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EFFECT OF LONG-TERM FERTILIZATION AND SOIL AMENDMENTS ON YIELD, GRAIN QUALITY AND NUTRITION OPTIMIZATION IN WINTER WHEAT ON AN ACIDIC PSEUDOGLEY

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ABSTRACT

About 60% of wheat fields in Central Serbia have a soil pH below 5.5. Therefore, increasing and maintaining crop yields require periodic use of soil amendment practices (liming, phosphorus treatment and humification), along with fertilization. This study was conducted over a period of five years (2007-2011) on a pseudogley soil to evaluate the effect of different fertilization methods and liming on grain yield, yield components and grain quality in three winter wheat (*Triticum aestivum* L.) cultivars. Results showed a significant effect of weather conditions on grain yield and quality in winter wheat. The combined use of NPK fertilizers (120 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}), lime (5 t ha^{-1} $CaCO_3$) and manure (20 t ha^{-1}) led to a drastic reduction in Al levels in the grain (by over 10 mg kg^{-1}), and positively affected grain yield and yield components in winter wheat. Less favorable agro-meteorological conditions and combined organic and mineral fertilization positively affected grain protein concentration in all winter wheat cultivars analyzed.

Key words: acid soil, Al, fertilization, yield, liming, protein, wheat.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most widely grown crop in the world. Due to its unique protein characteristics, it provides an important source of food and energy in Serbia. Wheat is the second ranking cereal crop in Serbia after maize in terms of harvested area and production. Most winter wheat (*Triticum aestivum* L.) crops grown in Central Serbia are intended for human consumption, whereas one part (30%) is used as a livestock feed.

Wheat productivity and grain quality in Central Serbia are governed by a range of factors, notably climate, soil, genetics and crop nutrition. Wheat productivity is the highest in northern parts of Serbia (Vojvodina Province) and is sustained by the use of good quality soils and cultivars with a high yield potential that require, inter alia, an intensive use of inputs such as fertilizers. However, wheat yields in Central Serbia are low, being the result of environmental conditions (acidic soils and a high mobile Al content) and poor technology, particularly fertilization. Soil acidity in wheat fields in Central Serbia has become a severe problem that leads to a significant decline in grain yield and quality of wheat (Jelic et al., 2010). Recent studies have shown that about 60% of arable land has a soil pH below 5.5 (Cakmak et al., 2009). Pseudogleys cover significant areas of Serbia, accounting for about 285,000 ha or 78.73% of the total land area in Western Serbia (Tanasijevic et al., 1966). Pseudogleys are rather poor in alkalis, being medium to strongly acid in reaction. They have a highly unfavorable structure, and a low content of organic matter. The acid reaction of pseudogleys, their low humus content, and low levels of available phosphorus and potassium are limiting factors for high crop yields (Dugalic et al., 2005). Regardless of their low fertility, these soils are intensively used for plant production, which leads to a drastic decrease in organic matter and biogenic nutrients in the long run. Apart from acidity, these soils are also often characterized by high contents of toxic forms of Al, Fe and Mn, and by deficits caused by leaching or decreased

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availability of P, Ca, Mg and some other micronutrients, especially Mo, Zn and B (Sumner, 2004; Welcker et al., 2005). In acidic soils, plant growth is often limited by Al toxicity, resulting in a marked reduction in shoot and particularly roots growth, which prevents the plants from using available soil phosphorus (P) effectively.

The use of liming materials to neutralize soil acidity is the principal soil amendment practice intended to mitigate and prevent further acidification of acid soils (Prado et al., 2007; Alvarez et al., 2009). Positive effects of these amendments in reducing Al toxicity in acidic soils when growing different crops were reported by many authors (Alvarez et al., 2009; Meriño-Gergichevich et al., 2010). Liming is currently used to reduce soil acidity because it increases pH and base saturation, contributing to increased nutrient availability and Al precipitation and representing a source of Ca and Mg as well. However, lime solubility in water is low, which restricts its effects mostly to the soil layers of lime application (Fageria and Baligar, 2008).

The objective of the present study was to evaluate the effect of different fertilization and liming treatments on grain yield, yield components and grain quality in winter wheat on extremely acid soil Pseudogley type. The aim of this study was, also, to achieve profitability of winter wheat production in such soil and climatic conditions at central part of Serbia, by nutrition optimization.

MATERIAL AND METHODS

Study area and soil analysis

This study was conducted over a period of five years (2007, 2008, 2009, 2010 and 2011) in the Kraljevo region, Western Serbia **(**44° 34′ N, 19° 46′ E), on a pseudogley soil, at Kraljevo location, 215 m a. s. l., in a temperate continental climate having an average annual temperature of 8.1°C typical of western regions in Serbia and a rainfall amount of about 540 mm. The study was carried out on stationary field at the experimental field of the Dr. Djordje Radic Secondary School of Agriculture and Chemistry in Kraljevo.

The chemical characteristics of the pseudogley are highly unfavorable (Table 1). Namely, the soil exhibited high acidity, with relatively low active acidity (pH in H_2O 5.24) in the arable horizon (0-20 cm) and a considerable decrease in acidity (pH in H_2O 6.04) observed in the deepest layers. Exchangeable acidity (pH in KCl) throughout the soil profile depth ranged from 4.48 to 4.80. The humus content of the topsoil (0-20 cm) was low (2.18%) and considerably decreased with increasing depth (Table 1).

Table 1. Agrochemical properties of pseudogley

Depth (cm)	pH		Humus (%)	N (%)	P_2O_5	K_2O	Ca	Mg	Al
	H_2O	KCl			(mg 100 g^{-1})				
0-20	5.24	4.48	2.18	0.14	16.71	8.08	106	44	12.4
20-40	5.55	4.58	1.84	0.13	16.69	9.79	105	45	10.6
40-60	5.46	4.42	0.66	0.09	26.24	20.02	165	40	4.3
60-80	5.64	4.52	0.71	0.07	26.29	21.31	248	31	0.1
80-100	6.04	4.80	0.63	0.02	25.62	22.02	183	24	-

Total nitrogen level in the arable soil layer was 0.14% on average and significantly decreased with increasing depth (0.02%). A low supply of readily available phosphorus was found in this soil i.e. 7.0-8.0 mg 100 g^{-1} soil in the 0-40 cm soil layer. The studied soil had a good supply of readily available potassium, thus being classified among soils with a medium supply (13.8 mg 100 g^{-1}).

The content of available Ca (106-248 mg 100 g^{-1}) and Mg (24-44 mg 100 g^{-1}) at soil is relatively low and vary going to depth of studied profile.

Experimental design

A randomized complete block design was used, with three replications in a split-plot arrangement. Plot size was 50 m^2 (5 m x 10 m). The trial included an untreated control

(F0) and thirteen different fertilization treatments, five of which were analyzed: F1 (100 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}); F2 (100 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}+ 2.5 t $CaCO_3$ ha^{-1}); F3 (100 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}+5.0 t $CaCO_3$ ha^{-1}); F4 (120 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}+ 2.5 t $CaCO_3$ ha^{-1}+ 20 t manure ha^{-1}) and F5 (120 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}+ 5.0 t $CaCO_3$ ha^{-1}+ 20 t manure ha^{-1}). The fertilizers applied were complex NPK fertilizers (8:24:16), superphosphate (17% P_2O_5), ammonium nitrate (AN=34.4% N), manure and powdered limestone. Lime fertilizer ("Njival Ca") is finely ground lime rock (grit 0.0-0.1 mm). Chemically, it is pure carbonate with 98.5% $CaCO_3$ and 1% $MgCO_3$ i. e. 55.3% recalculated CaO and 0.5% recalculated MgO. The presence of heavy metals and other elements is negligible while content of Fe, Al, Na and Mn oxide is very low (0.005-0.06%). Ameliorating fertilization (powdered limestone and manure) was conducted at intervals every fifth growing season (2006-07, 2010-11), at the beginning of October in parallel with deep primary tillage. Fertilization was regular and followed a long-time scheme. Total amounts of phosphorus and potassium fertilizers and half the nitrogen rate are regularly applied during pre-sowing cultivation of soil. The remaining amounts of nitrogen fertilizers were applied in a single treatment at the tillering stage of winter wheat.

Three winter wheat (*Triticum aestivum* L.) cultivars (Pobeda, Planeta and Nora) were grown at the experimental field. Sowing was performed at optimum dates, at a seeding rate of 700 viable seeds per m^2, using a tractor-drawn seed drill. Wheat sowing was done on two separated stationary fields (A and B) with corn rotation system. Conventional production technology was employed. The crops were harvested at full maturity using a threshing machine.

Measurements and Statistical Analyses

Soil samples were taken for analysis prior to the start of the experiment from exposed soil profiles at five depths (0-20, 20-40, 40-60, 60-80 and 80-100 cm). The soil was analyzed using chemical methods (soil pH was determined in a 1:2.5 soil - 1 M KCl suspension after a half-hour equilibration period; hydrolytic acidity by Ca acetate extraction using Kappen’s method; sum of exchangeable basic cations by Kappen’s method; humus content by Kotzmann’s method; total nitrogen by Kjeldahl, and available P_2O_5 and K_2O levels by the Egner-Riehm Al method (Riehm, 1958).

The crops were harvested at full maturity. Wheat grain properties were determined as follows: grain yield (t ha^{-1}, calculated on 14% grain moisture basis), kernel number per spike, kernel weight per spike (g), 1000 kernel weight (g), test weight (kg hl^{-1}) and protein content (%). Thousand kernel weight was determined using an automatic seed counter. Test weight is the weight of a measured volume of grain expressed in kilograms per hectoliter. Nitrogen was determined by the Kjeldahl method, while crude protein content was obtained by multiplying total nitrogen by 5.7.

The results were used to calculate the usual indicators of variation statistics: average values, error of the (arithmetic) mean and standard deviation. Statistical analysis was made using the Analyst SAS/STAT software (SAS Institute, 2000).

RESULTS AND DISCUSSION

The data presented in Table 2 for the wheat vegetation period (2007-2011) clearly suggest large differences in weather conditions in relation to the long-term average for the region. Averaged across the growing seasons, air temperature was higher in all years of the study compared to the long-term average (2.6°C in 2006-07, 0.6°C in 2007-08 and 2010-11, 1.5°C in 2008-09 and 1.1°C in 2009-10). However, total rainfall during the wheat growing seasons showed significant variations, especially during 2006-07, when a 103 mm decrease in total rainfall compared to the long-term average was reported, and during the 2009-10 growing season, when total rainfall increased by 226 mm compared to the long-term average.

Table 2. Temperature and rainfall in the growing seasons from 2007 to 2011 and in the 1961-2004 reference period, at Kraljevo location

Years	Month									Average
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	
Mean temperature (°C)										
2006-07	13.1	6.7	2.5	5.2	6.2	9.4	12.8	18.1	22.1	10.7
2007-08	10.6	3.2	0.2	1.6	4.5	8.0	12.4	17.5	21.1	8.7
2008-09	12.8	8.0	4.4	0.4	2.3	6.6	13.4	18.1	20.1	9.6
2009-10	11.3	8.2	3.8	1.1	2.7	7.2	12.1	16.6	20.2	9.2
2010-11	9.2	11.1	2.7	0.3	0.6	6.6	12.2	15.6	20.4	8.7
Average 1961-2004	11.1	4.2	1.2	-0.2	1.7	6.8	11.5	16.8	19.6	8.1
Total rainfall (mm)										Sum
2006-07	31	33	48	46	48	65	17	126	31	445
2007-08	117	116	39	33	22	72	63	40	73	576
2008-09	40	48	41	47	55	72	23	36	194	557
2009-10	138	63	98	34	82	39	100	84	136	774
2010-11	94	34	65	28	59	49	37	83	72	521
Average 1961-2004	58	89	50	42	38	48	54	86	83	548

In view of the fact that sufficient rainfall during the spring months, particularly its distribution, is a very important factor in the success of winter wheat production, the analysis suggested a high degree of non-uniformity of the distribution and total amount of rainfall during the study period. Therefore, rainfall deficiency during the spring and non-uniform distribution of rainfall across months accompanied by an increase in average air temperatures showed a negative effect on wheat yields.

Table 3 data show significant variation in grain yield across years and fertilization treatments. In the growing seasons (2007-08, 2008-09 and 2009-10) which were more favorable for wheat production in terms of agro-meteorological conditions (Table 2), a significantly higher grain yield was obtained in all winter wheat cultivars. However, during less favorable growing seasons (2006-07, 2009-10, 2010-11), grain yield, kernel number per spike, kernel weight per spike, test weight and 1000 kernel weight were significantly reduced compared to the seasons that favored wheat production.

Weather conditions, especially the amount and distribution of precipitation throughout the growing season, along with air temperatures, are the most important environmental factors that affect wheat development and yield. In general, large amounts of well-distributed precipitation and lower air temperatures during the three summer months benefit wheat growing (Josipovic et al., 2005; Jelic et al., 2011b). The amount and distribution of rainfall during the growing season contribute to variations in both grain yield and certain yield components (Li et al., 2009). Drought occurring due to a deficiency of rainfall leads to a decrease in grain yield, kernel number per spike and spike number. However, Jia et al. (2009) reported that an optimized supply of wheat plants with ample amounts of water can result in reduced grain yields. Moreover, they found that high soil moisture content at the milk stage is not useful and can lead to a reduction in kernel weight per spike and total yield. Most yield components and grain yield in wheat are generally governed by air temperature during the growing season.

Lihua et al. (2013) determined that kernel number per spike and grain formation processes are dependent on average temperatures during March and April. Low average temperatures during this part of the growing season enhance the tendency of the plant to increase kernel number per spike.

Different fertilization systems and liming were highly effective in improving grain yield in all winter wheat cultivars (Table 3). The results on the combined application of lime, manure and mineral fertilizers suggest a maximum increase in wheat grain yield compared to the control (more than a threefold increase). Interactions year x cultivar and year x fertilization were with high significant share in total grain yield variation, too. It means that grain yield value is result of ameliorative fertilization use and weather conditions through the year. Significant effects of soil amendments such as lime, manure and phosphorus fertilizer in increasing wheat yield through an increase in soil pH, neutralization of hydrolytic acidity and an intensive uptake of major biogenic elements (N, P, K, Ca and Mg) have been reported in a number of previous studies (Kovacevic et al., 2010; Jelic et al., 2011a; Iljkic et al., 2011).

Table 3. Factorial ANOVA for grain yield, test weight, 1000 kernel weight, kernel number per spike and kernel weight per spike in different winter wheat cultivars

	Source variation	D.f.	S.S.	M.S.	F_e	p
Grain yield, (t ha^{-1})	Year	4	76.078	19.019	9.581***	0.00000
	Cultivar	2	5.380	2.690	1.204	0.30172
	Fertilization	5	471.826	94.365	191.173***	0.00000
	Year x Cultivar	40	14.699	2.05899	7.1390***	0.00002
	Cultivar x Fertilization	10	0.11998	0.4910	0.244366	0.99130
	Year x Fertilization	20	0.95310	0.23727	4.01695***	0.00000
	Year x Cultivar x Fertilization	40	3.829	0.096	1.044	0.40986
Test weight (kg hl^{-1})	Year	4	11074.37	1.714	6460.359***	0.00000
	Cultivar	2	30.2267	167.3831	0.182	0.83488
	Fertilization	5	29.7488	168.9507	0.176	0.97137
	Year x Cultivar	40	9999.612	11.0941	901.3427***	0.00000
	Cultivar x Fertilization	10	1.82364	176.6837	0.010321	1.00000
	Year x Fertilization	20	1.67479	18.8183	0.08900	1.00000
	Year x Cultivar x Fertilization	40	0.4181	0.5789	0.722	0.88781
1000 kernel weight (g)	Year	4	801.09	4.006	199.988***	0.00000
	Cultivar	2	109.7460	15.1550	7.242***	0.00087
	Fertilization	5	116.5650	13.9509	8.355***	0.00000
	Year x Cultivar	40	614.720	4.5112	136.266***	0.00000
	Cultivar x Fertilization	10	1.29155	13.6930	0.094	0.99986
	Year x Fertilization	20	3.40810	4.8263	0.70615	0.81857
	Year x Cultivar x Fertilization	40	1.1162	0.2582	4.323***	0.00000
Kernel number per spike	Year	4	202.89	21.240	9.553***	0.00000
	Cultivar	2	585.8427	19.7321	29.690***	0.00000
	Fertilization	5	548.3868	14.0084	39.147***	0.00000
	Year x Cultivar	40	170.037	17.0101	9.996***	0.00000
	Cultivar x Fertilization	10	35.89524	8.6015	4.173***	0.00002
	Year x Fertilization	20	5.41749	12.1853	0.44459	0.98226
	Year x Cultivar x Fertilization	40	3.7294	5.6147	0.664	0.93656
Kernel weight per spike (g)	Year	4	0.91	0.087	10.442***	0.00000
	Cultivar	2	0.4193	0.0970	4.322*	0.01422
	Fertilization	5	2.8724	0.0469	61.239***	0.00000
	Year x Cultivar	40	0.687	0.0879	7.814***	0.00001
	Cultivar x Fertilization	10	0.05528	0.0436	1.267309	0.24936
	Year x Fertilization	20	0.04077	0.0370	1.10089	0.34904
	Year x Cultivar x Fertilization	40	0.0110	0.0298	0.370	0.99980

Df: Degree of freedom, ns, *, **, ***: non-significant and significant at 5%, 1% and 0.1% probability levels, respectively, S.S.: Sum of Squares, M.S.: Mean Square, F value.

Application of various fertilization systems in the research period showed significant effect on variation of studied grain quality indicators. Hectoliter grain mass was, mainly, dependent on year, while mass of 1000 grains was dependent on all three factors and their interactions (year x cultivar and year x cultivar x fertilization). Cultivar, therefore, varietal specificity, has been also proven by earlier investigations (Jelic et al., 2010; Iljkic et al., 2011).

Grain number and their mass per spike expressed significant dependence on all of three factors. However, the effects of their mutual interactions were not significant, except year x cultivar interaction in case of both traits and cultivar x fertilization interaction in case of grain number per spike. It could be concluded that grain number per spike is in significant dependence on applied fertilization system, in appropriate production conditions. The combined use of lime, manure and mineral NPK fertilizer was the most effective

Results clearly show that yield components (kernel number per spike, kernel weight per spike, test weight and 1000 kernel weight) were significantly affected by fertilization (Table 4). As illustrated in Table 4, the lowest values for grain yield and yield components were obtained in the untreated control (F0). Grain yield, 1000 kernel weight and kernel number per spike were the highest in the combined treatment with lime, manure and mineral NPK fertilizer at the rates of $CaCO_3$ of 5 t ha^{-1} and phosphorus of 100 kg P_2O_5 ha^{-1} (F5).

Table 4. Effect of fertilization on grain yield and yield components in winter wheat

Treatment	Grain yield (t ha^{-1})	1000 kernel weight (g)	Test weight (kg hl^{-1})	Kernel number per spike	Kernel weight per spike (g)
F0	2.05±0.24[1]	42.62±3.50	68.66±12.79	23.17±2.77	0.71±0.16
F1	3.60±0.54	43.95±3.64	69.53±13.14	30.45±3.09	1.06±0.24
F2	4.33±0.75	44.92±3.60	69.88 ±13.28	31.38 ±2.78	1.09±0.19
F3	4.61±0.83	45.42±3.61	70.33±13.37	31.37±2.79	1.18±0.29
F4	5.17±0.76	46.33±3.71	70.57±13.43	31.85±3.25	1.36±0.16
F5	6.33±0.59	47.06±3.96	70.91±13.71	32.64±2.69	1.43±0.15

[1]Values of the standard error of the mean are given after ±.

The low number and weight of kernels per spike were the main reason for the low grain yield in the untreated control, whereas the significant increase in grain yield in F5 treatment was attributed to the high kernel number per spike and high kernel weight. Fertilization treatments, particularly F3, F4 and F5, significantly improved grain test weight compared to the control, but no statistically significant differences were observed between the treatments. The results indicate that grain yield and yield components were significantly improved after combined mineral and organic fertilization. However, concerns for the environment and natural resources demand harmonization between further increases in wheat production and soil fertility preservation. Integrated use of organic and mineral fertilizers is useful in improving crop yields, soil pH, and N, P and K availability in soils (Sarwar et al., 2007; Kovacevic et al., 2010). Apart from its positive effect on wheat grain yield, organic fertilizer (manure) is beneficial in improving soil structure. It enhances root development, facilitates nutrient uptake, prevents loss of fertilizer nutrients, promotes their binding and assists in their gradual release as part of continuous plant nutrition throughout the growing season (Arshad et al., 2004).

Grain protein content in winter wheat showed significant variations across years (Figure 1). The highest average grain protein content was obtained in the 2006-07 and 2010-11 growing seasons (11.90 and 11.53%, respectively), whereas the 2009-10 season was superior in gain yield but inferior in average protein content (9.22%). Therefore, the results can be associated with variations in agro-meteorological conditions throughout the growing seasons. Overall, during the seasons that gave the lowest grain yield and the highest protein content, reduced rainfall amounts and increased average air temperatures were observed at intensive plant growth and grain fill stages (April - June). Similar findings were reported previously (Tea et al., 2004; Příkopa et al., 2005).

Maximum grain protein content (12.28%) in the 2007-08 growing season was found in cv. Planeta, whereas cv. Nora reached maximum values in 2006-07. When analyzed across years, the highest grain protein content in the 2007-08, 2008-09 and 2009-10 growing seasons was obtained in cv. Planeta, in 2006-07 in cv. Nora, and in 2010-11 in cv. Pobeda. The results clearly suggest that grain protein content in cereal crops is significantly affected not only by environmental factors, particularly drought and heat stresses, but also by the genetic background (Marinciu and Saulescu, 2009; Balla et al., 2011).

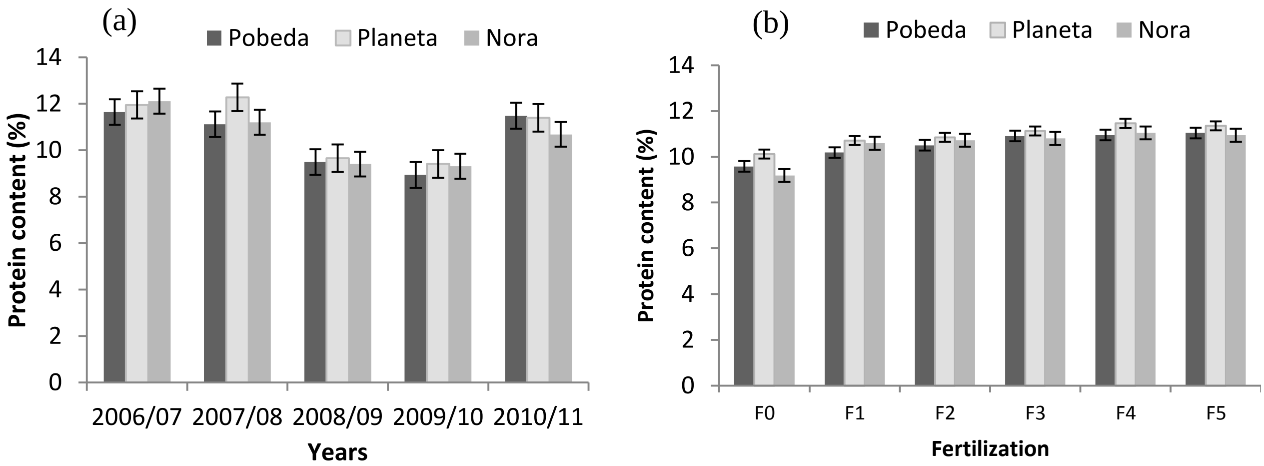

Figure 1. Grain protein content in winter wheat cultivars across years (a) and fertilization treatments (b)

The results in Figure 1 (b) show the impact of fertilization on grain protein content in wheat. The unfertilized control (F0) had the lowest protein content. Mineral fertilization increased grain protein content, whereas the increase was somewhat more significant after the combined NPK, lime and manure treatment. The positive impact of combined organic and mineral fertilization on seed protein is accounted for by increased nutrient availability due to improved soil physical properties. Therefore, improvement in these traits is conducive to intensified root development and, hence, increased water and nutrient uptake (Brady and Weil, 2005; Abedi et al., 2010).

Aluminium concentration in winter wheat grain expressed in ppm is presented in Figure 2. The results clearly show extremely high variations in aluminium levels across growing seasons and fertilization treatments. Significantly higher aluminium concentrations in wheat grain were measured in 2006-07, 2010-11 and 2008-09 growing seasons, in contrast to 2009-10 and 2007-08 growing seasons. The results clearly suggest that aluminium concentration in winter wheat grain depended on weather conditions during the study period, which was in agreement with the previous findings (Jelić et al., 2009). When analyzed across years, grain aluminium concentration in winter wheat cultivars was variable, ranging from the lowest in all years in cv. Planeta to significantly higher values in cultivars Pobeda and Nora. Wheat genotypes greatly differ in their tolerance to high Al concentrations in the soil solution. Tolerant wheat cultivars generally accumulate less Al and produce higher grain yields (Darko et al., 2004). The results in Figure 2 (b) show significant changes in aluminium concentration in winter wheat grain depending on applied treatment. The highest Al concentration in wheat grain was obtained in the control (F0). High values were also measured in NPK treatment (over 10 ppm). High aluminium concentrations in a nutrient medium and plants are known to have adverse effects on plant growth and development. These findings are in agreement with the results of previous studies (Ma, 2007; Zheng et al., 2007).

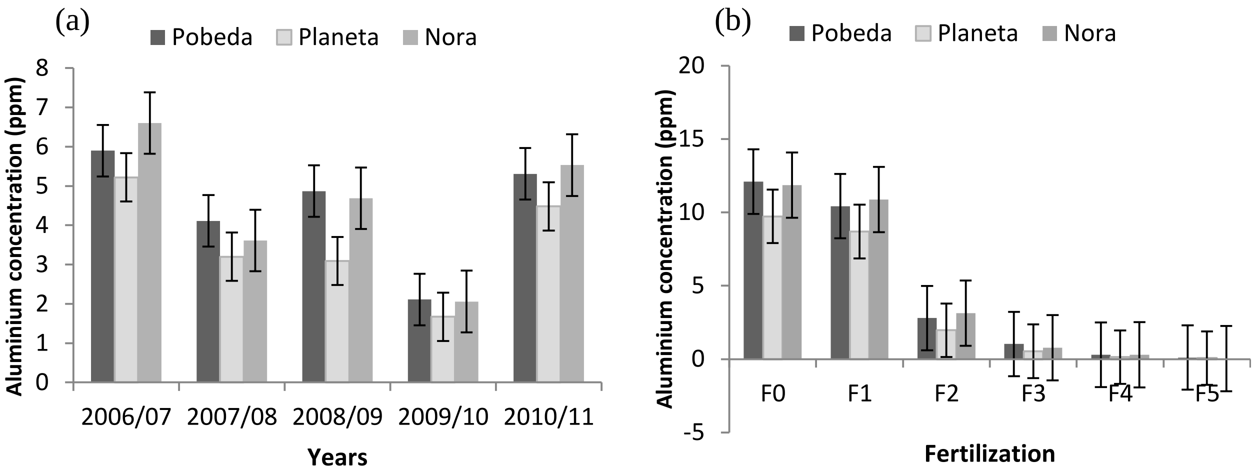

Figure 2. Grain aluminium content in winter wheat cultivars across years (a) and fertilization treatments (b)

Ameliorative liming (treatments F2 and F3), particularly combined lime and manure applications (F4 and F5) led to a significant decrease in grain Al concentration in all winter wheat cultivars. The combined NPK, lime and manure treatment (F4 and F5) almost completely eliminated Al presence in the grain of all winter wheat cultivars. Calcium derived from lime, particularly when combined with organic substances, neutralizes soil acidity and reduces Al mobility and uptake. The wheat cultivars tested largely differed in their grain Al concentration. Significantly lower values for grain Al concentration were found in cv. Planeta in all growing seasons and all fertilization treatments. Therefore, using Al-tolerant plant genotypes to mitigate Al toxicity is a successful alternative to liming in wheat production on acidic soils (Delhaize et al., 2004; Singh et al., 2011).

CONCLUSIONS

Grain yield and quality in winter wheat cultivars analyzed in this study showed significant variations depending on agro-meteorological conditions and fertilization treatments. A high effect on grain yield (a 3.07-fold increase), yield components and protein content was obtained in the combined NPK, lime and manure treatment (120 kg Nha^{-1}, 100 kg $P_2O_5ha^{-1}$, 60 kg K_2Oha^{-1}+ 5.0 t $CaCO_3ha^{-1}$+ 20 tha^{-1} manure).

Some cultivars (Planeta) are better adapted to local agro-environmental and soil conditions and can be recommended as suitable genotypes for wheat production on acidic soils. Therefore, integrating certain soil amending practices (liming and humification) and mineral fertilizers combined with cultivars that are better adapted to a low soil pH provides an optimal solution to increasing yield stability and grain quality in wheat grown on acidic pseudogleys in Central Serbia.

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