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Full Length Research Paper

Analysis of G × E interaction using the additive main effects and multiplicative interaction (AMMI) in potato cultivars

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This experiment were conducted on the 3 cultivars of potato (Agria, Satina and Caesar) and 4 irrigation regimes (after 30 mm evaporation from class A evaporation pan, after 30 mm evaporation from class A evaporation pan with spraying by potassium humate, after 60 mm evaporation with spraying by potassium humate and after 60 mm evaporation from class A evaporation pan) in 3 locations of Ardabil in northwestern Iran and in 2 years (2007 - 2008), experimental design was split plot with 3 replications. Potassium humate sprayed (250 ml ha^{-1}) in the 3 stages of emergence, before tuberization and during tuberization period. Combined analysis of variance showed that were significant differences between locations, years, irrigation regimes and cultivars and their interaction on tuber yield. The analysis of variance for the AMMI model of tuber yield showed that environments, cultivars × environments interaction and AMMI component1 were significant. Results show that Agria and Caesar cultivars had high tuber yield in all of sites and 4 irrigation regimes in 2 years, caesar cultivar had the less slop, S.E., MS-TXL, MS-REG and MS-DEV among other cultivars and was the most stable cultivar. The Agria cultivar has adapted in Alarog, Hassanbarog and Khoshkeroud sites under normal and normal with potassium humate conditions, Caesar and Satina cultivars in Alarog, Hassanbarog and Khoshkeroud sites under stress with potassium humate and stress conditions in order to ensure their yield stability and economic profitability.

Key words: AMMI, potato, potassium humate, stress.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is grown and eaten in several countries (Jackson, 1999). It is a crop that grows mainly in climates with cool temperate with full sunlight, moderate daily temperatures and cool nights. Short days generally induce tubers in potatoes, although many modern cultivars can initiate tuberization in the long days of north regions temperate (Tarn et al., 1992). Among the most important crops in the world (Fernie and Willmitzer, 2001) and Iran (FAO, 2008), potato is ranked in fourth grade in annual production after the cereal species rice, wheat and barley. Iran is the world's 12th potato producer and the third biggest producer in Asia, after China and India (FAO, 2008).

Genotype by environment interactions are important sources of variation in any crop and the term stability is sometimes used to characterize a genotype, which shows a relatively constant yield, independent of changing environmental conditions. On the basis of this idea, genotypes with a minimal variance for yield across different environments are considered stable (Sabaghniaa et al., 2006).

The stability methods can be divided into 2 major groups: univariate and multivariate stability statistics (Lin et al., 1986). Among multivariate methods, the additive main effect and the multiplicative interaction analysis (AMMI) are widely used for G × E investigation. This method has been shown to be effective because it captures a large portion of the G × E sum of square, it clearly separates main and interaction effects that present agricultural researchers with different kinds of opportunities, and the model often provides agronomically meaningful interpretation of the data (Ebdon and Gauch, 2002). The results of AMMI analysis are useful in supporting breeding program decisions such as

Table 1. Analysis of variance for the AMMI model.

Source	D.F.	S.S.	M.S.
Cultivars (Cul.)	2	150.50	75.25
Environments (Env.)	5	7456.41	1491.28 **
Cult.×Env.	10	412.08	41.210**
AMMI Component 1	6	397.48	66.250**
AMMI Component 2	4	14.604	3.6500
Total	17	8018.98	

specific adaptation and selection of environment (Gauch and Zobel, 1997). Usually, the results of AMMI analysis shown in common graphs are called biplot. The biplot shows both the genotypes and the environment value and relationships using singulars vectors technique.

The AMMI model has been extensively applied in the statistical analysis of multi-environment cultivar trials (Kempton, 1984; Gauch and Zobel, 1989; Crossa et al., 1990; Gauch and Zobel, 1997).

The objective of this study, therefore, was to determine the yield performance and to assess the yield stability of the 3 cultivars of potato and 4 irrigation regimes in 6 environments by using the AMMI statistical model.

MATERIALS AND METHODS

This experiment were conducted on the 3 cultivars of potato [Agria (susceptible), Satina (semi-tolerant) and Ceaser (tolerant to water deficit)] and 4 irrigation regimes [after 30 mm evaporation from class A evaporation pan (normal condition), after 30 mm evaporation from class A evaporation pan with spraying by potassium humate (normal condition with potassium humate), after 60 mm evaporation with spraying by potassium humate (stress condition with potassium humate) and after 60 mm evaporation from class A evaporation pan (stress condition)] in 3 locations of Ardabil (Alarog, Hassanbarog and Khoshkeroud) in northwestern Iran and 2 years (2007 - 2008). Experimental design was split plot with three replications.

Plots were 9 m^2 with 4 rows that each of them has 3 m length and 25 cm distance between plants and 75 cm distance between rows. Distances between plots were 1.5 m. The first irrigation was general, but the forward irrigation time was determined by below way.

Used water amount was calculated according to the collected class A evaporation pan every time and below equation:

$$IW/CPE = 0.8$$

IW = Irrigation water amount irrigation, and CPE = collected evaporation ratio calculated from class A evaporation pan.

The amount of irrigation treatments was measured by water meter. The start of irrigation was on base of 30 mm evaporation from class A evaporation pan. Amount of precipitation was measured by udometer and daily evaporation by class A evaporation pan.

Potassium humate sprayed (250 ml ha^{-1}) in the 3 stages of emergence, before tuberization and during tuberization period. In the growth period and after harvesting, some of characters were measured such as main stem number, plant height, tuber number and weight per plant, total and marketable tuber yield, dry matter percent and marketable tuber number and weight per plant. Mean tuber yield was estimated for each cultivars at each location (environment). Combined analysis of variances were done and comparison of means were done by LSD. G×E interaction was partitioned according to the additive main effects and multiplicative interaction (AMMI) model. AMMI analysis combines analysis of variance and principal component analysis into a single model with additive and multiplicative parameters. All analyses were carried out using the "CropStat" software packages.

RESULTS AND DISCUSSION

Combined analysis of variance showed that were significant differences between location (L), year (Y), irrigation regimes (A) and cultivar (B) and their interaction (L × A, L × Y × A, Y × B, L × B, L × Y × B, A × B, Y × A × B and L× A × B) on tuber yield. Because of their interaction significant differences for tuber yield, the below mentioned AMMI analysis were used to estimate the highest stable cultivars.

The analysis of variance for the AMMI model of tuber yield showed that environments, cultivars × environments interaction and AMMI component 1 were significant (Table 1).

Stability regressions of tuber yield for each cultivar on means of tuber yield at each environment showed in Table 2. Caesar cultivar had the less Slop (Slopes of regressions of cultivar means on environment index), S.E., MS-TXL (Contribution of each cultivar to interaction MS), MS-REG (Contribution of each cultivar to the regression component of the treatment by location interaction) and MS-DEV (Deviations from regression component of interaction) among other cultivars, and was the most stable cultivar (Table 2).

Fitted values from the AMMI model of tuber yield for 3 cultivars in 6 environments and 2 years showed in Tables 3 and 4. Results show that Agria and Caesar cultivars had high tuber yield in all of sites in 2 years (Table 3) and 4 irrigation regimes (Table 4).

In Figure 1 the PCA1 scores for both the cultivars and environments were plotted against the tuber yield for the cultivars and the environments and in Figure 2 the PCA1 scores for both the cultivars and environments were plotted against the PCA2 scores for the cultivar and the environments. The graphs space of Figures 1 and 2 are divided into 4 quadrants from lower yielding environments in quadrants 1 and 4 to high yielding in quadrants 2 and 3. Figures 1 illustrates tuber yield of the potato selections in the various environments. The cultivars or environments with large PCA1 scores (negative or positive) indicated high interactions, while the cultivar with low or PCA1 scores near zero resulted in small interactions.

AMMI biplot PCA1 vs. PCA2 for potato cultivar and environments shows no cultivar clustered close to the center of the biplot. Cultivars Satina and Caesar were far from the center (Figure 2). The Agria cultivar has

Table 2. Stability regressions of tuber yield for each cultivar on means of yield at each environment.

Cultivar	Mean	Slope	S.E.	MS-TXL	MS-REG	MS-DEV
Caesar	42.37	0.944	0.059	4.010	3.780	4.23
Satina	38.52	0.848	0.060	16.43	28.38	4.47
Agria	45.59	1.208	0.119	35.14	52.89	17.40

Slope: Slopes of regressions of cultivar means on environment index.
MS-TXL: Contribution of each cultivar to interaction MS.
MS-REG: Contribution of each cultivar to the regression component of the treatment by location interaction.
MS-DEV: Deviations from regression component of interaction.
R^2**: Squared correlation between residuals from the main effects model and the site index.

Table 3. Fitted values from the AMMI model of cultivars × locations × years interaction.

CVS	Alarog			Hassanbarog			Khoshkeroud			Total Mean
	2007	2008	Mean	2007	2008	Mean	2007	2008	Mean	
Caesar	44.67	40.38	42.53	21.42	16.34	18.88	72.25	59.15	65.70	42.37
Satina	42.34	35.42	38.88	18.94	15.68	17.31	64.45	54.26	59.36	38.51
Agria	43.44	37.05	40.25	21.95	15.23	18.59	72.05	83.81	77.93	45.59
Site Effects	43.48	37.62	40.55	20.77	15.75	18.26	69.58	65.74	67.66	42.16
AMMI 1 Site	-0.966	-1.083	-1.4***	-0.630	-1.1	-1.3***	-0.22	4.02	2.64	-
AMMI 2 Site	-0.41l	0.56 l	0.74***	-0.41	-0.97 l	-0.76***	1.46 l	-0.21 l	0.028	-

Table 4. Fitted values from the AMMI model of cultivars× irrigation regimes interaction

Cvs	Normal	Normal with potassium humate	Stress with potassium humate	Stress	Mean	T-Effects
Caesar	48.65	53.30	38.03	29.50	42.37	1.214
Satina	45.09	46.81	36.14	26.01	38.51	-0.097
Agria	54.58	54.33	42.13	31.32	45.59	-1.117
Site Effects	49.44	51.48	38.77	28.94	42.16	-
AMMI 1 Site	-1.119	0.9894	-0.4298	0.5597	-	-
AMMI 2 Site	-0.681	-0.781	0.8179	0.6414	-	-

adapted in Alarog, Hassanbarog and Khoshkeroud sites under normal and normal with potassium humate conditions, Caesar and Satina cultivars in Alarog, Hassanbarog and Khoshkeroud sites under stress with potassium humate and stress conditions in order to ensure their yield stability and economic profitability (Figures 1 and 2). The Agria and Caesar cultivars had the highest yield (45.59 and 42.37 ton ha^{-1}), while the lowest yield (38.52 t ha^{-1}) was recorded from Satina cultivar. Farmers are more interested in the cultivars that produce consistent yields under their growing conditions and breeders want to meet these needs (Mulema et al., 2008).

The AMMI model has been extensively applied in the statistical analysis of multi-environment cultivar trials (Kempton, 1984; Gauch and Zobel, 1989, 1997; Crossa et al., 1990). AMMI analysis should provide (i) an enhanced understanding of G × E, (ii) increasingly accurate yield estimates using means for multiplicative interaction effects and (iii) the increased probability of identifying the next royalty paying genotype. The interaction of the 3 cultivars with 6 environments was best predicted by the first 2 principal components of genotypes and environments. Consequently, biplots generated using genotypic and environmental scores of the AMMI 1 components can help breeders have an overall picture of the behavior of the genotypes, the environments and G × E (Manrique and Hermann1, 2000; Kaya

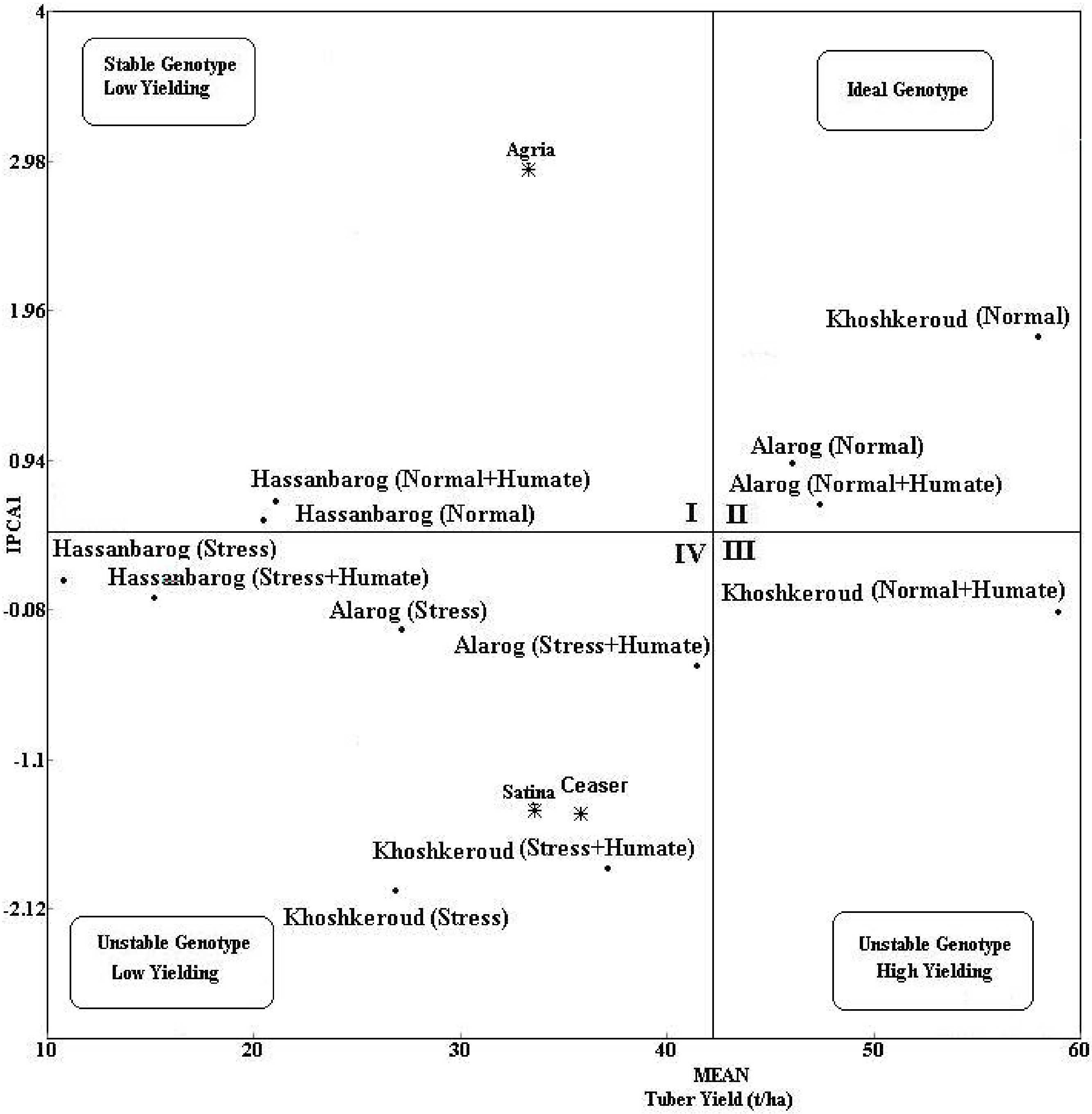

Figure 1. AMMI 1 biplot of interactions of cultivars × locations × irrigation regimes.

et al., 2002; Tarakanovas and Ruzgas, 2006).

Conclusions

The analysis of variance for the AMMI model of tuber yield showed that environments, cultivars × environments interaction and AMMI component 1 were significant. Caesar cultivar had the less Slop, S.E., MS-TXL, MS-REG and MS-DEV among other cultivars and was the most stable cultivar.

The biplot shows that Agria cultivar has adapted in Alarog, Hassanbarog and Khoshkeroud sites under normal and normal with potassium humate conditions, Caesar and Satina cultivars in Alarog, Hassanbarog and Khoshkeroud sites under stress with potassium humate and stress conditions in order to ensure their yield stability and economic profitability.

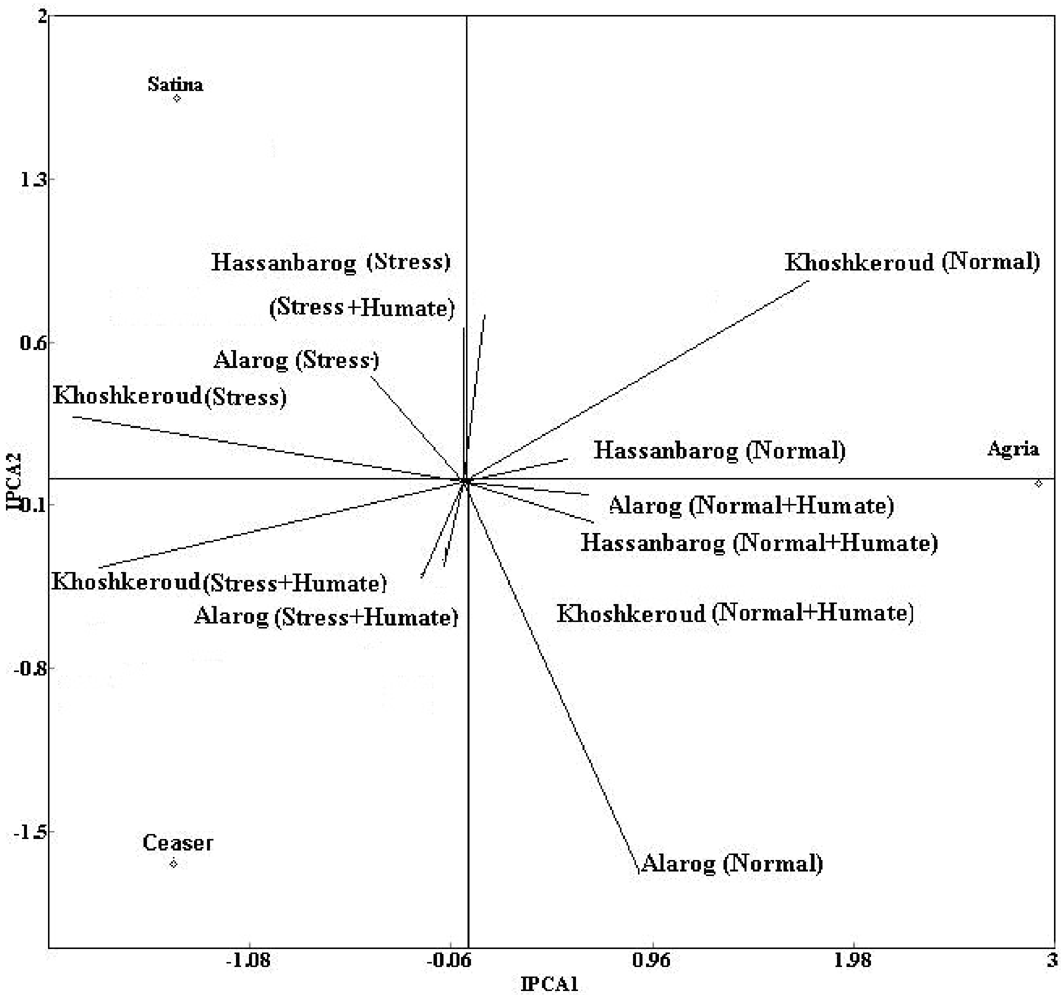

Figure 2. AMMI 2 biplot of interaction of cultivars × locations × irrigation regimes.

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