Carpathian Journal of Earth and Environmental Sciences, September 2011, Vol. 6, No. 2, p. 135 - 142

EFFECT OF INORGANIC AMENDMENTS ON GROWTH OF RYEGRASS AND PROPERTIES OF A SANDY SOIL

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Abstract: A greenhouse pot experiment was conducted to study the effect of natural zeolite and NPK application on the ryegrass and chemical properties of a sandy soil. The soil and plant samples were collected and analyzed for the pH, humus, cation exchange capacity, available P and K, total N, Cu, Zn, Mn, Fe and Ca and clay, and for the total P, K, Ca, Mn, Cu, Zn and Fe respectively, by the standard methods. The results showed that application of both zeolite and NPK resulted in a significantly increase in the shoot and roots yield of ryegrass compared to control. The highest yields were recorded in the treatment receiving 6 q zeolite ha^{-1} and NPK. The addition of zeolite to the soil improved uptake of P, K, Ca, Mn, Cu and Fe by 29.11%, 26.11%, 10.44%, 11.84%, 10.43%, and 37.01%, respectively. Among the various treatments, application of 6 q zeolite ha^{-1} and NPK was also found to be the best treatment in enhancing the uptake of Ca, Mn and Cu by ryegrass. The correlation analysis revealed the vital role of Ca, Cu and K in the yield of ryegrass. All the treatments generally decreased the analyzed soil properties. However, a significant decrease in humus, N, P, Ca, Fe and Zn losses due to application of zeolite and NPK was noticed. The zeolite at 6 q ha^{-1} + NPK was most significant in increasing crop yield and in maintaining and improving soil properties and nutrient status in soil.

Key words: natural zeolites; NPK fertilizers; nutrient uptake; problem soil; ryegrass; Albania

1. INTRODUCTION

It is of the utmost importance to make an efficient use of agricultural land in Albania. This because the area of agricultural land per capita (of about 0.2 ha) is lower compared to other European countries (Gjoka et al., 2004), and a great part of the land (about 27%) is occupied by problem soils, including sandy soils (Institute of Soils Study, 1985). The problem soils have such conditions which can severely limit their use for agriculture (White, 1997). The sandy soils generally are characterized by low organic carbon content, low water and nutrient storage capacity, high infiltration rate, and excessive deep percolation losses (FAO, 2001). These assertions dictate improving water and fertilization management to increase the crop performance and decrease the pollution of groundwater. One approach in this direction is utilization of natural zeolites. The zeolites have emerged as having considerable potential in a wide variety of applications, including agronomy and horticulture (Mumpton, 1999a). The use of zeolites in combination with other soil amendments (organic and inorganic fertilizers) was reported to improve the soil properties and increase the yields of crops (Allen & Ming, 1995, Mumpton, 1999b, Stead et al., 2002, Beqiraj Goga et al., 2008, Glisic et al., 2009). However, little is known about the effect of zeolite application on yield and nutrition of crops in the sandy soil, while in Albania this information is missing. Beqiraj Goga (2005) indicated that the natural zeolites from deposits of Munella, northern Albania, with Ca-trend, have optimal physical and chemical properties and can be used as soil amendments (Beqiraj Goga, 2005).

The present study was therefore, undertaken with the objective to find out the effect of application of natural zeolite (Stilbite-Stellerite) and inorganic fertilizers (NPK) on the performance of ryegrass crop *(Lulium multiflorium L.)*, and chemical properties of a sandy soil (Haplic arenosol, WRB – 1998).

2.1 Mineralogical and chemical analyses of the zeolitic material

The zeolitic material used in this study was obtained from the region of Munella, northern Albania. Zeolites from Munella region occur as separated layers intercalated with volcanic rocks of the eastern ophiolitic belt of Mirdita tectonic zone (Fig. 1). On the basis of petrographic characteristics and chemistry (Beccaluva et al., 1994), the following volcanic rocks, can be recognized within the ophiolitic complex of Albania: basalts and basaltic andesites, dacites and rhyolites. Based on SiO_2 content, zeolitic rocks from Munella region are classified as andesites –rhyodacites, i.e. they are basalts enriched in Si and poor in Ti.

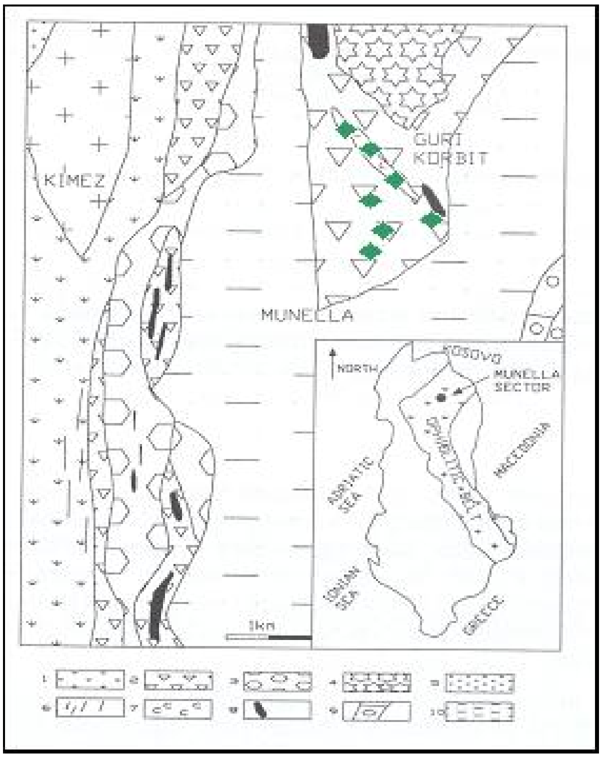

Figure 1. Geological map of Munella region (1:50000). 1-Basalt; 2- Andesite; 3- Dacite; 4- Rhyolite; 5- Plagiogranite; 6- Shetted Dyke; 7- Zeolitic rocks; 8- Sulphide Sulphide mineralization; 9- Limestones (Cr_1); 10-Melange ($J_3^t – Cr_1$).

From mineralogical point of view, the zeolite minerals can be classified to the "Heulandite" group, of Stilbite family identified as stilbite-stellerite solid solution (SS), which represents the main mineralogical phase of the zeolitic rocks. The content of zeolites comprises 75-80 % of the zeolitic rocks. The rest of the mineral assemblage consists of chlorite, quartz, carbonates (calcite and dolomite), scarce smectite and amorphous material. This later is represented by volcanic glass and the chlorite/smectite (Cl/S) gelatin mixture.

The zeolitic rocks were analyzed for the bulk chemical properties by the X-/fluorescence, in Activition Laboratories LTD, Canada (Table 1).

Table1. Chemical analyses of samples from zeolitic rocks

Sample	Mu1	Mu2/3	Mu3/5	Mu4/1	Mu5	Mu6
SiO_2	60,95	72,70	60,20	,26	64,77	69,97
Al_2O_3	11,97	10,08	12,44	11,63	11,40	10,10
Fe_2O_3	5,84	4,13	5,69	4,27	5,48	3,21
MnO	0,056	0,053	0,072	0,083	0,092	0,080
MgO	2,07	0,82	1,19	0,97	0,90	0,37
CaO	5,18	2,90	6,15	4,72	4,71	4,72
Na_2O	0,27	1,82	0,39	0,98	0,58	0,28
K_2O	0,09	1,01	0,14	0,54	0,80	0,27
TiO_2	0,378	0,308	0,411	0,362	0,364	0,305
P_2O_5	0,10	0,08	0,16	0,09	0,09	0,07
LOI	13,01	6,48	13,27	11,00	1,11	10,84
Total	99,92	100,38	100,11	99,89	100,28	100,23

The microprobe analysis of the zeolitic phases showed Si/Al and Na+K/Na+K+Ca+Mg ratios that range from 3-3.5 to 0.01-0.18, respectively (Beqiraj Goga, 2005). The most representative sample was tested for value of CEC and its selectivity according to the procedure proposed by Collela et al., 1982; Pansini, 1996; and Capelleti et al., 1999. The tests found that the zeolite has a cation exhange capacity of 190 -242 meq/100g, and the following selectivity for cations: $Zn^{2+} < Cu^{2+} < Pb^{2+}$ (Beqiraj Goga et al., 2008).

From genesis point of view, based on mineralogical, geochemical and isotopic data ($^{87}Sr/^{86}Sr$), the zeolitic rocks are the product of a continuous alteration process that started with an extensive palagonization of the volcanic glass. It was followed by K-Na zeolite formation and concluded with low-grade metamorphism products. This later is responsible for the depletion in K and Na and, as a consequence, the deviation of the SS solid solution towards the Ca-member (Stellerite) (Beqiraj Goga, et al., 2008).

2.2 The experimental soil

The soil used in the experiment was taken from the Ap horizon (0-30 cm) of a production field in Divjaka village, Lushnje. The soil represented sandy soil (sand 89.4%) belonging to haplic arenosol (FAO, 2001) (Table 2).

The soil had a low maximal water capacity (30.21%). It was alkaline in reaction (pH H_2O 8.5); low in humus (0.8%) and nitrogen (0.07%); medium in available phosphorous (1.32 mg $100g^{-1}$) and potassium (7.5 mg $100g^{-1}$), total calcium (8.8%), iron (4.6%), zinc (78.4 mg kg^{-1}) and copper (44 mg kg^{-1}); and low in manganese (0.07%), (Table 2). Because of these properties, this soil could be considered as a problem soil.

Table 2. Initial properties of the surface soil (0-30 cm)

Soil property/Unit	*Value*
pH (H_2O)	8.5
Humus (%)	0.8
Total N (%)	0.07
Available P (mg $100g^{-1}$)	1.32
Available K (mg $100g^{-1}$)	7.5
KKK (me $100g^{-1}$)	11.5
Maximal water capacity (%)	30.21
Sand (%)	89.4
Silt (%)	8.0
Clay (%)	2.6
Total Cu (mg kg^{-1})	44.0
Total Zn (mg kg^{-1})	78.4
Total Mn (%)	0.07
Total Fe (%)	4.6
Total Ca (%)	8.8

2.3 Setting up the experiment

A pot culture experiment was conducted in a glass-house of Agricultural University of Tirana, Albania (Fig. 2). One kg of air-dried and processed sandy soil was filled in each plastic pot for growing the test crop.

Figure 2. View of the experiment.

The experiment was laid out in a randomized block design with seven treatments replicated four times as detailed below:

T_1-Control;
T_2-NPK (148:75:60 kg ha^{-1} active substance);
T_3 -Zeolite 6 q ha^{-1};
T_4 -Zeolite 12 q ha^{-1};
T_5 -Zeolite 6 q ha^{-1} + NPK;
T_6 -Zeolite 12 q ha^{-1} + NPK;
T_7 -Zeolite at 5% (w/w basis).

Ryegrass seeds *(Lolium multiflorium L.)* were sown at the rate 1 pound/1000 square feet. A basal dose of 148 kg N, 75 kg P and 60 kg K per ha was applied.

The N was supplied as ammonium nitrate (by 34% N) and urea (by 46% N), P as granular superphosphate (by 20% P) and K as potassium sulphate (by 50% K).

Nitrogen was applied in 3 splits (basal 46 kg N per hectare and 3 top-dressings of 34 kg N per hectare each), and phosphorus and potassium as basal. The moisture level was kept at 70% of water capacity (55% in the initial phase), based on gravimetric method.

Several phenological observations and biometric measurements of plants are performed. The plants were cut at the maturity time, 2 cm above ground level, stored in paper containers and dried for 15 h at 60^oC temperature. After that, plant material was ground, sieved and stored in the glassy vessels.

2.4 Plant and soil analyses

The plant and soil analyses were conducted according to Albanian Standards (Directory of Standardization, 2007). The processed plant samples were digested in diacid mixture (H_2SO_4+$HClO_4$ in 2:1 ratio) and utilized for analysis of P, K, Ca, Mn, Cu, Zn, and Fe by the atomic adsorption spectrometer method (after Albanian Standards 1584/33: 1995).

The soil samples were taken from each treatment after the experiment for analyses of the main physicochemical properties. The soils were air-dried and sieved to < 2 mm. The particle size distribution was determined by the combined sieving and pipette method after dispersion in Na-pyrophosphate (after Albanian Standards 1584/14: 1990), pH (1:2.5) on suspension in 1 *N* KCl and distillated water using a pH-meter (after Albanian Standards 1584/9: 1989), carbonates by the gas-volumetric method using a calcimeter (after Albanian Standards 1584/7: 1989), humus by the Tyurin method (after Albanian Standards 1584/8: 1989), total N by the Kjeldahl method (after Albanian Standards 1584/2: 1989), CEC by barium saturation ($BaCl_2$ 1N, at pH 7) (after Albanian Standards 1584/32: 1994); available phosphorus was extracted by $NaHCO_3$ 0.5 M and determined by the Olsen method (after Albanian Standards 1584/5: 1989), exchangeable potassium was extracted by $NaHCO_3$ 0.5 M and measured by flame photometer (after Albanian Standards 1584/6: 1989), and total Cu, Zn, Mn, Fe and Ca concentrations were determined in Aqua Regia extract (AR) by the atomic adsorption spectrometer (AAS) (after Albanian Standards 1584/30: 1993).

The data were analyzed by ANOVA. The LSD test at $p<0.05$ was used for mean separation.

3. RESULTS AND DISCUSSION

3.1 Effect of soil amendments on dry matter yield of ryegrass

The application of zeolite as well as NPK fertilizers resulted in a significant increase in the shoot yield of ryegrass compared to control (T_1), but the yield due to alone application of zeolite at 6 and 12 q ha^{-1} (T_3, T_4) or in combination with NPK (T_5, T_6) did not differ significantly with the yield obtained under NPK treatment (T_2) (Fig. 3).

Among the various treatments, the combined application of zeolite at 6 q ha^{-1} and NPK (T_5) recorded the highest yield of shoot (4.29 g pot^{-1}). It seems that zeolite functioned as a good regulator of plant nutrition (by macro- and micronutrients) in the studied soil, which was alkaline in reaction and calcareous (see table 2). Although such properties affect the extent of phosphorous fixation in the soil (Nyle & Ray, 2002), the application of zeolite reduced the fixation of added phosphorous, improving the efficiency of phosphatic fertilizers.

The similar results are reported by other authors. Thus, it is shown that the application of zeolite: increased the amount of phosphorous in soil because of having phosphorous (P_20_5) in its structure and due to reduction of leaching (Mumpton, 1999a); reduced the leaching of ammonium and nitrate from the soil and increased the potassium status (Abdi et al., 2006), and improved the water use efficiency (Yasud et al., 1995, quoted by Abdi et al., 2006).

The applications of zeolite alone at 12 q ha^{-1} (T_4) or in combination with NPK ($T_{5,}$ T_6) and NPK fertilizers (T_2) increased the shoot yield significantly over application of zeolite at 5% (T_7).

The poor performance of zeolite applied alone at high dose may be explained with its potential for metal immobilization, including plant nutrients, due to its high ion exchange capacities and highly porous structure, and with its lower chemical reactivity in alkaline soils (where pH is > 8; Koon & Kaufmann, 1975, quoted by Venglovsky et al., 2005).

The order of increase in shoot yield of ryegrass was in the sequence: Zeolite 6 q ha^{-1} + NPK > Zeolite 12 q ha^{-1} + NPK > NPK > Zeolite 12 q ha^{-1} >Zeolite 6 q ha^{-1} >Zeolite at 5% > Control.

The shoot yield (y, g pot^{-1}) was regressed against the zeolite and NPK levels (Z and NPK, g pot^{-1}) applied as:

$$Y=3.603-0.012*Z+1.742*NPK$$

As regards yield of roots, aapplication of zeolite alone ($T_{4,}$ T_7) or in combination with NPK (T_5, T_6) increased significantly the yield of roots over the control, but this increase was not significantly over the NPK, except application of zeolite at 6 q ha^{-1} with NPK (T_5) (Fig. 4).

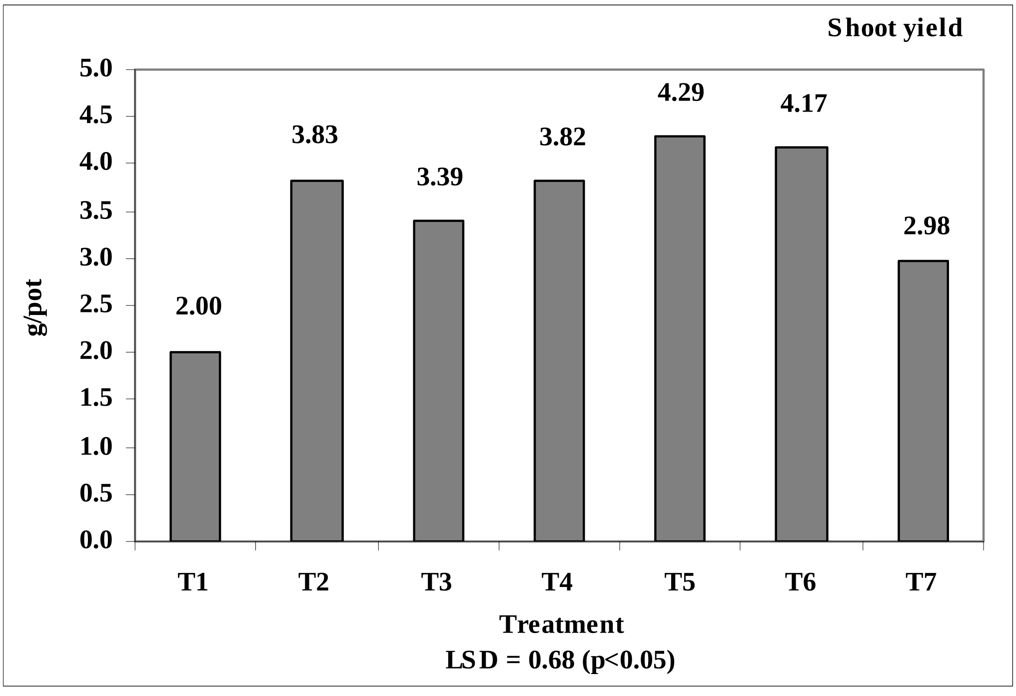

Figure 3. Variation in ryegrass shoot yield by treatments

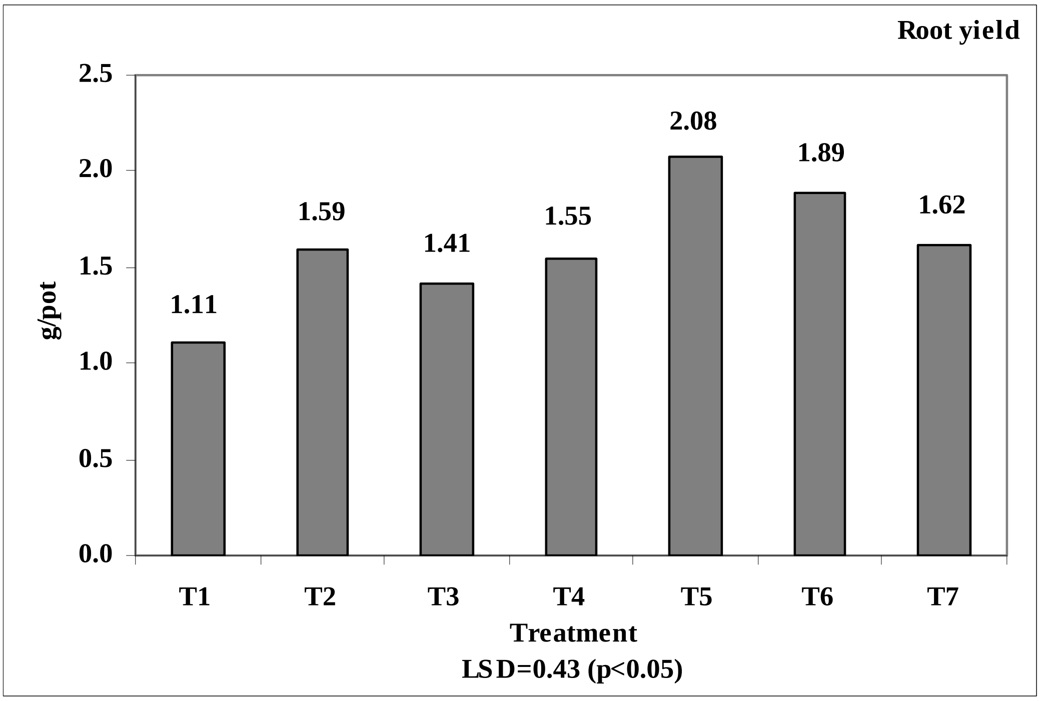

Figure 4. Variation in ryegrass roots yield by treatments

This application gave the highest yield of roots (2.08 g pot^{-1}). Application of zeolite at 5% recorded the highest root/shoot ratio (0.54) compared to other zeolite and NPK treatments. The shoot yield of ryegrass was found to has significant correlation with zeolite dose applied alone (r=- 0.857*), with total soil Zn (r=-0.786*), with $CaCO_3$ (r=-0.761*), with total shoot Mn (r=-828*) and Cu (r=-0.828*) and with Ca (0.999**), Cu (0.947**) and K uptake (0.849*). While, roots yield showed significant correlation with Cu (0.890**) and Ca uptake (0.847*) and with $CaCO_3$ (-0.773*). The roots yield was also correlated with shoot yield (r=0.849*).

The study reveals the interplay between nutrients in soil and shoot and yield. Nutrients like Ca, Cu and K play vital role in yield of ryegrass. The lower values of the correlation coefficients obtained for the relationship between the shoot yield and uptake of P (r=0.512), Mn (r=0.267), Zn (r=0.242) and Fe (r=0.295) suggest that these nutrients could not be implied as limiting factors for the growth of ryegrass.

3.2 Effect of soil amendments on nutrient content and uptake

The application of zeolite differentiated the content of nutrients in shoot of ryegrass (Table 3). The zeolite led to a considerable increase in the content of phosphorous (0.57% in T_3), potassium (1.96% in T_4), iron and calcium (0.048% and 0.228% in T_7), and zinc (0.055% in T_6) in shoot. The increase in contents of these elements in shoot is probably attributable to their greater availability in soil, which was increased by soil's acidification due to nitrification of ammonium.

The ammonium ions in the soil studied derive from the inorganic fertilizers used (e.g. ammonium nitrate and urea) and biological decomposition of soil organic material.

Table 3. Effect of treatments on nutrient contents in ryegrass shoot

Treatment	*P*	*K*	*Ca*	*Mn*	*Cu*	*Zn*	*Fe*
	(%)						
T_1 - Control	0.404	1.767	0.214	0.016	0.040	0.053	0.026
T_2 - $N_{148}P_{75}K_{60}$	0.299	1.434	0.202	0.011	0.030	0.051	0.016
T_3 -Zeolite 6 q ha^{-1}	0.571	1.711	0.206	0.012	0.034	0.053	0.033
T_4 - Zeolite 12 q ha^{-1}	0.345	1.963	0.205	0.012	0.030	0.054	0.029
T_5 - Zeolite 6 q ha^{-1} + NPK	0.357	1.520	0.210	0.011	0.030	0.010	0.022
T_6 - Zeolite 12 q ha^{-1} + NPK	0.308	1.723	0.222	0.011	0.025	0.055	0.033
T_7 - Zeolite at 5%	0.270	1.548	0.228	0.013	0.026	0.052	0.048

The zeolites are known for high affinity to ammonium ions. Leggo & Ledésert (2006) showed that ammonium ions, produced from the biological decomposition, are absorbed and exchanged by potassium into the soil pore water. The ammonium ions then oxidized to nitrate, increasing available nitrate-nitrogen. As a consequence of nitrification free hydrogen ions are produced that have the effect of dissociating metal cations from soil particles causing extensive mineralization in the soil.

The highest content of copper (0.04%) and manganese (0.016%) in shoot was observed in control. The increased content of copper is probably related to the selectivity for this cation ($Zn^{2+} < Cu^{2+} < Pb^{2+}$) of the zeolite used (Beqiraj Goga, 2005). Thus, the zinc can be up taken by plant more easily than copper which is probably fixed in porous structure of zeolite. Various cations interact differently with various zeolite framework and their associated electrical fields. This explains why zeolites display different affinities for cations (Pansini, 1996).

While the increased content of manganese in control may be due to high binding capacity of Fe-Mn oxides and aluminosilicates for metals. Thus, the immobilizing capacity of MnO_2 was higher than that of other metals. These effects were assumed to be related to immobilization of metals due to formation of insoluble metal-organic complexes and increased cation exchange capacity (Singth & Oste, 2001).

Correlation study showed that shoot P was negatively correlated with available soil P (r=-0.761*) and exchangeable soil Cu (r=-0.825*); shoot Ca was positively correlated with shoot Fe (r=0.876**) and negatively correlated with soil total Fe (r=-0.932**); shoot Mn was positively correlated with shoot Cu (r=0.999**), exchangeable soil Zn (r=0.951**) and total soil Zn (r=0.931**); shoot Cu was positively correlated with exchangeable soil Zn (0.951**) and total soil Zn (r=0.931**); shoot Fe was negatively correlated with total soil Fe (r=-0.922**).

The effect of zeolite and NPK fertilizers on nutrients uptake by ryegrass followed the same trend as the nutrient contents in shoot (Table 4). Compared to the control, higher uptake was observed under the treatments with zeolite applied alone (P, K and Fe) or in combination with NPK (Ca, Mn, Cu and Zn).

The improved uptake of nutrients stimulated by the zeolite was: 29.11% for P, 26.11% for K, 10.44% for Ca, 11.84% for Mn, 10.43% for Cu, and 37.01% for Fe. Thus with a such increase in assimilation of iron, the relative proportion of Cu and Mn in the total amount of micronutrients taken up by plants was lower than in the treatment with NPK fertilizers. According to calculations, the total K uptake by ryegrass exceeded the amount of the K applied as potassium sulphate (16 mg K/pot) showing that the soil and probably zeolite were important factors in the K uptake by the crop.

The dependence between the uptake of P, K, Ca, Mn, Cu, Zn and Fe and the contents of these nutrients in shoot of ryegrass was determined by the values of correlation coefficients (*r*): 0.694, 0.355, -0.154, 0.258, -0.633, 0.840*, and 0.713, respectively. The significant correlations between the P uptake and exchangeable soil Cu (-0.773*); the K uptake and Ca (r=0.839*) and Cu uptake (r=808*); the Ca uptake and Cu uptake (r=0.944**), shoot Mn (r=-833*) and Cu (r=-833*), CaCO3 (r=-0763*) and total soil Zn (r=-0.795*); the Fe uptake and shoot Ca (r=0.832*), soil CEC (r=0.859*), and total soil Fe (r=-0.764*) were also seen.

3.3 Effect of zeolite application on soil chemical properties

The application of zeolite and NPK fertilizers resulted in significant changes in chemical properties of the studied soil (Table 5). In general, the analyzed soil parameters decreased by all zeolite and NPK treatments in the end of experiment, except cation exchange capacity (CEC), $CaCO_3$ and total Fe that increased in treatments receiving NPK (T_2), 6 q zeolite ha^{-1} (T_3), and NPK (T_2) and 6 q zeolite ha^{-1} + NPK (T_5), respectively.

Table 4. Effect of treatments on nutrient uptake by ryegrass

Treatment	Nutrient uptake (mg pot $^{-1}$)						
	P	K	Ca	Mn	Cu	Zn	Fe
T_1 - Control	8.00	36.00	4.00	0.40	0.80	1.00	0.60
T_2 - $N_{148}P_{75}K_{60}$	11.49	53.62	7.66	0.38	1.15	1.92	0.77
T_3 -Zeolite 6 q ha^{-1}	20.34	57.63	6.78	0.34	1.02	1.70	1.02
T_4 - Zeolite 12 q ha^{-1}	11.46	76.40	7.64	0.38	1.15	1.91	1.15
T_7 - Zeolite at 5%	8.94	44.70	5.96	0.30	0.89	1.49	1.49
Mean (T_3, T_4, T_7)	13.58	59.58	6.79	0.34	1.02	1.70	1.22
T_5 - Zeolite 6 q ha^{-1} + NPK	17.16	64.35	8.58	0.43	1.29	0.43	0.86
T_6 - Zeolite 12 q ha^{-1} + NPK	12.51	70.89	8.34	0.42	1.25	2.59	1.25
Mean (T_5, T_6)	14.84	67.62	8.46	0.43	1.27	1.46	1.06

Table 5. Soil chemical properties at studied treatments before (1) and after (2) experiment

Soil property	*T_1 Control*		*T_2 NPK*		*T_3 Zeolite 6 q ha^{-1}*		*T_4 Zeolite 12 q ha^{-1}*		*T_5 Zeolite 6 q ha^{-1} + NPK*		*T_6 Zeolite 12 q ha^{-1} + NPK*		*T_7 Zeolite at 5%*		*LSD*
	1	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*($p<0.05$)*
Humus (%)	0.8	0.7*	0.8	0.6*	0.8	0.6*	0.8	0.6*	0.8	0.7*	0.8	0.7*	0.8	0.7*	0.05
N-total (%)	0.07	0.06	0.07	0.05*	0.07	0.05*	0.07	0.05*	0.07	0.06	0.07	0.06	0.07	0.06	0.01
Available P (mg/100 g)	1.32	0.77*	1.32	0.81*	1.32	0.67*	1.32	0.92*	1.32	0.95*	1.32	0.85*	1.32	0.21*	0.24
Exchange. K (mg/100)	7.5	.33*	7.5	4.83*	7.5	4.00*	7.5	4.83*	7.5	4.17*	7.5	4.22*	7.5	4.31*	0.31
CEC (me/100 g)	11.5	10.0	11.5	13.4*	11.5	11.8	11.5	12.7	11.5	12.8	11.5	10.7	11.5	9.6*	1.44
CaCO3 (%)	7.14	8.1*	7.14	7.5	7.14	8.0*	7.14	7.3	7.14	6.9	7.14	7.4	7.14	7.4	0.40
Total-Cu (mg kg^{-1})	44	40.0	44	35.2*	44	41.3	44	42.6	44	28.8*	44	40.4	44	25.6*	6.46
Total- Zn (mg kg^{-1})	78	63.2*	78	46.0*	78	52.3*	78	50.3*	78	49.2*	78	51.3*	78	49.2*	5.30
Total-Mn (%)	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.01
Total-Fe (%)	4.6	4.67	4.6	5.37*	4.6	4.57	4.6	5.08	4.6	5.37*	4.6	3.98	4.6	3.08*	0.73
Total-Ca (%[1])	8.8	4.36*	8.8	2.93*	8.8	5.33*	8.8	4.31*	8.8	3.04*	8.8	4.38*	8.8	3.42*	0.84

*Significant at 5% level ($p < 0.05$)

The significant lower content was observed for total N in NPK, 6 q zeolite ha^{-1}, 12 q zeolite ha^{-1} treatments; humus, available P and exchangeable K in all treatments; total Cu in NPK, 6 q zeolite ha^{-1} + NPK, 5% zeolite treatments; Fe in 5% zeolite treatment, Zn and Ca in all treatments; and CEC in 5% zeolite treatment. The lowest decrease in humus (12.5%) and nitrogen (14.3%) contents was observed in the treatments receiving zeolite + NPK (T_5, T_6) and zeolite at 5% (T_7), although this is a well-known phenomenon related to soil cultivation practices.

On the contrary, the highest decrease in available phosphorous (84.1%), total copper (41.8%), zinc (37.2%) and iron (33%) contents and CEC values (16.5%) were recorded in the treatment receiving zeolite at 5% (T_7), and exchangeable potassium (46.7%) in the treatment receiving zeolite at 6 q ha^{-1} (T_3), probably due to improved uptake of P by crops and absorption of K and micronutrients by zeolite.

The highest decrease in total calcium content (66.7%) was noted in the treatment receiving NPK. Effect of zeolite on CEC could be related to its mineralogical composition and soil conditions.

The results on the effect of zeolite on soil properties reported by other authors indicate that application of zeolite improved soil aeration and biological activity, thus increasing mineralization of biogenic substances by microorganisms (Antinis et al., 2002), increased solubilization of phosphate minerals (Lai & Erbel, 1986; Chesworth et al., 1987), and uptake of nutrients by crops (Barbarick et al., 1990). However, Stead et al. (2002) showed that environmental conditions as change in pH, redox conditions, microorganism activity and the amount of clay minerals may change the nature and effectiveness of the zeolite. It is also showed that application of zeolite to sandy soil increased sorption capacity, reduced average particle size, and consequently, lowered hydraulic conductivity (Ansari Mahabadi et al., 2007), decreasing mineralization and losses of nutrients from the soil.

On the basis of correlation coefficients, highly significant dependence was revealed between available soil P and CEC (r=0.817*), exchangeable soil K and exchangeable soil Mn (r=0.767*), and exchangeable soil Zn and total soil Zn (r=0.903**).

4. CONCLUSIONS

The results of the experiment discussed in this paper indicated that the zeolitic material used as amendment in a sandy soil improved the performance of ryegrass in terms of shoot and root biomass due to direct effect on increasing the retention of nutrients and water. The highest yields of shoot (4.29 g pot^{-1}) and roots (2.08 g pot^{-1}) were obtained in the treatment receiving 6 q zeolite ha^{-1} and NPK fertilizers. The incorporation of zeolite with NPK improved the NPK fertilizers efficiency which in turn increases the crop yield from 8.88 - 12.01%.

The zeolite functioned as a good regulator of plant nutrition in the soil studied, the improved uptake of nutrients stimulated by the zeolite was: 29.11% for P, 26.11% for K, 10.44% for Ca, 11.84% for Mn, 10.43% for Cu, and 37.01% for Fe. The application of 6 q zeolite ha^{-1} and NPK was most significant in maintaining and improving soil properties and nutrient status in the soil studied, the humus, N, P, Ca, Fe and Zn losses generally reduced resulting in more of these nutrients in the soil solution to be utilized by the plant roots. The further research is needed to determine the optimal zeolite:fertilizers ratio in a sandy soil.

5. ACKNOWLEDGEMENTS

This research was supported by the Ministry of Education and Science of the Republic of Albania. We wish to acknowledge and express our appreciation to them for their support.

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Received at: 18. 11. 2010
Revised at: 22. 03. 2011
Accepted for publication at: 02. 04. 2011
Published online at: 11. 04. 2011