The effect of zeolite, organic and inorganic fertilizers on soil chemical properties, growth and biomass yield of apple trees

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ABSTRACT

The objective of this study was to evaluate the influence of organic (cattle manure) and inorganic fertilizers [composite NPK (15:15:15)] and natural zeolites on soil properties, vegetative growth and yield of apple plants grown on vertisol under Cacak conditions (Western Serbia). The results showed that the combined fertilization induced a decrease in acidity, an increase in humus content, a partial increase in total nitrogen (N_{TOT}), and, primarily, a rise in available phosphorus (P) and potassium (K) levels. A highly significant ($P < 0.01$) interactive effect of the apple cultivars and nutrients on one-year-old shoot length and trunk cross-sectional area (TCSA) and a significant effect ($P < 0.05$) on yield per tree and yield per hectare were determined.

Keywords: fertilization; crop yield; vertisol; vegetative growth; zeolites

Over the past years, the excessive, frequently uncontrolled and routine use of mineral fertilizers in the Republic of Serbia has had a very adverse effect on yield efficiency and quality of fruits, including apples, as well as on soil chemical (pH), physical (structure) and particularly biological traits (the presence of beneficial macro- and microorganisms). Such soils generally lack optimum environmental conditions for normal growth and development of the root system of cultivated plants. Regeneration of these soils is a long-term process which can, assisted solely by nature, last for more than 20 years (Ruecker et al. 1998). Their remediation, i.e. conversion into cropland, is costly and long-term.

Organic fertilizers, such as cattle manure, have long since been known to improve physical, chemical and biological properties of soils, particularly increasing the humus content and decreasing acidity (Ganzhara 1998). One of the measures considered highly effective, biologically justified and environmentally safe, especially on degraded and other soils having unfavourable productive traits for crop cultivation, is the use of zeolite mineral (Polat et al. 2004). There are several zeolite types, one of them being clinoptilolite, a hydrated alumosilicate of alkali and alkaline earth metals (Na^+, K^+, Ca^{2+}, Mg^{2+}, Ba^{2+}) having an infinite three-dimensional crystal structure, a polyedric shape and a great open cavity (Daković et al. 2007).

Zeolites can be successfully used in cultivating different crops such as cereals, forage crops, vegetables, vine and fruit crops (Torii 1978) due to their exceptionally high ion-exchange capacity (Butorac et al. 2002). Their porous structure assures a permanent water reservoir in the root zone, improving the horizontal spread of water after irrigation (Treacy and Higgins 2001, Polat et al. 2004). Zeolites prevent unnecessary losses of nutrients, making them available exactly when needed (Podlešáková et al. 1967). They are excellent carriers, stabilizers and regulators of mineral fertilizers, themselves being a source of certain nutrients (Bagdasarov et al. 2004). As carriers of N and K fertilizers, they increase their efficacy by decreasing application rates for equal yields to be achieved (Polat et al. 2004). The stated author also suggested that zeolites, being of weakly alkaline reaction, can be combined with mineral fertilizers to maintain soil buffering and indirectly regulate soil pH. According to Torii (1978), zeolites improve the growth and development of plants, including apple. Zeolite applied to the soil in newly planted orchards at 2–8 kg/tree rate improves soil condi-

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tions in a long run due to the prolonged zeolite effect (Polat et al. 2004). Torii (1978) reported that zeolite application rate of 4–8 t/acre resulted in a 13–38% yield increase in apples.

The basic objective of this study was to examine changes in the chemical properties of soil and the soil-plant interaction as induced by the effect of Agrozel, natural zeolite applied in combination with cattle manure and/or composite NPK mineral fertilizer. Parameters monitored in this study include changes in soil characteristics and the vegetative growth and yield efficiency of apple cultivars Idared and Melrose, grown on vertisol during the ninth- and tenth-leaf periods, i.e. at the full crop stage.

MATERIAL AND METHODS

Study area. The research was conducted in Prislonica village located 15 km north-east from Cacak (43°53'N, 20°21'E), Western Serbia.

The study took place in a high density apple block of Idared and Melrose on M.9 rootstock planted in 1994 and trained in a slender spindle system. Tree spacing was 3.0 × 1.2 m (2.778 trees/ha). Orchard floor management involved grassy alley-ways and 1 m-wide herbicide strips in the tree-rows. Glifosate was used for weed control. Soil samples for analysis were collected from the herbicide strips under the tree canopy. The orchard was not irrigated.

Weather characteristics. There were no significant differences between the basic climatological parameters obtained for the years of observation and the long-term averages for the region of Cacak and surrounding areas (Table 1). In 2002, the mean temperature for the growing season (April–October) was 17.6°C, i.e. by 0.9°C higher than the long-term average. That year, August and September were extremely dry, showing only 46.3 mm and 50.8 mm of precipitation, respectively. Such dry conditions during the most intensive period of fruit growth and development had a negative effect on yield. Seasonal precipitation totals were 471.6 mm, i.e. by 8.0 mm higher than normal; normal being a 30-year average.

In 2003 the average temperature during the growing season was 17.1°C, i.e. by 0.5°C lower than in 2002 and by 0.4°C higher than normal. For the remaining part of the year the temperature was within the long-term average range for Cacak. The first part of the 2003-growing season received very little precipitation, namely 43.2 mm for April and 30.8 mm for May. Total precipitation for the season was by 45.2 mm lower than the long-term average (463.6 mm). The lack of rainfall during this period may have had a negative effect on the rate of vegetative growth.

Soil and land use. Vertisols and their subtypes cover 780 000 ha, which is 8.93% of total land area in Serbia (Protic et al. 2003). These fertile soils, developed through lake sediment degradation, are suitable for vegetable, fruit and vine crops production (Tanasijevic et al. 1966). Their worst characteristics, induced by a high clay content, include inferior physical properties (a prismatic polyedric structure with a frequent occurrence of angled aggregates). Furthermore, vertisol and cambisol, predominant soils in Central and Western Serbia, have high acidity (Protic et al. 2003).

Table 2 shows soil test results from the samples taken prior to trial establishment (mid-November

Table 1. Monthly and growing season precipitation and temperature in Cacak in 2002 and 2003*

Months	Air temperature (°C)			Precipitation (mm)		
	2002	2003	normal**	2002	2003	normal**
April	11.8	12.2	11.5	60.3	43.2	57.8
May	17.3	17.5	16.2	60.4	30.8	88.6
June	19.2	19.4	19.5	102.5	70.5	98.2
July	20.7	21.2	20.9	95.6	56.8	76.0
August	20.9	20.3	20.5	46.3	86.7	59.5
September	17.3	17.2	16.9	50.8	79.8	56.5
October	16.6	11.9	11.8	55.7	50.3	47.8
Mean or total	17.6	17.1	16.7	471.6	418.1	463.6

*at a straight-line distance of 15 km (NE-direction) from the experimental field; **normal refers to the long-term average (30-year average, i.e. 1961–1990 period)

Table 2. Soil chemical properties under different treatments

Soil depth (cm)	Soil properties	Prior to trial*	End of the trial (2 years later**)			
			NPK + Manure	NPK	Agrozel + Manure + NPK	Agrozel + NPK
0–20	pH	5.19[b]	6.42[a]	5.15[b]	6.67[a]	6.45[a]
	Humus (%)	2.96[a]	3.34[a]	3.10[a]	3.41[a]	3.15[a]
	N_{TOT} (%)	0.15[a]	0.16[a]	0.16[a]	0.17[a]	0.16[a]
	P (mg/kg)	73.0[b]	313.0[a]	310.0[a]	330.0[a]	322.5[a]
	K (mg/kg)	281.0[b]	337.0[a]	330.0[a]	350.0[a]	342.7[a]
20–40	pH	4.91[b]	5.89[a]	4.87[b]	6.01[a]	5.93[a]
	Humus (%)	1.89[a]	1.91[a]	1.90[a]	2.10[a]	1.91[a]
	N_{TOT} (%)	0.08[a]	0.08[a]	0.08[a]	0.09[a]	0.08[a]
	P (mg/kg)	26.5[b]	206.0[a]	204.5[a]	213.0[a]	206.5[a]
	K (mg/kg)	332.0[a]	335.0[a]	333.0[a]	373.5[a]	346.7[a]
40–60	pH	4.89[b]	5.35[a]	4.62[b]	5.22[a]	5.30[a]
	Humus (%)	1.03[a]	1.05[a]	1.04[a]	1.08[a]	1.06[a]
	N_{TOT} (%)	0.06[a]	0.07[a]	0.07[a]	0.08[a]	0.07[a]
	P (mg/kg)	31.5[b]	147.9[a]	147.6[a]	148.3[a]	146.0[a]
	K (mg/kg)	174.5[b]	213.5[a]	211.5[a]	220.0[a]	217.0[a]

*soil sampling for chemical analysis was conducted in mid-November 2001; **soil sampling for chemical analysis was conducted in mid-November 2003; the letter (s) in horizontal rows indicate a significant differences at $P < 0.01$ by LSD test

2001). The soil pH was in the range from 4.89 to 5.15, it had poor to moderate humus supply (1.03% to 3.01%) and a very low N_{TOT} content (0.06% to 0.15%). The values were gradually decreasing with depth. The contents of P and K in the soil depth of 0–60 cm ranged from 31.5 to 73.0 mg/kg and from 174.5 to 332.0 mg/kg, respectively.

Source and characteristics of the Agrozel type of natural zeolite and cattle manure. Natural zeolite, commercially available as 'Agrozel', comes from deposits in Eastern Serbia. Its final processing (grinding and packaging) is performed at the Institute for Technology of Nuclear and Other Raw Materials in Belgrade. It is being marketed as 'Agrozel' for use in plant production. Agrozel has a particle size of 0–1.0 mm, cavity volume of about 34%, high thermal stability, and the cation exchange capacity (CEC) of 216 mmol M^+ 100/g (Daković et al. 2007). The use of this material in fruit orchards in Serbia is considered ground-breaking. The ideal chemical formula may be written as:

$$M_{x/n}\,[Al_xSi_yO_2(x + y)]\;pH_2O,$$

where: M is a monovalent (Na^+, K^+) or divalent (Ca^{2+}, Mg^{2+}, Ba^{2+}) cation; n is the ion valence

Cattle manure used in this study came from a local dairy farm. The chemical composition of the manure was as follows: N_{TOT} – 0.5%; P – 0.3%; K – 0.6; electrical conductivity – 6.32; organic matter – 25%; and the C:N ratio – 18:1 (DeLuca and DeLuca 1997).

Methods and data analysis. The experiment was set up in a randomized block design in four replications, with ten trees per cultivar in each replication. In mid-November of 2001 and 2002, the nutrients used in the treatments were applied in 0.5 m wide bands on both sides of the tree-row. Upon broadcasting, the fertilizers were incorporated into the soil to a depth of 10 cm by rototilling. The treatments were as follows:

(a) treatment 1 (B_1) = NPK (0.1 kg/m^2) + cattle manure (5 kg/m^2);
(b) treatment 2 (B_2) = NPK (0.1 kg/m^2);
(c) treatment 3 (B_3) = Agrozel (1 kg/m^2) + cattle manure (5 kg/m^2) + NPK (0.1 kg/m^2);
(d) treatment 4 (B_4) = Agrozel (1 kg/m^2) + NPK (0.1 kg/m^2).

Before the treatments in November 2001, soil samples were collected for analysis to determine soil pH, humus content, N_{TOT} and available P and K. The samples were collected from the weed-treated bands on either side of the tree-row at 0.5 m distance from the trees. Soil samples were collected from the depth of 0–20 cm, 20–40 cm and 40–60 cm for each cultivar and each treatment. A grand total of 144 soil samples were examined.

The analysis was repeated at the end of the experiment, i.e. in mid-November 2003, to determine any changes in soil chemical composition. A Pye glass electrode pH meter-potentiometer (W.G. Pye, Cambridge) was used to measure pH in 0.01M KCl. The humus content was determined by oxidation with $KMnO_4$ solution (according to Kotzman). Soil N_{TOT} was measured using the Kjeldahl method with sulphuric acid and a metal catalyst. Available P and K were determined by extraction with Al solution, and P and K by colorimetry with molybdate and flame photometry, respectively.

The influence of various treatments on vegetative growth was determined by monitoring the seasonal growth by measuring the average one-year-old shoot length (cm) and TCSA (kg/cm^2), whereas the cropping capacity was examined through an average yield per tree (kg) and hectare (t). Measurements included 25 one-year-old shoots sampled from 5 trees per cultivar in four replications. The data for TCSA, yield per tree and yield per unit area were obtained from 10 trees per cultivar in four replications. The given values are average values for 2002 and 2003.

The experimental data were subjected to analysis of variance. An LSD test at $P < 0.05$ and $P < 0.01$ was used for mean separation. The data were analysed by the ANOVA statistical programme (SPS Statistica 6.0 Software).

RESULTS

Soil chemical properties. Table 2 shows the results of soil chemical analyses conducted at the end of the trial (November 2003, i.e. after a two-year period). Data suggest that the soil chemical composition underwent certain changes as compared to the control. All treatments (B_1, B_2, B_3 and B_4) led to increases in humus, N_{TOT} and particularly P and K for all depths. The humus and N_{TOT} increases were not significant. There were statistically significant increases in P and K content.

Soil pH was significantly increased by the B_1, B_3 and B_4 treatments and decreased by the B_2 treatment at all depths. After two years B_3 treatment induced the highest increase in soil pH from 5.19 before the trial to 6.67 at the soil depth of 0–20 cm. The same treatment showed a slight increase in the humus content, especially at the depth of 0–20 cm, from 2.96% before the trial to 3.41%. The N_{TOT} content slightly increased, especially in the B_3 treatment (from 0.15 before the trial to 0.17 after two years at the soil depth of 0–20 cm).

The content of P at the depth of 0–20 cm increased from 73.0 mg/kg before the trial to 310.0 mg/kg in B_2 and 330.0 mg/kg in B_3. At a depth of 20–40 cm, it increased from 26.5 mg/kg before the trial to 204.5 mg/kg in B_2 and 213.0 mg/kg in B_3. At a depth of 40–60 cm, it increased from 31.5 mg/kg to 147.9 mg/kg in B_1 and 148.3 mg/kg in B_3.

At the depth of 0–20 cm the content of K increased from 281.0 mg/kg to 342.7 mg/kg in B_4 and 350.0 mg/kg in B_3. At the depth of 20–40 cm K increased from 332.0 mg/kg to 346.7 mg/kg in B_4 and 373.5 mg/kg in B_3. At the depth of 40–60 cm K increased from 174.5 mg/kg to 217.0 mg/kg in B_4 and 220.0 mg/kg in B_3.

The vegetative growth and yield. The data presented in Table 3 show certain variations, both between the treatments and between the cultivars, in the studied parameters associated with the vegetative growth (shoot length and TCSA) and yield per tree and yield per unit area. The average shoot length of the apple cultivars examined was 34.12 cm for all treatments. The greatest shoot length (36.50 cm) was produced by the B_2 treatment, the smallest by the B_4 treatment, being 31.50 cm.

The average TCSA in all treatments and apple cultivars was 16.76 cm^2. The TSCA values during nutrient application in the B_1, B_2 and B_3 treatments were approximately identical, as opposed to the much lower value in the B_4 treatment. The highest and lowest TCSA were recorded in the B_1 and B_4 treatments, being 17.89 cm^2 and 14.48 cm^2, respectively.

The average yield per tree was 20.81 kg, with slight variations being exhibited between the treatments. It ranged from 19.00 kg/tree in the B_2 treatment to 22.00 kg/tree in the B_3 treatment, the B_1 and B_4 treatments having produced almost identical yields of 21.00 and 21.25 kg/tree. The average yield per hectare was as high as 57.81 t. As with the average yield per tree, it showed a tendency to vary, ranging from 52.78 t/ha (B_2) to 61.12 t/ha (B_3).

An analysis of vegetative and generative parameters across the studied apple cultivars (A) showed certain variations in the results obtained (Table 3). Melrose cultivar produced a greater length

Table 3. The effect of cultivar, fertilizer and cultivar × fertilizer interaction on the vegetative growth and yield of apple trees

Treatment		Shoot length (cm)	TCSA (cm^2)	Yield per tree (kg/tree)	Yield per hectare (t/ha)
Cultivar (A)					
Idared		30.00^{a}	17.26^{a}	21.75^{a}	60.42^{a}
Melrose		38.25^{a}	16.26^{a}	19.87^{a}	55.20^{a}
Fertilizer (B)					
B_1		33.50^{a}	17.89^{a}	21.00^{a}	58.34^{a}
B_2		36.50^{a}	17.38^{a}	19.00^{a}	52.78^{a}
B_3		35.00^{a}	17.29^{a}	22.00^{a}	61.12^{a}
B_4		31.50^{a}	14.48^{a}	21.25^{a}	59.03^{a}
A × B					
Idared	B_1	31.75^{e}	17.57^{a}	21.37^{ab}	59.38^{ab}
	B_2	33.25^{d}	17.32^{ab}	20.37^{bc}	56.60^{bc}
	B_3	32.50^{de}	17.27^{ab}	21.87^{a}	60.77^{a}
	B_4	30.75^{f}	15.87^{ab}	21.50^{ab}	59.72^{ab}
Melrose	B_1	35.87^{b}	17.07^{ab}	20.43^{bc}	55.20^{bc}
	B_2	37.37^{a}	16.82^{ab}	19.87^{c}	53.99^{c}
	B_3	36.62^{ab}	16.77^{ab}	20.93^{abc}	58.16^{abc}
	B_4	34.87^{b}	15.37^{b}	20.56^{bc}	57.12^{bc}
Average		34.12	16.76	20.81	57.81
ANOVA					
Cultivar (A)		ns	ns	ns	ns
Nutrient (B)		ns	ns	ns	ns
A × B		**	**	*	*

A, B – 'Cultivar' and 'Fertilizer' treatment; letter(s) in vertical columns indicate a significant difference between means at *$P < 0.05$ and **$P < 0.01$ by LSD test; ns – non-significant difference

(38.25 cm) of one-year-old shoots, as compared to Idared cultivar. (30.00 cm). The TCSA was higher in Idared cv. (17.26 cm^2) than in Melrose cv. (16.26 cm^2). The other parameters (yield per tree, yield per hectare) were higher in Idared cv. Namely, the average yield per tree in Melrose cv. was 19.87 kg, that in Idared cv. 21.75 kg. The yield per hectare category showed variations as did the yield per tree. The average yield per hectare in Idared cv. was 60.42 t, and that in Melrose cv. was 55.20 t.

The cultivar × fertilizer interactions had a highly significant effect ($P < 0.01$) on shoot length and TCSA, and a significant effect ($P < 0.05$) on yield per tree and yield per hectare (Table 3).

Analysis of changes in soil chemical properties. The combined fertilization in 2001–2003 induced changes in the soil chemical composition (Table 2). With the exception of the B_2 treatment which caused an increase in acidity, all treatments led to a statistically significant reduction in acidity at all depths. The incorporation of complex NPK fertilizers into the soil having an optimal content of K and a low to medium content of P caused additional increases in these contents, especially within the soil depth of 0–20 cm. Jelic et al. (2006) reported that mineral fertilization, primarily with large K and N_{TOT} rates applied to the vertisol undergoing degradation, caused a substantial increase in acidity (0.29 to 0.37 pH units in active acidity and 0.18 to 0.24 units in substitutionary acidity), humus, N_{TOT} and available P and K in the soil. Glisic et al. (2009) determined that high rates of complex NPK fertilizers broadcast annually across the rows in pear, blackberry and strawberry plantings, induced disturbances in mineral nutrition, primarily due to the accumulation of higher amounts of K and increases in the soil acidity. The results of the above authors were confirmed by the results of the present study. Our study supports results cited in literature (Iakimenko et al. 1996) that manure in combination with mineral fertilizer NPK and Agrozel (B_3) resulted in humus content increase and decrease in soil acidity particularly at the 0–20 cm depth level.

Given the average organic matter content of 25.0% in composted beef manure (DeLuca and DeLuca 1997), the reaction was as expected and in line with the results of the cited authors. Apart from increasing the humus content of soil, cattle manure had a favourable effect through decreasing acidity due to the significant proportion of H_2CO_3 reacting with the soil adsorption complex (Glisic et al. 2009). This results in the formation of $NaHCO_3$, which in an aqueous solution, breaking down into weak non-dissociating H_2CO_3 and strong dissociating NaOH, with several OH^- ions occurring in the soil, thus resulting in an acidity decrease (Chander and Joergensen 2002). The exchangeable cation sites of Agrozel are occupied by exchangeable divalent metal Ca^{2+} ions (Daković et al. 2007) being substituted in the soil solution with other ions. Once in the soil solution, they indirectly decrease acidity. Chander and Joergensen (2002) report that A_4-type zeolite increases soil pH as does $CaCO_3$, which was confirmed in our study.

The N_{TOT} content of the soil in our study was low; the value obtained being the most common one for vertisols in Serbia (Tanasijevic et al. 1966). Its increase induced by different treatments was not significant. Vertisols in Serbia are generally poor in available P (Protic et al. 1985). However, our study shows that the incorporation of the composite NPK mineral fertilizer with a P content of 15% was determined to be unnecessary due to its superfluous content in the soil (Table 2). The natural zeolite or Agrozel structure is mostly made up of the K^+-ion-containing mineral clinoptilolite. One of major zeolite traits is ion-exchange capacity. Zeolite has cation exchange capacity (CEC) of 216 mmol M^+100/g (Daković et al. 2007), K is among elements with the highest ion-exchange capacity (Treacy and Higgins 2001) and, consequently, it is very easily released from the crystal zeolite structure into the soil solution, eventually increasing its total content in the soil (Podlešáková et al. 1967). Our research shows that zeolite in combination with mineral NPK fertilizer containing 15% K raised the K level in the soil.

Analysis of apple vegetative growth and yields. Only the well balanced growth of an apple tree insures an early onset of cropping, high yields and high-quality fruit (Milosevic 1997). Therefore, neither excessive vigour nor excessive dwarfness of apple trees are advantageous. In the present study, the B_2 and B_3 treatments induced the highest shoot length (Table 3). However, the shoot length obtained in our study was almost identical to the lower optimum vegetative growth limit of 40–50 cm in the first 10 years (Milosevic 1997). An explanation for this relatively low vegetative growth could be found primarily in the lack of precipitations in April and May of 2003 (Table 1). In our opinion, the drought effect could have been more pronounced if it had not been mitigated by the positive contribution of Agrozel capable of releasing water from its porous crystal structure into the root system zone (Tracey and Higgins 2001), as well as having effect on soil pH, humus content and effect on soil regimes (Ganzhara 1998). Another explanation lies in the fact that the M.9 dwarfing vegetative rootstock for apple has a shallow root system that relatively rapidly responds to all topsoil changes.

Furthermore, differences in shoot growth resulting from the applied nutrients can also be due to available N derived from the complex NPK fertilizer (B_2) and manure combined with Agrozel (B_3). LSD test suggests that the differences in the shoot length were induced by a complex highly significant ($P < 0.01$) interactive effect between the examined apple cultivars (A) and the applied fertilizer treatments (B).

The highest TCSA value was determined in the B_1 and B_2 treatments without Agrozel and the lowest value in the B_4 treatment with the nutrient applied. In growing tree fruit species, including apple, minimum TCSA is preferable provided that it is accompanied by high regular yields per tree and hence per unit area, ensuring an optimum relationship between the vegetative growth and yield (Milosevic 1997). The LSD test revealed that there is a highly significant ($P < 0.01$) interactive effect between the cultivars (A) and treatments (B) (Table 3). Lepsis and Blanke (2004) reported that vegetative growth was, among other things, affected by categories and total number of growths, the TCSA being a more reliable indicator of vegetative growth intensity and a yield forecasting model in apple. Similar findings were reported by Kosina (2002) for Golden Delicious, Melrose and Gloster cultivars. Blažek and Hlušičková (2007) showed that the TCSA value increased with tree age, Idared cv. being lower than Melrose cv. Our results concur with the findings cited above.

Apple yield per tree and yield per unit area are highly complex categories dependent on genetics, biotic and abiotic factors and applied cultivation technology. The highest yield in our study, both per tree and per unit area, was produced with the B_3 treatment (Table 3). The yields per tree and per unit area were higher in Idared cv. than in Melrose cv. As both cultivars were equally treated and affected by identical biotic and abiotic factors, the highest yield was therefore achieved in the B_3 treatment due to the combined effect of Agrozel, cattle manure and composite NPK mineral fertilizer on the soil chemical composition and improved soil water, air and temperature regimes in the shallow root system zone of the M.9 dwarfing rootstock for apple (Ganzhara 1998, Butorac et al. 2002). Polat et al. (2004) report that the mineral clinoptilolite (zeolite) enhances the efficacy of applied fertilizers, ensuring better vegetative growth of crops and hence higher yields. According to the above authors, this mineral can improve the situation in newly planted apple orchards applied at a rate of 2–8 kg/tree. By using clinoptilolite-rich tuff as a soil conditioner, significant increases in apple yields (13–38%) were reported when 4–8 t/acre zeolite was used (Torii 1978). Our research is in accordance with Torii's results showing higher yield in the B_3 and B_4 treatments with Agrozel than in the B_1 and B_2 treatments without Agrozel. Blažek and Hlušičková (2007) reported that Melrose cv. grafted on M.9 rootstock gave a higher yield as compared to Idared cv. Much higher yields of Idared and Melrose cultivars produced in our study as compared to the results of the cited authors were due to a higher number of plants per unit area in the present study (2.778 tree/ha). Furthermore, according to Milosevic (1997), higher yields were achieved by Idared than by Melrose cultivar under Western Serbian conditions.

In conclusion, the results of the present study suggest that the applied treatments did not have a significant individual effect on the soil properties, vegetative growth and yield of apples. We observed their positive role and effect on the studied parameters through their interactive effect with the cultivars used.

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