NARDI FUNDULEA, ROMANIA
www.incda-fundulea.ro

ROMANIAN AGRICULTURAL RESEARCH, NO. 30, 2013
Print ISSN 1222-4227; Online ISSN 2067-5720

EFFECT OF LIMING AND FERTILZATION ON YIELD AND QUALITY OF OAT (*AVENA SATIVA* L.) ON AN ACID LUVISOL SOIL

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ABSTRACT

The uplands and highlands in Western Serbia are the most important oat production regions in Serbia. An experiment was conducted on a Luvisol soil in the Mt. Radočelo region (southwestern Serbia) in order to evaluate the effect of soil ameliorative operations (liming and humification) and fertilization on grain yield, test weight, 1000-grain weight and grain protein content in oat. The combined use of NPK fertilizers (120 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, 80 kg K_2O ha^{-1}), lime (5 t ha^{-1}) and manure (30 t ha^{-1}) provided an optimum supply of major nutrients, resulting in maximum grain yield (5.443 t ha^{-1}). The combined use of NPK, lime and manure induced a significant increase in test weight and protein content, and a moderate increase in 1000-grain weight. NPK fertilization increased grain yield and test weight, but showed no effect on 1000-grain weight and grain protein content. Nitrogen application resulted in a significant but lower increase in grain yield and quality, which was not likely to provide a significant economic benefit. The combined use of chemical ameliorative operations (liming and humification) and fertilization, especially with adequate rates of nitrogen and phosphorus, facilitate the optimization of the yield and quality of grain having a high market value.

Key words: Oat, acid soil, liming, fertilization, yield, quality, protein content.

INTRODUCTION

Oat (*Avena sativa* L.) stands out among small grains, but also among forage crops, for its specific and good quality chemical composition of both grain and straw. The chemical composition of oat grain and straw is highly variable due to genetic, climatic and edaphic factors, and the cultural operations applied. The quality and chemical composition of oat grain are closely associated with oat yields, being an important trait in terms of the production efficiency of oat in general and its use as a forage crop in particular (Nikolić et al., 2004). Compared to other cereal crops, oat is reputed to be better suited for production under marginal environments, including cool wet climates and low fertility soils (Hoffmann, 1995; Buerstmayr et al., 2007; Ren et al., 2007).

Soil acidity frequently affects agricultural production in Serbia, as in many other areas worldwide. The low content of calcium (Jelić, 1996) and aluminum toxicity (Arsenijević-Maksimović et al., 2001) affect root growth and the absorption of water and nutrients by plants, usually causing crop yield reduction in acid soils (Sumner et al., 1986). In acid soils, poor plant growth may result from phytotoxic substances such as soluble Al and Mn, nutrient deficiencies (P, Ca and Mg), and reduced uptake of nutrients (Beckie and Ukrainetz, 1996).

Oat is widely grown in Western Serbia for the milling, horse feed, and feed grain markets. Despite the relative importance of oat in this region, limited information is available regarding optimum fertilization. Both yield and quality, and thus the economic value of oat, may be strongly influenced by fertilizer management. For example, oats meeting specific quality standards, such as a high test weight and a low percentage of thin kernels, may garner price premiums in specialized milling and horse feed markets. The oat industry in Serbia has made very

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Received 15 October 2012; accepted 22 March 2013. First online: 10 April 2013. DII 2067-5720 RAR-239

good progress in recent years. In many countries worldwide, oat is considered the most profitable crop for the agricultural industry in the future.

Mineral fertilizers play a vital role towards improving crop yields, but one of the main constraints in achieving proven crop potential is imbalanced use of nutrients, particularly low use of P as compared to N. The optimum rate of P application is important in improving yields of most crops (Cisar et al., 1992).

In Serbia, farmers are using only nitrogen fertilizers for fodder crops while the use of P fertilizer is negligible. These crops are often grown on marginal lands. Hence, the production is low and quality is poor. The quality of fodder crops in Serbia is too poor to meet the nutritional requirements of animals (Nikolić, 2002).

Liming has long been recognized as the main strategy for improving the productivity of acidic soils. Positive crop responses to liming are due to the amelioration of one or more of the above-mentioned factors (Materechera and Mkhabela, 2002; Prado et al., 2007; Alvarez et al., 2009). 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 this study was to evaluate the effect of different fertilization systems (liming, humification and NPK fertilization) on the grain yield and quality of oat grown on a Luvisol soil. The study was also aimed at optimizing fertilization for maximum profitability in the future oat production in the uplands of Western Serbia.

MATERIAL AND METHODS

Study area and soil analysis

This study was conducted over a three-year period (2008, 2009 and 2010) in the Mt. Radočelo region, Western Serbia (44° 34′ N, 19° 46′ E), on a Luvisol soil, at Rudno location, 1300 m a.s.l., in a temperate continental climate having an average annual temperature of 8°C typical of highland regions in Serbia and a rainfall amount of about 700 mm.

The data presented in Table 1 for the oat growing season analyzed (2008-2010) clearly suggest differences in weather conditions between the years of the study and the long-term mean for the region. The average air temperature was 1.1°C, 1.4°C and 1.0°C higher in 2008, 2009 and 2010, respectively, as compared to the long-term mean, whereas the sum of rainfall was 79.3 mm, 63.2 mm and 125.6 mm higher in respective years as compared to the long-term mean. Compared to the long-term mean, total rainfall in the first year and, especially, the third year was considerably higher in April, whereas total rainfall in April 2009 decreased by 28.7 mm.

Table 1. Temperature and rainfall in the growing seasons from 2008 to 2010, and in the 1961-2004 reference period, at Rudno location

Years	Month					Average
	April	May	June	July	August	
Mean temperature (°C)						
2008	12.4	17.2	21.1	21.6	22.2	18.9
2009	13.4	18.1	20.1	22.3	22.2	19.2
2010	12.1	16.6	20.2	22.6	22.3	18.8
Average 1961-2004	11.2	16.2	19.4	21.3	21.0	17.8
Total rainfall (mm)						
2008	62.9	40.1	73.4	153.0	57.1	386.5
2009	22.8	36.2	194.0	58.1	59.3	370.4
2010	100.2	84.0	136.4	38.2	74.0	432.8
Average 1961-2004	51.5	64.8	79.3	62.5	49.1	307.2

However, in May 2010, total rainfall amounted to 84.0 mm, which was 19.2 mm higher than the long-term mean. Given the high importance of sufficient rainfall amounts during the spring months, particularly May, for oat production, the distribution and amount of rainfall during the 2010 growing season were considerably more favorable, resulting in increased yields in this year. Apart from the rainfall deficiency during the spring months and the non-uniform distribution of rainfall across months, an increase in average air temperatures was also observed.

The soil is typical of those used by the majority of small-scale farmers. Its limiting factors to crop production are principally P deficiency and acidity. Luvisol is suitable for the cultivation of potatoes and oats, which are tolerant of acid environments. The soil analyzed is a coarse-textured poorly skeletal clay soil (Table 2) having a low percentage (29.25%) of colloidal clay in the humus-accumulative horizon (Ah) of the profile, and a relatively high sand content (21.79%). A similar texture is also found in deeper soil layers, suggesting that the soil is coarse in texture (light clay soil).

Table 2. Texture of luvisol

Soil horizon	Depth (cm)	Percentage of soil particles (mm)							Textural class
		2-0.2	0.2-0.05	0.05-0.01	0.01-0.005	0.005-0.002	< 0.002	< 0.01	
Ah	0-30	8.39	13.40	25.05	11.52	12.39	29.25	53.15	Light clay soil
AhE	30-50	7.73	14.36	27.68	11.15	12.60	26.48	50.24	

The chemical properties of Luvisol are highly unfavorable in both horizons analyzed (Table 3). Namely, the soil is highly acidic, having relatively high active acidity (pH in H_2O 4.80) in the arable horizon, and somewhat lower acidity (pH in H_2O 5.10) in the deeper AhE horizon. The exchangeable acidity (pH in KCl) of this soil at different profile depths ranges from 3.90 to 4.10. Hydrolytic acidity (Y^1) is high in the arable Ah horizon (47.35 ccm), but considerably lower, though still high, in the subarable AhE horizon (27.76 ccm).

Table 3. Agrochemical properties of luvisol

Soil horizon	Depth (cm)	Humus (%)	Y^1 (ccm)	N (%)	T	S	T-S	pH		P_2O_5	K_2O
					meq 100^{-1} g			H_2O	KCl	mg 100^{-1}	
Ah	0-30	5.60	47.35	0.122	44.81	14.03	30.78	4.8	3.9	3.7	22.6
AhE	30-50	1.17	27.76	0.081	32.41	14.37	18.04	5.1	4.1	0.1	12.1

The soil tested is marked by a highly unfavorable composition of the adsorption complex (Table 3) i.e. very low values of adsorption capacity, sum of adsorbed base cations and base saturation. Humus content is significant only in the arable (Ah) horizon (5.60%), but considerably decreases in the AhE profile layer (about 1.17%). The reduced humus content in field luvisols profiles suggests the necessity of using humification when planning fertilization systems and soil ameliorative operations to be used to maintain and improve the soil adsorption complex. The luvisol profile analyzed has a moderate total nitrogen content in the humus horizon. Total nitrogen in the arable layer averages 0.122% and significantly decreases with increasing depth (0.081%). However, regardless of the satisfactory content of total nitrogen in these soils, the nitrogen regime for plants is quite unfavorable, due to other unfavorable properties. Readily available phosphorus in the Ah horizon is low (3.7 mg 100^{-1} g soil), whereas that in the subarable eluvial AhE is present in trace amounts (0.1 mg 100 g^{-1}). The test soil is very well supplied with readily available potassium, being, therefore, classified as a soil rich in readily available potassium (22.6 mg 100 g^{-1}).

Experimental design

A randomized complete block design was used, with three replications in a split-plot arrangement. Plot size was 100 m^2 (10x10 m). The spring oat cultivar used in the experiment was Slavuj, the dominant cultivar in the production region of Serbia. The preceding crop was potato. Seeding was performed at an optimum date in the second half of April at a rate of 500 germinating seeds m^{-2}. Weed control was achieved using recommended herbicides and rates based on the spectrum of weeds present. The other production technologies used were standard.

The experiment included: (1) unfertilized control and the following treatments: (2) 80 kg N ha^{-1}, (3) 120 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, 80 kg K_2O ha^{-1}, (4) 30 tha^{-1} manure and (5) 120 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, 80 kg K_2O ha^{-1} + 5 tha^{-1} lime + 30 t ha^{-1} manure. The fertilizers applied were complex NPK (15:15:15) and CAN (calcium ammonium nitrate) as a nitrogen fertilizer containing 27% N. The liming material was hydrated lime ($Ca(OH)_2$), with 99% of particles of <0.42 mm and a neutralizing value (or calcium carbonate equivalence, CCE) of 136%. Hydrated lime powder was applied to soil by uniform surface application only once, in March 2008, and incorporated to a 20 cm depth. The whole amount of the other fertilizers was applied at seedbed preparation (disking).

Measurements

The soil was sampled for analysis prior to trial establishment. The samples were collected from exposed soil profiles at two depths - 0-30 cm (Ah horizon) and 30-50 cm (AhE horizon). The soil was analyzed using standard physical methods (soil texture, by pipette method, a variant of pyrophosphate method modified by Živković, 1966); chemical methods (soil pH was determined in a 1:2.5 soil - 1 M KCl suspension after a half-hour equilibration period; hydrolytic acidity was determined by Ca acetate extraction using Kappen's method; sum of adsorbed base cations – by Kappen's method; humus content - by Kotzmann's method, total nitrogen by the Kjeldahl method, and available P_2O_5 and K_2O levels by the Egner-Riehm Al method).

The crop was harvested at full maturity. Grain yield (t ha^{-1}) was harvested and reported at 14% moisture. Three parameters of grain quality, namely test weight (kg hl^{-1}), 1000-grain weight (g) and protein content (%) were analyzed. Thousand grain 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 calculated by multiplying total nitrogen by 6.25.

Statistical Analysis

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 performed using the Analyst SAS/STAT software (SAS Institute, 2000).

RESULTS AND DISCUSSION

The grain yield of oat significantly varied across years, from 2.639 t ha^{-1} in 2008 to 3.985 t ha^{-1} in 2010 (Table 4). The sufficient amounts of rainfall during the spring months (Table 1), particularly May, which are vital to successful oat production, suggest that the distribution and total amount of rainfall during the growing season 2010 were considerably more favorable, resulting in an increased yield in this year as compared to the first two years. The significantly lower yield in 2008 and 2009 was due to a decline in total rainfall in the spring and its non-uniform distribution across months, accompanied by higher average air temperatures in these years. The results of the present study confirm the opinion of many authors that grain yield is genetically determined but is strongly modified by weather conditions (Doehlert et al., 2001; Petrson et al., 2005). According to Doehlert et al. (2001), the best oat yields with high quality grain are generated by warm, bright (high solar radiation) spring weather and cooler summer weather without excessive rains during grain filling. Fertilization had a significant effect on grain yield (Table 4). The average grain yield was lowest in the unfertilized control (1.674 t ha^{-1}) and significantly higher in fertilized treatments, ranging from 1.342 t ha^{-1} (N-treatment) to 3.769 t ha^{-1} (combined use of NPK, lime and manure - treatment 5). NPK fertilization (3) induced a significant increase in grain yield, which was 2.61 t ha^{-1} (2.5-fold) and 1.268 t ha^{-1} (42.03%) higher as compared to the control and N-treatment, respectively. Nitrogen, phosphorus and potassium application, particularly on acid soils poorly supplied with these nutrients, has a high effect on the grain yield of oats and other cereal crops (Mohr et al., 2007; Rashid et al., 2007).

Table 4. Grain yield, test weight, 1000-grain weight and crude protein content of spring oat

Traits	Fertilization	Years						Average	
		2008		2009		2010			
		$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S
Grain yield ($t\ ha^{-1}$)	1	1.130	0.075	1.870	0.128	2.023	0.254	1.674	0.439
	2	2.300	0.149	3.447	0.130	3.300	0.361	3.016	0.578
	3	3.210	0.204	5.043	0.080	4.600	0.436	4.284	0.864
	4	2.523	0.316	2.950	0.087	3.567	0.252	3.013	0.499
	5	4.033	0.115	5.863	0.660	6.433	0.777	5.443	1.201
	Average	2.639	1.014	3.835	1.514	3.985	1.574	3.486	1.488
Test weight ($kg\ hl^{-1}$)	1	49.533	0.907	43.813	0.380	46.313	0.366	46.553	2.538
	2	50.347	0.506	45.027	0.403	48.223	0.361	47.867	2.349
	3	47.50	0.818	45.467	0.702	47.633	0.520	46.867	1.210
	4	43.867	0.416	42.900	0.300	45.567	0.584	44.111	1.232
	5	50.687	0.441	47.380	1.051	47.833	0.709	48.633	1.691
	Average	48.387	2.662	44.917	1.669	47.115	1.132	46.806	2.377
1000 grain weight (g)	1	24.900	2.022	27.947	0.927	29.120	0.529	27.322	2.206
	2	26.88	0.771	28.467	0.862	27.167	0.777	27.504	1.011
	3	26.400	0.800	28.213	1.811	25.767	0.431	26.793	1.495
	4	26.433	0.709	29.213	0.230	28.587	1.949	28.078	1.638
	5	28.70	1.308	28.493	0.410	29.373	1.988	28.856	1.271
	Average	26.663	1.633	28.467	0.959	28.003	1.796	27.711	1.663
Grain protein content (%)	1	10.893	0.253	12.560	0.250	12.667	0.323	12.040	0.894
	2	10.727	0.420	12.123	0.409	12.517	1.032	11.789	1.008
	3	9.727	0.991	10.580	0.425	10.683	0.125	10.330	0.708
	4	10.977	0.481	11.957	0.816	12.187	0.781	11.707	0.829
	5	9.750	0.250	10.230	0.501	10.520	0.898	10.167	0.627
	Average	10.415	0.742	11.490	1.042	11.715	1.134	11.206	1.122

Maximum grain yield in all years was obtained with the combined ameliorative use of lime, manure and NPK fertilizer. These fertilizers reduced soil acidity and increased the efficiency of utilization of certain soil and fertilizer nutrients, primarily phosphorus, potassium and magnesium. The improved nutrient balance significantly contributed to oat grain yield. Bolland and Brennan (2005) observed that an increase in oat yield in phosphorus-deficient soils after phosphorus application is closely associated with higher phosphorus concentrations in plant tissues. Various soil factors including soil P concentration, soil temperature, moisture, pH, texture and bulk density, and plant factors such as root growth may affect the supply of P to the plant (Grant et al., 2001), and thus the potential for crop responses to P fertilizer application. Similar results on yield increases in oat and other cereals have been previously reported (Girma et al., 2007; Bolton, 2009; Chen et al., 2011). The year x fertilization interaction was significant for grain yield (Table 5). Mineral fertilization and liming led to an increase in grain yield in all years. Increased grain yields following the use of nitrogen, NPK and lime have also been reported by other authors (Mohr et al., 2007; Buckley et al., 2010). Oat exhibited a very weak response to manure used alone, with grain yield corresponding to or being lower than that obtained with nitrogen application. The result was realistic and expected, given the low fertility of the soil treated with fertilizers having a low nutrient content. Under such conditions, no significant increase in grain yield was possible.

Test weight is an indicator of grain quality, particularly of grain monetary value. Oat grains having a higher test weight are generally considered to be of higher quality than those with a low test weight. Table 4 presents average values for grain test weight across years and treatments. Grain test weight showed a significant dependence on year and treatment (Table 5). The average values for test weight in all treatments were as follows: 48.38 kg hl^{-1} (S = 2.66 kg hl^{-1}) in 2008, 44.92 kg hl^{-1} (S=1.67 kg hl^{-1}) in 2009 and 47.87 kg hl^{-1} (S=2.35 kg hl^{-1}) in 2010, suggesting significant variations in test weight during the three years of the study. Tamn (2003) found that grain yield and physical grain quality are mostly affected by climate and genetic conditions. Moreover, Dumlupinar et al. (2011) attributed differences between the years to environmental conditions. Mineral fertilization (N, NPK and NPK + lime + manure) led to a significant increase in grain test weight as compared to the control, whereas manure alone resulted in reduced test weight as compared to both the other treatments and the control. The average reduction obtained with this treatment as compared to the combined use of NPK, lime and manure which gave maximum test weight values was over 10%. The year x fertilization interaction was significant for test weight (Table 5). In all years, the use of different treatments induced a significant increase in grain test weight.

Table 5. Analysis of variance of the tested parameters (ANOVA)

Effect of year on the traits analyzed				
Traits	Mean sqr. Effect	Mean sqr. Error	F (df1.2) 2. 42	p-level
Grain yield (t/ha)	16.306	8.153	4.219	0.021
Test weight (kg hl^{-1})	46.206	3.718	12.428	0.0001
1000 grain weight (g)	13.163	2.271	5.796	0.006
Protein content (%)	7.242	0.974	7.439	0.002
Effect of fertilization on the traits analyzed				
Traits	Mean sqr. Effect	Mean sqr. Error	F (df1.2) 4. 40	p-level
Grain yield (tha^{-1})	23.134	0.168	137.900	0.0000
Test weight (kg hl^{-1})	26.537	3.560	7.453	0.0001
1000 grain weight (g)	5.581	2.484	2.246	0.0811
Protein content (%)	7.050	0.679	10.379	0.0000
Effect of the year x fertilization interaction on the traits analyzed				
Traits	Mean sqr. Effect	Mean sqr. Error	F (df1.2) 8. 30	p-level
Grain yield (tha^{-1})	3.974	0.947	4.341	0.001
Test weight (kg hl^{-1})	4.878	0.366	13.324	0.0000
1000 grain weight (g)	3.767	1.431	2.633	0.026
Protein content (%)	0.225	0.363	0.619	0.755

Thousand grain weight in the test period was highest in 2009 (28.47 g), but significantly decreased in 2008 (by 1.80 g or 6.76%). However, no statistically significant differences were observed between the third year (2010) and the second year (2009). Fertilization had a significant effect on 1000-grain weight, but the effect was much lower than on the other traits analyzed (Table 5). Furthermore, 1000-grain weight was significantly affected by the year x fertilization interaction. A number of authors (Chalmers et al., 1998; May et al., 2004; Browne et al., 2006) underlined that 1000-grain weight was a cultivar-specific trait, with considerably higher variations being observed among genotypes than among treatments or environmental factors.

The crude protein content of spring oat grain was variable, depending on environmental conditions and treatments (Tables 4 and 5), being lowest (10.41%) in the first year (2008) and showing a tendency to increase in the following two years (2009 and 2010) - 11.49 and 11.71%, respectively. The difference between the first and second year was statistically significant. Rainfall reduction in the first year and the low efficiency of utilization of soil and fertilizer nutrients, nitrogen in particular, cause a reduction in grain protein content in oats (Nikolić et al., 2004). The effect of liming and fertilization on grain protein content is given in table 4. Maximum crude protein content was measured in 2010 in the control (12.52%), whereas the highest average values in fertilized treatments were obtained with nitrogen and manure applications (11.79% and 11.71%, respectively). The increase was significant as compared to the other treatments (Table 5). Nitrogen application enhances nitrogen uptake and assimilation in organic nitrogenous compounds and proteins (Pecio and Bichonski, 2010; Chen et al., 2011).

Table 6 presents correlation coefficients between yield and the other grain traits analyzed. Grain yield exhibited different responses to each trait analyzed. Namely, grain yield was significantly negatively correlated with protein content in all three years, as consistent with the general rule of genetics that grain yield and grain protein content are negatively correlated. However, 1000-grain weight and test weight were significantly positively correlated with grain yield only in the first year ($r=0.69^{*}$) and second year ($r=0.698^{*}$), respectively. The results suggest that grain yield and quality formation was affected by both genetic and environmental factors (Doehlert et al., 2001; Tamn, 2003; Dumlupinar et al., 2011). The other traits analyzed showed no correlations during the research period.

Table 6. Correlations between the traits analyzed during 2008-2010

Traits	Grain yield ($t\ ha^{-1}$)	Test weight ($kg\ hl^{-1}$)	1000-grain weight (g)	Protein content (%)
Correlations between the traits analyzed in 2008				
Grain yield ($t\ ha^{-1}$)	1.00	ns	0.69^{*}	-0.58^{*}
Test weight ($kg\ hl^{-1}$)		1.00	ns	ns
1000 grain weight (g)			1.00	ns
Protein content (%)				1.00
Correlations between the traits analyzed in 2009				
Grain yield ($t\ ha^{-1}$)	1.00	0.81^{**}	ns	-0.89^{**}
Test weight ($kg\ hl^{-1}$)		1.00	ns	-0.67^{*}
1000 grain weight (g)			1.00	ns
Protein content (%)				1.00
Correlations between the traits analyzed in 2010				
Grain yield ($t\ ha^{-1}$)	1.00	0.50	ns	-0.71^{*}
Test weight ($kg\ hl^{-1}$)		1.00	ns	ns
1000 grain weight (g)			1.00	ns
Protein content (%)				1.00

Significant positive correlations were observed (Table 7) between grain yield and crude protein content in all treatments except manure treatment. Overall, grain yield and grain protein content in oats were closely associated and, generally, negatively correlated. However, under conditions less favorable for yield formation, the utilization of nutrients, particularly nitrogen, is slow and extends throughout the second part of the growing season, when maximum grain protein accumulation is achieved. Grain yield was found to correlate positively with 1000-grain weight and test weight in the control ($r=0.75^{*}$) and manure treatment ($r=0.79^{**}$), respectively. Peterson et al. (2005) reported a significant dependence of grain test weight on certain productive traits, as induced by grain filling dynamics and intensity under certain weather conditions.

A significant correlation between 1000-grain weight and protein content was observed in the control. Namely, the low plant density of the control yields larger grains with a higher protein accumu-lation rate. Negative and weak correlations were observed between grain yield and test weight following the treatment with nitrogen (r=-0.64*) and the combined use of NPK + lime + manure (r=-0.55*). Negative correlations were also found between test weight and 1000-grain weight in the control (r=-0.53*), nitrogen treatment (r=-0.77**) and NPK treatment (r=-0.52*), whereas the control showed significant negative correlations between test weight and protein content.

Table 7. Correlation coefficients for the traits analyzed across treatments

Traits	Grain yield (t ha^{-1})	Test weight (kg hl^{-1})	1000 grain weight (g)	Protein content (%)
Correlations between the traits analyzed in the unfertilized control				
Grain yield (t ha^{-1})	1.00	ns	0.75*	0.93***
Test weight (kg hl^{-1})		1.00	-0.53*	-0.70*
1000 grain weight (g)			1.00	0.86**
Protein content (%)				1.00
Correlations between the traits analyzed in the nitrogen treatment				
Grain yield (t ha^{-1})	1.00	-0.64*	ns	ns
Test weight (kg hl^{-1})		1.00	-0.77**	ns
1000 grain weight (g)			1.00	ns
Protein content (%)				1.00
Correlations between the traits analyzed in the NPK treatment				
Grain yield (t ha^{-1})	1.00	ns	ns	0.63*
Test weight (kg hl^{-1})		1.00	-0.52*	ns
1000 grain weight (g)			1.00	ns
Protein content (%)				1.00
Correlations between the traits analyzed in the manure treatment				
Grain yield (t ha^{-1})	1.00	0.79**	ns	ns
Test weight (kg hl^{-1})		1.00	ns	ns
1000 grain weight (g)			1.00	0.50*
Protein content (%)				1.00
Correlations between the traits analyzed in the NPK + lime + manure treatment				
Grain yield (t ha^{-1})	1.00	-0.55*	ns	0.55*
Test weight (kg hl^{-1})		1.00	ns	ns
1000 grain weight (g)			1.00	ns
Protein content (%)				1.00

The use of fertilizers and certain amendments on extremely acid soils in certain years, particularly those less favorable for production, almost certainly has different effects on grain filling, resulting in diverse relationships between productive and qualitative traits. The present results confirm the opinion of many authors that the traits analyzed and their correlations are genetically determined but are strongly modified by the nutrient status of the environment and weather conditions (Chalmers et al., 1998; Peterson et al., 2005; Bolton, 2009).

CONCLUSIONS

Environmental conditions (weather and soil) and fertilization had a significant effect on grain yield and quality in oats. Grain yield showed a tendency to increase in the years having a higher total amount and better distribution of rainfall during critical plant development stages.

Nitrogen application resulted in a significant but lower increase in grain yield and quality, which was not likely to provide a significant economic benefit. NPK fertilization increased grain yield and test weight, but showed no effect on 1000-grain weight and grain protein content.

The results of the present study clearly suggest that maximum grain yield and quality on Luvisol can be obtained with the combined ameliorative use of lime (5 t ha^{-1}), manure (30 t ha^{-1}) and an optimum rate of NPK fertilizer (120 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, 80 kg K_2O ha^{-1}).

The effect of environmental factors on grain quality was clearly evident. The physical quality of the grain declined in the years that were less favorable for oat production (decreased total rainfall and unfavorable rainfall distribution), whereas crude protein content increased and was negatively correlated with grain yield.

Acknowledgements

The present study is part of the TP 31054 project titled "Development of New Technologies of Small Grains Production on Acid Soils Using Modern Biotechnology" funded by the Ministry of Education and Science, Republic of Serbia.

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