Bulgarian Journal of Agricultural Science, 20 (No 6) 2014, 1320-1325
Agricultural Academy

EVALUATION OF MAIZE HYBRIDS FOR GRAIN YIELD STABILITY UNDER RAINFED AND IRRIGATED CONDITIONS USING GGE BIPLOT ANALYSIS

D. BOSHEV, M. JANKULOVSKA*, S. IVANOVSKA, L. JANKULOSKI, B. KUZMANOVSKA and V. TANASKOVIC
Faculty of Agricultural Sciences and Food, 1000 Skopje, Republic of Macedonia

Abstract

BOSHEV, D., M. JANKULOVSKA, S. IVANOVSKA, L. JANKULOSKI, B. KUZMANOVSKA and V. TANASKOVIC, 2014. Evaluation of maize hybrids for grain yield stability under rainfed and irrigated conditions using GGE biplot analysis. *Bulg. J. Agric. Sci*., 20: 1320-1325

Stable performance of maize hybrids at a specific growing region is critical for obtaining high and stable yield. The objectives of this study were to evaluate grain yield stability of sixteen maize hybrids from different origin in Ovce Pole region, in rainfed and irrigated conditions during 2009, 2010 and 2011 growing seasons, to graphically summarize the effects of G and GE interaction and to identify "which won where" and to recommend maize hybrids for this specific growing region, using GGE biplot. The GGE biplot was useful in identification that the hybrids 16, 15 and 13 were the highest yielding and consequently the most desirable hybrids for growing in Ovce pole region. Furthermore, it was concluded that high and stable yields could be expected only with irrigation. The hybrid 4 had the lowest seed yield (6910 kg ha-1) and was the least stable across different environments. This technique can serve as a useful tool for recommendation of maize hybrids for specific growing region taking into account the specificities of hybrids and growing conditions.

Key words: maize, GGE biplot, stability, genotype x environment interaction

Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops in the world after wheat and rice (Golbashy et al., 2010). The considerable genotypic variability for different traits among various maize genotypes (Grzesiak, 2001) is a key to crop improvement. The ability to develop high yielding and stable cultivars is an ultimate goal in most breeding programs. The consistent performance of a genotype, both with high or low yield across different environments is referred as yield stability (Epinat-Le Signor et al., 2001). An ideal maize hybrid should have a high mean yield combined with a low degree of fluctuation under different environments (Annicchiarico, 2002). One of the most important goals of maize breeders has been to enhance the stability of performance of maize when exposed to stresses (Campos et al., 2006). Drought stress influences the reduction of growth, development and production of plants (Mohammadai et al., 2012). Understanding the environmental and agronomic responses of maize hybrids is fundamental to improving efficiency of maize production. For the sites where drought is frequent the main objectives of maize breeding, besides yielding capacity, are yield stability and drought tolerance (Bonea and Urechean, 2011). Consequently, newly introduced hybrids generally need to be tested for several years before being recommended for a given site (Beiragi et al., 2011; Tonk et al., 2011). The specificities of hybrids and growing conditions of the regions (Mitrovic et al., 2012) must be considered before giving the recommendations.

Experimental trials are usually carried out in different environments with an aim to evaluate yield stability of different crops under varying environmental conditions (Yan et al., 2000; Yan and Rajcan, 2002). The main environmental effects (E) and genotype environment interaction (GE) have been reported as the most important sources of variation for the measured yield of crops (Dehghani et al., 2006; Yan et al.,

*Corresponding author: mirjanajankulovska@yahoo.com

2007; Sabaghnia and Sabaghpour, 2008). Although the measured yield is a combined result of the effects of the genotype (G), E and GE interaction, only G and GE are relevant to cultivar evaluation. Typically, E explains most (80% or higher) of the total yield variation, while G and GE are usually small (Yan and Kang, 2003). There are number of statistical methods for evaluation of hybrid's performance and their genotypic interactions with the environment. They differ in the parameters used in the assessment, the biometric procedures employed and the analysis.

Yan et al. (2000) proposed methodology known as GGE-biplot for graphical display of GE interaction pattern. It allows visual examination of the relationships among the test environments, genotypes and the GE interactions. It is an effective tool for: (i) mega-environment analysis (e.g. "which-won-where" pattern), where specific genotypes can be recommended to specific mega-environments (Yan and Kang, 2003; Yan and Tinker, 2005), (ii) genotype evaluation (the mean performance and stability), and (iii) environmental evaluation (the power to discriminate among genotypes in target environments) (Ding et al., 2007).

Different researchers used GGE biplot for the analysis of GE interactions and evaluation of maize genotypes (Butron et al., 2004; Fan et al., 2007; Yan and Kang, 2003; Samonte et al., 2005; Dehghani et al., 2009, Balestre et al., 2009; de Oliveira et al., 2010; Tonk et al., 2011). The aim of this study was to i) investigate the stability of grain yield in maize hybrids under rainfed and irrigated conditions in Macedonia via the GGE biplot, ii) graphically summarize the effects of G and GE interaction and to identify "which won where" iii) recommend maize hybrids for the specific growing region taking into account the specificities of hybrids and growing conditions.

Materials and Methods

The experiment was conducted during summer crop seasons 2009, 2010 and 2011 at Ovce Pole region, Republic of Macedonia. Sixteen maize hybrids from diverse backgrounds and maturity groups were sown in a nested design with three replications, and two treatments: with and without irrigation. As a result, six environments were obtained. The environments with irrigation in the three subsequent years were assigned as E1, E3 and E5, while the environments without irrigation as E2, E4 and E6. The hybrids used for the investigation are presented in Table 1. Distance between the rows was 0.7 m with hills spaced according to the maturity group. Plots were overplanted and thinned, obtaining a final density of approximately 68027 plants/ha for the hybrids which belong to FAO 300, 62111 plants/ha for the hybrids from FAO 400, 57143 plants/ha for hybrids from FAO 500 and 52910 plants/ha for the hybrids from FAO 600. The central two rows from each plot were harvested at maturity and the fresh ear weight was measured in each plot.

Table 1
Maize hybrids included in the study

Hybrid code	Hybrid	FAO maturity group	Seed company
1	ZP360	FAO300	Maize Research Institute "Zemun Polje", Serbia
2	OS378	FAO300	Agricultural Institute, Osijek, Croatia
3	ZP480	FAO400	Maize Research Institute "Zemun Polje", Serbia
4	OS499	FAO400	Agricultural Institute, Osijek, Croatia
5	ZP599	FAO500	Maize Research Institute "Zemun Polje", Serbia
6	OS552	FAO500	Agricultural Institute, Osijek, Croatia
7	ZP677	FAO600	Maize Research Institute "Zemun Polje", Serbia
8	OS602	FAO600	Agricultural Institute, Osijek, Croatia
9	NS300	FAO300	Institute of field and vegetable crops Novi Sad, Serbia
10	Stira	FAO300	Pioneer Hi-Bred Ltd.
11	NSSK444	FAO400	Institute of field and vegetable crops Novi Sad, Serbia
12	Colomba	FAO400	Pioneer Hi-Bred Ltd.
13	NS5010	FAO500	Institute of field and vegetable crops Novi Sad, Serbia
14	Cecilia	FAO500	Pioneer Hi-Bred Ltd.
15	NS6010	FAO600	Institute of field and vegetable crops Novi Sad, Serbia
16	Constanza	FAO600	Pioneer Hi-Bred Ltd.

Statistical analysis

The GGE biplot analysis was performed using R statistical package GGEbiplotGUI (Bernal and Villardon, 2012). It was used to generate graphs which are showing (i) "which-won-where" pattern, (ii) ranking of hybrids on the basis of yield and stability, (iii) environment vectors, and (iv) comparison of environment to ideal environment (Yan and Kang, 2003). The GGE biplot represents the first two principal components (PC1 and PC2, referred as primary and secondary effects, respectively) derived from subjecting environment centered yield data (yield variation due to GGE), to singular value decomposition (Yan et al., 2000).

Results and Discussion

Best Hybrid in each Environment

GGE biplot method can be used to identify superior maize genotypes for target sites (Dehghani et al., 2009). The biplot (Figure 1) represents a polygon, where some of the hybrids are positioned on the vertexes, while the rest are inside the polygon. As the hybrids positioned on the vertexes have the longest distance from the biplot origin, they are supposed to be the most responsive. Responsive hybrids are either best or the poorest at one or every environment (Yan and Rajcan, 2002). Considering this, the hybrids 13, 15 and 16 had the highest seed yield when irrigation was applied. The three environments with irrigation were positioned in the same sector on the graph, which indicates that those environments did not differ significantly between themselves. The environments without irrigation were placed in three different sectors. Hybrids 10 and 12 were the highest yielding in E2, 1, 9, 11 and 14 in E4 and 5, 6, 7 and 8 in E6. None of the environments fell in the sectors with hybrids 2, 3 and 4, indicating that these hybrids are not suitable for growing at this specific location.

Yan et al. (2000) stated that ideal genotypes could be considered those that have a large PC1 score (high yielding ability) and small or absolute PC2 score (high stability). Similarly, the ideal test environment should have a large PC1 score which means that it is more discriminating of the genotypes in terms of the genotypic main effect and small or absolute PC2 score (more representative of the overall environment). When an "ideal" view is drawn (Figure 2), it can be observed that the hybrid 16 was the closest to the ideal genotype, followed by 15. According to Yan and Kang (2003), an ideal genotype could be defined as one which is the highest yielding across test environments and is absolutely stable in its performance.

Average Yield and Stability of Hybrids

The average grain yield of the hybrids vs. their stability is presented in Figure 2. The performance line (average tester coordination, ATC) passes through the biplot origin with an arrow indicating the circle for the "ideal" genotype. The geno-

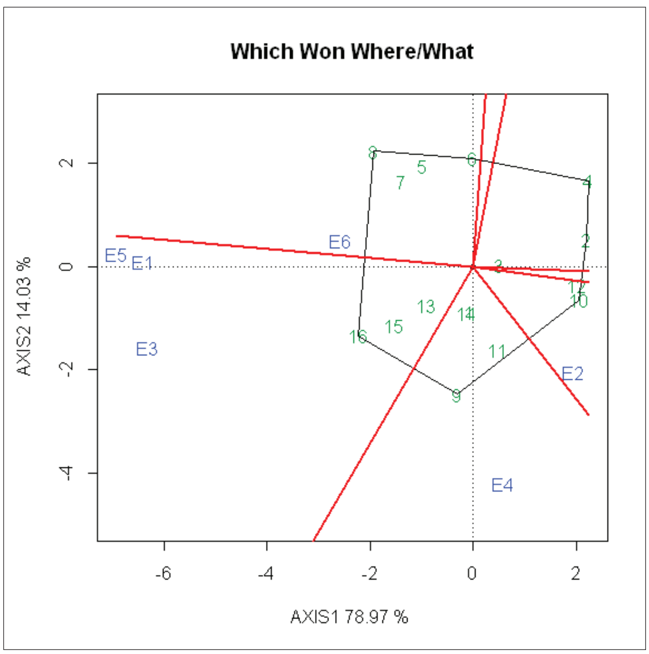

Fig. 1. A genotype + genotype × environment interaction bi-plot showing hybrids performance in each environment

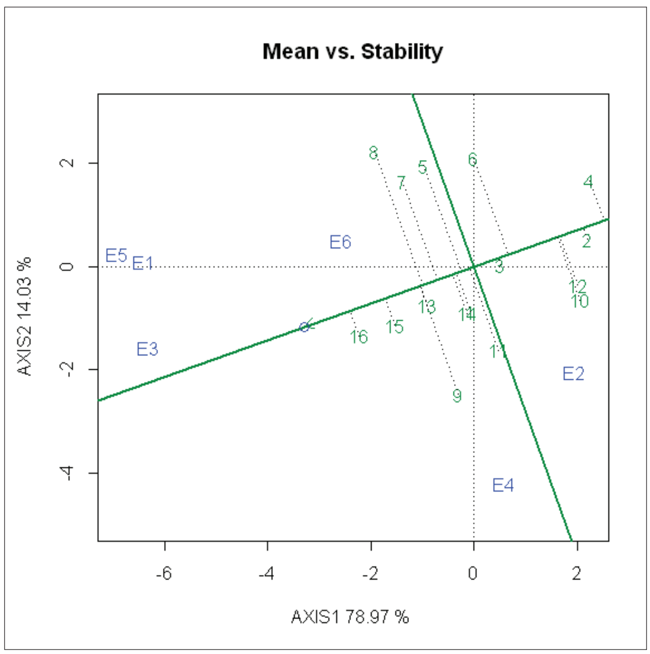

Fig. 2. Average tester coordination (ATC) view of the GGE biplot. Environments are denoted by 'E' while hybrids are marked with numbers. AXIS1 and AXIS2 are first and second principal components, respectively

types positioned the closest to the circle are the highest yielding, those on the upper side of the line are stable, and those in the lower part of the biplot are not stable. Considering this, the hybrid 16 has the highest average grain yield (10012 kg ha^{-1}), as having the highest projection on the performance line, followed by 15 (9552 kg ha^{-1}) and 13 (9088 kg ha^{-1}), which are located very close to the hybrid 16 (Table 2). It could be also observed that these hybrids are not stable over various environments, which is due to the very poor performance in the conditions without irrigation. Consequently, these hybrids may be considered for growing in Ovce Pole region, but only with irrigation. The hybrid 4 had the lowest seed yield (6910 kg ha^{-1}).

In Figure 3 the center of the concentric circles is where an ideal hybrid should be; its projection on the ATC X-axis was designed to be equal to the longest vector of all hybrids, and its projection on the ATC Y-axis was obviously zero, indicating that it is absolutely stable. Therefore, the smaller the distance from a hybrid to such a virtual hybrid, the most ideal the hybrid is. Thus, hybrid 16 was the closest to the concentric center. Hybrid 15 did not seem to be meaningfully different from hybrid 16, while the hybrid 4 was the least stable across the environments.

Environment Ranking Based on both Discriminating Ability and Representativeness

Discriminating ability and representativeness of the environments is presented in Figure 4. An ideal environment is the one that is most discriminating for genotypes (longest distance between the marker of the environment to the plot origin, is a measure of its discriminating ability) and is representative (shortest projection from the marker of location onto the ATC Y-axis is the measurement of its representative-

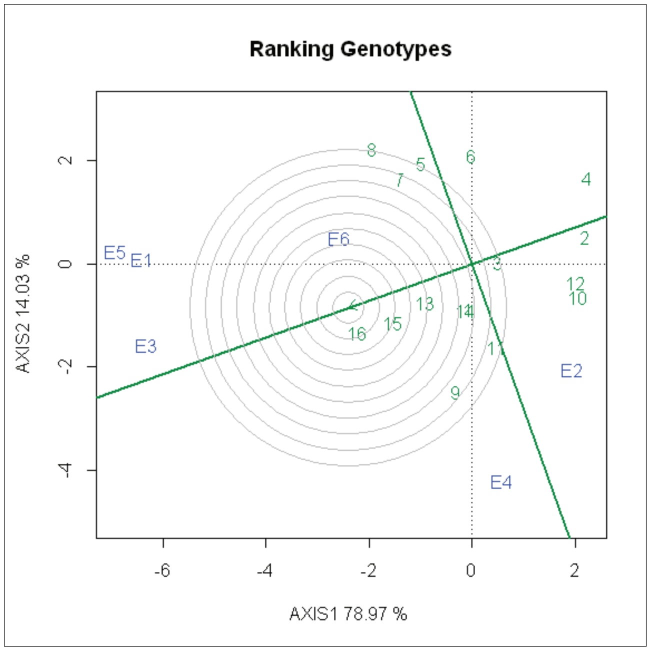

Fig. 3. Comparison of hybrids with the ideal hybrid

Table 2
Mean grain yield (kg ha^{-1}) of sixteen maize hybrids across six environments in Ovce Pole region and their average grain yield

Hybrids	E1	E2	E3	E4	E5	E6	Average grain yield, kg ha^{-1}
1	10920	4790	11230	5450	13010	7710	8852
2	8200	4290	9110	4690	9710	6670	7112
3	10480	3630	10660	5180	11600	7440	8165
4	7920	3530	8050	4400	10330	7230	6910
5	12490	2300	12160	3520	12780	8190	8573
6	11040	2990	10080	3820	12760	8480	8195
7	12160	2930	12920	3320	13930	8420	8947
8	12480	2430	12390	3340	15650	8940	9205
9	11075	5120	12120	6580	13010	7710	9269
10	8655	4490	9410	5680	9710	6670	7436
11	10570	4405	11130	6310	11600	7440	8576
12	7985	3965	9190	5815	10330	7230	7419
13	12325	2910	12470	5855	12780	8190	9088
14	10560	3405	11420	6150	12760	8480	8796
15	12540	3125	13425	5870	13930	8420	9552
16	12435	2885	14020	6140	15650	8940	10012

ness) of all other environments (Yan, 2001; Yan and Kang, 2003). Considering this, E3 was the most discriminating as well as most representative, as it is far away from the plot origin and had the shortest projection onto ATC Y-axis, respectively. The other environments where irrigation was applied (E1 and E5) were positioned close to E3, which indicates that stable production of maize in this region is possible only with irrigation. According to Tonk et al. (2011), those are the best environments for genetic differentiation of experimental hybrids. On the other hand, the environments where irrigation was not applied didn't have the discriminating ability (were not far away from the origin) and were not representative, as they had large projection onto the ATC Y-axis (Figure 4).

Relationship among Environments

Relationship among the tested environments is indicated in Figure 5. It represents the vectors of all six environments, facilitating the determination of the relationship between environments. The vector length also represents the discriminating ability of the respective environment, and the cosine of the angle between two environments shows the relationship among them (Yan, 2001). Both E5 and E1 had the longer vectors, thus they were the best for genetic differentiation of hybrids. E6 was the least representative environment in this study. The smallest angles between the vectors of E1 and E5 indicated that they had a strong relationship.

The seed companies are always competing for increasing their share on the hybrid maize seed market (Tonk et al., 2011). An essential goal in a breeding program is to provide reliable information that will serve as a guide for selection of the best genotypes that should be planted in following years and to be able to predict yield as precisely as possible based on limited experimental data (Crossa et al. 1990). GGE biplot effectively identified the maize hybrids which should be considered for growing in Ovce Pole region. Furthermore, using this technique it was clearly established that high and stable yields could be obtained only with irrigation. Different researchers also found that GGE biplot analysis is a useful tool for detecting test locations to select superior experimental maize hybrids (Balestre et al., 2009; Ilker et al., 2009; de Oliveira et al., 2010; Tonk et al., 2011; Khalil et al., 2011; Beyene et al., 2011).

Conclusions

The GGE biplot analysis identified the hybrids 16, with an average grain yield of 10012 kg ha^{-1}, 15 (9552 kg ha^{-1}) and 13 (9088 kg ha^{-1}) to be the most desirable hybrids for growing in Ovce pole region. As those hybrids were not stable in non-irrigated conditions, they may be considered for growing in this region, but high and stable yield could be expected only with irrigation. The hybrid 4 had the lowest seed yield (6910 kg ha^{-1}) and was the least stable across different environments. Also, the GGE biplot

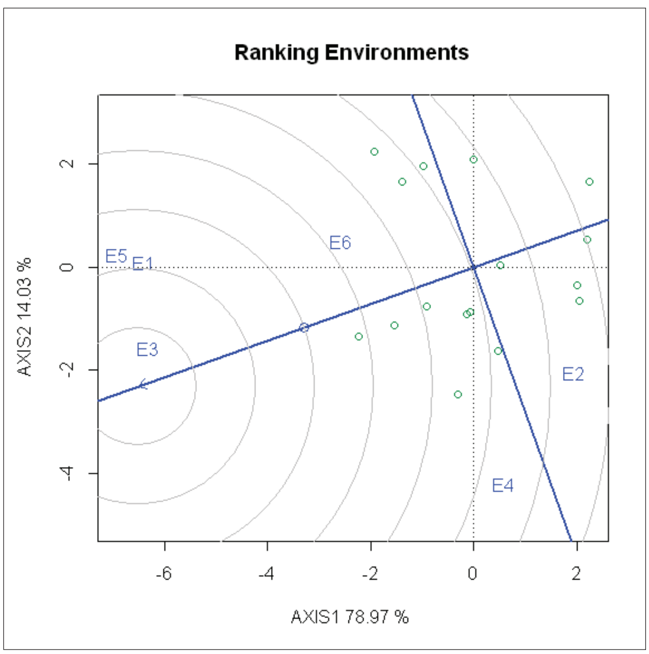

Fig. 4. Comparison of environments with an ideal environment. The hybrids are indicated by scattered small circles while the environments are in upper case

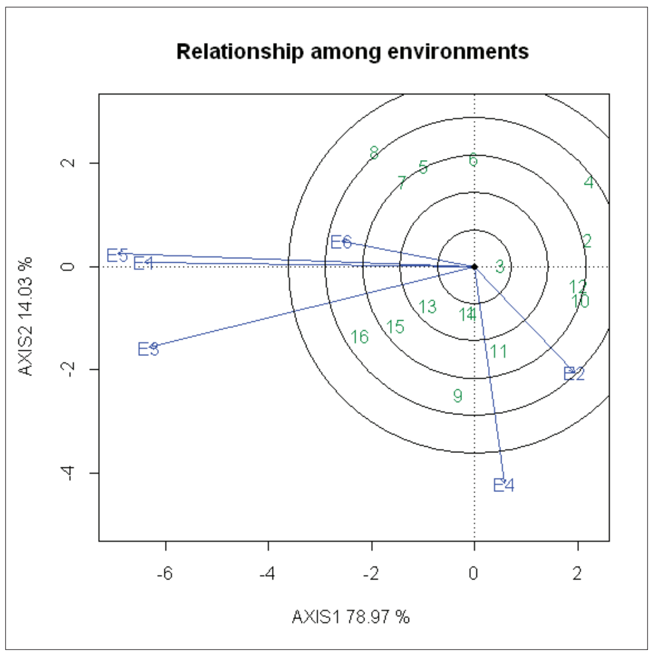

Fig. 5. A genotype + genotype × environment interaction biplot showing relationships among six environments

methodology was useful tool for identification of environments in which maize hybrids will have an optimal performance. This technique can serve as a useful tool for recommendation of maize hybrids for specific growing region taking into account the specificities of hybrids and growing conditions.

References

Annicchiarico, P., 2002. Genotype × environment interaction: Challenges and opportunities for plant breeding and cultivar recommendations. *FAO Plant Prod. & Prot. Paper 174.* FAO United Nations, Rome.

Balestre, M., J. C. Souza, R. G. V. Pinho, R. L. Oliveira and J. M. V. Paes, 2009. Yield stability and adaptability of maize hybrids based on GGE biplot analysis characteristics. *Crop Breeding and Applied Biotechnology,* **9:** 219-228.

Beiragi, M. A., S. Khavari Khorasani, M. S. Nabavi, F. Nikzad and E. Zandipour, 2011. Study of yield stability of commercial corn hybrids (*Zea mays* L.) evaluated in two planting dates in Iran. *African Journal of Agricultural Research*, **6** (13): 3161-3166.

Bernal, E. F. and P. G. Villardon, 2012. Package 'GGEBiplotGUI' http://cran.r-project.org/…ages/GGEBiplotGUI/GGEBiplotGUI.pdf

Beyene, Y., S. Mugo, C. Mutinda, T. Tefera, H. Karaya, S. Ajanga, J. Shuma, R. Tende and V. Kega, 2011. Genotype by environment interactions and yield stability of stem borer resistant maize hybrids in Kenya. *African Journal of Biotechnology,* **10** (23): 4752-4758.

Bonea, D. and V. Urechean, 2011. The evaluation of water stress in maize (Zea mays L.) using selection indices. *Romanian Agricultural Research*, **28:**79-86.

Butron, A., P. Velasco, A. Ordás and R. A. Malvar, 2004. Yield evaluation of maize cultivars across environments with different levels of pink stem borer infestation. *Crop Sci.,* **44:** 741–747.

Campos, H., M. Cooper, G.O. Edmeades, C. Löffler, J. R. Schussler and M. Ibañez, 2006. Changes in drought tolerance in maize associated with fifty years of breeding for yield in the U.S. corn belt. *Maydica,* **51:** 369-381.

Crossa, J., 1990. Statistical analyses of multilocation trials. *Adv. Agron*., **44:** 55-85.

Dehghani, H., A. Ebadi and A. Yousefi, 2006. Biplot analysis of genotype by environment interaction for barley yield in Iran. *Agron. J.,* **98:** 388-393.

Dehghani, H., N. Sabaghnia and M. Moghaddam, 2009. Interpretation of Genotype-by-Environment Interaction for Late Maize Hybrids' Grain Yield Using a Biplot Method. *Turkish Journal of Agriculture and Forestry*, **33:** 139-148.

Ding, M., B. Tier and W. Yan, 2007. Application of GGE biplot analysis to evaluate Genotype (G), Environment (E) and GxE interaction on P. radiata: a case study. Australasian Forest Genetics Conference Breeding for Wood Quality, 11-14 April 2007, Hobart, Tasmania, Australia.

Epinat-Le Signor, C., S. Dousse, J. Lorgeou, J. B. Denis, R. Bonhomme, P. Carolo and A. Charcosset, 2001. Interpretation of genotype x environment interactions for early maize hybrids over 12 years. *Crop Sci.*, **41:** 663–669.

Fan, X. M., M. S. Kang, H. Chen, Y. Zhang, J. Tan and C. Xu, 2007. Yield stability of maize hybrids evaluated in multi-environment trials in Yunnan, China. *Agron. J.,* **99:** 220-228.

Golbashy, M., M. Ebrahimi, S. Khavari Khorasani and R. Choucan, 2010. Evaluation of drought tolerance of some corn (*Zea mays* L.) hybrids. *Iran. Afr. J. Agric. Res.,* **5** (19): 2714-2719.

Grzesiak, S., 2001. Genotypic variation between maize (Zea mays L.) single-cross hybrids in response to drought stress. *Acta Physiol. Plant. J.,* **23** (4): 443-456.

Ilker, E., F. Aykut Tonk, O. Caylak, M. Tosun, I. Ozmen, 2009. Assessment of genotype x environment interactions for grain yield in maize hybrids using AMMI and GGE biplot analyses. *Turkish J. of Field Crops,* **14** (2): 123-135.

Khalil, I. A., H. Rahman, N. U. Rehman, M. Arif, I. H. Khalil, M. Iqbal, H. Ullah, K. Afridi, M. Sajjad and M. Ishaq, 2011. Evaluation of maize hybrids for grain yield stability in northwest of Pakistan. *Sarhad J. Agric.,* **27** (2): 213-218.

Mitrovic, B., D. Stanisavljevic, S. Treski, M. Stojakovic, M. Ivanovic, G. Bekavac and M. Rajkovic, 2012. Evaluation of experimental maize hybrids tested in multy-location trials using AMMI and GGE biplot analyses. *Turkish Journal of Field Crops,* **17** (1): 35-40.

Mohammadai, H., A. Soleymani and M. Shams, 2012. Evaluation of Drought Stress Effects on Yield Components and Seed Yield of Three Maize Cultivars (Zea mays L.) in Isfahan region. *International Journal of Agriculture and Crop Sciences,* **4** (19):1436-1439.

de Oliveira, R. L., R. Garcia Von Pinho, M. Balestre and D. V. Ferreira, 2010. Evaluation of maize hybrids and environmental stratification by the methods AMMI and GGE biplot. *Crop Breeding and Applied Biotechnology*, **10:** 247-253.

Sabaghnia, D. N. H. and S. H. Sabaghpour, 2008. Graphic analysis of genotype × environment interaction of lentil yield in Iran. *Agron J.,* **100:** 760- 764.

Samonte, S. O. P. B., L. T. Wilson, A. M. McClung and J. C. Medley, 2005. Targeting cultivars onto rize growing environments using AMMI and SREG GGE biplot analysis. *Crop Sci.,* **45:** 2414-2424.

Tonk, F. A., E. Ilker and M. Tosun, 2011. Evaluation of genotype x environment interactions in maize hybrids using GGE biplot analysis. *Crop Breeding and Applied Biotechnology,* **11:** 1-9.

Yan, W., L. A. Hunt, W. Q. Sheng and Z. Szlavnics, 2000. Cultivar evaluation and mega-environment investigation based on the GGE biplot. *Crop Sci.,* **40:** 597–605.

Yan, W., 2001. GGE Biplot- A windows application for graphical analysis of multi-environment trial data and other types of two-way data. *Agron. J.,* **93:** 1111–1118.

Yan, W. and I. Rajcan, 2002. Biplot analysis of test sites and trait relations of soybean in Ontario. *Crop Science,* **42:** 11–20.

Yan, W. and M. S. Kang, 2003. GGE biplot analysis: A graphical tool for breeders, geneticists, and agronomists. *CRC Press, Boca Raton*, FL.

Yan, W. and N. A. Tinker, 2005. An integrated system of biplot analysis for displaying, interpreting, and exploring genotype by environment interactions. *Crop Sci.,* **45:** 1004-1016.

Yan, W., M. S. Kang, B. Ma, S. Woods and P. L. Cornelius, 2007. GGE Biplot vs. AMMI analysis of genotype-by-environment data. *Crop Sci.,* **47:** 643- 655.

Received November, 21, 2013; accepted for printing June, 2, 2014.