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Early effect of clinoptilolite on yield and quality of oat (*Avena sativa* L.)**

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A b s t r a c t. The effects of 0 (control), 1, 4 and 8 t ha^{-1} doses of natural clinoptilolite on the yield and quality of oat were evaluated. The experiment was carried out in a triplicate split-plot system on brown pseudopodzolic soil, with N fertilization applied on all plots. For comparison, standard NPK fertilization was applied on extra plots. As compared to the control variant, the highest dose of zeolite significantly influenced the plant density per 1 m^2, the number of grains in the panicle, and the length of both the straw and the panicle, thus increasing the yield per hectare. The NPK had a greater effect on yield whereas no effect was found of either NPK or zeolite on the quality of the grain.

K e y w o r d s: zeolite, oat, yield components

INTRODUCTION

Except for its use as a valuable fodder component, oat (*Avena sativa* L.) is more extensively used as a food ingredient with advantageous chemical composition and functional properties. Oat needs early sowing as it requires high soil water content for germination and initial development. Since it has low soil requirements, it can be grown on all soils; however, as all other cultivars, it gives the highest yield on nutrient-rich areas. In the world, oat is grown on about 11.7 million ha which accounts for about 2% of the area occupied by grain crops. In Poland, oat is produced on around 550 thousand ha (5% of the area).

The yield and quality of the grain are the primarily variety features but they are also largely governed by habitat conditions and agronomic factors during plant vegetation and grain ripening (Hrušková *et al*. 2006; May *et al*., 2004; Muste *et al*., 2010; Rivera-Reyes *et al*., 2008). Among many agrotechnical factors that may affect both the improvement of soil fertility and yield increase, an introduction of zeolite into the soil receives currently more interest as being an environmentally-friendly and effective long-term procedure.

Zeolites are hydrated crystalline aluminosilicates containing large amounts of nutrient cations, including in particular potassium, calcium and magnesium. An extremely high amount of zeolite pores is filled with water molecules, the so-called zeolitic water which is not tightly bound and is easily reversibly dehydrated (Xiubin and Zhanbin, 2001). A high degree of isomorphic substitution during mineral synthesis leads to the natural zeolites' showing high cation exchange capacity, up to 400 cmole kg^{-1}, which is comparable to CEC of the soil organic matter. Small-size channels leading to larges structural spaces retard the release of the exchangeable cations from the inner part of the network (a slow release of nutrients), while the cations occupying external exchange positions are readily available (Mumpton, 1999; Rehakova *et al*., 2004).

Zeolite has been used on a variety of soil types and for a number of crops, such as potatoes, maize, rice, tomatoes, eggplant and carrots, for which an increase in the yield was observed under long-term application conditions (Burriesci *et al*., 1984; Valente *et al*., 1982; Yapparov *et al*., 1988). Since the literature reports on the use of zeolites in cereal cropping are rare, and small numbers of data are available for the early stages of zeolites addition, we have undertaken studies on the zeolite effect on oat that was sown a few days after the mineral application.

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MATERIAL AND METHODS

Use was made of the Oat (*Avena sativa* L.), *cv* .Gniady, purchased from the Seed Central in Lublin, series number12/61/5536/KK002. This variety of brown coloured husk is characterized by very good health, and especially high resistance against powdery mildew. It contains higher level of exogenous amino acids and has a higher nutritional value of proteins, as compared to the yellowish grain varieties.

Zeolite derived from a clinoptilolitic tuff located in Socirnica (Ukraine), milled below 1mm particle diameter, was used as a soil fertilizer/conditioner.

The field experiment was established in Rogozno, (Ludwin commune, Poland, 51° 13^ N, 22° 37^E) on the arable soil of class III, containing 7% of clay, 42% of silt and 51% of sand and 1.8% of organic matter. The pH of the soil was 5.7 (H_2O) and 4.9 (KCl). In 100 g of the soil, 53 mg of P_2O_5, 76 mg of K_2O and 41 mg of MgO were measured. The experimental field was divided into five plots of 20 m^2, which were amended with zeolite in doses of 0 (control), 1, 4, 8 t ha^{-1}, and with a commercial phosphorus/potassium fertilizer, Agrofoska PK 20-30, in the amount of 100 kg ha^{-1}(reference PK variant), respectively. All the above plots were additionally nitrogen-fertilized with 150 kg ha^{-1} of Saletrosan® 26 macro. The fertilizers were uniformly introduced into the soil manually before sowing, and then mixed with the soil by means of 10-cm-deep disking. The experiment was performed in 3 replicates.

At the beginning of April, 180 kg of oat per hectare were sown with a seed drill. In the tillering stage, 20 g ha^{-1} of an aqueous solution of 0.1% TITUS® 35WG, and in the shooting stage, 400 l $ha^{-1}$of a 0.5% aqueous suspension of AMINOPIELIK SUPER 464 SL herbicides, were applied. During vegetation, the rainfall and the temperature values were recorded. At the beginning of August, in each fertilization variant, plants from 3 randomly chosen plots of 1 m^2 were harvested, and the number of plants per square meter was estimated. The yield components (the mass of plants, straws and panicle; the length of straws and panicle; the number and mass of grains) were estimated using 100 plants randomly collected from each surface. The remaining plants were harvested and threshed traditionally (scythe + flail) to minimize grain loss. The grains were weighted and stored at about 18°C with relative humidity of about 85%. The protein content of grains by NIR with the Inframatic 9200 device, which was calculated on the basis of the total nitrogen content and a conversion factor of 6.25 (PN-A-0401), the falling number according to the standard PN-ISO309, and the bulk density of the grain according to DIN 74007-73R, were determined.

The results were statistically analysed using Statistica 12.0 (StatSoft Inc., Tulsa, OK, USA). The yields, yield components and grain quality factors were analysed with the F-Snedecor and Tukey post hoc tests, where $\alpha = 0.05$. The correlation between the crop structure and quality parameters, as well as fertilization was assessed using the Principal Components Analysis (PCA).

RESULTS AND DISCUSSION

The weather conditions during the experiment are shown in Table 1. The lowest average daily air temperature (9.5°C) was recorded in April, and the highest (17.8°C) in July. Except for April, for which the average long-term temperature was +1.5°C, the average temperatures measured were lower than the long-term ones occurring in this region by 0.5-1.5°C. The overall rainfall recorded in April and May was by 40 and 150% higher, respectively, whereas in June and July it was by 53 and 8% lower than the long-term regional monthly averages, respectively.

The dates of the subsequent oat development stages (the BBCH scale) are shown in Table 2. The arrangement of the development stages did not differ significantly from the standard arrangement established for these regional geographical conditions, and it was not affected by any differences in fertilization.

The structure of selected yield elements is presented in Table 3. A positive effect of zeolite fertilization on plant density was observed. The largest number of plants per 1 m^2 was recorded in the PK variant, and the two largest doses of zeolite (8 and 4 t ha^{-1}) gave similar values.

Table 1. Climatic data of the experimental site during growing season of oat (2014 year)

Climatic data	April	May	June	July
	IV	V	VI	VII
Rainfall (mm)	54.5	150	31	74
Long term*	39.8	59.9	66.5	80.6
Temperature (°C)	9.5	12.6	14.9	17.8
Long term*	8.0	13.5	16.1	18.2

*Date involved 1981-2010.

Table 2. Oat development stages

Development phases	Date
Emergence	18.IV
Tillering (beginning)	06.V
Tillering (end))	20.V
Shooting of culm (1 node)	25.V
Shooting of culm (2 node)	29.V
Flag leaf	13.VI
The appearance of a panicle	17.VI
Milk maturity	26.VI
Wax maturity	13.VII
Full maturity	29.VII

Table 3. Yield structure of oat (*Avena sativa* L.) *cv.* Gniady, depending on fertilization with zeolite and phosphorus and potassium

Parameters	Fertilizing					Analysis of variance	
	N + zeolit (t ha^{-1})						
	0	1	4	8	N + PK	F	p
Number of panicles ($1m^2$)	393 ± 11a	392 ± 13a	454 ± 4b	473 ± 26b	475 ± 35b	9.35	0.001
Weight of 100 plants (g)	82.8 ± 25.8	98.2 ± 20.6	123.9 ± 22	154.9 ± 19.6	127.6 ± 55.6	1.97	0.135
Weight of 100 straws (g)	32.2 ± 10.1	37.0 ± 8.3	38.5 ± 13.3	46.7 ± 18.2	45.8 ± 16.8	1.90	0.147
Weight of 100 the panicle (g)	50.5 ± 15.7	61.1 ± 12.3	76.4 ± 13.9	77.2 ± 31.6	88.9 ± 36.1	1.89	0.148
Length of straws (cm)	44.3 ± 7.0a	50.5 ± 4.8a	61.7 ± 7.3ab	63.7 ± 9.8b	65.4 ± 8.4b	2.99	0.041
Length of panicle (cm)	9.2 ± 1.0a	10.1 ± 0.7a	10.6 ± 0.5a	12.2 ± 1.7a	13.4 ± 1.5ab	2.67	0.051
Number of grains (panicle)	17.5 ± 4.1a	20.5 ± 2.1a	24.0 ± 4.9b	24.9 ± 5.7b	25.0 ± 9.3b	3.83	0.017
Yield factor	0.61	0.62	0.62	0.65	0.70		

Data presented are average from three replicates ± SD at 95% significance interval. F (5; 12) - value of the statistical test, p – significance level. The same letters in each row indicate no significant differences. Tukey's HSD post-hoc test (α = 0.05).

Table 4. Distinguishing features of the quality of grain oat (*Avena sativa* L.) variety Gniady, depending on the fertilization zeolite and a phosphorus and potassium

Grain quality	Fertilizing					Analysis of variance	
	N + zeolit (t ha^{-1})						
	0	1	4	8	N + PK	F	p
Protein content (% dry weight)	7.9 ± 0.5	8.3 ± 0.8	6.9 ± 0.9	9.8 ± 0.7	9.9 ± 4.2	1.37	0.285
Grain moisture (%)	11.2 ± 0.1	11.2 ± 0.1	11.2 ± 0.1	11.1 ± 0.1	11.3 ± 0.02	1.50	0.241
Volumetric density (kg hl^{-1})	40.1 ± 1.9	40.1 ± 1.8	42.5 ± 1.2	42.5 ± 1.6	43.4 ± 1.6	2.25	0.096
Weight of 1000 grains (g)	31.3 ± 1.5	31.3 ± 1.3	31.8 ± 1.5	32.0 ± 1.5	32.8 ± 1.0	0.28	0.920

Data presented are average from three replicates ± SD at 95% significance interval. F (5; 17) - value of the statistical test, p – significance level.

The weight and length of the plants were the smallest for the control plots and the largest for the PK plots. The growing zeolite doses consecutively increased the above values. However, the statistically significant differences were noted only for the parameters characterizing the length of the straw and panicle ears. Zeolite did not influence the number of panicle storeys; however, along with the increase in the zeolite dose, one could observe an increase in the number of grains in the panicle, which, in respect to the control variant, increased significantly on the plots with PK fertilization, and with the highest zeolite dose by 43 and 42%, respectively.

The grain quality indicators were practically not influenced by fertilization (Table 4). However, a clear effect of fertilization on oat yield per hectare was recorded (Fig. 1). The application of 4 and 8 t ha^{-1} of the zeolite increased the oat yield by 59 and 73%, as compared to the control variant, respectively, which is similar to the PK fertilization variant.

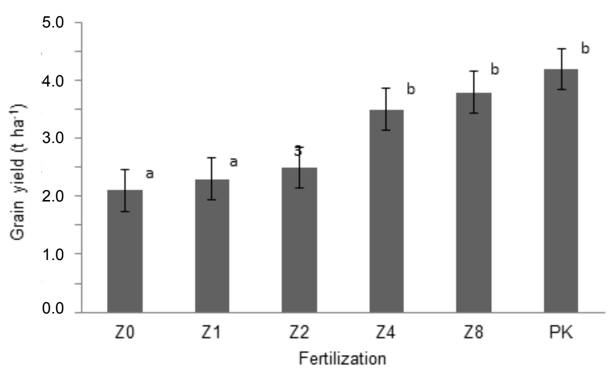

Fig. 1. Yield of oat grains depending on fertilization. The number following letter Z stands for the zeolite dose. The bars represent standard deviation at 95% confidence interval of three replicates. The same letters indicate no significant differences. HSD Tukey's test for α = 0.05.

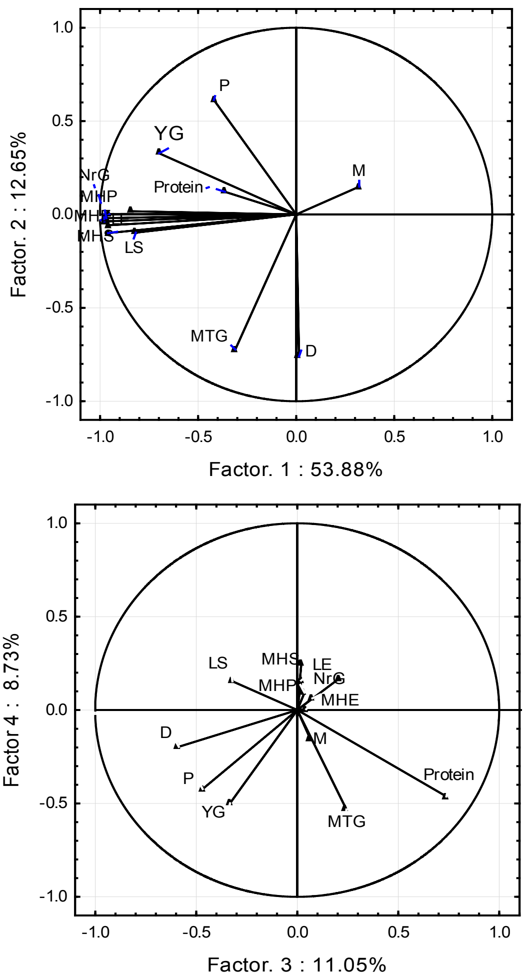

Fig. 2. PCA analysis. Four axes of the main components analysis (PC1, PC2 and PC3, PC4) showing the vectors of primary variable feature *i.e.* yield and elements of the yield structure and factors oat grain quality. The arrow points represent eigenvectors representing the force (determined by the length of the vector) and the direction of the correlation of the trait (primary variables) with respect to the principal components (PC1, PC2 and PC3, PC4). The position of the vectors of primary variables relative to each other indicates the correlation between these primary variables. Abbreviations for the variables are given thus: P – number of panicles per 1 m^2, MHP - weight of 100 plants, MHS-weight of 100 straws, MHE - weight of 100 panicle, LS – the length of straws, LE – the length of panicle, NrG - number of grains per panicle, MTG - weight of 1000 gains, M - grain moisture, D - Volumetric density of grain, Protein content, YG – grain yield.

The correlation of the examined yield, structure and grain quality parameters, and their relation to fertilization was analysed using the PCA method. PCA is statistical analysis used by many authors (Dehghani *et al*., 2008; Sabaghnia *et al*., 2011). Also, due to the simultaneously performed analysis of both quantitative and qualitative traits, the use of PCA appears more practical (Mohebodini *et al*., 2017).

In our research, four main components were derived. The relationship between the primary variables (tested parameters) and the calculated principal components is shown graphically in Fig. 2.The first component attributes 53.88% of the whole variance to the weight of plants, straw and panicle, the length of straw and panicle, the amount of grain in panicle and the yield of grain per hectare. The above variables are negatively correlated with the first principal component. The second principal component accounts for 12.65% of the whole variance by the number of plants (and ears) per 1 m^2 (positive correlation), and the weight of thousand grains (MTG) and grain volumetric density (negative correlation). The third principal component accounts for 11.05% of the variability of data by protein content (positive correlation) and grain volumetric density (negative correlation). The grain moisture, and partly MTG and yield, are negatively correlated with the fourth principal component which carries 8.7% of the variance of the original variables. For the latter two principal components, the vectors of primary variables are located at some distance from the edge of the circle, and, thus, their representation is poor. In general, these four principal components account for 86.3% of the total variance of the primary variables. The angles between the vectors representing the original variables of the yield structure are smaller than 90° which reflects a high positive correlation between the original variables. The angle > 90° between the vectors, representing the number of plants (panicles) per 1 m^2, MTG and grain volumetric density, indicates a strong negative correlation between these parameters. The PCA analysis showed a strong mutual correlation between the studied yield structure elements. However, a large number of principal components (four) may suggest that the yield and yield quality are affected not only by the studied factors.

The results of the experiment in question showed an important positive effect of zeolite and PK on the oat yield and yield structure, but no effect on grain quality. Similarly, no effect of zeolite on yield quality was reported by Junrungreang *et al*. (2002) for sugar content in sugar cane, and by Ozbahce *et al*. (2015) for protein content in bean. However, both authors observed a significant positive effect of zeolite on the yield. In contrast, Koljajic *et al*. (2003) reported that the zeolite addition significantly increased the protein and the fibre content in beet. Also, Jelic *et al*. (2013) reported that NPK fertilization did not affect the weight of 1000 grains and protein content, but it clearly differentiated the yield of oat grains. Probably, the quality of a given species is much more affected by their genetic features than by fertilization.

Despite the fact that in our experiment the fertilization did not significantly differentiate the weight of one thousand grains, the increase in both plant density and the amount of grain in panicle contributed to the increase in the oat yield per hectare under the influence of fertilization. Generally, the yield of the studied oat was low. According to the Coboru agricultural agency, the standard (average) yield of the Gniady variety is 6.2 t ha^{-1}. In our experiment, even for the PK variant, the average yield was about 38% of the latter value. Most probably, this is due to late sowing and very unfavourable weather conditions. The recommended sowing date is the middle of March, and in our experiment it was the beginning of April. The oat sieved earlier develops better roots and tillers, and uses the post-winter water more efficiently. Large rainfall shortages in June, occurring at the stages of panicle formation and at the beginning of the grain formation, could also reduce the yield. High water needs of oat in these stages result mainly from high transpiration rates (Danielewicz *et al.,* 2016; May *et al.,* 2004; Sułek, 2010). According to May *et al.* (2004), a delay in the sowing date reduces the oat yield, especially in dry years. In addition, the fore-crop has a significant impact on the yield of oat. In our experiment, oat was sown in monoculture. Despite its lower yield, monoculture oat is planted for phytosanitary reasons (Wanic *et al.*, 2004)). In the present studies, the yield was similar to that of different oat varieties that were grown after cereals (1.6-3.4 t ha^{-1} according to Bednarek *et al.,* 2013).

Our experiment showed that, despite the unfavourable weather and soil conditions, oat from PK and zeolite (4 and 8 t ha^{-1}) fertilization variants gave almost twice higher yield than that obtained in the control area (with N fertilization only). In the case of zeolite, the supply of potassium and phosphorus, as well as the storage of some extra water, may play a certain role in this matter. The zeolite application of 8 t ha^{-1} (similar to our experiment) significantly increased the cucumber yield as reported by Bozorgi *et al*. (2012).

CONCLUSIONS

1. An early application of Trans-Carpathian clinoptilolite had a favourable effect on the amount of oat plants per square meter, on the length of straw and panicle, and on the amount of grains in panicle.
2. No significant effects on the quality of oat grains were observed in different fertilization variants.
3. Zeolite doses of 4 and 8 t ha^{-1} increased the final oat yield to a similar extent as mineral P and K fertilizers.

Conflict of interest: The Authors do not declare conflict of interest.

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