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Forage Yield Stability of Common Vetch (*Vicia sativa* L.) Genotypes in the Çukurova and GAP Regions of Turkey

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Abstract: Improving forage production for an expanding livestock population is essential in the Çukurova and GAP (South-eastern Anatolia Project) regions of Turkey. Feed shortages, especially evident during winter, can be alleviated by introducing high yielding common vetch (*Vicia sativa* L.) cultivars into crop rotations. The objectives of this research were to determine the genotype × environment interactions and stability parameters for hay yield of 15 vetch lines and cultivars. The vetch genotypes were evaluated in the Çukurova (2 locations for 3 years) and South-eastern Anatolia (1 location for 2 years) regions. In the South-eastern Anatolia region, the rainfall limits plant growth, while the Çukurova region has much better soil and climatic conditions. Since local climatic variation is significant, each location in each year is treated as a separate environment, to give 8 environments. Linear regression techniques were used to analyse genotype × environment interactions (G × E). The hay yield was significantly different between genotypes and environments, while a genotype × environment interaction was present. The variation amongst environments was highly significant, and the mean hay yield ranged from 7453 kg ha^{-1}, in Doğankent (2002-03), to 2687 kg ha^{-1}, in Balcalı (2003-04). The genotypes 'V7' and 'V12', which had regression coefficients significantly greater than 1.0 and produced mean hay yields above the overall mean, were well adapted to favourable environments. Three entries (V5, V9, and V10) possessed regression coefficients significantly less than 1.0, with hay yield above the grand mean, suggesting that these genotypes were better adapted to poor environments and insensitive to environmental change. Our study demonstrated that previously selected genotypes and cultivars can be successfully grown and make a significantly positive contribution to animal husbandry in the Çukurova and South-eastern Anatolia regions.

Key Words: Vica sativa, common vetch, genotype × environment interaction, forage yield stability

Çukurova ve GAP Bölgesinde Yaygın Fiğ (*Vicia sativa* L.) Genotiplerinin Ot Verimi Stabilitesi

Özet: GAP (Güney-doğu Anadolu Projesi) ve Çukurova bölgelerinde artan hayvan populasyonu için yem bitkileri üretiminin artırılması zorunludur. Yüksek verimli yaygın fiğ (*Vicia sativa* L.) çeşitlerinin ekim nöbeti sistemleri içerisinde yetiştirilmesi, özellikle kış dönemlerinde belirgin olan yem açığını azaltacaktır. Bu araştırmanın amacı 15 yaygın fiğ hat ve çeşidinde ot verimi bakımından genotip çevre interaksiyonu ve stabil genotipleri saptamaktır. Fiğ genotipleri, Çukurova bölgesinde 2 lokasyonda (Balcalı ve Doğankent) 3 yıl, GAP bölgesinde bir lokasyonda (Akçakale) 2 yıl süreyle denenmiştir. Çukurova bölgesi çok daha iyi toprak ve iklim koşullarına sahipken, GAP bölgesinde yağış bitki büyümesini sınırlandırmıştır. Lokal iklim değişikleri önemli olduğundan, her yıl ve her lokasyon ayrı bir çevre olarak kabul edilerek toplam 8 çevre oluşturulmuştur. Genotip × çevre interaksiyonlarının analizi için linear regresyon teknikleri kullanılmıştır. Genotip çevre interaksiyonu mevcut olduğunda, ot verimleri bakımından genotipler ve çevreler arasındaki farklılıklar önemli bulunmuştur. Çevreler arasında varyasyon yüksek düzeyde önemli olup, ortalama kuru ot verimi 7453 kg ha^{-1} (Doğankent, 2002-03) ile 2687 kg ha^{-1} (Balcalı, 2003-04) arasında değişmiştir. V7 ve V12 genotipleri, regresyon katsayılarının 1'den ve verimlerinin de genel ortalamadan daha yüksek olması nedeniyle iyi koşullara iyi adapte olmuştur. V5, V9 ve V10 genotiplerinin, regresyon katsayıları 1'in altında, ortalama verimleri genel ortalamadan yüksek olması, bu genotiplerin kötü koşullara daha iyi adapte olabileceğini ve çevre değişiklerine karşı hassas olmadıklarını göstermiştir. Çalışmamız, daha önceden seçilen genotip ve çeşitlerin GAP ve Çukurova koşullarında başarılı bir şekilde yetiştirilebileceğini ve yem üretimine önemli katkı sağlayacağını göstermiştir.

Anahtar Sözcükler: Yaygın fiğ, Vica sativa L., genotip × çevre interaksiyonu, ot verimi stabilitesi

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Introduction

Improving forage production for an expanding livestock population is essential in the Çukurova and GAP (South-eastern Anatolia Project) regions of Turkey. Feed shortages, especially evident during winter, can be alleviated by introducing common vetch (*Vicia sativa* L.) cultivars into crop rotations. Common vetch occupies 320,000 ha of cultivated land, which was only 5.5% of the arable land in Turkey in 2004 (SIS, 2005). Over the last 3 years, its cultivation area has steadily increased in the Çukurova region (Tarım ve Köy İşleri Bakanlığı, 2006).

It is mainly produced for hay, and is planted in autumn (November) and harvested in spring (April). It is well suited to the cotton – common vetch (or cereals) – cotton rotation as a winter crop (Genç et al., 1977; Sağlamtimur et al., 1991). In the South-eastern Anatolia region, the native pastures provide most of the feed supply for animals, but overgrazing on these grazing lands has severely degraded the native vegetation, leading to feed shortages. The irrigated area has gradually increased over the last 2 decades, and common vetch has become the primary forage crop to introduce into crop rotations.

Common vetch, with its winter growth potential for both regions, is considered an important crop. The development of stable vetch cultivars with good adaptation and high yield would greatly contribute to increasing the feed supply for livestock. Currently, there is inadequate information available on the stability and yield performances of promising common vetch lines. Hence, it is important to establish multi-location experiments, so that many genotypes can be evaluated in different locations and years before making the final selection of desirable genotypes (Sabancı, 1997; Zubair et al., 2002; Arshad et al., 2003; Nazar et al., 2003). The adaptability of a variety over diverse environments is usually assessed by the degree of its interaction with different environments in which it is grown. A genotype is regarded as well-adapted and stable if it possesses a high yield but low yield fluctuation when grown over diverse environments (Arshad et al., 2003). However, the genotype × environment interaction (G × E), occurring due to the yield variation in different environments, is one of the greatest hurdles in developing stable varieties. To overcome this impediment, the analysis of adaptation and stability parameters was performed by several researchers (Lin and Binns, 1988; Altınbaş and Tanyolaç, 1999; Kara, 2000).

Numerous methods have been developed to determine the stability of a genotype. Finlay and Wilkinson (1963) first described stability as a linear relationship between the yield of genotype over many environments given by the regression coefficient (b_i), where a genotype with $b_i = 1$ was 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. Francis and Kannenberg (1978) used the coefficient of variation (CV_i) as a measure of stability while Pinthus (1973) presented the coefficient of determination (R_i^2), the quantity of variation explained by the regression as a portion of the total variation.

The objective of this research was to determine genotype × environment interactions for hay yield of 15 vetch lines and cultivars in order to identify stable genotypes.

Materials and Methods

Materials: Seven common vetch (*Vicia sativa* L.) lines, namely 2505 (V1), 2558 (V2), 2559 (V3), 2563 (V4), 2637 (V5), 2638 (V6), and 2639 (V7)) selected in previous years for greater hay yield, and 8 commercial cultivars, namely Emir (V8), Nilüfer (V9), Uludağ (V10), Cumhuriyet 99 (V11), Kubilay-82 (V12), Ürem-79 (V13), Selçuk-99 (V14), and Karaelçi (V15), were tested over 2 or 3 years in 2 distinct southern regions of Turkey.

Locations: The yield trials were conducted in the Çukurova and South-eastern GAP regions (the GAP region covers about 10% of Turkey's total area. GAP is a regional development project, and covers 9 provinces [Adıyaman, Batman, Diyarbakır, Gaziantep, Kilis, Mardin, Siirt, Şanlıurfa, and Şırnak] that lie in the Euphrates and Tigris delta and the upper Mesopotamia plane) during the winter in place of the usual main-cereal crop rotation. The experiment in the Çukurova region consisted of 2 locations, namely Doğankent and Balcalı, and was conducted during the growing seasons of 2001-02, 2002-03, and 2003-04. In Akçakale, the experiment was established in 2 consecutive seasons: 2003-04 and 2004-05.

The locations have a typical Mediterranean climate with cool, wet winters and hot, dry summers. The soil and climatic characteristics of the locations are shown in Table 1. The 2 regions chosen for the experiment have distinct climate conditions. In the Akçakale site, in the South-eastern Anatolia region, the long-term annual rainfall is 303 mm with low relative humidity, which is less than half of total rainfall received in the Çukurova region (Table 1). For that reason, Akçakale is considered a drier environment.

Table 1. Location, elevation, soil, and meteorological data for the 3 locations in the Çukurova and GAP regions of Turkey.

Environments	Location Latitude–Longitude		Elevation (m)	Soil Properties			Long-Term Climatic Parameters		
				Textures	pH	OM (mm)	Precipitation (°C)	Temperature (%)	Humidity
Çukurova Region; Balcalı	41°04′N	36°71′E	36	CL	7.6	2.0	646.8	15.4	66.0
Çukurova Region; Doğankent	40°82′N	36°70′E	15	CL	7.6	2.4	774.2	13.7	70.0
GAP Region; Akçakale	37°08′N	38°46′E	410	CL	7.8	1.5	303.0	17.8	57.4

OM: Organic matter (%); CL: Clay-loam; C. Clay

Experimental design: The trials in all locations were established in a complete randomised block design with 3 replicates. Since local climatic variation is significant, each location in each year was treated as a separate environment, to give 8 environments. Each plot was formed with 5 rows, and row spacing and length were 25 cm and 5 m, respectively. The seeding rate was calculated so that 200 seeds per square metre were sown. The plantings at all locations were completed in November in all years. Hay yield was measured at the full bloom stage. In each plot, the crops were cut to ground level, fresh weight was recorded, and 500-g sub-samples were taken from each plot to determine hay yield. Because of the farmers' practices in the South-eastern Anatolia region, supplementary irrigation (80 mm) was applied once a year at the initiation of the flowering stage to restore soil moisture to field capacity.

Statistical procedures: The coefficient of determination (R^2) (Pinthus, 1973) was computed from individual linear regression analysis. Significance of regression coefficients (b_i) (the forage yield of a single genotype on mean environment) was tested by employing the *t*-test (Steel and Torrie, 1960). The mean square for deviation from the regressions (S^2d_i) gauges the stability or responses to environmental change. Analysis of variance of the combined data was conducted to determine the significance test for the mean square for deviation from the regression and for the hay yield as suggested by Eberhart and Russell (1966). In all statistical analysis the JMP software program was used (SAS Institute, 2002).

Results

Mean hay yields of the genotypes and environments

There were highly significant differences among the 15 genotypes in terms of hay yield (Table 2). The mean hay yield of these genotypes varied from 4446 to 5868 kg ha^{-1} (Table 3). The cultivar Nilüfer (V9) produced the greatest yield, followed by Uludağ (V10) and Karaelçi (V15) (Table 3).

The variation among environments was also highly significant (Table 2), with the mean hay yield ranging from 7453 kg ha^{-1} at Doğankent, in 2002-03, to 2687 kg ha^{-1} at Balcalı, in 2003-04 (Table 4). Maximum yields at the 3 locations over the years were of similar magnitude, indicating that yield differences between years contributed most of the environmental variation.

Table 2. Analysis of variance for hay yield estimated for the 15 genotypes over 8 environments.

Variance sources	D.F.	Mean squares
Genotypes (G)	14	3,904,347 **
Environment (E) + G × E	105	8,332,402 *
E (Linear)	1	650,339,560 **
G × E (linear)	14	11,420,713 **
Pooled deviation	90	718,585
Pooled error	224	612,457

* and ** indicate significant differences at 5% and 1% levels of probability, respectively.

Table 3. Estimates of stability parameters (b_i, S^2d_i, CV_i, R^2) of the hay yields of the 15 common vetch genotypes based on 3 sites in the Çukurova and GAP regions during 2001-02, 2002-03, 2003-04, and 2004-05.

Genotypes (code)	Accession number	Mean (x_i) (Min-Max)	b_i ± S.E. (b_i)	S^2d_i	CV_i (%)	R^2_i
V1	2505	4971 (2080-8760)	1.15 ** ± 0.25	5,594,223**	38.55	0.77
V2	2558	5090 (2200-8240)	1.14** ± 0.23	4,402,373**	35.57	0.81
V3	2559	5016 (2950-7380)	0.79** ± 0.10	930,786**	25.30	0.91
V4	2563	4875 (2270-9240)	1.09** ± 0.11	967,311**	34.48	0.95
V5	2637	5336 (2580-8920)	0.94** ± 0.24	4,965,254**	34.48	0.72
V6	2638	4826 (3160-7930)	0.88** ± 0.16	2,093,204**	29.30	0.84
V7	2639	5289 (2710-9900)	1.22** ± 0.27	6,365,922**	37.25	0.77
V8	Emir	4601 (2000-7910)	1.03** ± 0.15	1,905,341**	34.82	0.88
V9	Nilüfer	5868 (2330-9460)	0.98* ± 0.39	13,048,277*	33.67	0.52
V10	Uludağ	5746 (2120-9950)	0.93* ± 0.35	10,798,274*	34.85	0.54
V11	Cumhuriyet-99	4466 1940-7460	0.94** ± 0.20	3,433,194**	34.64	0.77
V12	Kubilay-82	5369 (2210-9380)	1.29** ± 0.17	2,534,982**	37.07	0.91
V13	Ürem-79	4901 (2630-8080)	0.90** ± 0.15	2,023,589**	28.70	0.82
V14	Selçuk-99	5022 (2200-9450)	1.12** ± 0.21	3,755,239**	37.94	0.85
V15	Karaelçi	5626 (3460-7800)	0.61 ± 0.26	5,811,150	23.72	0.48

*, ** indicate significance at 5% and 1% levels of probability, respectively.

Genotype × environment interactions

Estimates of the stability parameters are shown in Table 3. The environment + genotype × environment term was significant ($P < 0.05$) (Table 2), indicating that certain genotypes changed their position in yield rank across different locations. The genotype-environment interactions (linear) were highly significant ($P < 0.01$) for hay yield (Table 2), indicating differences among the regression coefficients, while the deviation around the regression lines was not significant.

The linear regression of the average yield of a single genotype on the average yield of all genotypes in each environment generated the regression coefficients (b_i), which ranged from 0.61 to 1.29 for hay yield (Table 3 and Figure). This wide range of regression coefficients indicates that the 15 genotypes had different responses to environmental changes. The Figure is a graphic summary of the data useful in the identification of stable genotypes. The vertical lines are the grand mean yields and confidence limits, and the horizontal lines the regression coefficients

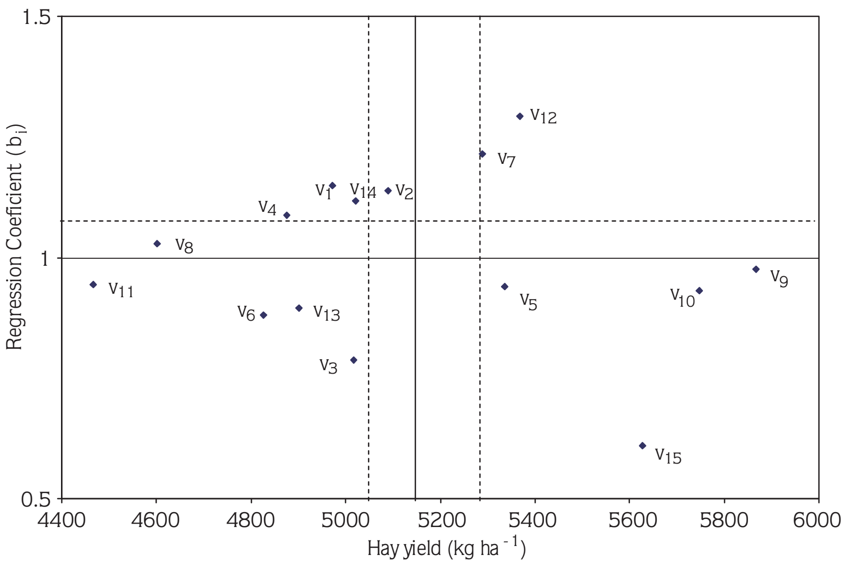
Table 4. Mean hay yield (kg ha^{-1}) of the 15 genotypes, and December to April rainfall (mm), and plus indicating supplementary irrigation (mm) for the 8 environments.

Environments with locations and years	Hay yield	Rainfall
Doğankent, 2001-02	5521	715
Doğankent, 2002-03	7453	453
Doğankent, 2003-04	4464	579
Balcalı, 2001-02	6012	715
Balcalı, 2002-03	4331	453
Balcalı, 2003-04	2687	579
Akçakale, 2003-04	4590	253 + 80
Akçakale, 2004-05	6013	270 + 80
Mean	5133	-
S.E.	508	-

(b_i = 1.0) and its confidence limits. The regression coefficient of the genotype V15 (cv. Karaelçi) did not differ significantly from 1.0, and had hay yield (5626 kg ha^{-1}), indicating that this cultivar has general adaptability (Table 3). Moreover, the S^2d value (Table 3) of the cultivar Karaelçi was not significantly different from zero, and so it can be considered a genotype with good adaptability. The genotypes V7 and V12 had $b_i > 1.0$, produced hay yields above the overall mean (Table 3), were sensitive to the environmental changes, and were well adapted to favourable environments. Three entries (V5, V9, and V10) possessed $b_i < 1.0$, with hay yield above the grand mean (Table 3), suggesting that these genotypes were better adapted to poor environments and insensitive to changing environments. These genotypes could be better for cultivation only in unfavourable conditions.

Francis and Kannenberg (1978) reported that the coefficients of variation (CV_i %) estimated from the variances over environments of the genotypes grown in different environments are used as the stability parameter. In this study, the coefficient of variation varied from 23.7% to 38.6% (Table 3).

The coefficients of determination (R^2) ranged from 0.48 to 0.95 (Table 3), indicating stability differences among accessions. The coefficient of determination is often considered a better index for measuring the validity of the linear regression than S^2d_i, because its value ranges between zero and one.



Confidence limit for average hay yield 5133 ± 204, Confidence limit for regression coefficient 1.00 ± 0.088

Figure. Relationship between the regression coefficients of genotype yield on environment yield (b_i) for the mean hay yield of the 15 common vetch genotypes. The dark horizontal and vertical lines are the confidence limits (1%) for the regression coefficient and mean yields, respectively.

Discussion

The development of new forage vetch cultivars embraces breeding of cultivars with desired characteristics such as high hay yield, tolerance to biotic and abiotic stress, and stability of these traits in target environments. Inconsistent genotypic responses to environmental factors such as rainfall, temperature, pests, and soil fertility level over locations and years are a function of genotype × environment (GE) interactions (Rao et al., 2002). Baker (1988) described the genotype-environment interaction as "failure of genotypes to achieve the same relative performance in different environments". To describe 'good' and 'poor' environments, it appears to be reasonable for hay yield that environments can be discerned in accordance with rainfall, soil fertility, and temperature. Obviously, for the usefulness of the stability analysis, the environments for good and poor performances need to be identified in terms of their attributes for successful plant growth. In our case, Doğankent and Akçakale tended to be good environments (higher yields), while Balcalı was relatively poor (lower yields). Although Balcalı had the same amount of rainfall as Doğankent, the low water holding capacity and fertility level of the soil were probable causes of the yield losses, especially noticeable in the hay yield (2687 kg ha^{-1}) of the 2003-04 season (Table 4). Eberhart and Russell (1966) proposed that an ideal genotype is one which has the highest yield over a broad range of environments, a regression coefficient or (b) value of 1.0, and a deviation mean square (S^2d_i) of near zero.

The results of our study revealed that the genotype-environment interaction component was a linear function of the environmental means. Therefore, it enabled us to judge the stability of the 15 genotypes using the interaction component and to consider their mean performances. Accordingly, genotypes V5 and V7 were reasonably stable and gave high hay yields with relatively high coefficients of determination (R^2_i). Their immediate use as a cultivar or for breeding purposes is therefore desirable. In most cases deviations from regressions were due to specific genotype × environment interactions, which were abruptly favoured by pathogen or drought incidence (Abd El Moneim and Cocks, 1993). The cultivars Nilüfer (V9) and Uludağ (V10) were unstable (high S^2d values) although they produced high hay yields. Their high yield can be attributable to their immense responses to the irrigation in the South-eastern Anatolia region, where they produced the greatest yield. However, the cultivar Kubilay-82 (V12) was the most stable one with high hay yield. Eberhart and Russell (1966) were primarily concerned with specific instability as measured by S^2d_i. They found evidence for the heritability of S^2d_i and suggested that it is more important than the instabilities measured by the statistic b. In our study it was apparent that specific instability is often related to soil and climatic conditions. Therefore, any occurrence of large S^2d_i values should be closely investigated. For example, in our case the genotypes (cv. Nilüfer and Uludağ) should not be cultivated without irrigation.

Because of the low coefficient of variation of V15, V3, V13, and V6, these genotypes can be evaluated as stable (Francis and Kannenerk, 1978). In this research, CV_i (%) was high as a result of differences between the minimum and maximum values in the different environments (Table 3). The results also showed that the stable genotypes with the low CV_i (%) values had low b_i values.

Our research results suggest that some previously selected genotypes and superior cultivars can be successfully grown and make a significantly positive contribution to animal husbandry in the Çukurova and South-eastern Anatolia regions. Their introduction into cotton-cereal crop rotation will greatly increase hay yield and overall sustainability by acting as a disease break and contributing immensely to soil fertility.

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