RESPONSE OF SOME WINTER WHEAT GENOTYPES TO SOIL ACIDITY AND HIGH MOBILE ALUMINIUM CONTENT

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Abstract: *The increased soil acidity is usually solved by applying liming as pedomeliorative technique that leads to its neutralisation. However, low pH values and increased content of mobile aluminum in deeper soil subsurface layers can be solved by selection, breeding and development of wheat genotypes with higher tolerance to these stress factors. The aim of this study was to test genetically divergent winter wheat genotypes for their response to low soil pH and high mobile Al levels, applying biotest method. The experiment was conducted in vegetation pots on very acid Al-toxic pseudogley soil ($pH_{(KCl)}$ □ 4.5). The Al content of the soil was above 10 mg 100^{-1} g soil. The experiment included the following mineral nutrition treatments: C – control – neutral reaction soil (Humogley) + 30 µg g^{-1} NPK, H- very acid soil + 30 µg g^{-1} NPK, HCa- very acid soil + 30 µg g^{-1}NPK + 200 µg g^{-1} $CaCO_3$, HP_1- very acid soil + 30 µg g^{-1} NPK + 25 µg g^{-1} superphosphate. The formulation of the NPK fertilizer was as follows: 15:15:15; CAN (27% N) and superphosphate (17% P_2O_5). $CaCO_3$ as finely ground lime ("Njival Ca") was added to the soil before sowing, whereas several applications of the fertilizer solution were used during the first part of the growing season (spring period). The experiment involved testing of 50 highly divergent winter wheat cultivars of different geographic origin. This paper presents yield parameters (grain number per spike, grain weight per spike and 1,000-grain weight) of 15 winter wheat genotypes (Sana; NS Rana5; Odeskaya; Rubens: Kalyanscna; Renesansa; Bezostaya I; Sonja; Zorrin; Saroz 95; Nevesinjka; Rapsodija; MV-Palma; Ornil; Roane). The winter wheat genotypes tested in this study showed very significant differences in tolerance to extremely low soil pH and high mobile aluminum levels in the soil. On very acid Al-toxic pseudogley soil, the genotypes Ornil, Roane, Rapsodija and Nevesinjka exhibited the highest degree of tolerance. The test genotypes, particularly Ornil, Roane and NS Rana 5, showed a very good response to the combined use of NPK, lime fertilizer and increased rates of phosphorus fertilizer.*

Key words: *Acidity, aluminum, genotype, soil, wheat*

INTRODUCTION

Low soil pH and high Al concentrations directly and indirectly inhibit various life processes in plants and induce numerous anatomical and morphological changes in winter wheat plants (ARSENIJEVIĆ-MAKSIMOVIĆ et al., 2001). Nevertheless, low Al concentrations can be useful for plant development. High Al levels in the soil solution frequently disturb the state of homeostasis in plants. However, plants (including winter wheat) tend to alleviate or climate toxic effects of heavy metals and Al, but the ability of different genotypes and ecotypes to do so is not identical. Mineral stress, induced by an excess of an element, especially Al, is considered to be the major limiting factor in biomass production (compared to other environmental factors). In view of the above and considering the increasing intensity of environmental pollution and the large agricultural land area under acidic soils, great attention has been paid recently to studies on the effect of higher concentrations of heavy metals and Al on plants. Research has been conducted not only in terms of the impact of these elements on metabolism and, hence, organic matter production, but also in an attempt to develop genotypes tolerant of excess amounts.

Genetic differences in plant tolerance to excess concentrations of aluminium are well-known and have been recently investigated in individual genotypes of winter wheat (MOSSOR-PIETRASZEWSKA, 2001, ROUT et al., 2001; GARVIN and CARVER, 2003). Knowledge of the genetic and physiological bases of plant tolerance to high concentrations of Al is of paramount importance in breeding programmes. Differences in tolerance to Al between cultivars, i.e. genotypes within a species, are frequently larger than those between species. As wheat tolerance to Al is generally based on the existence of genetic divergence, success in breeding tolerant cultivars is the result of genetic variability in the initial material. Natural populations were mainly the first sources of Al tolerance, as well as the initial material which was used to develop a selection tolerant of Al by crossing and selection. For example, Brazilian cultivars grown on acid soils acquired superior tolerance to Al as compared with those from other parts of the world. Winter wheat cultivars which show high tolerance to Al have been selected. Atlas 66 and Seneca are recognized as typical representatives of wheat cultivars tolerant of Al (KERRIDGE et al., 1971; BONA et al., 1993; RENGEL and ZHANG, 2003; RAMAN et al., 2010).

The objective of this study was to test genetically divergent winter wheat genotypes for their response to low soil pH and high mobile Al levels and single out genotypes tolerant of these environmental stress factors. Moreover, an important aspect of the study was to evaluate the efficiency of NPK, lime and increased rates of phosphorus fertilizers in increasing the productivity of the test genotypes grown on extremely acid soils.

MATERIAL AND METHODS

The present study was conducted in vegetation pots on very acid Al-toxic pseudogley soil ($pH_{(KCl)}$ 4.5). The Al content of the soil was above 10 mg 100^{-1} g soil. The experiment included the following mineral nutrition treatments: C – control – neutral reaction soil (Humogley) + 30 µg g^{-1} NPK, H- very acid soil + 30 µg g^{-1} NPK, HCa- very acid soil + 30 µg g^{-1}NPK + 200 µg g^{-1} $CaCO_3$, HP_1- very acid soil + 30 µg g^{-1} NPK + 25 µg g^{-1} superphosphate. The formulation of the NPK fertilizer was as follows: 15:15:15; CAN (27% N) and superphosphate (17% P_2O_5). $CaCO_3$ as finely ground lime ("Njival Ca") was added to the soil before sowing, whereas several applications of the fertilizer solution were used during the first part of the growing season (spring period).

The experiment involved testing of 50 highly divergent winter wheat cultivars of different geographic origin. This paper presents yield parameters (grain number per spike, grain weight per spike and 1,000-grain weight) of 15 winter wheat genotypes (Sana-1; NS Rana5-2; Odeskaya-3; Rubens-4: Kalyanscna-5; Renesansa-6; Bezostaya I-7; Sonja-8; Zorrin-9; Saroz 95-10; Nevesinjka-11; Rapsodija-12; MV-Palma-13; Ornil-14; Roane-15).

The experiment was conducted during the 2009/2010 growing season in three replications. Wheat seeds were sown in pots in November. During the winter months, the plants were kept under greenhouse conditions without heating. Until harvest, they were kept in a wire cage outside the greenhouse. The plants were harvested at full maturity, the spikes were separated from the straw, the grains were harvested and counted, and grain weight per spike was measured. The results are presented as average values and subjected to mathematical and statistical methods of the analysis of variance (MEAD, 1996).

RESULTS AND DISCUSSIONS

The soil used in the study has unfavourable physical and chemical properties, an extremely acid reaction ($pH_{(KCl)}$ 3.80), a low humus content (2.23%), low levels of readily available phosphorus (6.7 mg 100 g^{-1}) and potassium (9.8 mg 100 g^{-1}) and a relatively satisfactory content of total nitrogen (0.130 %), as shown in Table 1. The level of mobile aluminium is high and the soil exhibits poor microbial activity. This induces low mineralization of organic nitrogen and, hence, a markedly high effect of nitrogen and phosphorus fertilizers on this soil, particularly when fertilizing small grains.

Table 1.

Chemical properties of pseudogley soil

Depth	pH		Humus	N	P_2O_5	K_2O	Al
	H_2O	KCl	(%)	(%)	mg 100 g^{-1} soil		
0-20 cm	5.12	3.80	2.23	0.130	6.7	9.8	12.5

Winter wheat genotypes were evaluated for tolerance i.e. susceptibility using important indicators of their productivity, including grain number per spike, grain weight per spike and 1,000-grain weight. The test winter wheat cultivars highly differed in their response to low soil pH and high mobile Al content of the soil.

Grain number per spike is an important yield component in winter wheat. Significant differences were observed in grain number per spike, as dependent upon mineral nutrition and genotype (table 2). On acid soil (H), grain number per spike was highest in cvs. Ornil, Roane and Nevesinjka, and lowest in cvs. Sana and Kalyanscna.

The combined use of NPK fertilizer, lime fertilizer and increased phosphorus rates led to a significant increase in grain number in all winter wheat genotypes tested (table 2), even in genotypes that gave a very low number of grains per spike (Kalyanscna and Sana) on extremely acid soil (H). All mineral nutrition treatments resulted in a significant increase in grain number per spike in the test genotypes. The highest statistically justified increase in grain number per spike was obtained in cv. Ornil (28.2), as compared to the other winter wheat cultivars tested. The positive effect of mineral nutrition on grain number per spike was also previously reported (FISCHER, 1993; SAVIĆ, 2009).

Table 2.

Grain number per spike

Cultivars	Fertilization treatments				*Average*
	C	H	HCa	HP_1	
Sana	21.9	9.8	21.8	22.4	19.0
NS Rana 5	22.0	10.5	24.6	24.8	20.5
Odeskaya	19,8	13.4	23.2	23.7	20.0
Rubens	20.2	12.2	24.1	24.6	20.3
Kalyanscna	16.4	6.9	20.6	20.4	16.1
Renesansa	21.4	14.8	23.4	23.6	20.8
Bezostaya I	22.3	14.6	24.8	25.8	21.9
Sonja	21.8	14.6	24.0	24.6	21.2
Zorrin	20.6	14.9	21.2	21.6	19.6
Saroz 95	21.4	14.9	23.0	24.1	20.8
Nevesinjka	23.2	20.5	24.2	25.6	23.4
Rapsodija	22.3	19.7	24.8	25.5	23.1
MV- Palma	23.4	19.8	25.0	24.4	23.1
Ornil	25.6	22.3	28.2	28.0	26.0
Roane	24.4	21.6	26.3	26.9	24.8
Average	21.8	15.4	23.9	24.4	21.4
LSD	A		B	AB	
0.05	0.346		0.178	0.692	
0.01	0.457		0.236	0.914	

Grain weight per spike can be considered a reliable indicator of crop yield and yield quality. Table 3 shows changes in grain weight per spike in wheat genotypes depending on soil acidity and mineral nutrition treatment. On extremely acid soil (H), the highest grain weight per spike was obtained in cvs. Roane, Rapsodija and Nevesinjka (0.60-0.66 g). The results obtained suggest an increased degree of tolerance of these winter wheat genotypes to both low soil pH and increased mobile aluminium levels. The present results comply with those reported by other authors (KERRIDGE et al., 1971; JELIĆ et al., 2000; BAKER et al., 2000; RAMAN et al., 2010). The other cultivars produced considerably lower values for grain weight per spike, most particularly cvs. Kalyascna, Sana and Zorrin (0.25-0.39 g).

Table 3.

Grain weight per spike (g)

Cultivars	*Fertilization treatment*				*Average*
	C	H	HCa	HP_1	
Sana	0.83	0.32	0.87	1.01	0.76
NS Rana 5	0.88	0.54	0.98	0.99	0.85
Odeskaya	0.79	0.45	0.93	0.97	0.78
Rubens	0.80	0.43	0.96	0.86	0.76
Kalyanscna	0.66	0.25	0.82	0.86	0.65
Renesansa	0.86	0.44	0.94	1.01	0.81
Bezostaya I	0.89	0.55	0.87	1.08	0.85
Sonja	0.87	0.52	0.86	0.98	0.81
Zorrin	0.82	0.39	0.85	0.88	0.73
Saroz 95	0.86	0.49	0.87	0.96	0.79
Nevesinjka	0.93	0.60	0.92	1.00	0.86
Rapsodija	0.89	0.61	0.94	1.02	0.86
MV- Palma	0.80	0.48	0.95	0.95	0.79
Ornil	0.90	0.56	1.07	1.09	0.90
Roane	0.83	0.66	0.99	1.02	0.87
Average	0.84	0.49	0.92	0.98	0.80
LSD	A		B	AB	
0.05	0.008		0.004	0.016	
0.01	0.011		0.005	0.021	

Different mineral fertilization treatments had an important effect on grain weight per spike in test genotypes (Table 3). The combined use of NPK, lime fertilizer and increased P fertilization rates resulted in a significant increase in grain weight per spike in all cultivars, ranging up to 100%. The highest increase in grain weight per spike in the combined treatment with NPK and lime fertilizer was observed in cvs. Ornil, Roane and NS Rana 5. Moreover, NPK fertilization coupled with the use of increased phosphorus rates produced a highly positive effect on grain weight per spike in a number of cultivars (Ornil, Bezostaya I, Rapsodija, Roane, Renesansa, Sana).

Thousand-grain weight is an important yield component, mostly genetically defined but in some cases depending on the use of cultural practices, fertilization in particular (table 3). On extremely acid soil (H), the winter wheat genotypes had low values of 1,000-grain weight. Grain weight was higher in genotypes Odeskaya, Sonja and Kalyanscna, being likely due to the formation of a considerably lower number of grains per spike in these genotypes. Therefore, this yield component was not found to be a reliable criterion for the selection of winter wheat genotypes tolerant of low soil pH and high mobile Al levels.

Mineral nutrition, particularly the combined use of NPK and lime fertilizer induced an increase in 1,000-grain weight by 33% on average as compared to the treatment on acid soil (H). Individually, the highest statistically justifiable increase in grain weight as compared to the other genotypes tested was obtained in cv. Sonja (46.2 g). As previously reported (NOAMAN and TEYLOR, 1990; MILOŠEV, 2002), 1,000-grain weight has little effect on yield, which is not in agreement with the results of the present study. However, results of other authors similar to the present findings suggest that mineral fertilization, particularly with nitrogen, under certain agroenvironmental conditions, leads to up to a 30% increase in 1,000-grain weight (KOSTIĆ, 1988; JELIĆ and KOSTIĆ, 1992).

Table 3.

1,000-grain weight (g)

Cultivars	*Fertilization treatment*				*Average*
	K	H	HCa	HP_1	
Sana	42.2	33.0	42.4	42.7	40.1
NS Rana 5	42.3	35.0	43.4	43.0	40.9
Odeskaya	44.8	37.0	45.8	44.4	43.0
Rubens	42.2	33.0	44.3	43.9	40.8
Kalyanscna	45.4	35.5	45.5	44.8	42.8
Renesansa	40.2	30.0	42.8	43.6	39.1
Bezostaya I	34.2	25.5	35.5	34.8	32.5
Sonja	45.7	36.0	46.2	45.8	43.4
Zorrin	42.4	32.0	43.6	43.0	40.2
Saroz 95	42.8	32.0	43.5	43.0	40.3
Nevesinjka	39.8	28.5	41.4	39.0	37.2
Rapsodija	39.9	33.0	42.0	41.8	39.2
MV- Palma	32.4	24.0	34.6	35.5	31.6
Ornil	34.0	25.0	35.3	34.7	32.2
Roane	39.2	31.0	40.5	41.2	38.0
Average	40.5	31.4	41.8	41.4	38.8
LSD	A		B	AB	
0.05	0.834		0.431	1.669	
0.01	1.103		0.570	2.206	

CONCLUSION

The winter wheat genotypes tested in this study showed very significant differences in tolerance to extremely low soil pH and high mobile aluminum levels in the soil.

On very acid Al-toxic pseudogley soil, the genotypes Ornil, Roane, Rapsodija and Nevesinjka exhibited the highest degree of tolerance.

The test genotypes, particularly Ornil, Roane and NS Rana 5, showed a very good response to the combined use of NPK, lime fertilizer and increased rates of phosphorus fertilizer.

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