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Original scientific paper

ASSESSMENT OF SUGAR BEET ROOT YIELD BY AMMI ANALYSIS

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Sugar beet cultivars have different responses in various environments, such as different locations, years, mineral nutrition treatments or the combination of these factors, due to genotype × environment interaction. Additive main effect and multiplicative interaction (AMMI) is one of the most commonly used multivariate methods for analysis and visualization of genotype × environment interaction data. The main goals of the present study were to (i) investigate the application of AMMI method in the analysis of genotype × fertilizer interaction in sugar beet, (ii) to assess genotype × fertilizer interaction, and (iii) to identify sugar beet cultivars with the most stable response and high yield performance across different mineral nutrition treatments. The trial with eight sugar beet cultivars was conducted in two successive growing seasons at Rimski šančevi, Serbia. The different levels of nitrogen, phosphorous and potassium fertilizers (0, 50, 100 and 150 kg ha^{-1}) and their combinations represented specific environments for testing genotype × fertilizer interaction. Results from the analysis of variance indicated that the fertilizer treatment, cultivars, and their interaction significantly affected root yield variation in both seasons. Results from our study suggest that AMMI model with two and three first IPCA axes were recommended in 2014 and 2015, respectively. According to AMMI 1 and AMMI 2 biplot, E14 and E15 were high yielding and among the most stable treatments in both years. Among high yielding genotypes in 2014, G4 and G8 stand out as the most stable, while in the following year G3 had the lowest interaction score. AMMI analysis enabled identification of specific associations between cultivars and different mineral nutrition treatments, which was important for adjustment of

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fertilizer management for each cultivar in order to achieve high root yield with decreased and more rational fertilizer doses.

Keywords: *Beta vulgaris* L., G × E interaction, mineral nutrition, multivariate analysis, root yield

INTRODUCTION

Sugar beet is the most significant crop for sugar production in temperate climate regions and accounts for about 35% of the world's sugar production (LIU *et al*., 2008). Production of sugar beet is widespread in Europe - it is grown from the Baltic states in the north to Spain and Greece in the south. Northern Serbia, a part of the Pannonian plain, is an important region for sugar beet cultivation with a five-year average harvested area over 62,000 ha and root yield of 48 t ha^{-1} (FAOSTAT, 2016). However, climate changes cause high year to year variability and more frequent occurrence of undesirable growing seasons (OLESEN *et al*., 2011), which complicates sugar beet growing. These unfavourable years are characterized by high fluctuation of meteorological parameters, especially rainfall and temperature during crop development. Nevertheless, good agricultural practices (application of fertilizers, well scheduled sowing date and appropriate sowing density) adjusted and specified for different sites and genotypes could reduce negative effects of environmental conditions, thus enabling higher yield and quality of sugar beet (ĐULAKOVIĆ *et al*., 2015).

In addition to good weather condition during the growing season, sugar beet cultivation is a highly intensive production which requires large amounts and appropriate fertilizer rates, especially nitrogen (N), phosphorus (P) and potassium (K) for achieving high yields (CARIOLLE and DUVAL, 2006). For example, insufficient N dose can reduce root yield, while its excessive application will result in lower sugar concentration and increased impurities (ABDEL-MOTAGALLY *et al*., 2009). Therefore, inappropriate fertilization management has a much stronger negative impact on sugar beet production than on other crops (JAĆIMOVIĆ *et al*., 2008).

Cultivars have different responses in various environments, such as different locations, years, mineral nutrition treatments or the combination of these factors, due to genotype × environment interaction (GEI). This phenomenon has been investigated in many crops such as wheat (HRISTOV *et al*., 2011), pepper (PANAYOTOV and DIMOVA, 2014), rice (BOSE *et al*., 2014), ryegrass (LAKIĆ *et al*., 2015) and is often shown as a rank change of cultivars in different environments (NDHLELA *et al*., 2014). It complicates the evaluation of new cultivars and interpretation of the obtained field trial results (MALOSETTI *et al*., 2014). Most of the recent GEI studies are focused on the investigation of genotype × location, genotype × year or genotype × year × location interaction (GIREK *et al*., 2013; STOJAKOVIĆ *et al*., 2015; PRŽULJ *et al*., 2015). However, various cultivars often have inconsistent reactions to different mineral nutrition doses, especially in regards to the yield performance (MALHI and GILL, 2006; ALMODARES *et al*., 2008). Therefore, knowledge about interaction between cultivar and fertilizers is important for improving agricultural practice for a specific cultivar. Moreover, increased cost of fertilizers (JU *et al*., 2016) and their negative environmental impact (MOSS, 2008) demands further research and development of cultivars with better fertilizer utilization.

Many statistical methods, like regression, nonparametric and multivariate analysis, are used to study GEI data (GAUCH *et al*., 2008). Nonparametric, aditive (ANOVA) and linear regression models are are often inadequate for good understanding of GEI. Additive main effect and multiplicative interaction (AMMI) is one of the most commonly used multivariate methods for analysis and visualization of GEI data. AMMI combines the analysis of variance (ANOVA) and principal component analysis (PCA) in a single model (GAUCH, 2013). Further, AMMI separates the additive effect from interaction by ANOVA and then analyses interaction structure by PCA method.

As far as we know, only few studies have used AMMI method to analyse genotype × fertilizer interaction. Therefore, main objectives of the present study were to: (i) investigate the application of AMMI method in the analysis of genotype × fertilizer interaction in sugar beet, (ii) to assess genotype by fertilizer interaction, and (iii) to identify sugar beet cultivars with the most stable response and high yield performance across different mineral nutrition treatments.

MATERIALS AND METHODS

Experimental design and treatments

The plant material consisted of eight sugar beet hybrids (Table 1), usually grown in northern Serbia. The trial was conducted in two successive growing seasons (2014 and 2015), arranged in a split plot design with three replications at location Rimski šančevi (45°20´N and 19°51´E), Serbia. The experimental plot size was 24 m^2 (12 m long with four rows), with wheat as the preceding crop. The distance between rows was 0.5 m and within rows 0.2 m, with density of 100,000 plants ha^{-1}. Crops were sown on 18 March 2014 and 21 March 2015. In each season, there were 20 different fertilizer treatments, which represent specific environments, designated as E1 - E20 (Table 1). Four levels of N, P, and K fertilizers (0, 50, 100, and 150 kg ha^{-1}) and their combinations were applied in autumn before ploughing, with the exception of N which was applied in two identical rates. The first rate was applied together with P and K, and the second rate was applied in spring before sowing. Each of these various fertilizer combinations presented the specific environments for testing genotype × fertilizer interaction, i.e. GEI. Recommended fungicide and insecticides were used for pests and diseases control, while weeds were periodically manually removed. Crops were not irrigated. Plants from two central rows were used for measuring root yield.

Table 1. Genotype abbreviation, mineral fertilizer treatment abbreviation and combination

Cultivar abbrev.	Cultivar name	Treatment abbrev.	Fertilizer level	Treatment abbrev.	Fertilizer level
G1	Sara	E1	Control	E11	N100 P50 K50
G2	Lara	E2	N100	E12	N100 P100 K50
G3	Tibor	E3	P100	E13	N100 P100 K100
G4	Original	E4	K100	E14	N100 P150 K50
G5	Taiphun	E5	N100 P100	E15	N100 P150 K150
G6	Alfonsa	E6	N100 K100	E16	N150 P50 K50
G7	Marianka	E7	P100 K100	E17	N150 P100 K50
G8	Begonia	E8	N50 P50 K50	E18	N150 P100 K100
		E9	N50 P100 K50	E19	N150 P150 K100
		E10	N50 P100 K100	E20	N150 P150 K150

Data analysis

The collected GEI data were analysed using AMMI model defined by the following formula (GAUCH and ZOBEL, 1996):

$$Y_{ger} = \mu + \alpha_g + \beta_e + \sum \lambda_n \gamma_{gn} \delta_{en} + \rho_{ge} + \varepsilon_{ger}$$

where Y_{ger} presents the yield for the genotype g in the environment e the replication r. The additive parameters are presented with: μ – the grand mean, α_g – the genotypic mean deviation from the grand mean, β_e – the environmental mean deviation. The multiplicative parameters are: λ_n– a singular value for n interaction principal component axis n, γ_{gn} – the genotypic eigenvector for IPCA axis n, δ_{en} – the eigenvector of the environment for IPCA axis n, ρ_{ge} – a residue when not all PCA axis are included and ε_{ger} – the error.

Software STATISTICA 12 was used for two-way ANOVA, and the means were compared using Duncan test. AMMI analyses were performed using Excel Biplot Macros (LIPKOVICH and SMITH, 2002).

RESULTS AND DISCUSSION

Meteorological data

Meteorological data (monthly precipitation and average temperature) were collected from the weather station located near the experimental field (Figure 1). Weather conditions, especially the distribution of precipitation, varied significantly across the growing seasons. Total amount of precipitation during crop growth cycle was 709 mm in 2014 and 469 mm in 2015. In both growing seasons, extremely high levels of rainfall (about 200 mm) were recorded in May. The growing season of 2014 was very humid with abundant precipitation which continued until the end of the vegetation period. The lack of rainfall in 2015, especially in July, marked this month as critical stage for crop growth and root development. Additionally high temperatures in July and August of 2015 (by 4°C higher than in the previous season) intensified unfavourable environmental impact on plants. Therefore, summer drought in 2015 had a major negative effect on sugar beet and its root yield formation.

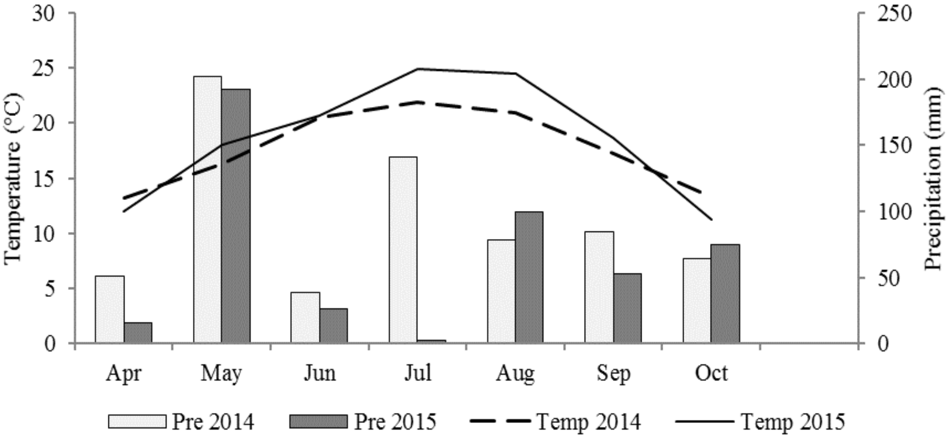

Figure 1. Monthly average temperature and rainfall amount during the two growing seasons (2014 and 2015)

ANOVA and AMMI model

The ANOVA for AMMI analysis indicated that the influences of fertilizer treatment (environment) - E, genotype - G and their interaction - GEI, were significant ($p < 0.01$) in both growing seasons (Table 2). Fertilizer combinations had the most important effect on sugar beet root yield, and this factor explained 62.2% of treatment variation in 2014 and 39.3% in 2015. The effect of G was higher in the unfavourable year (24.5% in 2015) for sugar beet production, while the effect of E was more pronounced in the year characterized by better environmental conditions for sugar beet production (2014). This result leads to the conclusion that appropriate cultivar selection has larger impact under less favourable conditions, while in favourable years (or conditions) effect of mineral nutrition has greater influence, as previously reported by SHRESTHA *et al.* (2010). Furthermore, our data confirm the findings of different studies which state that environmental condition, including fertilizer management and other good agricultural practices (MALNOU *et al.*, 2008), and difference between years or location (SKLENAR *et al.*, 2000), have strong effect on root yield.

Table 2. The additive main effects and multiplicative interactions analysis of variance for sugar beet root yield in 2014 and 2015

Source of variation	df	SS	MS	F values	SS (%)	SS	MS	F values	SS (%)
		2014				2015			
Treatments	159	72164	453.9	10.0**	-	24393	153.4	6.0**	-
Gen (G)	7	8311	1187.3	26.1**	11.5	5982	854.6	33.3**	24.5
Block	40	1087	27.2	0.6	-	4361	109	4.2	-
Fert (E)	19	44880	2362.1	86.9**	62.2	9577	504.1	4.6**	39.3
G × E	133	18972	142.6	3.1**	26.3	8833	66.4	2.6**	36.2
IPCA1	25	5461	218.4	4.8**	28.8	2571	102.8	4.0**	29.1
IPCA2	23	4037	175.5	3.9**	21.8	2055	89.4	3.5**	23.3
IPCA3	21	3066	146	3.2**	16.2	1834	87.3	3.4**	20.8
IPCA4	19	2684	141.3	3.1**	14.1	1091	57.4	2.0**	12.4
IPCA5	17	2051	120.7	2.6**	10.9	-	-	-	-
Residuals	28	1672	59.7	1.3	-	1283	28.5	1.1*	-
Error	280	12740	45.5	-	-	7195	25.7	-	-

* - Significant at the 5% level ;** - Significant at the 1% level

GEI participated in total variance with 26.3% in 2014 and 36.2% in 2015, while the influence of G explained 11.5% in 2014 and 24.5% in 2015. LAUFER *et al.* (2016) also reported significant influence of genotype × fertilizer treatment interaction on root yield. Moreover, AL JBAWI *et al.* (2016) reported a significant variation in sugar beet root yield as the result of GEI.

Based on GEI signal (GEI$_{S}$) percent that was captured by IPCA axes, AMMI model with two and three first IPCA axis were recommended in 2014 and 2015, respectively. Significance of

IPCA axes determined by F-test is often not relevant indicator, since it is well known that this test diagnoses too many components (GAUCH, 2013). Generally, AMMI model with first several IPCA axes is recommended since these axes explain the highest percent of GEI interaction, while the further axes are buried in GEI noise (GEI$_N$). In 2014, the first and the second IPCA captured 34% and 23% of GEI$_S$, and were less buried in GEI$_N$ (IPCA1 – 21% and IPCA2 – 26%). The third IPCA axis separated only 16% of GEI$_S$ and captured 31% of GEI$_N$. The fourth axis explained only 14% of GEI, while the fifth axis explained 10% of GEI$_S$. In the following year, first four IPCA axes captured 36%, 27%, 24% and 11% of GEI$_S$, respectively. These axes buried 24%, 29%, 29% and 45% of GEI$_N$. Therefore, it could be concluded that in 2014 AMMI model that includes first two axes was the most appropriate, while in the following season AMMI model should include first three axes. Similarly, PIDGEON *et al.* (2006) and MORADI *et al.* (2012) reported that influence of genotype and GEI is usually smaller than the influence of the environment.

Table 3. Average root yields (t ha^{-1}) of eight sugar beet cultivars over 20 fertilazer treatments in 2014

Fertilizer	Cultivar								Average
	G1	G2	G3	G4	G5	G6	G7	G8	
E1	57.1	52.7	63.2	60.1	71.4	54.9	66.0	65.1	61.3^{m}
E2	77.0	69.1	84.8	68.6	70.1	72.1	83.4	82.3	75.9^{j}
E3	79.5	76.1	89.8	80.3	70.8	89.4	84.9	86.7	82.2^{gh}
E4	56.1	72.7	75.0	84.4	60.2	75.3	69.8	71.6	70.6^{k}
E5	60.7	78.9	77.4	88.0	80.1	74.7	64.1	72.6	74.6^{j}
E6	73.9	86.2	76.7	82.3	89.6	74.8	87.1	91.7	82.8^{g}
E7	58.4	61.4	80.7	78.2	73.8	58.4	52.4	67.4	66.3^{l}
E8	66.7	73.9	72.9	83.4	73.3	79.0	90.4	91.3	78.9^{i}
E9	81.6	75.6	94.8	70.7	73.8	84.5	72.3	83.8	79.6^{hi}
E10	91.8	88.1	104.3	109.2	86.1	101.3	101.6	104.4	98.3^{a}
E11	83.5	72.7	87.2	90.6	87.8	100.6	91.7	104.2	89.8^{de}
E12	83.0	77.6	86.6	85.7	82.7	106.0	81.0	87.8	86.3^{f}
E13	79.8	81.0	99.5	92.1	85.3	87.1	100.0	87.5	89.0d^{ef}
E14	80.7	88.1	98.6	104.2	80.6	90.6	102.7	97.1	92.8^{bc}
E15	81.0	90.9	102.6	102.7	101.8	93.8	99.7	93.1	95.7^{ab}
E16	85.5	85.2	90.9	85.2	77.8	98.5	95.0	84.1	87.8^{ef}
E17	91.2	79.7	98.5	91.8	79.8	85.5	84.6	84.9	87.0^{ef}
E18	87.6	72.4	101.0	98.3	95.0	95.3	92.1	89.7	91.4^{cd}
E19	76.4	79.3	89.1	87.3	84.1	80.9	77.4	85.3	82.5^{gh}
E20	91.8	77.2	87.5	103.6	92.1	103.5	102.2	95.0	94.1^{bc}
Average	77.2^{c}	76.9^{c}	88.0^{a}	87.3^{a}	80.8^{b}	85.3^{a}	84.9^{a}	86.3^{a}	83.3

Different letters indicate significant difference at $P<0.05$ level.

Environmental conditions in 2014 were more favourable for sugar beet production than in 2015, and accros treatments and cultivars average root yied was 83.3 t ha^{-1}. Among cultivars, average root yield varied from 76.9 t h^{-1} (G1) to 88.0 t ha^{-1} (G3) (Table 3). Influence of different fertilizer treatments also had significant effects on the root yield in this season. The highest average root yield (95.7 t ha^{-1}) was recorded in the environment E15 - treatment with fertilizer combination: 100 kgN ha^{-1}, 150 kgP ha^{-1} and 150 kgK ha^{-1}, indicating the importance of these mineral elements, their combination and ratio in achieving high root yields. On the other hand, the lowest root yield was recorded in the control treatment where fertilizer was not applied.

Table 4. Average root yields (t ha^{-1}) of eight sugar beet cultivars over 20 fertilizer treatments in 2015

Fertilizer	Cultivar								Average
	G1	G2	G3	G4	G5	G6	G7	G8	
E1	24.1	36.6	46.2	42.9	37.3	37.6	43.1	37.4	38.1^{ef}
E2	42.0	44.5	54.5	49.9	43.5	45.1	61.0	51.2	48.9^{abcd}
E3	32.6	34.0	49.5	34.0	33.2	41.1	33.8	38.0	37.0^{f}
E4	41.4	43.2	44.8	42.9	42.8	51.4	53.1	49.1	46.1^{abcd}
E5	49.0	48.6	55.8	53.9	47.3	64.2	48.9	47.8	51.9^{a}
E6	44.4	31.3	47.7	41.8	44.5	51.1	52.0	53.2	45.7^{abcd}
E7	41.1	36.8	47.5	38.2	35.2	52.5	41.7	48.6	42.7^{def}
E8	41.1	46.2	56.8	57.3	41.4	49.5	55.5	41.3	48.6^{abcd}
E9	44.5	46.5	52.7	44.5	39.0	46.5	55.6	54.7	48.0^{abcd}
E10	28.1	42.7	46.1	39.4	34.7	33.9	47.7	35.5	38.6^{ef}
E11	42.6	33.1	49.9	53.7	41.5	46.9	43.3	39.6	43.8^{cde}
E12	38.5	40.6	44.6	47.9	40.5	53.4	49.1	44.8	44.9^{bcd}
E13	39.3	39.0	55.2	53.7	41.3	48.8	56.3	51.5	48.1^{abcd}
E14	40.9	55.2	55.2	51.8	46.4	53.1	61.0	51.4	51.9^{a}
E15	49.5	47.8	53.9	55.6	46.0	49.5	55.2	52.1	51.2^{ab}
E16	45.9	50.0	57.2	54.1	47.0	56.8	52.3	48.1	51.42^{ab}
E17	42.1	43.2	40.4	55.3	48.2	49.5	57.0	51.0	48.3^{abcd}
E18	40.4	36.5	39.1	50.6	40.7	37.3	53.2	43.6	42.7^{def}
E19	48.6	53.6	48.2	56.5	43.2	51.7	44.9	54.2	50.1^{ab}
E20	50.2	45.2	47.3	57.3	44.2	51.7	47.9	39.1	47.8^{abcd}
Average	41.3^{c}	42.7^{c}	49.6^{a}	49.1^{a}	41.9^{c}	48.6^{ab}	50.6^{a}	46.6^{b}	46.3

Different letters indicate significant difference at $P<0.05$ level.

Across fertilizer treatments and cultivars in 2015, root yield ranged from 24.1 t ha^{-1} to 64.2 t ha^{-1} (Table 4). Average root yield in this season was 44% lower than in the previous growing season. This reduction in root yield emphasizes negative influence of high temperatures and precipitation deficit (drought) on plant growth and productivity. In many rain-fed agricultural systems across Europe, drought is a major problem for sugar beet production since the level of summer precipitation is often insufficient for regular crop growth and development (PIDGEON *et al.*, 2001). Numerous studies indicate that water deficit hastens the senescence of leaves, reduces photosynthetic efficiency and amount of light intercepted by the crop canopy (HOFFMAN, 2010; CHOLUJ *et al.*, 2014). Although negative environmental conditions caused major yield reduction among cultivars in 2015, significant differences in root yield were found between the studied genotypes and fertilizer treatments. Across cultivars, average root yield varied between 37.0 and 51.9 t ha^{-1}, suggesting that proper agricultural practices such as good and rational fertilizer management can moderate the negative influence of environmental conditions. Further, the highest average yield was recorded in cultivar G7 followed by G3, G4 and G6 indicating that these cultivars had better drought tolerance compared to other low yielding cultivars such as G1 and G5. Information about genotypic variation in susceptibility to drought could be used for cultivar recommendation in drought-prone environments. According to results from both years, genotypes G7, G4, G3 and G6 stand out as high yielding genotypes.

Results from ANOVA (Table 2) indicated that interaction between genotype and fertilizer had significant effect on root yield variation in both seasons. Therefore, it is necessary to conduct additional analysis to better understand the response of cultivars to various fertilizer treatments. Different approaches for GEI analysis have widely been used in plant breeding (YAN *et al*., 2015). One of the most frequently used methods for analysis of GEI data is AMMI model (AKBARPOUR *et al*., 2014; RODRIGUES *et al*., 2014). AMMI methods have previously been used for the analysis of GEI in different agricultural crops (MARJANOVIĆ-JEROMELA *et al*., 2011; SILVEIRA *et al*., 2013; GIREK *et al*., 2013), including sugar beet (PAUL *et al*., 1993). However, it should be emphasized that AMMI was mainly used for analysis of genotype × location or genotype × year interaction, while genotype × fertilizer interaction was neglected, especially in sugar beet.

AMMI 1 biplot simultaneously represents main additive effect (root yield) and the effect of the first interaction component. Lower absolute values of IPCA1 score indicate smaller interaction. G or E which have small values of IPCA1 are more stable. According to Figures 2 and 3, G and E showed different behaviour patterns in different years. In the favourable year (2014), genotypes had root yield of about and above general average and different interaction values. G8 and G3 showed higher stability than other cultivars. Treatments E17, E13, E18, E14 and E9 had small contribution to the interaction, and among them treatment E9 had average value of main effect slightly below the general average. Average root yield at treatments E2, E8, E9, E5, E4, E1 and E7 were just below the general average and these treatments were without N (E4, E1, E7) or with lower N dosage (E8 and E9) and treatment which had only N (E2). Furthermore, treatments E10, E15, E20, E14, E11 and E18 had the highest average yields, and among them treatments E14 and E18 had small contribution to the interaction. Additionally, treatments with combination of high N and P and moderate and low K content had high and stable yield of sugar beet root. These treatments are recommended for all genotypes under the conditions of favourable water regime. Under the same conditions, G6, G7 and G8 would have better performance with treatment E10, while treatment E15 would be better for genotypes G3, G4 and G5, since they have the same interaction sign. Control treatment had the lowest yield and relatively small contribution to the interaction. Therefore, in the favourable year genotypes grown under treatments with high and balanced levels of NPK fertilizers accomplished the highest root yield.

Genotypes and treatments had different positions at AMMI 1 biplot in 2015. Genotypes and treatments were more separated by horizontal axis than by vertical axis, indicating that influence of treatments was less pronounced in this year. Therefore, G2, G5, G8, G4 and G3 had small interaction scores and similar response to all applied treatments. In this year G7, G6, G3 and G4 had higher root yield, and among them G4 and G3 were the most stable genotypes. Similar root yield and high levels of interaction were recorded for genotypes G7 and G6. Treatment E15, with moderate level of N and high levels of P and K fertilizers, showed high average yield and stability in this year. Root yield at treatments E3, E10, E7, E11 and E18 was not significantly higher than at control treatment, and therefore the application of these fertilizer combinations was not economically justified in this dry year.

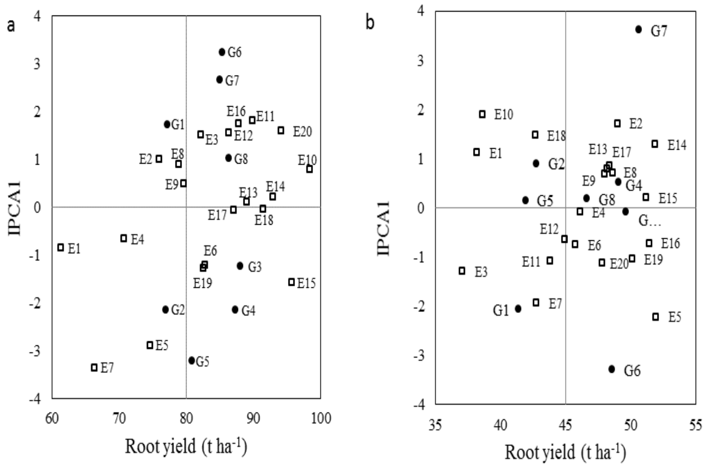

Figure 2. AMMI 1 biplot of eight sugar beet cultivars over 20 fertilazer treatments in 2014(a) and 2015(b)

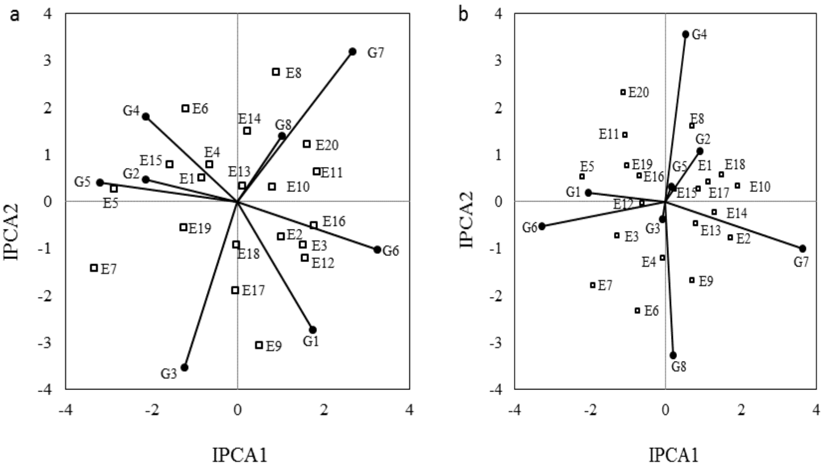

Figure 3. AMMI 2 biplot of eight sugar beet cultivars across 20 fertilizer treatments in 2014(a) and 2015(b)

AMMI 2 biplot (Figures 3a and 3b) was constructed using genotypic and environmental scores of the first two IPCA axes. Genotypes positioned near the biplot origin were more stable than the genotypes positioned further away. Greater dispersion of points on AMMI 2 biplot graphs in 2014 indicates that treatments characteristics are more expressed under favourable conditions. In 2014 high positive IPCA2 values were recorded for treatments E8, E6 and E14 (treatments without or with low P levels), while high negative values were recorded for E7, E17 and E9 (treatments with moderate P levels). This indicates that second IPCA axis is correlated with P effect. Simultaneously, treatments E8, E9, E4 and E7 achieved average yields slightly below the general yield average in 2014. The most stable treatments in 2014 were E18, E19, E2, E10, E13, E4 and E1, and among them E10 and E18 had high root yields at the same time. Among the tested genotypes, G2 and G8 in 2014 had the smallest interaction vectors and could be highlighted as the most stable genotypes. On the other hand, G1, G3, G6 and G7 were placed furthest from the biplot origin suggesting that these cultivars had specific fertilizer demands. In 2015, genotypes G1, G5, G3 and G2 had the lowest interaction values. Treatments E20, E8 and E11 (with similar levels of PK fertilizers) had the highest positive values of the second IPCA axis, while treatments E6, E7 and E9 had the highest negative values of IPCA2. Treatments E20 and E9 were unstable and low yielding and should not be recommended for environments similar to conditions in 2015. Small interaction vectors and high average yields were recorded in treatments E14, E15 and E16 which stand out and were recommended as stable treatments for sugar beet production under drought conditions. Further, in AMMI 2 cultivars with similar vector direction and length show resembling interaction response with applied treatments, such as G2 and G5 in both years. Additionally, genotypes and environments which were placed closer to each other had the positive association (G8 and E20 in 2014), which enables creation of specific agronomic zones, or in our case recommendation of appropriate fertilizer combination for specific cultivars. For instance in 2014, G1 was associated with E9, but reacted negatively with E6. In 2015, G4 was positively associated with E8, but also with E11 and E20, and under this conditions achieved highest yield in the trial. These results are particularly important from the perspective of a sugar beet producer, since they can accomplish equal or even higher yields with lower inputs of fertilizer (E8 versus E11 and E20). Other associations between cultivars and environments are shown in Figure 3.

CONCLUSIONS

Results from this study showed that AMMI 1 and AMMI 2 models are very applicable for the analysis of sugar beet genotypes and different fertilizer treatments interaction. Significant differences in root yield between cultivars and treatments in the unfavourable growing season of 2015 indicate that the appropriate application of fertilizer and selection of cultivars could moderate the negative impact of environmental conditions. Results from our study suggest that AMMI model with two and three first IPCA axes were recommended in 2014 and 2015, respectively. According to AMMI 1 and AMMI 2 biplot, E14 and E15 were high yielding and among the most stable treatments in both years. In favourable year, among high yielding treatments E14 and E18 had small contribution to interaction. Under drought conditions, small interaction vectors and high average yields were recorded in treatments E14, E15 and E16. Among the high yielding genotypes in 2014, G4 and G8 stand out as the most stable, while in the following year G3 had low interaction score. Identification of specific association between cultivars and different mineral nutrition treatments could enable adjustments of fertilizer management for each cultivar in order to achieve high root yield with decreased and more rational fertilizer levels.

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OCENA PRINOSA KORENA ŠEĆERNE REPE KORIŠĆENJEM AMMI ANALIZE

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Izvod

Sorte šećerne repe imaju drugačiju reakciju u raznim sredinama poput različitih lokacija, godina, tretmana sa mineralnim hranivima ili kombinaciji navedenih faktora usled prisustva interakcije genotipa i sredine. Metod glavnih efekata i višestruke interakcije (AMMI) je jedan od najčešće primenjivanih multivarijacionih postupaka za analizu i vizuelizaciju podataka o interakciji genotip × sredina. Glavni ciljevi ove studije su (i) ispitivanje primenljivosti AMMI metoda u analizi interakcije genotip × mineralna ishrana kod šećerne repe, (ii) procena interakcije genotipa i mineralne ishrane i (iii) identifikacija najstabilnije i najprinosnije sorte šećerne repe u okviru različitih tretmana mineralne ishrane. Ogled sa osam sorti šećerne repe je sproveden tokom dve uzastopne sezone na lokaciji Rimski šančevi, Srbija. Različiti nivoi azotnih, fosfornih i kalijumovih đubriva (0, 50, 100 and 150 kg ha^{-1}) i njihove kombinacije predstavljale su specifične sredine za testiranje interakcije genotipa i mineralne ishrane. Rezultati analize varijanse su pokazali da su tretmani mineralne ishrane, sorte i njihova interakcija imali značajan uticaj na prinos korena u obe sezone. Na osnovu rezultata istraživanja, za prikaz interakcije genotipa i mineralne ishrane u 2014 godini preporučuje se AMMI model koji uključuje prve dve IPCA ose, dok se za sledeću godinu predlaže model sa prve tri IPCA ose. Prema AMMI 1 i AMMI 2 biplotu, E14 i E15 mogu da se izdvoje kao tretmani mineralne ishrane na kojima genotipovi ostvaruju visoke i stabilne prinose u obe sezone. Među visoko prinosnim genotipovima, u 2014. godini G4 i G8 se izdvajaju kao najstabilniji, a u narednoj sezoni G3 je imao najmanji interakcijski skor. AMMI analiza je omogućila identifikovanje specifičnih asocijacija između sorti i različitih tretmana mineralne ishrane, što je važno zbog prilagođavanja tehnologije đubrenja kako bi svaka sorta ostvarila visok prinos korena uz niže i racionalne doze đubriva.

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