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The Influence of Solonetz Soil Limited Growth Conditions on Bread Wheat Yield

M. Dimitrijević[1], S. Petrović[1], M. Belić[1], B. Banjac[1], M. Vukosavljev[1], N. Mladenov[2] and N. Hristov[2]

1. Faculty of Agriculture, University of Novi Sad, Sq. Dositeja Obradovića 8 21000, Serbia

2. Institute of Field and Vegetable Crops, St. Maksima Gorkog 30, 21000 Novi Sad, Serbia

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Abstract: The wheat yield variation on solonetz and chernozem soil in six environments was in study in order to obtain information for use of genetic variability and for building strategy in plant breeding for less productive and marginal environments. The sample of eight bread wheat varieties: Renesansa, Pobeda, Rapsodija, Dragana, Cipovka, Evropa 90, NSR-5 and Nevesinjka, which are characterized by tolerance to stressful growing conditions and broader adaptability, was selected for the study. The trial was established by Randomized Complete Block Design in three replications at two locations in the Pannonian Plain, Northern Serbia in two vegetation periods 2004/2005 and 2008/2009. Locations differed in a soil type, primarily. The tested locality was on solonetz, while control locality was on chernozem soil type. Additive Main and Multiplicative Interaction model (AMMI) grouped varieties that exhibited strong reaction to environmental improvement (Nevesinjka and Evropa 90), varieties showing fairly small GE interaction (Renesansa, Cipovka and Pobeda) and varieties having the ability for maximum use of less productive soil in better meteorological conditions (Dragana, Rapsodija and NSR-5). Meteorological conditions significantly influenced the effect of soil quality variation on grain yield in trial. Varieties have interacted differently with the environment, depending on their genetic background.

Key words: Wheat, yield, AMMI (Additive Main and Multiplicative Interaction model), interaction, solonetz, stress.

1. Introduction

Global climate change has and will have, according to expert predictions, multiple consequences. Major changes of global and regional climate conditions, as well as major changes of distribution of plant and animal species, are to be expected [1]. A thoughtful multidisciplinary research policy is required, which will respond to changes and lead to appropriate strategies in the areas of human activity, including food production [2-4]. Intensification of agricultural production during the twentieth century caused numerous changes, affecting the degradation of the human environment, as well. The consequences of that process are complex and manifold conditions of stress in plant production-air and land drought, low temperature, degradation of soils formed by erosion, salinization and other processes. Success of food production and further directions of development in agriculture will greatly depend on the effectiveness of responses to these challenges at different levels [5-7].

More than 10% of arable land and almost half of irrigated land worldwide are affected by salinization, decreasing the potential yields for most major crops by more than 50% [8]. The increased salt content makes the soil unsuitable for the growth and development of plants. Solonetz soil that commonly occurs in dry climatic zones of steppe areas, with impeded vertical and lateral drainage, is stressing environment for cultivar production. Solonetz has unfavorable physico-chemical properties, accumulation of sodium salts in solonetz leads to higher pH value and subsurface layer that contains a significant amount of clay. About 0.5% of Europe is covered with solonetz

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Corresponding author: M. Dimitrijević, Ph.D., associate professor, research field: genetics and plant breeding. E-mail: mishad@polj.uns.ac.rs.

soil, known as alkaline, clay and sodium reach land mainly in Russia, Ukraine, Hungary, Bulgaria, Romania, and Kazakhstan [9]. There are about 80,000 ha of solonetz soil in Vojvodina (Pannonian plane at the Northern part of Serbia), as well [10]. These soils could be intensively utilized using ameliorative measures, chemical treatment, drainage, suitable crops and plant breeding for improving tolerance of crops to stress growing on saline soils [11-13].

Solonetz soil is characterized by higher pH values and high sodium content [14]. Phosphogypsum is a chemical ameliorative tool that is used to improve performance of solonetz [15, 16]. As a by-product, phosphogypsum is generated in the production of phosphate fertilizers. Acid reaction of phosphogypsum affects the neutralization of alkalinity and cation exchange reaction. Calcium carbonate in the soil under the influence of dissolved CO_2 and Na^+ ions is replaced by Ca^{2+} ions in the adsorptive complex. This leads to improved physical and chemical properties of soil. Application of phosphorus gypsum should be accompanied by an effective drainage system that improves formed Na_2SO_4 drainage in the deeper layers of soil outside the root system zone [17, 18].

Cereals as durable, highly adaptable, cultivars with low general input are suitable for growing in stress environments. Bread wheat shows much variability for salt tolerance among existing cultivars and landraces [7]. Wheat (*Triticum* sp.) is a crop that can play a role in bioremediation and increasing use value solonetz. Thready root has a beneficial effect and improves the physical properties of the soil sowing layer, and after harvest residue enhances the organic matter content. However, genotypes that are to be grown in stress environment, including soil stress conditions of solonetz, ought to have economically acceptable yield, as well. To achieve that, tolerance to salinization is required followed by good response to ameliorative measures. Breeding of crops for increased tolerance to salinization, requires gene donor genotypes that show tolerance to salt stress. Genotype × environment interaction (G × E) plays an important role in the evaluation of genotype behavior in different environments, as well as, salinity stress and helps in donor genotypes identification [19]. The search for wheat genotypes tolerant to salinity stress, as well as other stress conditions could result in selection of more tolerant genotypes, convenient for bioremediation and broadening of wheat production [11, 20].

The aim of this paper is to examine the variation of wheat grain yield and to study the nature and quantity of G × E interaction effect on the solonetz soil type using AMMI analysis in order to assess the potentially useful salinity stress tolerance genetic variability capable to produce economically competitive yield in solonetz soil stress growing conditions, as well as, to set recommendations for developing salt tolerance breeding program.

2. Materials and Methods

2.1 Plant Material

The experiment included eight varieties of *Triticum aestivum* ssp. *vulgare* L., of the Institute of Field and Vegetable Crops in Novi Sad: Renesansa, Pobeda, Rapsodija, Dragana, Cipovka, Evropa 90, NSR-5 (winter types) and Nevesinjka (facultative). All the varieties are resistant to low temperatures, while the varieties Renesansa and Rapsodija are particularly resistant to drought conditions. Varieties chosen for the experiment are grown in Serbia and neighboring countries, while variety Rapsodija is grown beyond the region, in the EU and Ukraine. Varieties Renesansa, Rapsodija, Pobeda, NSR-5 and Evropa 90 are selected as particularly adaptable genotypes. Varieties Nevesinjka and NSR-5 can grow on poor soil fertility.

2.2 Locations and Soil Conditions

Sites of the experiment are in Pannonian Plain-Banat region—Kumane village (latitude: 45.521994° N, longitude: 20.194919° E) with solonetz soil type (pH = 9.86) and Test field of the Institute of Field and Vegetable Crops—near Novi Sad (latitude: 45.324936°

N, longitude: 19.842883° E) on the chernozem soil type (pH = 6.86). The solonetz soil type is characterized by unfavorable chemical and physical properties, caused by the high content of clay and the presence of adsorbed Na in the B_t horizon. Sodium causes peptization of colloids and highly alkaline reaction [21]. The trial was set on non-ameliorated solonetz (control variation), as well as, on solonetz ameliorated by 25 t/ha and 50 t/ha of phosphogypsum, and drained by 10 cm spaced drains. Amelioration led to the increment in humus content in deeper layers and changes of soil chemical reactions (reduction of alkalinity) due sodium rinsing and the replacement of sodium with calcium. Chernozem (black soil) is classified as automorphic soil, with favorable air and thermal regime. Texture is predominantly loamy and crumbly structure with stable aggregates. Chemical properties were favorable: the content of humus and plant nutrients is high, with a neutral to slightly alkaline reaction [21].

2.3 Vegetation Periods

The results of experiments in two vegetation seasons 2004/2005 and 2008/2009 are given. Because the period from October 2004 to September 2005 was characterized by unusually large amounts of precipitation for the climate of Serbia, the crops were perfectly secured humidity, almost all the time. During that vegetation period no large and long-term variation in air temperature values from multi-year average was observed. Vegetation period 2008/2009 was characterized by deficit of rainfall and the occurrence of drought in April that extended to May. In the third decade of June, there was an abundance of rainfall, which significantly disrupted the harvest in the first part of July.

2.4 The Experiment Setting

The experiment was set up by Randomized Complete Block Design in three replications. Each variety was sawn in eight 12.5 cm spaced rows, 155 m of length. Fifty kilograms of NPK 15:15:15 fertilizer was applied with sowing. Analyzed grain yield was measured in representative samples of 4 × 5 m^2 (solonetz) and 6 m^2 (chernozem) and calculated per hectare. The genotype by environment interaction was investigated using the AMMI model (Additive Main Effects and Multiplicative Interaction) [22]. Data processing was done in GenStat 8th Edition (trial ver.) VSN International Ltd (www. vsn-intl.com).

3. Results and Discussion

3.1 Phenotypic Variability of Grain Yield Expressed through Mean Values

Significant variation was manifested in the experiment due to heterogeneous weather and soil conditions. The effect of 25 t/ha phosphogypsum amelioration was visible in both vegetative periods, particularly in less advantageous 2008/2009 vegetation period. The effect of weather conditions was a significant source of yield variation. The grain yield on chernozem in 2008/2009 was only about 1 t/ha on average higher than the yield on the 25 t/ha phosphogypsum ameliorated solonetz in more favorable 2004/2005. Different individual reaction of varieties in the experiment was notable, not only because of ameliorative measures, but also because of environmental conditions. Two reactions of plants to environmental conditions changing are desirable, from the standpoint of targeted plant breeding. The first preferred reaction is small genotype by environment interaction (GEI), with higher mean values of the observed properties, in this case-grain yield. Another preferred reaction is the trait variability that indicates a good varietal reaction to ameliorative measures, which provides an increase of observed properties mean values, in this case the grain yield in the improved conditions by amelioration. The typical representative of the first preferred reaction appeared to be the variety Renesansa having small crossover interaction and the average yield ($\overline{x} = 4.47$ t/ha) slightly above overall trial mean ($\overline{x} = 4.30$ t/ha). Variety Pobeda is an example of good genotype reaction to ameliorative measures, showing steady yield average increment that followed soil conditions improvement regardless to year as a variation source. Favorable year conditions at the solonetz were particularly well used by variety Evropa 90. Variety Evropa 90 gave the best yield ($\overline{x} = 7.15$ t/ha) in more favorable conditions of year (2004/2005) at the solonetz soil with ameliorative measures at the level of 25 t/ha of phosphogypsum applied. That grain yield was at the same level as the highest grain yield average of variety Dragana ($\overline{x} = 7.11$ t/ha) in more favorable soil conditions (chernozem), but in less favorable year (2008/2009). Generally, variety Evropa 90 responded well in both vegetative periods to amelioration with phosphogypsum in amount of 25 t/ha, but the yield average level greatly depended on year conditions. This indicates the existence of a useful genetic variation that could be utilized in production on solonetz with adequate ameliorative measures, as well as, in breeding programs targeted for the examined stress environment. The only facultative variety in trial Nevesinjka performed well ($\overline{x} = 6.38$ t/ha) on control variant, solonetz with no drainage and phosphogypsum applied, in more favorable vegetation period of 2004/05. Variety Nevesinjka was bred for growing in poor soil fertility environment, but has never been tried in such extreme stress soil environment like alkaline solonetz soil.

Variation expressed by variance (σ^2) per treatment showed that less favorable growth conditions reduce the differences between genotypes, which is in accordance with previous observations [23]. Variance expressed in the treatment of S05-50, indicating that the reported low yield average, appeared in a possible consequence of water laying in micro-depressions in this part of the field and increased rainfall in 2005 (Table 1).

3.2 Trial Variation Partitioned by AMMI Analysis of Variance

Analysis of variance (ANOVA) indicates that the sources of variation in the experiment presented a significant variation of genotypes and highly significant variation due to the environment. Statistically insignificant GEI mean square expressed the antagonism of the statistical models and the nature of sources of variation. ANOVA model is additive and effectively describes the main (additive) effects, while the interaction (residual from the additive model) is non additive. Consequently, the statistically significant and important agronomical multiplicative (non-additive) variation, expressed through mean square values, frequently appears non-significant due to high degree of freedom. Hence, other techniques, such as principal component analysis (PCA), are required to identify multiplicative components of trial variation, like G × E interaction [22]. As expected, the largest share the total trial variation sum of squares had environmental variation (37%), as well as, error (29.6%), not only in a consequence of the experiment stressful conditions, but also because of vegetative period differences. GEI has participated with the 17.3% in the total variation of the experiment. An agronomically explainable significant PCA axis, that makes about 60% of the GEI variation sum of squares, was denoted. Highly significant differences between blocks indicate the complex soil conditions in experiments on solonetz and further explain the heterogeneous results in the treatment marked S05-50 (Table 2). Heterogeneity of soil configuration in the treatment abbreviated as S05-50 was indeed the reason for the exclusion of this treatment in the experiment of the 2008/2009.

3.3 Types of Trial Variation Analyzed by AMMI Model Biplot

The Additive Main-effect and Multiplicative Interaction (AMMI) model is a combined statistical approach joining ANOVA (for additive component) and PCA (for multiplicative component) for analyzing two-way (genotype by environment) data structure [22]. Biplot analysis closely registers variation types in the trial and in this study belong to AMMI 1 type [24]. In

Table 1 Yield mean values (t/ha) of 8 wheat varieties in 6 agro-ecological environments. Genotypic and environmental values, the variance (σ^2), and the first axis of variation (IPCA 1) are given.

Genotype	Environments						$\overline{X}_G$	IPCA$_G$1
	Solonetz					Chernozem		
	2004/2005			2008/2009		2008/2009		
	Control	25 t/ha Phospho gypsum	50 t/ha Phospho gypsum	Control	25 t/ha Phospho gypsum			
	S05-C	S05-25	S05-50	S09-C	S09-25	C09*		
Renesansa	4.80	4.37	4.17	3.00	3.60	6.89	4.47	0.141
Pobeda	4.20	4.83	5.33	2.80	3.20	6.53	4.45	-0.246
Rapsodija	3.97	5.73	2.77	3.00	3.20	6.86	4.25	0.679
Dragana	4.98	4.20	1.45	2.30	3.20	7.11	3.87	0.930
Cipovka	4.30	5.90	4.47	3.10	2.95	5.58	4.38	0.125
Nevesinjka	6.38	4.40	6.52	2.70	2.05	4.86	4.49	-1.539
NSR-5	3.32	4.80	2.55	1.40	3.90	5.83	3.63	0.643
Evropa 90	6.32	7.15	3.20	1.50	4.10	6.64	4.82	-0.733
$\overline{X}_E$	4.78	5.17	3.81	2.48	3.28	6.29	4.30	
σ^2	5.350	3.671	6.884	0.422	0.368	1.043		
IPCA$_E$1	-0.610	0.223	-1.668	0.404	0.738	0.912		

*Abbrevation for agroecological environment; LSD$_{0.05}$=1.186; LSD$_{0.01}$=1.577.

Table 2 Analysis of variance of yield (t/ha) of 8 wheat varieties in 6 agroecological environments.

Sources of variation	Degree of freedom	Sum of squares	Mean square	F values	F probability
Total	143	647.7	4.530	-	-
Treatments	47	386.5	8.224	3.60	0.00000
Genotypes	7	34.5	4.927	2.16	0.04644
Environment	5	239.8	47.951	8.32	0.00000
Blocks	12	69.2	5.766	2.52	0.00693
GE interaction	35	112.3	3.208	1.40	0.10563
IPCA	11	67.5	6.135	2.68	0.00527
Residue	24	44.8	1.866	0.82	0.70671
Error	84	192.0	2.286	-	-

AMMI 1 biplot type, abscissa contains genotypic and environmental means as main effects, and their IPCA scores are given on the ordinate, as multiplicative effects. The array of genotypes and environments in the biplot reveal the nature of expressed variability and the contribution to GEI. Small GEI leads to good genotype stability over environments and could be detected by scores close to zero. Genotypes having the same IPCA 1 sign as environments express good specific adaptability to those environments.

3.3.1 Environments

Array of examined environments follow the results of AMMI ANOVA showing that the first grouping criterion was meteorological conditions of years in study. Grouping in two groups is clearly present. Environments S09-C and S09-25 were placed in less productive part of the biplot, to the left of overall average vertical line, exhibited more pronounced additive over multiplicative component of variation. That confirms the standpoint that less productive environments enhance error and diminish the differences between genotypes [25]. Ameliorative measures at S09-25 had the certain positive impact, but still below trial grain yield average. That is the first sign that variation of the weather conditions significantly influences the effect of amelioration. More favorable 2004/2005 vegetation period, enhanced yield averages of environments S05-C, S05-25 and

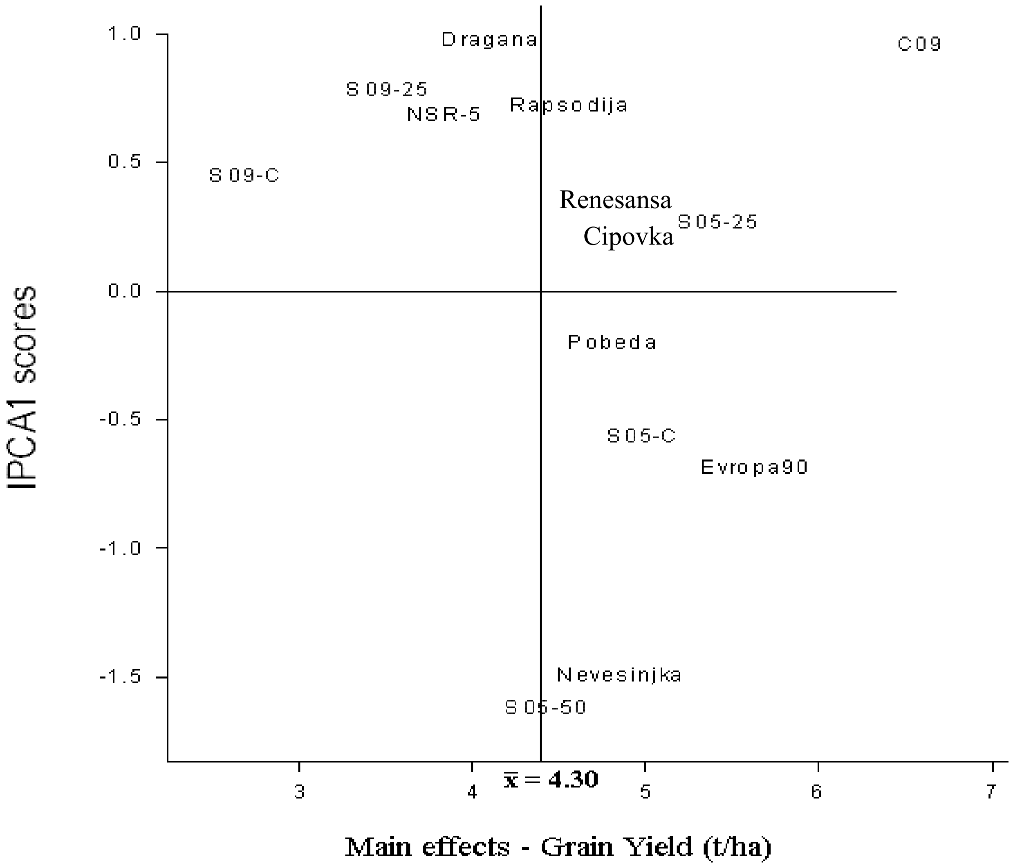

Fig. 1 Biplot of yield (t/ha) of 8 wheat varieties in 6 agroecological environments.

S05-50. Better meteorological conditions in that period had good impact on ameliorative measures effect (S05-25, 25 t/ha phosphogypsum applied). According to array, in 2004/2005 multiplicative components of total variation appeared to be predominant than additive, because more favorable environments increased differences in varietal reactions to environmental variation. Control productive variant of C09 had the highest grain yield average, as expected, and quite high positive value of IPCA 1 showing diversity in varietal performance.

Analyzing jointly Table1, and Fig. 1, it could be observed that the main cause of that diversity was facultative variety Nevesinjka. The most stable environment was S05-25, having the smallest IPCA 1 value at grain yield average higher than grand mean. Finally, favorable environments for particular varieties could be identified by high average and large IPCA score with the same sign as of genotype IPCA score [26].

3.3.2 Genotypes

Varieties in trial were the sample of the same breeding program of semi-dwarf high yielding varieties, selected under similar general selection criterions. Consequently, the additive component of variance appeared to be considerably small, grouping all the genotypes in a small portion of abscise and around the great mean. However, multiplicative component of variation was highly expressed exhibiting differences in the interaction effects. Varieties Renesansa, Cipovka and Pobeda expressed the most stable reaction in variable conditions of the experiment, achieving the mean yield slightly above the average of the experiment. Variety Europe 90 and in some extent variety Nevesinjka showed the best utilization of unfavorable soil, but in favorable weather conditions. Varieties Rapsodija and NSR-5 reacted best to ameliorative measure in less favorable 2008/2009. Variety Dragana reacted intensively to environmental improvements, especially to the best productivity of chernozem (Fig. 1).

4. Conclusions

Treatments were grouped primarily according to the meteorological conditions, and these conditions significantly influenced the effect of soil quality variation on grain yield of varieties in trial. Varieties have interacted differently with the environment, depending on their genetic background. Varieties of a stable response were clearly separated from the varieties that had a pronounced genotype by environment interaction increasing the yield in response to any improvement of growth conditions, as well as those that used most effectively more stressing environmental conditions. Varieties Pobeda and Renesansa gave small GEI, hence the satisfactory stable reaction in the variable environmental trial conditions. Variety Evropa 90 expressed good tolerance to stressful growing solonetz conditions, as well as, good reaction to ameliorative measures. Variety Rapsodija reacted well to amelioration in less favorable conditions of the year. These results of variable varietal behavior in respect to grain yield are necessary in wheat breeding program targeted for stress growing conditions and in wide production. Varieties Pobeda and Renesansa are included in a small wheat breeding program targeted to stressful alkaline soil conditions that have been recently established. The rest of examined genetic variability is going to be included in program, or studied some more. Considering immediate usability in wide production on ameliorated solonetz, variety Evropa 90 could be convenient to put to use. According to results, though examined wheat varieties came from intensive varieties breeding program, there is usable genetic variability in the existing gene pool for utilizing in marginal environments.

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