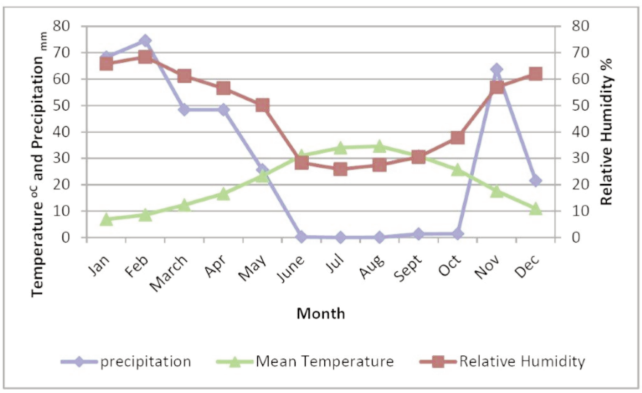

Fig. 1 - Precipitation, mean temperature and relative humidity during five years of experiment.

Table 2 - Physical and chemical soil characteristics

Soil depth (cm)	Particle-size distribution (%)			OC (%)	pH	TNV (%)	Ava. K (mg/kg)	Ava. P (mg/kg)	Total N (%)
	Clay	Silt	Sand						
0-30	34	52	14	2.25	7.7	41	520	6.2	0.18
31-60	40	37	23	0.78	7.7	45	275	2.6	0.06

Table 3 - Irrigation water chemical characteristics

EC (dS/m)	TDS (mg/l)	pH	Meq/L								S.S.P (%)	S.A.R
			CO_3^{-2}	CO_3H	Cl^-	SO_4^{-2}	Sum Anions	Ca^{2+}+ Mg^{2+}	Na^+	Sum Cations		
550	352	7.28	0	4.6	0.3	1.9	6.8	6.6	0.2	6.8	2.94	0.11

Data analysis methods

Fruit yield was measured during 5 years from 2004 to 2008. As fruit yield was low in the years 2004 and 2005, therefore 3 years (2006, 2007 and 2008) were analyzed to determine yield stability. SPSS, IRRISTAT and Excel were used for statistical analysis and the mean comparison was done by Duncan's multiple range test at p<0.05. The model of AMMI analysis is presented in equation (1).

$$Y_{ger} = \mu + \alpha_n + \beta_e + \Sigma_n \lambda_n \alpha_{gn} \gamma_{en} + \rho_{ge} + \varepsilon_{ger} \quad (1)$$

Where α_n is the main effect of genotype; βe is the main effect of environment; n is the number of main components in AMMI model; λ_n is a single value related to the n remained main components in the model; α_{gn} is thespecific vector for the g genotype from n main component; γ_{en} is the specific vector for the e environment from n main components; ρ_{ge} is the noise and g_{er} is the error (Clay *et al.*, 1995).

The following parameters were calculated to analyze yield stability, coefficient of variability (CV_i) (Francis and Kannenberg, 1978), Wricke's (1962) ecovalance (W_i2), Shukla's (1972) stability variance (σ_i^2), Pinthus's (1973) coefficients of determination (R^2), and Finlay and Wilkinson (1963) regression coefficient (*bi*).

Alternate bearing index (ABI) was calculated during three successive years from 2006 till 2008, using the following equation (2) (Monselise and Goldschmidt, 1982):

$$ABI = \frac{1}{n-1} \times \left\{ \frac{a2-a1}{a2+a1} + \frac{a3-a2}{a3+a2} + ... \frac{an-an-1}{an+an-1} \right\} \quad (2)$$

Where n = number of years, and a1, a2... an = yields in the corresponding years.

3. Results and Discussion

Fruit yield analysis of variance

The results of variance analysis for yield of olive (kg/tree) show that the genotype, environment (year) and interaction effects were significant (*p*<0.01) (Table 4). Specific response of the cultivars to ecological factors over a 3-year period were confirmed by the results of Duncan Multiple Range-Test,

Table 4 - Analysis of variance for olive fruit yield

S.O.S	df	SS	MS
Replication	2	2083	0.115 NS
Cultivar	11	3026.53	275.14 **
Error	22	199.59	9072
Year	4	1023.13	511.567 **
Cultivar x year	44	1423.3	64.696 **
Error	96	285115	5.94
CV%			19.18%

which proved that cultivar and year interaction effect was also significant (Table 5). It is evident from data in Table 5, for 3 study years, 'Konservolia' had thehighest mean yield, 24.69 kg/tree, while 'Roghani' had the lowest mean yield, 4.87 kg/tree. Fruit yield variability was depending on the year but olive varieties show different responses (Table 5). So, this indicates that the genotypes present different behavior in that environment. This may be due to differences in genetic basis of cultivars (Rakonjac and Živanovic,

Table 5 - Fruit yield (Kg tree^{-1}), mean yield (Kg tree^{-1}) and Alternate Bearing Index of olive cultivars during 2006-2008

Cultivar	2006	2007	2008	Mean	Alternate bearing index
Amphissis	7.03 hij	3.5 j	16.37 cdef	8.97 efg	0.16
Konservolia	26.03 b	14.57 c-g	33.47 a	24.69 a	0.06
Zard	17.37 cd	8.23 hij	16.67 cde	14.09 cd	0.01
Amigdalolia	15.39 cdef	6.533 ij	10.43 fghi	10.78 def	0.1
Koroneiki	23.8 b	13.33 d-h	16.7 cde	17.94 bc	0.08
Roghani	7.1 hij	4.5 ij	3 j	4.87 g	0.21
Manzanillo	24.53 b	7.86 hij	6.27 ij	12.89 de	0.31
Abou-Satl	7.78 hij	7.17 hij	9.1 ghij	8.02 fg	0.04
Mission	14.53 c-g	8.07 hij	14.33 c-g	12.31 def	0.003
Arbequina	7.36 hij	10.18 fghi	16.08 cdef	11.21 def	0.19
Sevillano	25.13 b	10.8 e-i	20.48 bc	18.81 b	0.04
Shenge	10.34 fghi	6.4 ij	7.13 hij	7.96 fg	0.09
Mean	15.53	8.43	14.17	12.71	

2008). Olive varieties with yield stability are important for sustainable production. Stable cultivars have high yield with lower variation during the years. Based on the results, 'Konservolia', 'Zard', 'Koroneiki', 'Amigdalolia', 'Arbequina' and 'Sevillano' have higher fruit yield with moderate yield fluctuation during the years.

Analysis of variance is only able to express the presence or absence of interaction and is not possible to interpret yield stability. For this reason, using univariate and multivariate nonparametric interpret better interaction of cultivars and years in the sustainability debate (Gauch, 1992; Falconer and McKay, 1996; Arciniegas-Alarcon *et al.*, 2011; Gauch, 2013).

AMMI analysis

The ANOVA for fruit yield using the AMMI method is presented in Table 6. There were significant differences among the genotypes, environments (Years) and G × E interaction. In this experiment environments were the years based on Citadin *et al.* (2013) method. Combined analysis of variance (ANOVA) for fruit yield of olive cultivars indicated that genotypes, year and genotype-by-year interactions (GEI) were the most important source of fruit yield variation (Table 6). The contribution of variation caused by the cultivar, year and GEI were 52.56%, 17.77%, and 24.72%, respectively. This result showed that olive cultivars had different yield performance across years. The high share of interaction in the total sum of squares is very important to use stability analysis for fruit yield of olive varieties. Similar results were reported in yellow passion fruit by Oliveira *et al.* (2014) and peanuts (Oliveira and Godoy, 2006). Maulión *et al.* (2014) stated that the significance of

Table 6 - Analysis of variance for fruit yield of 12 olive cultivars by AMMI during 2006 -2008

S. O. V	df	SS	SS%	MS
Genotypes	11	3026.52	52.56	275.14 **
Year	2	1023135	17.77	511.57 **
Cultivar x year	22	1423305	24.72	64.7 **
IPC1	12	985614	69.25	82.13 **
Noise	10	437688	30.75	43.77 NS
Error	96	285115	4.95	2.97
Total	35	5758075		

the environmental effect and GEI were used as a starting point to study yield stability among peach accessions.

AMMI analysis indicated that two first IPCA were significant (P<0.01). The IPCA1 accounted for 69.25% of the GE interaction (Table 6). However, based on these results most information can be graphically displayed using IPCA1. Biplot graph of the model (IPCA1 *vs.* yield) is presented in figure 2. According to figure 2, 'Zard' and 'Mission' showed greater yield stability by values near the origin of the IPCA1 axis. However, mean yield of 'Mission' was lower than total mean yield. 'Konservolia' with highest fruit yield and 'Roghani' with the lowest fruit yield were unstable cultivars and the others were in the intermediate stability.

One of the most important parameter in olive stability is alternate bearing. This index seems to be useful in determining the sustainability of production in fruit trees. Based on biplot AMMI1 analysis, 'Konservolia' was more productive (Fig. 2) in all years than the others and its alternate bearing index was low (Table 5). So it is recommended to use this parameter in stability evaluation. In this experiment, variability due to the year was greater than variability

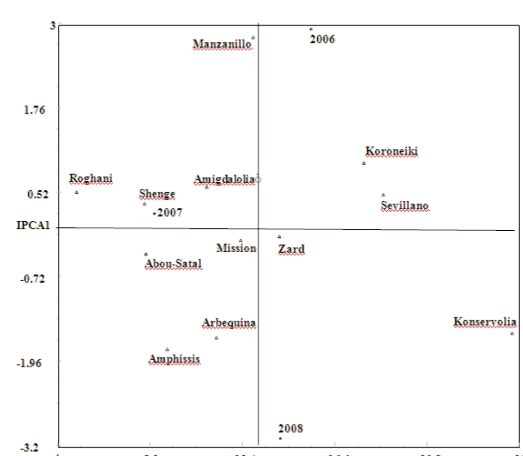

Fig. 2 - Biplot AMMI1 (means *vs* PC1) for the data on the yield of olive (Ton ha^{-1}) with 12 cultivars (•) and five years (Δ).

caused by varietal effects based on scattered effect (Fig. 2). AMMI analysis method is highlighted to study G x E interaction which combines a univariate method for the additive effects of genotypes and years with a method for the multiplicative effects of the G x E interaction (Zobel *et al.*, 1988; Citadin *et al.*, 2013). Gauch and Zobel (1996) stated that this method can contribute to the identification of widely adapted genotypes with high yields, as to the agronomic zoning for regional cultivar recommendation. A genotype will be ideal with high yields and IPCA1 values near zero. In general, according to the results of AMMI analysis Zard was the most stable cultivar with high yield and IPCA1 values near zero. 'Konservolia' and 'Sevillano' had high yield but higher IPC1 values than zero, therefore we recommend them as superior cultivars for pickling purpose. Ferreira *et al*. (2006) reported that an undesirable genotype has low stability as well as low yields.

Cluster analysis

According to the obtained dendrogram from cluster analysis using Ward method, genotypes were divided in three groups (Fig. 3). This result is confirmed by Biplot AMMI1 (Fig. 2).

Stability analysis results

Eberhart and Russell's (1966) stated that a stable cultivar is considered to be the one that has regression coefficient approximating 1.0 and standard error of regression as low as possible. According to this model a genotype with the higher mean fruit yield has general adaptability. In the present research, regression coefficients ranged from 0.02 to 2.11 for fruit yield (Table 7). This variation in regression coefficients indicates that cultivars had different responses to year's fluctuations. A genotype would be adapted to favorable conditions when regression coefficient is higher than one and other would be adapted to unfavorable conditions when regression coefficient is less than one. A genotype with regression coefficient equal to one would have an average adaptation to all environments.

According to Table 7, 'Amphissis', 'Mission' and 'Amigdalolia' with regression coefficients near to one are most stable all the years. 'Koroneiki', 'Zard', 'Manzanillo', 'Sevillano' and 'Konservolia' with regression coefficients higher than one were stable (Table 7, Fig. 2), while other cultivars like Abequina,

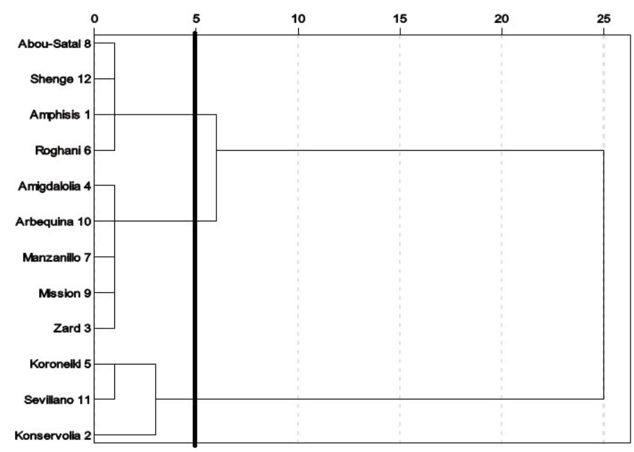

Fig. 3 - Dendrogram from cluster analysis based on Ward method.

Table 7 - Mean yields (kg/tree) and various stability measurements and their ranking orders of 12 olive cultivars evaluated during five years 2006-2008

Cultivar	Fruit yield (Kg/tree)	Rank	*bi*	Rank	S^2_{di}	Rank	*Wi*	Rank	δ_i^2	Rank	CV_i	Rank	R_i^2	Rank	ASV	Rank
Amphissis	8.97	9	1.01	6	59.32	11	59.32	9	33.44	9	74.14	11	0.33	3	0.291	4
Konservolia	24.69	1	2.11	12	54.93	10	89.87	11	51.77	11	38.57	6	0.7	7	1951	12
Zard	14.09	4	1.34	9	0.66	2	3.94	2	0.21	1	36.08	5	0.99	10	0.546	6
Amigdalolia	10.78	8	1.08	7	6.27	6	6.44	3	1.71	2	41.14	9	0.84	9	0.032	2
Koroneiki	17.94	3	1.21	8	15.34	8	16.62	5	7.81	5	29.78	4	0.73	8	0.184	3
Roghani	4.87	12	0.18	3	7.67	7	26.73	8	13.88	8	42.63	10	0.11	2	1345	10
Manzanillo	12.89	5	1.57	10	134.4	12	143.68	12	84.05	12	78.49	12	0.34	4	0.5	5
Abou-Satal	8.02	10	0.16	2	1.22	3	21.27	6	10.61	6	12.33	1	0.37	5	1239	8
Mission	12.31	6	0.96	5	0.65	1	0.69	1	1.74	3	29.86	3	0.98	11	0.027	1
Arbequina	11.21	7	0.02	1	39.64	9	66.81	10	37.93	10	39.73	8	0.0004	1	1265	9
Sevillano	18.81	2	1.92	11	2.13	4	26.21	7	13.57	7	38.88	7	0.98	11	1349	11
Shenge	7.96	11	0.43	4	3.57	5	12.85	4	5.56	4	26.36	2	0.59	6	0.937	7

bi = Finlay and Wilkinson's (1963) regression coefficient; *Sdi2* = Eberhart and Russell's (1966) deviation from regression parameter; Wi = Wricke's (1962) ecovalence; δ_i^2 = Shukla's (1972) stability variance; CV% = Francis and Kannenberg's (1978) Coefficient of variability; Ri^2= Coefficient of determination; ASV = AMMI stability value

Shenge, Abou-Satal and Roghani with regression coefficients less than one were unstable (Fig. 2). 'Konservolia' (*bi*=2.11) was productive during 2006 and 2008 than the others. High yielding varieties were not found stable with regression coefficients (*bi*). Similar results were found by Maulión *et al.* (2014) in peach stability evaluation. As olives have alternate bearing, 'Konservolia' had the highest fruit yield in non-bearing year (2007) in compare to the others (Table 5).

The most stable cultivars with the lowest S^2_{di} values were Mission and Zard. The most unstable cultivarswith the highest S^2_{di} values were Manzanillo, Amphissis and Konservolia. According to the Eberhart and Russell's (1966) model, regression coefficients (*bi*) approximating 1.0 coupled with S^2_{di} of zero indicate an average stability. 'Mission' and 'Zard' with regression coefficients near to 1 and S^2_{di} near to zero were most stable than the others. Zard cultivar had higher mean yield so it has general adaptability all the years.

Concept of ecovalence was defined by Wricke (1962), where the genotypes with low eco valence have smaller fluctuations across environments and therefore are stable. The most stable cultivars according to the ecovalence method of Wricke (1962) were Mission and Zard. These cultivars were in the ranked 6 and 4 for mean yield, respectively. The most unstable cultivars according the eco valence method were Manzanillo and Konservolia with the mean yield rank of 5 and 1 respectively (Table 7). This method would not be suitable to select high-yielding cultivars but it is useful to select cultivars with the same yield of the mean yield (Table 5). For this reason, genotypes with a low *Wi* value have smaller deviations from the mean across years and are thus more stable.

Shukla's (1972) stability variance (δ_i^2) revealed that 'Zard', 'Amigdalolia' and 'Mission' had the smallest variance across the years and were stable, while Manzanillo and Konservolia cultivars had the largest δ_i^2 and were unstable. The 'Konservolia', ranked first for mean yield, showed insteadpoor stability based on Shukla's stability variance.

The mean CV analysis was proposed by Francis (1977) to study the physiological basis of yield stability. The stable cultivar is the one that provides a high yield performance and consistent low CV (Crossa *et al.,* 1990). According to this method, 'Abou-Satal', 'Shenge', 'Mission' and 'Koroneiki' were the most stable; 'Zard', 'Konservolia', 'Sevillano' and 'Arbequina' were intermediate stable, while Amigdalolia, Roghani, Amphissis and Manzanillo were the most unstable cultivars (Table 7). Moghaddam and Dehghanpour (2001) stated that the main problem with this method is that low-yielding cultivars are placed into the category of stable cultivars. In this experiment high yielding varieties were in intermediate parts of classification.

A greater coefficient of determination (Ri^2) value is desired because higher Ri^2 values indicate favorable responses to environmental changes (Sayar *et al.*, 2013). In our study, Zard, Mission and Sevillano cultivars had higher Ri^2 values for fruit yield and 'Amigdalolia', 'Koroneiki', 'Konservolia' and 'Shenge' with medium Ri^2 values have high and medium stability in yield, respectively while others with low Ri^2 values were unstable cultivars (Table 7).

According to the ASV ranking, the following cultivars were the most stable, Mission, Amigdalolia and Koroneiki, while the most unstable were 'Konservolia', 'Sevillano', 'Roghani', 'Arbequina' and 'Abou-Satal' .

Based on yield cluster analysis olive cultivars were classified into three categories. Category 1 was cultivars having high yield and medium alternate bearing ('Konservolia', 'Sevillano' and 'Koroneiki') (Fig. 3). These cultivars are widely adapted around the world (Barranco *et al.*, 2000; Therios, 2009). Barranco *et al.* (2000) reported that 'Konservolia' has a high productivity and alternate bearing but 'Sevillano' is productive with constant production in Mediterranean regions. Also, Therios (2009) stated that 'Sevillano' is cultivated in warmer regions in Spain and Italy without any problems. Our results revealed that 'Sevillano' had relatively constant production during the experiment. Koroneiki is one of the most important olive oil cultivar in the Greece with high fruit yield and good oil quality (Barranco *et al.*, 2000). Our results indicated that its productivity was relatively high and constant but oil content (data not presented) was low.

Category 2 was cultivars having medium yield and medium or high alternate bearing ('Zard', 'Manzanillo', 'Mission', 'Arbequina' and 'Amigdalolia') (Fig. 3). Results showed that 'Arbequina' had medium productivity with medium alternate bearing. Our result was not confirmed by Therios (2009) and Barranco *et al.* (2000) findings, where 'Arbequina' has a high productivity with constant yield and high oil content in the Italy. Therios (2009) stated that Manzanillo is categorized as a good performance olive cultivar in the world. In our research, 'Manzanillo' had medium productivity with high alternate bearing. Mission is a dual-purpose commercial olive cultivars in the world (Therios, 2009). Mission's productivity was medium and alternate in our research. Amigdalolia is an olive cultivar originated from Greece with medium productivity and alternate bearing (Barranco *et al.*, 2000). Our result represent that this cultivar show medium productivity and alternate bearing.

Category 3 was cultivars having low yield and low, medium or high alternate bearing ('Abou-Satl', 'Shengeh', 'Roghani' and 'Amfissis') (Fig. 3). We do not recommend these cultivars for planting in warm environmental condition.

4. Conclusions

In conclusion, one of major purpose of yield-trial research is to select the best cultivar for a growing region. An ideal cultivar should have the highest mean performance and be highly stable. Such an ideal cultivar would have the greatest vector length of the high-yielding genotypes and zero (G × E). In this study, Zard cultivar performed as the ideal cultivar based on almost mentioned methods. Konservolia, Sevillano and Koroneiki were the highest yielding cultivars in the regional trials. Generally, 'Konservolia' and 'Sevillano' are introduced for pickling use; while 'Koroneiki' is not suitable for cultivation in hot and dry regions due to low oil content (data not presented).

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