Applicability of zeolites in potassium and nitrate retention in different soil types

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Abstract: Environmental protection and sustainable agricultural production require the use of inexpensive and environmentally acceptable soil supplements. Objectives of this study were to investigate the influence of the addition of the natural zeolite – clinoptilolite (NZ) and its iron(III)-modified form (FeZ) on the potassium and nitrate leaching from sandy, silty loam and silty clay soils. The zeolites were added in two amounts: 0.5 (FeZ) and 1.0 wt. % (NZ and FeZ). The experiments were carried out in columns organized in eight experimental systems containing unamended (control specimens) and amended soils. The concentration of K^+ and NO_3–N in the leachates was monitored during 7 days. The obtained results indicate that the K^+ and NO_3–N leaching mainly depends on the soil type and pH of the soil. The NZ and FeZ addition has the highest impact on the K^+ retention in the acidic sandy soil. The highest NO_3–N retention is obtained with FeZ in acidic silty loam soil. The K^+ leaching kinetics for all the studied soils follow the Avrami kinetics model with the parameter *n* < 1. This study demonstrates that NZ and FeZ can be a good soil supplement for the K^+ retention for all studied soils and in the NO_3–N retention for silty loam and silty clay soils.

Keywords: adsorption; clay; clinoptilolite; iron oxide; leaching.

INTRODUCTION

Chemical elements such as nitrogen and potassium are important for the plant growth and are widely used as fertilizers. Mineral fertilization improves the plant production but excessive fertilization leads to a decrease of the soil quality and causes environmental pollution. The extensive research efforts have focused on the improvement of the soil fertility and on a simultaneous prevention of nutrient loss to surface and ground water.[1]

Different soil amendments have been reported to reduce the nutrient leaching, to increase the nutrient holding capacity and water retention[2,3] as well as to improve the drainage control of soils.[4] Among them, natural zeolites attract great attention due their unique adsorption, ion-exchange, and molecular sieving properties.[5] These hydrated aluminosilicates, with a three-dimensional crystal structure have a porous lattice with geometrically shaped channels and cavities occupied by water molecules, and movable cations. Zeolites have a high cation exchange capacity (*CEC*), usually up to 300 mmol M^+/100 g depending of the Si/Al mole ratio[6], their specific surface area is up to 40 m^2 g^{-1}, and they exhibit a high affinity for the ammonium ion.[7] Some potassium-rich zeolites were recently reported to reduce the nitrate and ammonium leaching and increase their retention in sandy and sandy loam soils.[8,9] The NH_4-enriched natural zeolite was found to influence the physical and hydraulic properties of the soil and its use has been suggested as an adequate method for decreasing the chemical fertilizer application rates.[2] Also, due to a high water storage capacity, the use of zeolite contributes to water storage in soil, reducing the surface run-off and protecting soil from erosion.[10]

The aims of the present work were to study the influence of the addition of natural zeolite – clinoptilolite (NZ) and its iron(III)-modified form (FeZ) to three different types of soils on the leaching of potassium and nitrate ions using the columns of amended soils. The first type of soil was from Norway, classified as sandy, whereas two others were from the Balkan Peninsula: silty loam from Serbia and silty clay from Bosnia and Herzegovina. The soils were the subject of a research interest initiated by the Norwegian Programme in Higher Education, Research and Development (HERD) with the aim of contributing to the economic growth and social development of the Western Balkans.

EXPERIMENTAL

Materials

Natural zeolitic tuff (NZ) was provided from the Zlatokop mine (Vranjska Banja, Serbia). The tuff contained 73 wt. % of zeolite – clinoptilolite and quartz (12.8 wt. %) and feldspars (14.6 wt. %) as major impurities.[11] The chemical analysis of the clinoptilolite phase was performed by an energy dispersive X-ray spectroscopy using the scanning electron microscope (JEOL, JSM-6610LV, USA) taking into acount that a aluminosilicate phase with the Si/Al mole ratio of 4.5–5.5 belongs to clinoptilolite.[12] The analysis gave the following composition expressed by oxide mass %: SiO_2 – 68.71, Al_2O_3 – 12.07, Fe_2O_3 – 2.77, Na_2O – 0.58, K_2O – 1.65, CaO – 3.13 and MgO – 1.19; loss on ignition – 10.1.[13] For all experiments, the as--received NZ and its iron(III)-modifed form (FeZ) were used with the range of particle size 0.063–0.2 mm.

Modification of NZ was performed according to the procedure published by Habuda--Stanić *et al.*[14] The procedure included a treatment of NZ with Fe(III) ions in an acetate buffer solution (pH 3.6) followed by treatment with NaOH and NaCl. Fe(III)-containing sample

(FeZ) was than heated to dryness and calcined in air (500 °C, 1 h). The obtained FeZ contained 7.25 at. % of Fe belonging to maghemite Fe_2O_3 (JCPDS card No. 39-1346).[13]

The soil samples were collected from Norway (59°41'09" N and 10°46'37" E), Bosnia and Herzegovina (Kakanj, 44°07'53" N and 18°06'27" E) and Serbia (Varna, Šabac county, 44°40'24" N and 19°39'25" E). The samples were sourced from the top layer (0–20 cm) from different locations within the field site to minimize heterogeneity. Prior to the experiments the samples were homogenized at room temperature, air dried, sieved through a 2 mm sieve mesh and stored in polyethylene bags.

Potassium nitrate (KNO_3, 99 %) was used as a source of potassium and nitrate and purchased from Acros Organics, Morris Plains, NJ, USA.

Soil characterization

Mineral composition of the soil samples was obtained by a powder X-ray diffraction analysis using a Philips PW 1710 (Philips, Almelo, The Netherlands) diffractometer with the CuKα radiation ($\lambda = 0.15418$ nm) in the 2θ range 2–70° with a 2θ step of 0.02°. In order to obtain more detailed information on the clay minerals present, the soil samples were treated prior to the powder X-ray diffraction (PXRD) analysis by the following procedures: 1) air--drying, 2) saturation with ethylene glycol and 3) heating at 300 or at 550 °C.[15] Qualitative mineralogical composition was established according to Brown.[16] A semi-quantitative analysis of minerals was performed by measuring the peak intensities calculated from the PXRD patterns and by comparing them to the peak intensities of pure minerals.[17] The content of sand, silt and clay fractions in the soils were determined by pipette method.[18]

Physicochemical properties of the soils were analyzed using standard procedures: pH was measured in distilled water (with a soil to solution mass ratio of 1:2.5) at room temperature using Orion SA 720 pH meter[19] (Orion, Cambridge, MA, USA) while the organic content (OM) was determined as the loss on ignition at 550 °C[20] (Nabertherm, LE 6/11/B150, Lilienthal, Germany). Total nitrogen content (N_{TOT}) was determined by Dumas method,[21] where samples are heated with CuO at a high temperature in a stream of purified CO_2 and the gases liberated are led over hot Cu to reduce nitrogen oxides to N_2 and then over CuO to convert CO to CO_2. The obtained mixture of N_2–CO_2 is collected in a nitrometer containing the concentrated alkali which absorbs CO_2 and the volume of N_2 gas is the measure. The analysis of N_{TOT} was performed at 1050 °C using LECO CHN 1000 analyzer (LECO Corporation, St. Joseph, MI, USA). The concentration of the plant available K was determined by extracting the samples with an ammonium lactate solution by the Egners Al-method.[22] Soil samples were extracted with 0.1 mol dm^{-3} ammonium lactate solution and 0.4 mol dm^{-3} acetic acid (pH 3.7) with a soil to solution mass ratio of 1:20 for 90 min. Then, the concentration of K is measured by an inductively coupled plasma optical emission spectrometer (ICP-OES, Perkin-Elmer Optima 5300 DV, Waltham, MA, USA).

Leaching experiments

The leaching experiments were performed at room temperature using a column system. Columns were organized in eight experimental systems with three replications of each: I (only soil, control system), II (soil + KNO_3), III (soil + 1 wt. % NZ), IV (soil + 1 wt. % NZ + KNO_3), V (soil + 0.5 wt. % FeZ), VI (soil + 0.5 wt. % FeZ + KNO_3), VII (soil + 1 wt. % FeZ) and VIII (soil + 1 wt. % FeZ + KNO_3). The amount of added KNO_3 corresponded to 10 mg N (100 g soil)$^{-1}$ and 28 mg K (100 g soil)$^{-1}$ which amounts to 200 kg N and 550 kg K ha^{-1} soil. The N amount was the usually applied rate for grass (clover) production.[23] The K amount was high, compared to the usual agricultural production, but suitable for the leaching experiments

in which a high amount of water was used for irrigation. The amounts of NZ (1 wt. %) and FeZ (0.5 and 1 wt. %) corresponded to about 10 and 20 t zeolite ha^{-1}, respectively, which are suitable amounts to be used in the agricultural practice.[24]

Columns were prepared for each system by filling a Plexiglass column (diameter = 24 mm, length = 30 cm) manually with soil or with dry homogenized mixture of soil and amendments (NZ/FeZ or KNO_3). Homogenization of the solids was accomplished by a rotating shaker during 24 h using locked plastic beakers. The column was carefully knocked against the table to compress the soil to the same height in all systems. At the bottom of each column, a nylon filter covered with PVC balls (about 2 cm in height) was placed to prevent the loss of soil. In order to provide an effective distribution of water, the top of each column was covered with the PVC balls.

For the leaching experiment, the filled columns were previously saturated with distilled water and then regularly irrigated homogenously with distilled water from the top of the column, at a flow rate of 1.3 cm^3 h^{-1}. The flow rate corresponded to 500 mm of precipitation during 7 days in order to investigate the effect of NZ and FeZ addition on the leaching of K and NO_3–N through the heavy precipitation over a short period of time which is a real phenomenon in some countries such as Norway. All experiments were performed in the absence of light to prevent the possible grow of the plants which fragments or seeds are present in cultivated soils.

Leachate analyses

The leachates (of about 30 cm^3) were collected at the column bottom every day during seven days. The samples were stored in a refrigerator prior to the analysis. The K concentration was measured by a Corning 405 flame photometer (Corning, Halstead Essex, UK). The NO_3–N concentration was determined by a flow injection analysis (FIAstar 5000, ISO 13395--1996, FOSS, Hilleroed, DK).

The obtained results were analyzed by the different kinetic models, which are usually applied in studying the leaching kinetics: zero-order, first-order, second-order, parabolic diffusion, Elovich and Avrami model.[25,26] Statistical data analysis was done by the Paired Samples T-Test using statistical software – Statistical Package for the Social Sciences (SPSS, ver. 22). The statistical significance was defined at $p < 0.05$.

RESULTS AND DISCUSSION

Soil properties

The PXRD analysis confirmed the presence of different minerals in the soil samples (Fig. 1A–F). Nonclay minerals such as quartz (Q) and feldspar (F) were present in all three samples. Quartz was dominant in the Norway (NW) sample which is evident by diffractions at 2θ 20.81 and 26.63°. Diffractions at 2θ 13.90, 22.1, 23.6, 24.3, 28.1 and 30.2° correspond to feldspars which were an abundant mineral group in the NW sample.[27] The diffraction at 2θ 29.6° corresponding to calcite (C) was present only in the Bosnia and Hertzegovina (BH) sample.

To identify all clay minerals, the PXRD analysis was performed after each of the four soil treatments (Fig. 1). The NW soil displayed weak reflections related to clay minerals, confirming the low clay content. Kaolinite was present in the BH and Serbia (SRB) samples displaying diffractions at 2θ 12.4, 20.1, 25.7 and 35.1°. Saturation with ethylene glycol and heating at 300 °C did not affect the kao-
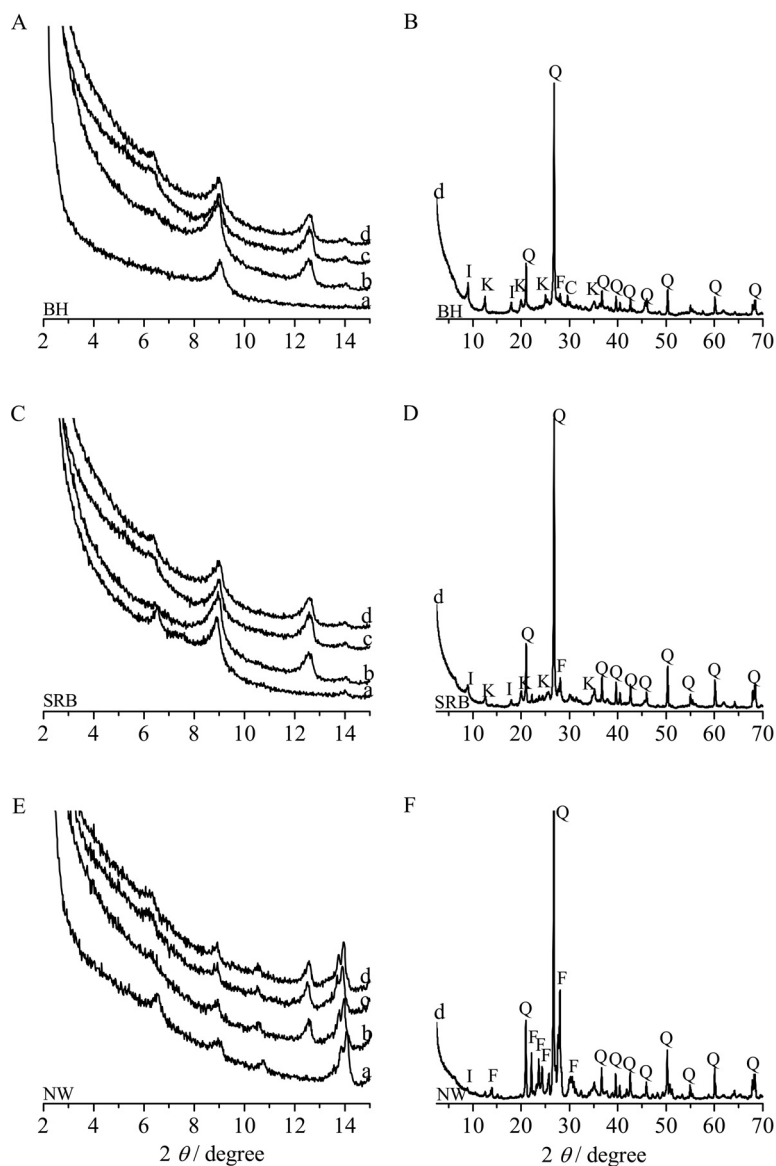
Fig. 1. Powder X-ray diffraction patterns of the soil samples; a - heating at 550 ºC; b - heating at 300 ºC; c - saturation with ethylene glycol; d - air-drying treatment (A, B - BH soil; C, D - SRB soil and E, F - NW soil).

linite crystallinity which structure collapsed after heating at 550 °C.[28,29] The diffraction at 2θ 12.4° which was present in the pattern of the NW sample most likely belongs to a second order reflection of vermiculite and chlorite which has its first order reflection at 2θ 6.5°. NW soil is less than 10,000 years old, which is

reflected in the presence of less weathered clay minerals as illite, vermiculate and chlorite.[30] The diffraction at 2θ 9.07° was found in all three patterns and it corresponds to illite (I). The diffraction was unaffected by treatments with ethylene glycol and heating. An additional diffraction of illite at 2θ 18.0° was evident only in the patterns of BH and SRB samples.

According to the World Reference Base and the content of sand, clay and silt fraction, the studied soil samples can be classified as sand soil (NW), silty loam (SRB) and silty clay (BH).

The selected physicochemical properties of the soil samples are given in Table I. The sandy and silty loam soil are acidic whereas the silty clay is slightly alkaline. The BH and SRB soils are old cultivated grasland and pasture with a higher content of organic matter and N_{TOT} than the NW forest soil. All soils contain the K rich clay mineral illitte which is reflected in the K-AL values. The BH soil has the highest clay content and a higher K content than the NW and SRB soils.

TABLE I. The selected physicochemical properties of the soil samples; OM – organic matter; N_{TOT} – total nitrogen; K-Al – concentration of the plant available K

Sample	Sand	Silt	Clay	OM[a]	N_{TOT}	pH	K-Al, mg kg^{-1}
			wt. %				
NW	94	3	3	1.3	0.01	5.1	10
SRB	4	73	23	4.3	0.16	5.7	115
BH	8	50	42	11.5	0.47	7.5	286

Potassium leaching

Leaching data were expressed as percentage of the leached K amount (*X*) over time. The *X* values were calculated as the ratio of the K amount (mg K kg^{-1} soil) leached from the soil after time *t* and the total K amount calculated as a sum of the plant available K and the K added by KNO_3 (mg K kg^{-1} soil). The calculated amount underestimates the real total K amount in the soils but probably represents the leaching potential for the experimental period of seven days.

For all studied systems, K leaching from the NW sample was higher than from the SRB and BH samples. In the control system I, 18.6 % of K was leached from the NW, 5.4 % from BH and 4.4 % from SRB soils. For the NW soil (Fig. 2) the addition of 1 wt. % of NZ and FeZ (systems III and VII, respectively) reduces K leaching. FeZ in comparison to NZ significantly reduced the K leaching (6.8 and 16.4 %, respectively). A slightly visible but statistically significant reduction ($p < 0.05$) was also evident for the SRB and BH samples after the addition of zeolites (not shown).

The system II included the addition of KNO_3 as a typical mineral fertilizer to the soil samples. The influence of the zeolite addition on the K leaching amounts and the kinetics was studied in the systems IV, VI and VIII. For the NW soil the

addition of NZ reduced the K leaching from 44.6 to 26.0 % whereas FeZ reduced the K leaching depending on the zeolite amount as follows: to 27.0 % (0.5 wt. % FeZ, the system VI) and to 12.0 % (1.0 wt. % FeZ, the system VIII). The results clearly showed a positive effect of FeZ on the K retention in the sandy soil.
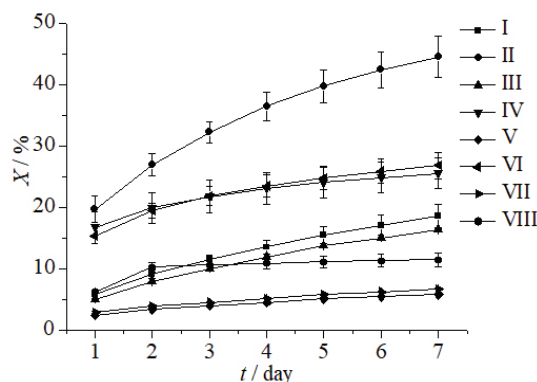

Fig. 2. Percentage of leached potassium (X) over time from NW soil (systems: I – soil; II – soil + KNO₃; III – soil + NZ; IV – soil + NZ + KNO₃; V – soil + FeZ 0.5 wt. %; VI – soil + FeZ 0.5 wt. % + KNO₃; VII – soil + FeZ 1 wt. %; VIII – soil + FeZ 1wt. % + KNO₃).

The K leaching from SRB and BH samples in the system II was significantly smaller (8.3 and 6.0 %, respectively) than from the NW sample, confirming that clayey soils have a higher retaining ability for K than sandy ones. For these two samples the addition of both forms of zeolite had a positive effect on the K retention. 1.0 wt. % of FeZ reduced the K leaching from the SRB sample to 3.3 % and to 4.2 % for the BH sample.

The K leaching is most pronounced for the NW sample confirming a high mobility of K from sandy soils.[31,32] Both NZ and FeZ improve the K retention which is evident in the control system as well as in the systems containing KNO₃. The better efficiency of FeZ than of NZ could be explained by a better adsorption ability of FeZ towards K than that of NZ. The FeZ contains particles of Fe₂O₃ at the surface of the clinoptilolite phase, which enhances the adsorption ability of the zeolite towards different cations.[33] The K⁺ sorption mechanism for NZ proceeds by ion-exchange, whereas for FeZ physisorption can also participate.

In contrast to the sandy NW soil, the NZ addition has a very low reduction effect on the SRB and BH samples, which are silty loam and silty clay, respectively. The presence of FeZ has a somewhat higher effect, which could be attributed to its better adsorption ability. The results clearly show that the K leaching depends on the soil type.

The kinetics data were analyzed by the different kinetics models given in Table II. The best agreement ($R^2 \approx 1$) was found for the Avrami model. The values of n (Avrami constant) and ln k_A (k – Avrami rate constant of the K leach-

ing) were calculated from the slope and the intercept of the plot $\ln [-\ln (1–X)]$ *versus* $\ln t$, respectively. The obtained values of the parameters and coefficients of determination (R^2) are shown in Table II. The model has earlier been applied to batch and dynamic column systems[34–36] describing well kinetics of different processes including mineral dissolution[37] and leaching.[26] According to the Avrami model, the parameter n describes the mechanism of the leaching process: the initial rate of reaction approaches zero for $n > 1$, being infinite and decreases with time for $n < 1$ or being finite for $n = 1$. It is evident that the Avrami parameter n for all the studied systems indicates that the initial rate of leaching is high and decreases with time ($n < 1$).

TABLE II. Kinetic models used to describe the K leaching; q_t and q_0 – the amounts of leached K from soil (mg kg^{-1}) after time t (day) and at $t = 0$, respectively; k_0 – zero-order rate constant (mg kg^{-1} day^{-1}); k_1 – first-order rate constant (day^{-1}); k_2 – second-order rate constant ((mg K kg^{-1})$^{-1}$); k_p – diffusion rate constant ((mg K kg^{-1})$^{-0.5}$); α_s – initial K leaching rate (mg K kg^{-1} day^{-1}); β_s – K leaching constant (mg K kg); X – percentage of the leached K; k_A – Avrami rate constant of K leaching; n – Avrami constant

Kinetic model	Equation	R^2	Mean	Ref.
Zero-order	$q_t = q_0 - k_0 t$	0.5954–0.9999	0.96	38
First-order	$\ln q_t = \ln q_0 - k_1 t$	0.6007–0.9999	0.97	38
Second-order	$1/q_t = 1/q_0 - k_2 t$	0.6060–0.9999	0.97	38
Parabolic-diffusion	$q_t = q_0 + k_p t^{0.5}$	0.7063–0.9998	0.98	40
Elovich	$q_t = 1/\beta_s \ln (\alpha_s \beta_s) + 1/\beta_s \ln t$	0.8165–1	0.96	40
Avrami	$\ln [-\ln (1–X)] = \ln k_A + n \ln t$	0.8823–1	0.99	41

Kinetic parameters of the K leaching obtained by Avrami model								

System	NW			SRB			BH		
	n	$\ln k_A$	R^2	n	$\ln k_A$	R^2	n	$\ln k_A$	R^2
I	0.6313	–4.8042	0.9997	0.9051	–7.7212	0.9998	0.8770	–7.3682	0.9997
II	0.5111	–3.1322	0.9997	0.6430	–5.7606	0.9994	0.5633	–5.6299	0.9904
III	0.6367	–4.9709	0.9998	0.8941	–7.6740	0.9999	0.8232	–7.1861	0.9991
IV	0.2430	–2.4508	0.9979	0.6099	–5.6914	0.9990	0.4702	–5.5571	0.9942
V	0.4566	–5.1479	0.9993	0.8882	–7.8628	1	0.7639	–7.2289	0.9988
VI	0.3176	–2.7720	0.9977	0.5391	–5.6109	0.9940	0.6856	–6.2227	0.9980
VII	0.4396	–4.9191	0.9993	0.8185	–7.5899	0.9999	0.7589	–7.1802	0.9988
VIII	0.2875	–3.4967	0.8823	0.6793	–6.9145	0.9962	0.7759	–7.1196	0.9999

Nitrate leaching

Previous study showed that NZ has no affinity towards nitrates, contrary to the Fe(III)-modified form (FeZ) which adsorbs nitrate.[13] Nitrate ions have some ligand ability and it seems likely that nitrate, like arsenate, selenite or phosphate ions forms innersphere complexes with oxide particles of iron(III).[42–44] Due to its binding ability towards nitrate ions, the FeZ was studied in the column leaching experiment as a soil supplement.

The NW and SRB samples exhibited significantly lower leaching rate in the control system I (0.9 and 4.9 mg kg^{-1}, respectively) in contrast to the BH sample (21.9 mg kg^{-1}). The addition of both NZ and FeZ had a positive effect on the NO$_3$-N retention in the SRB and BH samples (Fig. 3). The leaching amounts were significantly reduced by NZ (2.7 and 16.3 mg kg^{-1}, respectively). The influence of FeZ depended on its amount. The results from the system VII show that adding 1.0 wt. % FeZ decreases the leaching amount from the SRB sample to 1.9 mg kg^{-1} and to 11.1 mg kg^{-1} for the BH sample. However, NZ and FeZ exerted negative effect on the NO$_3$–N leaching from the NW sample (a slight increase in the leached NO$_3$–N was observed) which was also evident in all other treatments (not shown).
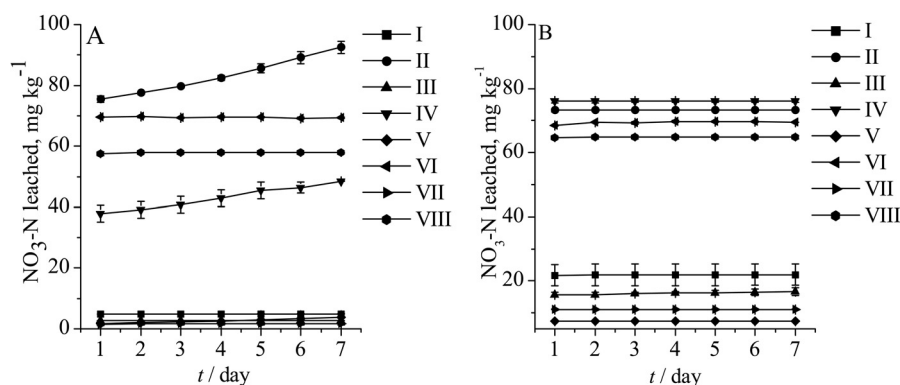

Fig. 3. Amount of the leached NO$_3$–N for the studied systems over time from SRB (A) and BH (B) soils (systems: I – soil; II – soil + KNO$_3$; III – soil + NZ; IV – soil + NZ + KNO$_3$; V – soil + FeZ 0.5 wt. %; VI – soil + FeZ 0.5 wt. % + KNO$_3$; VII – soil + FeZ 1 wt. %; VIII – soil + FeZ 1wt. % + KNO$_3$).

For the SRB and the BH soils the addition of FeZ and NZ had a positive influence on the NO$_3$–N leaching in the systems with KNO$_3$ (systems IV, VI and VIII). For the SRB soil, NZ and FeZ (1.0 wt. %) showed a similar effect: the leached amount of NO$_3$–N was reduced from 94.0 to about 55.0 mg kg^{-1}. For the BH sample, FeZ showed a better retention effect than NZ: the leached amount of NO$_3$–N was reduced from 73.0 to about 65.0 mg kg^{-1}.

The retention of NO$_3$–N is higher in the SRB soil than in the BH soil, which could be attributed mainly to the differences in physicochemical properties of these two soil types. The BH soil is alkaline in contrast to the acidic SRB soil and in the BH soil the nitrate ions seem to compete with hydroxide ions for the adsorption sites on the zeolite surface. A similar effect has been reported for Italian chabazite added to the silty clay and to a sandy soil.[45]

Irrespective of the soil types or treatments, the highest amount of NO$_3$–N leached out during the first day of experiment (about 90 %) and then the leaching

proceeded slowly until the end of the experiment, which could be attributed not only to a high amount of irrigation water, but also to high nitrate solubility.

In this study, we investigated the effectiveness of natural zeolites in the prevention of leaching potassium and nitrate ions using the columns of amended soils. To get an insight into the flow and transport properties on the soils, tracer tests[46–48] and flow interruption techniques[49] should be performed. Modelling of the results will likely get the relevant information on the mobility of the target species and their leaching behaviour. These tests and analyses are planned for future research.

CONCLUSIONS

The obtained results showed that the addition of zeolites had a retention effect towards K which depends on soil types. The effect increased in the following order: silty loam < silty clay << sandy soil. The FeZ exhibited a better retention effect than NZ which was attributed to the presence of Fe_2O_3 at the NZ surface. The K leaching kinetics followed the Avrami model for all three soil types. The Avrami n parameter was smaller than 1, indicating a fast initial leaching rate which decreases with time.

The NO_3–N leaching was reduced by the zeolite addition only for the silty loam and silty clay soils. Both NZ and FeZ showed a better NO_3–N retention effect in the silty loam which was acidic than in the alkaline silty clay soil. This was explained by a competition between hydroxide and nitrate ions for the adsorption sites at the zeolite surface.

The nitrate pollution from agricultural sources is a severe problem all over the world mainly due to poor agricultural management practice, resulting in the application of a high rate of nitrogen fertilizers. The results from this study are important for the agricultural practice since they clearly show benefits of the natural zeolite application in the K retention for all studied soils and in the NO_3–N retention for silty loam and silty clay soils.

И З В О Д

ПРИМЕНЉИВОСТ ЗЕОЛИТА У ЗАДРЖАВАЊУ КАЛИЈУМА И НИТРАТА У
РАЗЛИЧИТИМ ВРСТАМА ЗЕМЉИШТА

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Заштита животне средине и одржива пољопривредна производња захтевају упо-
требу економски и еколошки прихватљивих суплемената. Циљ овог истраживања био је
да се испита утицај додатка природног зеолита – клиноптилолита (NZ) и гвожђе-моди-
фикованог зеолита (FeZ) на излуживање калијума и нитрата из три врсте земљишта:
пескуше, прашкасте иловаче и прашкасте глине. NZ и FeZ су додати у количини: 0,5 и
1,0 мас. %. Експерименти су изведени у колонама, коришћењем осам експерименталних
система. Концентрација калијума и нитрата у филтратима праћена је током седам дана.
Добијени резултати показују да излуживање калијума и нитрата зависи од врсте зем-
љишта и pH вредности земљишта. Додатак NZ има највећи утицај на задржавање кали-
јума у киселом, песковитом земљишту. Највећи степен задржавања нитрата остварен је
додатком FeZ у киселу, прашкасту иловачу. Кинетика излуживања калијума за све ана-
лизиране системе следи кинетику Avrami модела. Ово истраживање показује да је NZ
добар суплемент за задржавање калијума у свим анализираним земљиштима и за задр-
жавање нитрата у прашкастој иловачи и прашкастој глини.

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