Euphytica (2008) 163:449–457
DOI 10.1007/s10681-008-9712-7

Response to conventional and organic environment of thirty-six lentil (*Lens culinaris* Medik.) varieties

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Received: 4 January 2008 / Accepted: 2 May 2008 / Published online: 22 May 2008

Abstract Thirty-six lentil varieties were evaluated under organic and conventional environment for three consecutive years in order to see whether the promising genetic material for an organic plant breeding program are different from those of a conventional system. The genetic material studied originated from various countries. In the conventional trial plots standard cultural practices (P mineral fertilization & pest control) were applied throughout the growing season, while in the organic ones no fertilizers or pest agrochemicals were applied. Significant regression, but of low value, between grain yield ranking and earliness or harvest index ranking was detected. Combined ANOVA indicated significant differences between genotypes, years, environments and genotype × environmental interactions (GEI). It was observed that under conventional management most of the genotypes had a higher yield compared to the organic one. The mean grain yield ranking of the genotypes in each of the environments revealed that some of the genotypes occupied the same ranking position at both the organic and the conventional environment (non-crossover GEI), while others exhibited a significant alteration in their ranking (crossover GEI) under the two environments. Crossover GEI and non-cross over GEI revealed two types of lentil varieties. Varieties with specific adaptation and varieties with broad adaptation. It was concluded that grain yield was in general higher when lentil varieties were grown under a conventional environment compared to the grain yield produced under an organic environment. Yet, there are lentil genotypes with a higher yielding ability under the organic management and therefore should be targeted by the breeder.

Keywords *Lens culinaris* · Lentil · Organic plant breeding · Ranking · GE interactions

Abbreviations

P_2O_5 Phosphorus pentoxide

Introduction

The significant environmental problems identified during the last decades and their impact on the diet and health of consumers, have focused the interest of public opinion and research community to organic agriculture. Various groups of farmers, scientists and nutritionists, after 1920s, observed a direct connection between farming practice and plant, animal,

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human and environmental health. So, organizations such as Demeter (1928), Soil Association (1946) and many others were founded and developed organic standards for agriculture practices. In addition, the regulation of European Union 2092/91 (Anonymous 1991) was an attempt to define the terms and conditions under which organic agriculture should be practiced. Thus it was soon realized that modern cultivars of field crops do not satisfy all the requirements and demands of organic agriculture. This is because during the last 50 years, varieties were developed targeting to high yield under high input environments (Phillips and Wolfe 2005). Many of these varieties, selected and cultivated under high input systems, cannot produce satisfactorily under a low input system such as organic agriculture. The main problem of those varieties under an organic system of cultivation is their confrontation with biotic and abiotic stresses (Erskine et al. 1994; Lammerts van Bueren et al. 2002). Therefore, breeders should pay more attention and develop specific cultivars adapted to the agronomic conditions prevailing on organic farms and complying with the philosophy of organic agriculture (Lammerts van Bueren et al. 2003).

Lentil (*Lens culinaris* Medik.) is an important crop throughout the Mediterranean region, W. Asia, and N. America (Erskine 1997). It is widely used for human food as it is a significant source of protein and in some areas it is also used as livestock feed. Lentil is broadly used in organic agriculture for its grain diet quality and because it is considered an important factor in rotation systems with cereals (Muehlbauer et al. 2002).

However, varieties appropriate for organic agriculture could be released following two types of breeding programs: conventional breeding including testing of advanced lines under organic conditions in the later stages of the breeding program and organic breeding programs where all steps in the breeding process are taken under organic conditions (Wolfe et al. 2008). Under this point of view, both wide and specific cultivar adaptation seems to be useful for organic systems.

In Hellas, lentil is a traditional crop cultivated in many regions in non-irrigated fields. The annual output of lentil in Hellas is about 1,565 tonnes from an area of about 1,400 ha (Hellenic National Statistical Service 2005). In addition, land cultivated with lentils has increased lately because: (1) they are used in nitrogen reduction programs, (2) lentil is included in the Mediterranean diet and (3) organic agriculture has been adapted by farmers.

The main objectives of the current research were: (1) to evaluate the effect of the organic and conventional systems on the productivity of lentil genotypes and their ranking alterations, and (2) to see whether the promising genetic material for an organic plant breeding program are different from that of a conventional system.

Materials and methods

Thirty-six lentil varieties were evaluated under organic and conventional environments. Field experiments were established and repeated during three consecutive growing seasons, 2004–2006, at the Fodder Crops and Pastures Institute in Larissa, Hellas (latitude 39°36′ N, longitude 22°25′ E). Soil type and climatic parameters are presented in Table 1. Olsen method was used to assess soil phosphorus content before planting. The genetic material studied, has originated from material developed in Hellas in the last 50 years (14 varieties), ICARDA (9 varieties), as well as from Morocco, India, Turkey, Jordan, Chile, Canada, USA, Algeria and Bulgaria (Table 2).

The experimental field arrangement was the triple lattice 6 × 6 with three replications. Each experimental plot had an area of 4 m^2 and consisted of five rows with 0.25 m spacing between rows. All plots in each replication were separated by a 1 m buffer zone and replications were separated by a 2 m buffer zone. The organic and conventional fields were about 300 m apart. According to 1,000 seeds weight, lentil varieties were classified in small seeded and large seeded types. Small seeded varieties are those with 1,000 seeds weight less than 50 g and large seeded varieties are those with 1,000 seeds weight more than 60 g. Thus, depending on lentil type, planting rate was adjusted to 1,700,000 plants ha^{-1} for small seeded lentils and to 1,500,000 plants ha^{-1} for large seeded lentils.

In the conventional trial plots, standard cultural practices (P mineral fertilization, prometryne application for broad-leaf weeds control and fluazifop-butyl for *Graminae* spp. weeds, preventive pest control) were applied throughout the growing season.

Table 1 Climatic parameters prevailed in the experimental field during the three culture periods and soil type characteristics of the field

Culture period	Precipitation (mm)	Temperature (°C)			Conventional system		Organic system	
		Min	Max	Avg	Soil type	P (mg/kg)	Soil type	P (mg/kg)
Nov 04–Jun 05	213.4	−6.6	38.5	12.0	CL	14	C	9
Nov 05–Jun 06	385.8	−7.6	38.4	11.6	C	11	CL	13
Nov 06–Jun 07	184.1	−5.2	42.7	12.3	C	14	C	10

The main pests were *Bruchus signaticornis* and *Etiella zinkenella*. A 2-year rotation was applied in the conventional system consisting of durum wheat/lentil or vetch. Wheat was fertilized with N (106 kg ha^{-1}) and phosphate (58 kg ha^{-1}) while the legume crop was fertilized with phosphate (60 kg ha^{-1}).

The organic management was based on the same rotation system, durum wheat/lentil, but no fertilizers were applied either on the previous culture (wheat) or on lentil. Appropriate culture practices (deep summer field ploughing, weeds removed by hand etc.) were applied. No pest or other agrochemicals were used.

Anthesis date was recorded at the 10% of the plants blooming stage. Earliness was measured as the number of days from sowing date to anthesis. Harvest index (HI) was measured as the ratio of grain yield to plant dry matter weight (Donald 1962). Plants were harvested at the physiological maturity stage for each variety. The harvested area was 2 m^2 per plot, as only the three central rows were harvested. Grain yield was measured at 13% grain moisture content.

Values presented here in represent averages from 3 year trials.

A combined-over environments analysis of variance (ANOVA) was performed. Partitioning of sum squares treatment (SS_{TRMT}) was applied to indicate the effect of each variance component. Ranks were assigned to genotypes for yield, earliness and harvest index and Spearman's rank correlation coefficient (r_s') was calculated. Linear, polyonymic, hyperbolic and logarithmic equations were tested for their suitability to describe the relationship between grain yield ranking order and earliness or harvest index ranking order. The equation with the highest coefficient of determination (R^2) values was judged to be the most appropriate. In these regression equations, earliness and harvest index were the dependent variables (y) and grain yield the independent (x). Fisher's protected LSD procedures were used to detect and separate mean treatment differences at $P = 0.01$. The program MSTAT (v1.2) was used to conduct ANOVA and regression analysis was conducted at the program STAT Graphics (v2.1).

Results

Yield

Most genotypes exhibited a higher yield under conventional management compared to the organic one (Table 2). The highest difference scored was 43.98% reduction in grain yield under organic management.

Significant ($P < 0.01$) differences among lentil varieties and among environments for grain yield were detected after combined analysis of variance. Genotype × environmental interaction (GEI) was also significant. Partitioning of the sum squares treatment (SS_{TRMT}) indicated that genotype was the main source of variation, followed by year and environment (Table 3). Finally, significant differences were detected for all variance components.

Spearman's rank correlation coefficient for grain yield ranking between conventional versus organic system was significantly high (0.905**). Cubic regression was the best fit to describe the relationship for grain yield ranking between conventional and organic environment (Fig. 1).

The ranking of the mean yield per variety and management system, differed between the two environments (Fig. 2).

Earliness

Combined ANOVA indicated significant differences for earliness between varieties and environments (Table 2). Almost all varieties that were cultivated in

Table 2 Differences in yield, earliness and harvest index between organic and conventional systems across 3-year trials

Code name	Origin or donor organization	Seed type	Grain yield (g/2 m^2)			Earliness		Harvest index	
			Conv	Org	D (%)	Conv	Org	Conv	Org
SAMOS	HELLAS	SS	417.23	347.76	16.65	147.3	144.7	0.26	0.30
ATHENA	HELLAS	SS	480.55	368.33	23.35	134.7	134.3	0.42	0.41
ARTEMIS	HELLAS	SS	377.75	337.21	10.73	137.7	134.3	0.33	0.40
DIMITRA	HELLAS	SS	380.01	296.69	21.93	146.3	143.7	0.28	0.23
M-17003	HELLAS	SS	428.32	328.31	23.35	137.3	135.3	0.43	0.36
F-82	HELLAS	SS	360.02	201.68	43.98	149.0	150.0	0.28	0.18
F-85	HELLAS	SS	350.55	261.65	25.36	151.3	147.7	0.35	0.25
F-86	HELLAS	SS	429.43	397.22	7.50	146.7	140.7	0.30	0.35
M-15305	HELLAS	LS	422.21	435.01	−3.03	140.7	137.0	0.44	0.43
IKARIA	HELLAS	LS	155.56	142.20	8.59	146.3	143.0	0.12	0.24
THESSALIA	HELLAS	LS	291.11	249.45	14.31	146.3	143.3	0.26	0.21
LEMNOS	HELLAS	LS	199.99	201.66	−0.84	148.0	142.3	0.19	0.26
F-81	HELLAS	LS	287.76	251.12	12.73	142.0	143.7	0.25	0.25
F-83	HELLAS	LS	300.56	270.55	9.98	147.7	146.0	0.28	0.26
FLIP 92-36L	ICARDA	SS	457.25	499.45	−9.23	133.7	132.0	0.47	0.42
FLIP 03-24L	ICARDA	SS	426.10	384.45	9.77	137.3	134.7	0.44	0.46
FLIP 02-1L	ICARDA	SS	368.88	259.45	29.67	130.3	126.3	0.45	0.50
FLIP 94-5L	ICARDA	SS	341.66	365.55	−6.99	133.3	135.3	0.43	0.43
ILL-7698	ICARDA	SS	562.76	518.90	7.79	145.0	139.3	0.48	0.42
FLIP 03-12L	ICARDA	SS	438.33	418.35	4.56	135.7	134.7	0.45	0.42
FLIP 03-57L	ICARDA	SS	403.90	441.68	−9.35	133.7	130.7	0.49	0.42
FLIP 03-50L	ICARDA	SS	335.55	247.76	26.16	135.0	132.0	0.40	0.30
ILL-6811	ICARDA	SS	579.45	549.45	5.18	135.3	132.7	0.48	0.46
ILL-96	MOROCCO	SS	261.11	195.55	25.11	140.7	138.0	0.35	0.41
ILL-590	TURKEY	SS	579.45	486.68	16.01	127.3	127.0	0.48	0.45
LL-35	INDIA	SS	408.86	389.45	4.75	131.7	128.0	0.62	0.48
HC-125	BULGARIA	SS	343.89	270.00	21.49	146.0	144.0	0.32	0.24
73	ALGERIA	SS	339.99	300.55	11.60	134.3	133.3	0.43	0.39
81S15	JORDAN	SS	525.55	488.32	7.08	136.7	135.3	0.51	0.37
US 1	USA	SS	329.45	214.45	34.91	157.7	154.7	0.21	0.34
LC-960254	USA	LS	348.90	323.31	7.33	130.3	131.7	0.46	0.38
US 2	USA	LS	193.32	123.33	36.20	152.3	151.0	0.18	0.23
33-032-10403	CHILE	LS	358.90	275.00	23.38	146.3	143.3	0.31	0.25
CAN 1	CANADA	LS	156.13	103.34	33.81	154.3	152.3	0.15	0.18
CAN 2	CANADA	SS	252.78	201.12	20.44	155.3	152.7	0.21	0.20
CAN 3	CANADA	SS	235.55	234.45	0.47	150.7	148.3	0.31	0.26
			CV: 17.30			CV: 5.5		CV: 18.5	
			LSD: 100.3			LSD: 2.04		LSD: 0.164	

SS: small-seeded; LS: large-seeded; D: percentage of yield increase or reduction under conventional environment in relation to yield under organic environment

the organic environment reached anthesis earlier compared to the conventional environment. Correlation between yield and earliness within each of the environments (conventional and organic) indicated cubic regression as the best fit for grain yield ranking versus earliness ranking (Figs. 3, 4). Spearman's rank

Table 3 Partitioning of the treatment sum squares (SS_{TRMT}), across 3 year evaluation of 36 lentil varieties under conventional and organic environment for yield

Sources	SS_{TRMT} (%)
Genotype	46.16**
Year	19.01**
Environment	4.13**
Year × environment	0.97**
Year × genotype	24.38**
Environment × genotype	2.08**
Year × environment × genotype	3.27**

** Significance level: $P < 0.01$

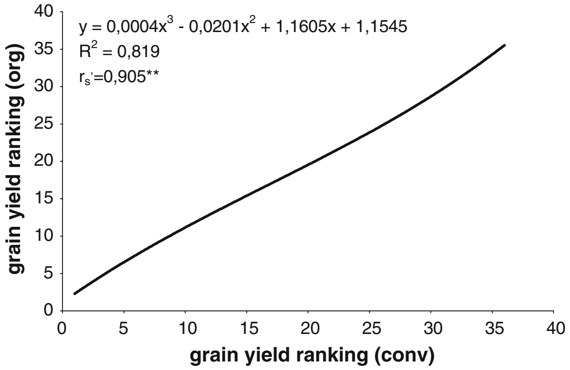

Fig. 1 Cubic regression line for grain yield ranking under conventional (x axis) and organic environment (y axis). Coefficient of determination (R^2) and Spearman's rank correlation (r_s') across 3-year trials were significant at the 0.01 probability level

correlation (r_s') for grain yield ranking versus earliness ranking was significant ($P < 0.01$) in both environments. Correlation for earliness among the two environments indicated that linear regression is the best fit. Spearman's index that described the correlation of earliness ranking under conventional and organic environment was highly significant ($r_s' = 0.95^{**}$).

Harvest index

Significant differences for harvest index between varieties and environments were detected. Mean values of harvest index were low for both environments (0.34 for organic and 0.36 for conventional). Ranking correlation (r_s') between grain yield values and harvest index values was positively significant for both, the conventional (Fig. 3) and the organic (Fig. 4) environment. Correlation between yield and harvest index within each of the environments indicate cubic regression as the best fit for grain yield versus harvest index under conventional environment (Fig. 3) and linear regression as the best fit for grain yield versus harvest index under organic environment (Fig. 4). Spearman's rank correlation for harvest index ranking in conventional and organic environment was significantly high ($r_s' = 0.83^{**}$) and cubic regression was the best fit for harvest index ranking in both environments (Fig. 5).

Discussion

Yield

Grain yield under organic systems is generally lower than the conventional ones. Thus Ryan et al. (2004) working with wheat reported a yield reduction of 17–84% under organic management. Similarly Burger et al. (2008) reported 5–25% reduction of grain yield in maize under organic farming conditions compared to the conventional ones. The grain yield reduction observed in this study ranged from 0.47% to 44%. Saxena (1981) attributed the yield reduction observed under organic management to phosphate fertilization and to pest control. In addition, it is known that phosphorus interacts with rhizobium inoculants and provides significant benefits to lentil crops (Sekhon et al. 1986). Thus fertilization could have played a significant role for the yield increase observed under the conventional system since soil content in phosphorus was low at both organic and conventional field plots (Table 1). Beyond this general observation however, there were certain varieties in this study that performed better under the organic environment (Table 2). These varieties originated from ICARDA (FLIP 92-36L, FLIP 03-57L, FLIP 94-5L) and Hellas (LEMNOS and M-15305). Grain yield differences ranged from 0.84% to 9.35% increase under organic conditions. This is likely due to the better adaptability of these varieties at an organic system. Similar results are also reported by Koparanis et al. (2006) and Przystalski et al. (2007). In addition, Malhotra et al. (1971) in a study with lentil concluded that some lentil varieties produce higher yields under rich environments, as it is

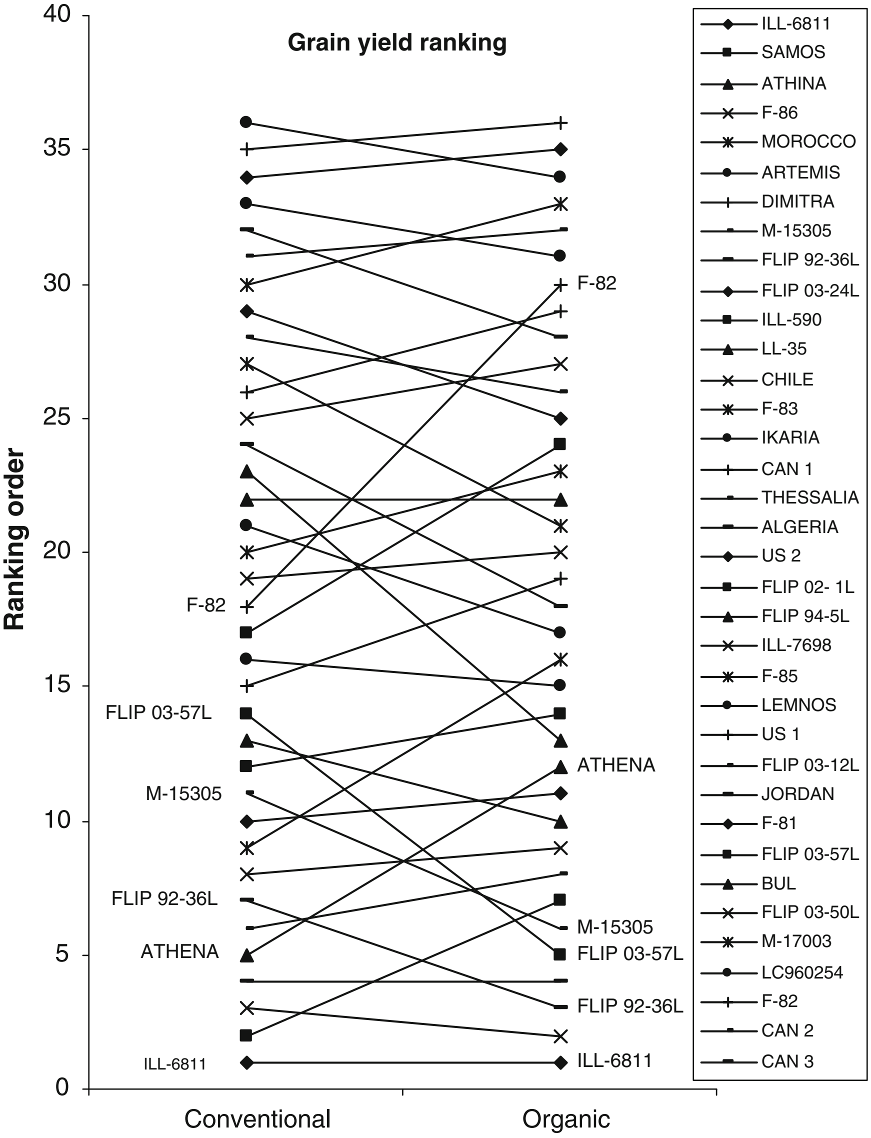

Fig. 2 Ranking order of the mean grain yield per variety and cultivation environment across 3 year trials

expected, whilst others yield better-than-average under poor environments but they fail to exploit better environmental conditions. The results reported in this study however, cannot be fully attributed to the environment, at least for the Hellenic varieties, since they were developed under conventional conditions. In addition, it could be expected that Hellenic varieties should perform better than the introduced varieties since they are well adapted in the area genotypes. However, it is well known (C Iliadis, pers. commun.) that some introduced varieties, mainly from the Middle East and Asian areas, perform better than the local ones because they incorporate resistance genes to *Fusarium wilt* and drought tolerance. Although these varieties are valuable genetic material for breeding programs, they don't have commercial value for the Hellenic market because of their appearance and quality characteristics such as seed color, seed size, cooking time etc.

The partitioning of the treatment sum squares indicated that the genotypic differences explained the main percentage of variability, which in turn indicates strong heritability differences between the genotypes (Table 3). This should be associated with the observation that the year, as a variance component, also explained a significant percentage of

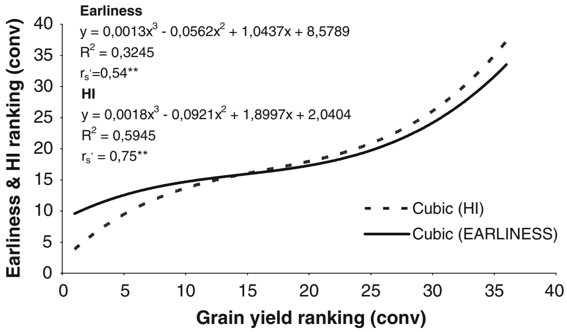

Fig. 3 Temporal pattern where lines describe cubic regression for grain yield ranking (x axis) with earliness and harvest index (HI) ranking (y axis) under conventional environment across 3-year trials. Coefficient of determination (R^2) and Spearman's rank correlation (r_s') were significant at the 0.01 probability level

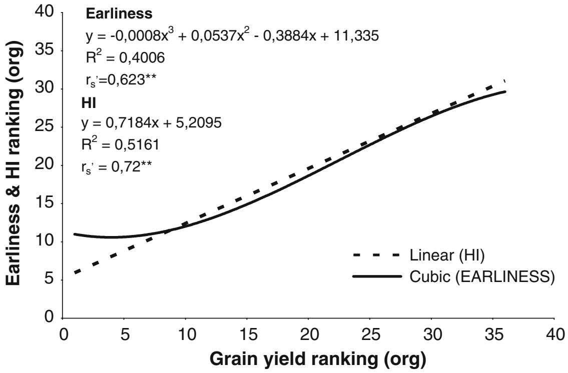

Fig. 4 Temporal pattern where lines describe cubic regression for grain yield ranking (x axis) with earliness and linear regression for grain yield ranking versus harvest index (HI) ranking (y axis) under organic environment across 3-year trials. Coefficient of determination (R^2) and Spearman's rank correlation (r_s') were significant at the 0.01 probability level

variation. This was mainly attributed to the differences in precipitation among seasons (Table 1). Erskine and El Ashkar (1993) reported that 80% of the variation in lentil grain yield in the Mediterranean climates was accounted for by differences in seasonal rainfall. Yet, genetic variation exists in drought tolerance of lentil. For example, small seeded varieties in comparison with large seeded varieties were found to be better adapted to dry environments (Erskine 1996). Finally, plants in 2006–2007 season were affected seriously by *Fusarium wilt*, which could have also resulted in a reduction of the effect of the culture system, as a variance component.

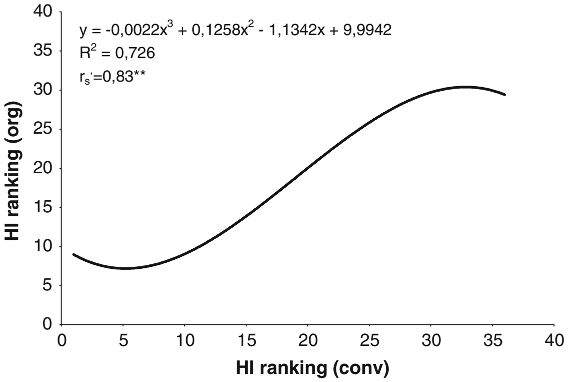

Fig. 5 Cubic regression line for harvest index ranking under conventional (x axis) and organic environment (y axis) across 3-year trials. Coefficient of determination (R^2) and Spearman's rank correlation (r_s') were significant at the 0.01 probability level

Significant GEI differences for grain yield indicate that the final grain yield produced depends on the variety response in each environment. This resulted in a different ranking order under the two culture environments studied. Although there is a strong correlation (Spearman's index = 0.905) between organic and conventional grain yield ranking, the ranking of the mean yield per variety and environment revealed two types of GEI (Fig. 2). Firstly, genotypes occupying the same ranking position at both the organic and the conventional environment (non-crossover GEI), and secondly, those that exhibited a significant alteration in the ranking (crossover GEI) under the two environments. For example, although variety FLIP 03-57L occupied the fifth place in the organic environment ranking, it is located at the fourteenth place on the conventional environment ranking. Such varieties that indicate crossover GEI are considered by some researchers (Baker 1988) more important for breeders. This observation is more significant for low input environments, such as the organic ones. Ceccarelli (1996) suggested that genotypes targeted for low input environments should be selected under these unfavorable conditions. However, it was observed that the 5 (15%) highest yielding varieties tested under the conventional environment also included 3 (60%) out of the 5 (15%) highest yielding varieties tested under the organic environment (Table 3). It could be stated that these three genotypes exhibited broad adaptability and stability over years and culture environments.

This latter observation reinforces the aspect that among lentil varieties adaptable to conventional cultivate system, one could isolate cultivars with good performance under organic management. Variety ILL-6811 is a typical example with broad adaptability and stability under both environments over years since it is at the top of both ranks.

Earliness

The earlier anthesis observed for almost all varieties at the organic environment (approx. 2.3 days per variety) could be attributed to the lower inputs of this environment that pushed the plants to flower earlier. The significant but not high ranking correlation between grain yield and earliness observed under the two environments (Figs. 3, 4) provide an evidence that earliness could be exploited with difficulty as an indirect selection criterion. This is further enhanced by the observation that correlation between grain yield and time to flowering is not constant, since it has been reported as positive (Balyan and Singh 1986; Zaman et al. 1989), negative (Singh and Singh 1969; Joshi et al. 2005), and non-existent (Tyagi and Sharma 1985). Finally, it was observed that under the two environments genotypes ranked similarly for earliness (Spearman's correlation $r_s = 0.95^{**}$).

Harvest index

Pulses in general are known to produce sufficiently high vegetative matter, but very little grain yield, resulting in poor harvest index (Jain 1971). This is what has been observed in this study (Table 2). In addition, Singh (1977) and Hamdi et al. (1991) working also with lentil reported that grain yield per plant was positively correlated with harvest index. Furthermore, other researchers have suggested that harvest index could be a useful selection criterion for higher yields (Kumar et al. 2002; Solanki 2006; Yadav et al. 2005). In this study however, under both environments (Figs. 3, 4), no valuable regression was observed between grain yield ranking and harvest index. It could be stated therefore, that although there is a general significant correlation between grain yield and harvest index, harvest index could be exploited with difficulty as a secondary selection criterion.

Conclusions

The results of this study indicate that: (1) Grain yield performance was increased up to 44% for lentil varieties when cultivated under conventional environment compared to grain yield performance when cultivated under organic environment. Yet, certain varieties cultivated under organic conditions exceeded the grain yield produced when they were grown under conventional conditions. (2) Ranking order was strongly influenced by environment. Crossover GEI and non-cross over GEI revealed two types of lentil varieties. Varieties with specific adaptation and those with broad adaptation. It should be mentioned however, that broad adaptation varieties were detected among high-yielders. (3) Although there is a significant regression between grain yield ranking and earliness or harvest index ranking, it could be difficult to isolate high yielding genotypes when selecting for these two traits.

Acknowledgments Authors would like to acknowledge Dr. Costas Iliadis, director of Fodder Crops and Pastures Institute, for valuable advices during the experimental period. This work was supported by grants from the National Agriculture Research Foundation of Hellenic Ministry of Agriculture.

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