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GENOTYPE–ENVIRONMENT INTERACTIONS AND STABILITY ANALYSIS FOR DRY-MATTER YIELD AND SEED YIELD IN HUNGARIAN VETCH (*Vicia pannonica* CRANTZ.)

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ABSTRACT

This study was conducted to determine genotype–environment interactions and the stability status of twelve Hungarian vetch (*Vicia pannonica* Crantz.) genotypes in terms of dry-matter yield and seed yield under the ecological conditions of the Southeastern Anatolia Region of Turkey. The experiments were performed in five locations in the region during the 2008-2009 and 2009-2010 growing seasons. The experiments were performed according to a complete randomized block design with three replications. Genotype–environment interactions were found to be highly significant (*P* < 0.01) for dry-matter yield and seed yield, indicating that the Hungarian vetch genotypes' dry-matter yield and seed yield were significantly affected by the year and condition of the location. The stability of the genotypes was estimated using the mean yield of genotypes (x_i), regression coefficient (*bi*), regression deviation mean square (S^2d_i), determination coefficient (R^2), and regression line intercept (*a*). Stability analysis indicated that although the most stable genotype was the Ege Beyazi-79 cultivar in terms of dry-matter yield, the Oguz-2002 cultivar was the most stable in terms of seed yield.

Keywords: Dry-matter yield, genotype–environment interactions, Hungarian vetch (*Vicia pannonica* Crantz.), seed yield, stability parameters

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INTRODUCTION

Hungarian vetch (*Vicia pannonica* Crantz.) is adapted to the environments of large areas of the world (Magness et al., 1971). The species is one of the most promising annual vetch species, and its cultivation is especially recommended for places with harsh winter conditions (Acikgoz, 1988; Tahtacioglu et al., 1996; Nizam et al., 2011). Winter temperatures in the Southeastern Anatolia region can fall far below 0°C in some years. This situation makes it risky to cultivate forage crops species such as common vetch (*Vicia sativa* L.) and forage pea (*Pisum sativum* var. *arvense* L.), which are vulnerable to harsh winter conditions. For this reason, the cultivation of these species can only occur through spring sowings. In rainfed conditions, especially when there has been a dry spring, the dry-matter yield and seed yield of winter sowings are significantly higher than those of spring sowings for annual legume species. With the anticipated drought caused by global warming, Hungarian vetch is of great importance in this respect.

Yield stability is an interesting feature of today's plant breeding programs, owing to the high annual variation in mean yield, especially in the arid and semi-arid areas (Mohammadi et al., 2012). Producers are most interested in a cultivar that gives consistent yields under different growing conditions; thus, plant breeders usually try a series of genotypes in multi-environments, before a new improved variety is released for production to farmers (Naghavi et al., 2010). Genotype–environment interactions (GEI) can be defined as the response of genotypes to different environments. Genotype–environment interactions are extremely important in the development and evaluation of plant varieties because they can reduce genotypic stability values in diverse environments (Hebert et al., 1995).

An understanding of genotype–environment interactions requires information on the existence and magnitude of the response of individual lines to their environments, but awareness of such interactions provides no quantitative measurements that indicate the stability of individual lines (Abd El- Moneim and Cocks, 1993; Bozoglu and Gulumser, 2000). Recently, interest has focused on regression analysis, an approach originally proposed by Yates and Cochran (1938) and later modified by Finlay and Wilkinson (1963), where stability as a linear relationship between the yield of genotypes over many environments is given by the regression coefficient (b_i), and a genotype with $b_i = 1$ can be considered stable. Eberhart and Russell (1966) further developed the idea by implementing the regression deviation mean square (S^2d_i) as a measure of stability. Genotypes with low (close to 0) deviation from the regression (S^2d_i) value and high (above average) mean efficiency are regarded as stable. Pinthus (1973) presented the coefficient of determination (R_i^2) as the quantity of variation explained by the regression as a portion of the total variation. A high coefficient of determination (R_i^2) (Pinthus, 1973; Teich, 1983) and positive high regression line intercept (*a*) (Smith, 1982) are also desired criteria in terms of genotypic stability.

A number of stability studies have previously been carried out on different crops in Turkey (Sabanci, 1996; Albayrak et al., 2005; Akcura et al., 2005; Acikgoz et al., 2009; Yucel et al., 2009, Nizam et al., 2011). However, no stability study has been performed for Hungarian vetch in the Southeastern Anatolia region. The objectives of this study were to (1) evaluate the dry-matter yield and seed yield capacity of Hungarian vetch genotypes (G) in different environments (E); (2) identify and assess the G × E interactions; and (3) determine the stability of these interactions using different stability parameters.

MATERIALS AND METHODS

Materials

Twelve Hungarian vetch (*Vicia pannonica* Crantz.) genotypes, including six commercial cultivars and six promising lines, were used as the genetic materials in this study. Five of the lines used, Line-3, Line-10, Line-15, Line-18, Line-55, were supplied from the Eastern Anatolia Agricultural Research Institute, Erzurum, Turkey. The remaining Line 2109 was selected from a breeding program performed in GAP International Agricultural Research and Training Center (GAP IARTC) Diyarbakir, Turkey. In addition to these lines, other cultivars used were Tarm Beyazi-98, Budak, Anadolu Pembesi-2002, Ege Beyazi-79, Oguz-2002 and Beta.

The cultivars were supplied by their breeders' institutions. Accordingly, Tarm Beyazi-98, Anadolu Pembesi-2002, Oguz-2002 were provided by the Central Research Institute for Field Crops, Ankara, Turkey; Ege Beyazi-79 was supplied by the Aegean Agricultural Research Institute, İzmir, Turkey; the Budak cultivar was obtained from the Transitional Zone Agricultural Research Institute, Eskisehir, Turkey; and Beta, which originated in Hungary, was supplied by Serta Agriculture Production Import Export Trade Limited Company, Ankara, Turkey.

The locations where experiments were conducted are given in Table 1. The Southeastern Anatolia region is one of Turkey's seven census-defined geographical regions, and the region is characterized by a continental climate. In this region, summers are dry and hot, whereas winters are cool and rainy. The experiments were conducted under rainfed conditions at five locations having different climate and soil characteristics during two consecutive growing seasons (2008–2009 and 2009–2010) in the Southeastern Anatolia region of Turkey.

Table 1. The environments and some climatic and agronomic information of the locations.

Code	Growing seasons	Locations	Altitude (m)	Soil properties	Sowing date	The average temperature (ºC)	Total rainfall (mm)
E1	2008-2009	Diyarbakir	603	pH=7.86 clay-silt	14.11.2008	12.4	455.0
E2	2009-2010	Diyarbakir	607	pH=7.85 clay-silt	20.11.2009	14.3	517.9
E3	2008-2009	Cınar	701	pH=7.84 clay-silt	17.11.2008	12.9	366.3
E4	2009-2010	Cınar	675	pH=7.85 clay-silt	24.11.2009	15.0	417.0
E5	2008-2009	Ergani	995	pH=7.76 clay-silt	07.11.2008	13.8	768.8
E6	2009-2010	Ergani	936	pH=7.77 clay-silt	19.11.2009	14.6	963.6
E7	2008-2009	Cungus	970	pH=7.78 sandy-silt	07.11.2008	9.7	725.0
E8	2009-2010	Cungus	915	pH=7.79 sandy-silt	19.11.2009	11.2	825.2
E9	2008-2009	Hazro	815	pH=7.65 clay-silt	06.11.2008	11.9	927.4
E10	2009-2010	Hazro	808	pH=7.64 clay-silt	17.11.2009	13.8	1055.6

*Data from the Regional Directorate of Meteorology, Diyarbakir, Turkey.

The experiments were conducted according to a randomized complete block design with three replications. Each plot consisted of six rows 5 m in length, and rows were spaced 20 cm apart. The seeding rates were 220 seeds m^{-2} (Munzur et al., 1992). Seeds were sown using an experimental drill. The environment, geographical coordinates of location, growing season, soil properties, rainfall, temperature, and sowing dates at each location

during the growth periods are summarized in Table 1. In the experiments, half of each plot was harvested in May to calculate dry-matter yield, and the other half was harvested in June to calculate seed yield. Dry-matter yield and seed yield were determined according to the technical instructions for leguminous forage crops published by the Seed Registration and Certification Centre, Ankara, Turkey, in 2001.

Statistical analysis and procedures

We computed the combined analysis of variance on phenotypic data from trials in 10 environments (Comstock, Moll, 1963). The genotypic responses to environmental changes were assessed using a linear regression coefficient (b_i) and the variance of the regression deviations ($S^2 d_i$) using the following formulas proposed by Finlay and Wilkinson (1963) and Eberhart and Russell (1966).

$$b_i = 1 + \frac{\sum_i (Xij - \overline{X}i. - \overline{X}.j + \overline{X}..)(\overline{X}.j - \overline{X}..)}{\sum_j (\overline{X}.j - \overline{X}..)^2}$$

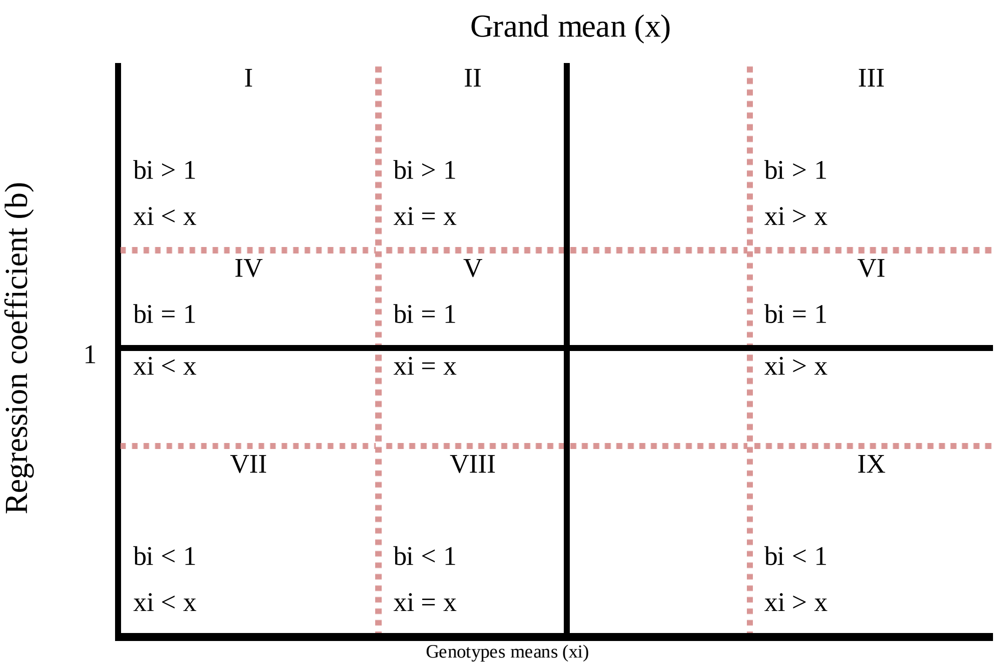
$$S^2_{di} = \frac{1}{E-2} = \left[\sum_i (Xij - \overline{X}i. - \overline{X}.j + \overline{X}..) - (b_i - 1)^2 \sum_i (\overline{X}.j - \overline{X}..)^2 \right],$$

where Xij is the dry-matter or seed yield of genotype i in environment j, $\overline{Xi}$ is the mean yield of genotype i, $\overline{X.j}$ is the mean yield of environment j, $\overline{X}$. is the grand mean, and E is the number of environments. The coefficient of determination (R_i^2) (Pinthus, 1973) was computed from individual linear regression analyses. Also, the regression line intercept (a) was evaluated as a stability parameter (Eberhart, Russell, 1966), and the significance of the regression coefficient (the yield of a single genotype on the mean environment), and the grand means of dry-matter and seed yields, were tested by employing the t-test (Steel, Torrie, 1960). The confidence intervals were estimated based on the formula given below:

Confidence interval = $\overline{X} \pm t$- value $\times s_x$.

For dry-matter yield and seed yield, regression curves of twelve Hungarian vetch genotypes were developed using the equation y = $b_i \times x + a$ by making use of an environmental index.

All statistical analyses were performed using the MSTAT–C statistical computer package software program, version 3.00/EM (Freed et al., 1989). The means were compared using a Duncan test at a 0.05 probability level. The grand mean, regression coefficient, and their confidence intervals were taken into account when the stability status of the genotypes was evaluated over nine different environments (Figure 1).



I = Poor adaptability to favorable environmental conditions
II = Average adaptability to favorable environmental conditions
III = Better adaptability to favorable environmental conditions
IV = Poor adaptability to all environmental conditions
V = Average adaptability to all environmental conditions
VI = Better adaptability to all environmental conditions
VII = Poor adaptability to unfavorable environmental conditions
VIII = Average adaptability to unfavorable environmental conditions
IX = Better adaptability to unfavorable environmental conditions

Figure 1. The mathematical explanation of stability environments

RESULTS

In this study, twelve Hungarian vetch genotypes were studied in five different locations for two years. The variation among environments in both dry-matter yield and seed yield was significant ($P < 0.05$) (Table 2). Mean dry-matter yield varied from 3.973 t ha^{-1} in environment 7 to 7.804 t ha^{-1} in environment 1. Seed yield ranged from 0.653 t ha^{-1} in environment 3 to 1.104 t ha^{-1} in environment 9 (Table 2).

Table 2. Mean, min. and max. yields of dry matter and seed yields in the environments.

Environments	Growing seasons	Locations	Dry matter yield (t h^{-1})			Seed yield (t h^{-1})		
			Mean *	Min.	Max.	Mean*	Min.	Max.
E1	2008-2009	Diyarbakir	7.804 a	7.053	8.710	1.016 b	0.780	1.500
E2	2009-2010	Diyarbakir	5.458 cd	4.517	6.130	0.851 de	0.662	1.350
E3	2008-2009	Cınar	6.955 b	6.033	7.710	0.653 h	0.463	1.030
E4	2009-2010	Cınar	5.778 c	4.810	6.910	0.719 g	0.547	0.869
E5	2008-2009	Ergani	5.715 c	4.803	7.653	0.816 ef	0.498	1.080
E6	2009-2010	Ergani	5.061 e	4.200	6.887	0.787 f	0.614	0.962
E7	2008-2009	Cungus	3.973 f	2.423	6.843	0.878 d	0.801	1.107
E8	2009-2010	Cungus	5.716 c	4.633	7.303	0.939 c	0.738	1.085
E9	2008-2009	Hazro	7.226 b	5.823	8.543	1.104 a	0.965	1.280
E10	2009-2010	Hazro	5.211 de	3.477	7.577	0.866 de	0.648	1.260

*Means followed by different letters within a column insignificant differences at the level of $P < 0.05$ for Duncan Range Test

The mean dry-matter yield and seed yield of the twelve Hungarian vetch genotypes ranged respectively from 5.315 t ha^{-1} to 6.999 t ha^{-1}, and 0.748 t ha^{-1} to 1.113 t ha^{-1}. The highest dry-matter yield and seed yield were obtained from Anadolu Pembesi-2002 (3) and Oguz -2002 (9) cultivars, respectively (Table 4).

The results from variance analysis for dry-matter yield and seed yield are shown in Table 3. For dry-matter yield, years, locations, year–location interaction, replications, genotypes, location–genotype interaction, and year–location–genotype interaction were highly significant ($P < 0.01$). Also, the year–genotype interaction was found to be significant ($P < 0.05$). On the other hand, except for the replications, which were not significant ($P > 0.05$), all other interactions were found to be highly significant ($P < 0.01$) for seed yield (Table 3). For both dry-matter yield and seed yield, the second-order interactions (genotype × year × location) was highly significant ($P < 0.01$). This indicates that each location in each year could be treated as a separate environment for the both traits.

Table 3. Analysis of variance for dry matter yield and seed yield in Hungarian vetch genotypes.

Source of variation	df	Dry matter yield: Sum of square	Dry matter yield: Mean square	Dry matter yield: F value	Seed yield: Sum of square	Seed yield: Mean square	Seed yield: F value
Years (Y)	1	71.262	71.262	128.636**	0.337	0.337	30.7272**
Locations (L)	4	160.502	40.125	72.4308**	4.109	1.027	93.6301**
Y × L	4	188.236	47.059	84.9467**	1.342	0.335	30.5818**
Replications	20	22.283	1.114	2.0111**	0.193	0.010	0.8782ns
Genotypes (G)	11	97.270	8.843	15.9621**	4.499	0.409	37.2859**
Y × G	11	13.688	1.244	2.2463*	0.282	0.026	2.3335**
L × G	44	91.311	2.075	3.746**	2.102	0.048	4.3545**
L × G × Y	44	67.686	1.538	2.7768**	1.343	0.031	2.7831**
Error	220	121.876	0.554		2.413	0.011	
General	359	834.115			16.620		

*: $P < 0.05$ at significance; **: $P < 0.01$ at significance; ns: not significant.

Dry-matter yield

An analysis of variance revealed that genotype–environment interactions were highly statistically significant ($P < 0.01$) for dry-matter yield (Table 3), and regression coefficients ranged from 0.283 to 1.325 for dry-matter yield (Table 4). This large variation in regression coefficients reflects the different responses of different genotypes to environmental changes. With respect to dry-matter yield, the Tarm Beyazi-98 and Budak cultivars showed average adaptability to favorable environmental conditions ($b_i > 1$ and $xi = x$). The varieties that obtained the highest dry-matter yield were Anadolu Pembesi-2002 and Oguz-2002. Due to their small b_i values, they were accepted as having better adaptability to unfavorable environmental conditions ($b_i < 1$ and $xi > x$). These cultivars were relatively better adapted to poor environments and were insensitive to environmental changes. Therefore, the cultivation of such cultivars under unfavorable conditions can be recommended with respect to their dry-matter yield (Table 4, Figure 2 and Figure 3).

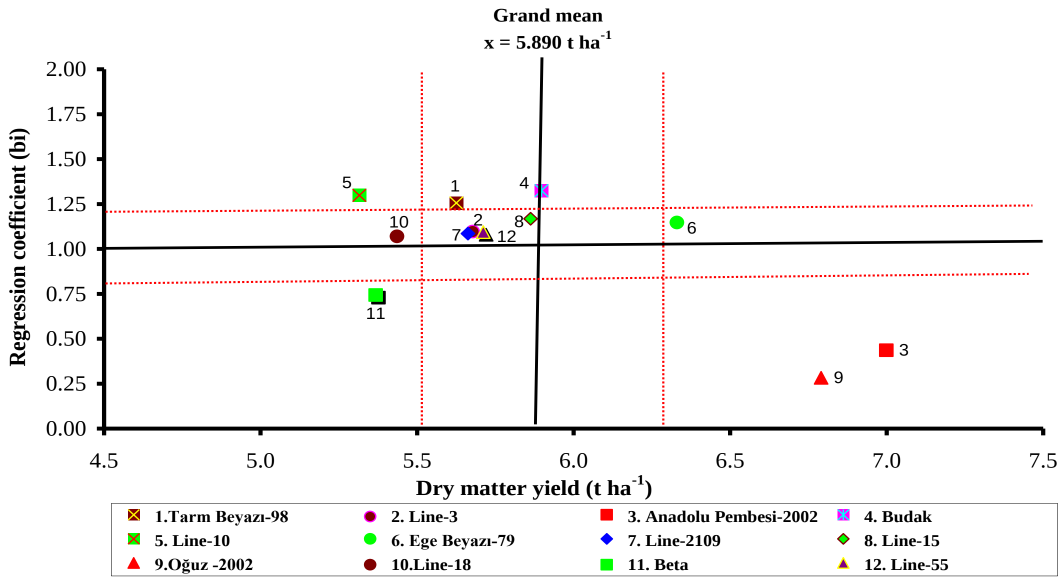


Figure 2. The relationship between the regression coefficients and mean dry matter yield (t ha^{-1}) for twelve Hungarian vetch genotypes.

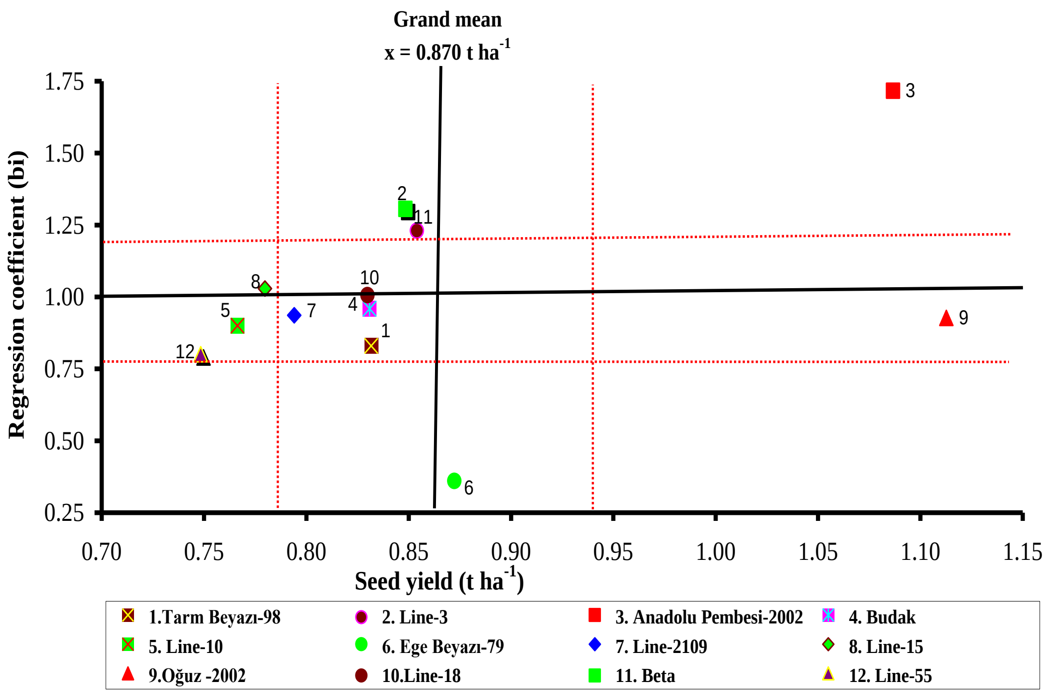


Figure 3. The relationship between the regression coefficients and mean seed yield (t ha^{-1}) for twelve Hungarian vetch genotypes.

Table 4. Stability parameters of Hungarian vetch genotypes for dry matter yield and seed yield

Code	Genotypes	Dry matter yield					Seed yield				
		x_i (t ha^{-1})	b_i	S^2d_i	a	R_i^2	x_i (t ha^{-1})	b_i	S^2d_i	a	R_i^2
1	Tarm Beyazi-98	5.625	1.256*	41.233**	-1.771	0.848	0.832	0.830	0.554*	0.115	0.714
2	Line-3	5.678	1.096	28.550**	-0.778	0.860	0.854	1.23*	1.461**	-0.207	0.675
3	Anadolu Pembesi	6.999**	0.436**	63.469**	4.433	0.304	1.0866**	1.717**	3.397**	-0.395	0.636
4	Budak	5.898	1.325**	100.871**	-1.907	0.717	0.831	0.959	0.803**	0.003	0.697
5	Line-10	5.315**	1.298*	18.396*	-2.327	0.930	0.7663*	0.900	0.518	-0.010	0.758
6	Ege Beyazi-79	6.33*	1.147	20.162*	-0.424	0.905	0.872	0.360**	0.332	0.561	0.440
7	Line-2109	5.663	1.085	51.978*	-0.730	0.768	0.794	0.936	1.721**	-0.014	0.506
8	Line-15	5.863	1.168	25.286**	-1.017	0.887	0.779*	1.029	0.426	-0.109	0.833
9	Oguz -2002	6.790**	0.283**	67.596**	5.122	0.148	1.113**	0.927	1.491**	0.313	0.537
10	Line-18	5.436*	1.070	27.111**	-0.864	0.860	0.830	1.006	0.877**	-0.038	0.699
11	Beta	5.368**	0.743*	61.971**	0.993	0.565	0.848	1.306**	1.063**	-0.278	0.763
12	Line-55	5.712	1.094	32.321**	-0.730	0.844	0.748**	0.801	0.552*	0.058	0.700
Average		5.890	1.000				0.837	1.000			
Confidence limits (0.05)		± 0.349	± 0.213	± 15.784			± 0.074	± 0.206	± 0.544		
Confidence limits (0.01)		± 0.486	± 0.300	± 22.274			± 0.105	± 0.209	± 0.768		

* Significant difference at $P < 0.05$; ** Significant difference at $P < 0.01$.

(x_i): The yield mean, (b_i): Regression coefficient, (S^2d_i): Regression deviation mean square, (a): Regression line intercept, R_i^2: Coefficient of determination

With its high dry-matter yield and a regression coefficient that did not differ significantly from 1.0, the Ege Beyazi-79 cultivar showed better adaptability to all environmental conditions. For dry-matter yield, four lines (Line-3, Line-18, Line-55, and Line-2109) showed average adaptability to all environmental conditions (the regression coefficients did not differ significantly from 1.0), with yields nearly equal to or higher than the grand mean. These varieties along with Ege Beyazi-79 can be considered as the most widely adaptable and stable lines in terms of dry-matter yield for the Southeastern Anatolia region (Table 4, Figure 2).

Seed yield

The genotype–environment interaction was highly significant (P < 0.01) for seed yield (Table 3). In this study, the regression coefficient for seed yield ranged from 0.36 to 1.71. With respect to seed yield, despite the fact that Beta and Line-3 showed average adaptability to favorable environmental conditions ($b_i > 1$ and $x_i = x$), Tarm Beyazi-98, Budak, Line-18, and Line-2109 genotypes showed average adaptability to all environmental conditions (bi = 1, xi = x). Although the Anadolu Pembesi-2002 cultivar showed better adaptability to favorable environmental conditions (bi > 1; xi > x), Ege Beyazi-79 showed average adaptability to unfavorable environmental conditions (bi < 1; xi = x). Also, Oguz-2002 showed better adaptability to all environmental conditions (bi = 1; xi > x).

The coefficients of determination (Pinthus, 1973) ranged from 0.148 to 0.930 and from 0. 440 to 0.833 for dry-matter yield and seed yield, respectively. In terms of dry-matter yield, the highest R_i^2 value was found for Line-10; with regard to seed yield, the highest value R_i^2 was identified in Line-15. However, the lowest R_i^2 values were recorded for Oguz-2002 and Ege Beyazi-79 for dry-matter yield and seed yield, respectively (Table 4).

Regression line intercept (a) values ranged from -2.327 to 5.122 and from -0.395 to 0.561 for dry-matter yield and seed yield, respectively. The highest intercept value was recorded in Oguz-2002 for dry-matter yield. Also, Ege Beyazi-79 had the highest intercept value for seed yield. In contrast, Line-10 and Anadolu Pembesi-2002 were found to have the lowest line intercept values for dry-matter yield and seed yield, respectively (Table 4).

DISCUSSION

Genotype–environment interactions were found to be highly significant not only for dry-matter yield but also for seed yield (Table 3). Similarly, Yucel et al. (2009) and Nizam et al. (2011) found significant genotype–environment interactions in some vetch species in terms of dry-matter yield. Also, many researchers have found genotype–environment interactions to be significant for seed yield in different forage crops (Sabanci, 1996; Albayrak et al., 2005; Acikgoz et al., 2009; Nizam et al., 2011). This indicates that these traits differed between locations and planting years. Several researchers stated that genotype–location and genotype–location–year interactions were more important than genotype–year interaction (Akcura et al., 2005 and Ezzat et al., 2010). Becker and Leon (1988) also indicated that the assessment of stability in many locations and years could increase the reliability of both important traits. Here, the mean squares indicated that the effect of location was more important than that of year for all traits (Table 3), and similar results were reported by Ezzat et al. (2010).

In stability analysis, genotypes with high mean yield, a regression coefficient equal to unity (bi = 1), and a small regression deviation mean square ($S^2d_i = 0$) are considered stable (Finlay and Wilkinson 1963; Eberhart and Russell 1966). Additionally, a higher R_i^2 value (Pinthus, 1973) and higher regression line intercept value (Smith, 1982) indicate a reliable stability.

In this study, regression coefficient values for Tarm Beyazi-98, Line-10 and Budak genotypes for dry-matter yield were significantly above unity (bi > 1); also, seed yields in Line-3, Beta, and Anadolu Pembesi-2002 had high regression coefficient values, significantly above unity (bi > 1) (Table 4, Figure 2, Figure 3). Accordingly, these genotypes can be said to be sensitive to environmental change and to have greater specificity of adaptability to high-yield environments (Wachira et al., 2002; Kılıc and Yagbasanlar, 2010). On the other hand, the b_i values of Oguz-2002, Anadolu Pembesi-2002, and Beta cultivars for dry-matter yield and those of Ege Beyazi-79 for seed yield were both significantly below unity ($bi < 1$) (Table 4, Figure 2, Figure 3). Therefore, these genotypes can be considered as having greater resistance to environmental change increased specificity of adaptability to low-yield environments (Wachira et al., 2002; Kılıc and Yagbasanlar, 2010).

The regression deviation mean square (S^2d_i) values of Ege Beyazi-79, Line-15, and Line-10 were smaller than the other genotypes and were not significantly different from zero in terms of seed yield (Table 4). Therefore, these genotypes are able to conserve seed-yield traits in differing environments (Eberhart and Russell, 1966). However, no genotype had a S^2d_i value significantly different from zero in terms of dry-matter yield (Table 4), although, the S^2d_i values of Line-10 and Ege Beyazi-79 were closer to zero than were those of the other genotypes in terms of dry-matter yield (Table 4).

The coefficient of determination is often considered better for measuring the validity of the linear regression than is S^2d_i because its value ranges between zero and one. A greater R_i^2 value is desired because higher R_i^2 values indicate favorable responses to environmental changes. In the present study, Line-15, Ege Beyazi-79, and Line-10 genotypes had higher R_i^2 values for dry-matter yield. On the other hand, Line-10, Beta, and Line-15 genotypes had higher R_i^2 values for seed yield compared with the other genotypes (Table 4). This indicates that when environmental conditions improve, these genotypes will produce more dry-matter yield and seed yield than will those with lower R_i^2 values.

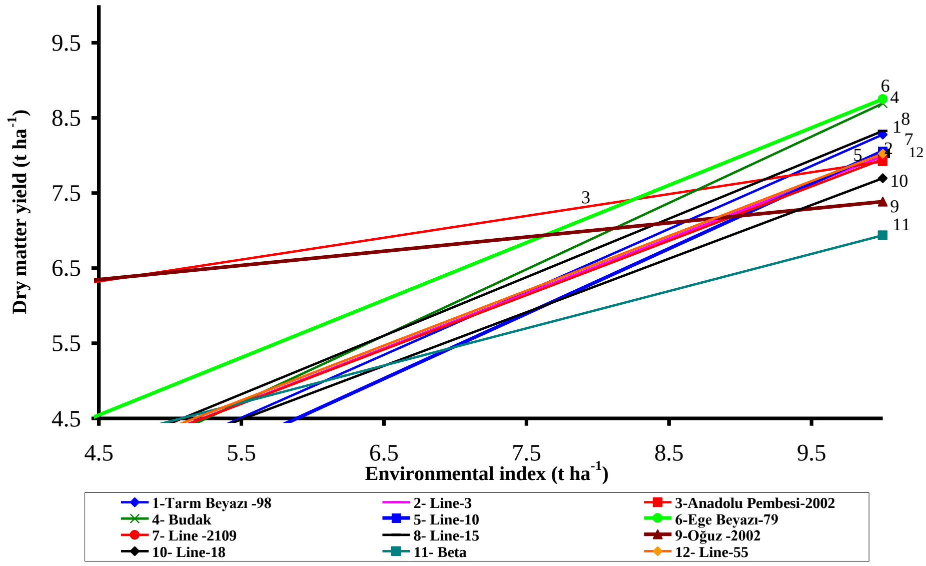


Figure 4. Comparison of Hungarian vetch genotypes by their expected dry matter yield estimated from their regression (stability) equations.

For stability, a positive and higher regression line intercept (a) is desired (Teich, 1983; Ozcan et al., 2005; Kılıc and Yagbasanlar, 2010). In this study, Oguz-2002, Anadolu Pembesi-2002, and Beta cultivars had positive and higher regression line intercepts (a) in terms of dry-matter yield when compared with the other genotypes. Furthermore, Ege Beyazi-79, Oguz-2002, and Tarm Beyazi-98 displayed positive and higher regression line intercepts (a) for seed yield. Genotypes with positive and higher regression line intercepts (a) give above-average dry-matter yield and seed yield under unfavorable environmental conditions, and these genotypes are well adapted to unfavorable environmental conditions. In contrast, Line-10, Budak, and Tarm Beyazi-98 had negative regression line intercepts (a) for dry-matter yield, and Anadolu Pembesi-2002, Beta, and Line-3 genotypes had negative regression line intercepts (a) values for seed yield. These genotypes give below-average dry-matter yield and seed yield under poor environmental conditions (Table 4, Figs 2, 3, 4 and 5).

Ege Beyazi-79 was the most stable genotype in terms of dry-matter yield. Its regression coefficient was near unity, and it had relatively low S^2d_i and high R_i^2 (90%), thus confirming its stability. However, its low line intercept (a) value indicated that this cultivar has low dry-matter yield potential under unfavorable environmental conditions. Similarly, Nizam et al. (2011) reported that the Ege Beyazi-79 variety could be considered widely adapted for conditions in the Thrace region with a b_i value for dry-matter yield equal to 1 and a low S^2d_i value. On the other hand, b_i values for Anadolu Pembesi-2002 and Oguz-2002 cultivars were below 1, and they had high S^2d_i

values combined with low R_i^2 values; therefore, these genotypes were found to be unstable in terms of dry-matter yield, but their high regression line intercepts indicated that these cultivars have high dry-matter yield potential under unfavorable environmental conditions (Table 4, Figs 2, 3, 4 and 5).

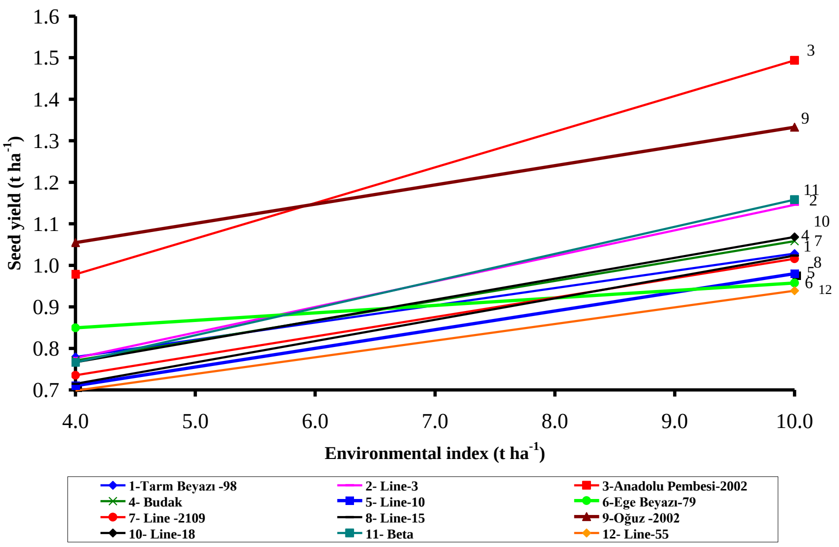


Figure 5. Comparison of Hungarian vetch genotypes by their expected seed yield estimated from their regression (stability) equations.

The highest seed yields were obtained for Anadolu Pembesi-2002 and Oguz-2002 cultivars. However, due to the high regression coefficient, Anadolu Pembesi-2002 is less likely to repeat this feature when compared with Oguz-2002. Therefore, Anadolu Pembesi-2002 showed better adaptability to favorable environmental conditions. On the other hand, with its high mean seed yield, which was significantly higher than the grand mean yield, and with a regression coefficient value not significantly different from 1.0, Oguz-2002 showed better adaptability to all environmental conditions. Thus, Oguz-2002 can be considered the most widely adaptable and stable variety in terms of seed yield for the Southeastern Anatolia region. In fact, one of the most interesting results was that although Line-15 performed well in terms of almost all of the stability parameters (b_i, S^2d_i , R_i^2), is not recommended for seed cultivation due to its lower mean seed yield when compared with the grand mean seed yield (Table 4 and Figure 3).

CONCLUSION

This study was carried out during the 2008–2009 and 2009–2010 growing seasons in five different locations. Genotypes–environment interactions were investigated, and the interactions were found to be highly significant ($P \leq 0.01$) for both dry-matter yield and seed yield. The stability analysis in this study showed that among the twelve genotypes, the Ege Beyazi-79 cultivar was found to be the most stable for dry-matter yield, and the Oguz-2002 cultivar was found to be the most stable genotype for seed yield.

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