JORDANIAN ZEOLITIC TUFF AS A RAW MATERIAL FOR THE PREPARATION OF SUBSTRATES USED FOR PLANT GROWTH

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ABSTRACT

One of the problems faced in front of industry for potting media is limited amount of quality row materials (mainly peat) for unlimited production of quality substrates in the future. The using of natural minerals for production of substrates or as amendments for existing substrates is possible solution for this problem. The natural zeolites with their specific properties – high CEC, high content of macro and microelements are one of good alternatives to the traditional potting media. Each zeolite deposit has unique chemical composition, physical and mechanical properties. That is why obligatory preliminary condition for their successful application in agriculture is caring out of biological study with agricultural plants for determination of the optimal parameters of chemical and physicochemical properties of the substrates.

KEY WORDS: zeolite substrate, vegetable seedlings, macro elements

INTRODUCTION

Natural zeolites are among the minerals often used in attempts to develop new substrates for plant growing: for seedling production, rooting of cuttings, potting of ornamental plants etc. Natural zeolites' strong sorption properties, high CEC and reach macro and micro nutrients content make them an attractive alternative to peat moss and other natural products used in the industrial production of substrates.

Each zeolite deposit has unique chemical composition, physical and mechanical properties. That is why the caring out of biological study with crop plants for determination of the optimal parameters of chemical and physicochemical properties of the substrates is obligatory preliminary condition for their successful application in agriculture.

Zeolite substrates developed in Bulgaria have been studied since 60's. The main goal of the studies was to found optimal values of macro and microelements in the substrates (Dzhabarov, [2]; Stoilov and Gorbanov, [16]; Manolov, [6, 9]; Stoilov and Manolov, [17, 18]; Panayotov et al. [11, 12]; Manolov and Stoilov, [7, 8]).

Studies with zeolite substrates were carried out also in other countries – Greece, Yugoslavia, UK, Russia, etc. Issa [3] obtained good, similar results for greenhouse gerbera production comparing 3 growing media (zeolite, perlite, and zeolite:perlite, 1:1). Markovic et al [10] compared different substrates for pepper seedling production - compost, peat and enriched zeolites (Zeoplant). The best results were obtained from the mixture peat and Zeoplant (2:1). Pivert et all [13] successfully have grown sweet pepper on the same zeolite substrate three consecutive years without yield decreasing.

The goal of this investigation was to study the possibilities for growing of vegetable seedlings in zeolite substrate based on Jordanian zeolitic tuff and optimization of substrate's chemical properties by its mixing with other zeolite mineral and organic matter. The results were compared with zeolite substrate based on Bulgarian zeolite.

MATERIAL AND METHODS

Jordanian brown zeolite tuff (JZT) from North – East Jordan deposit (Aritain area), which belongs to phillipsite type of zeolites (approximately 30 % philipsite content in the mineral) and Bulgarian zeolite (BGZ) from Eastern Rhodops, which belongs to clinoptilolite type of zeolites (approximately 80% clinoptilolite in the mineral) were used for production of two base substrates. The both substrates JZT and BGZ were produced by the same technology. On the base of these substrates several substrate mixtures were produced.

Water field capacity (WFC) of zeolite substrates is comparatively low about 20 %. To improve this substrate parameter, 0.1 % (by weight) compound TERAWET (TW) was added to some of the mineral substrates. TERAWET is a potassium polycrylate/polyacrylamide polymer absorbing 400 times more water than its weight. The experiment included the following substrates:

The main chemical characteristics of "earthworm humus" were: 31.7 % dry matter, 118 mg NH_4^+/1000g, 22 mg NO_3/1000g, 435 mg P_2O_5/100g, 1400 mg K_2O/100g.

Cucumbers and tomatoes were studied as a test plants in pot experiment in 10 replications.

Pots ø 16 were used for cucumber growing. One seed per pot was sowed on 26.07.2004. The end of the experiment with cucumber plants was on 1.09.2004.

Pots ø 13 were used for tomatoes growing. Two seeds per pot were sowed on 27.07.2004. The end of the experiment with tomato plants was on 3.09.2004.

The pots were regularly irrigated with tap water in order to be maintained humidity suitable for plant growing.

The substrates before starting of experiment and after it finishing were analyzed for:

pH and conductivity – after shaking of substrate and water in ratio 1 : 5 for 1 h on pH/conductivity meter (MPC227 Mettler Toledo);

exchangeable NH_4^+ and NO_3^- - after extraction with 1% KCl and consequent distillation of both ions [14],

P_2O_5 – water soluble phosphorus, calorimetrically [14],

exchangeable Ca^{2+}, Mg^{2+}, K^+, Na^+ - were extracted by 1 N $(NH_4)_2SO_4$;

Ca^{2+} and Mg^{2+} - were determined complexometrically [5];

K^+ and Na^+ - photometrically (Plame Photometer JENWAY PEP 7).

Substrate A (JZT)	Substrate A (JZT) +TW
Substrate B (BGZ)	Substrate B (BGZ) +TW
Substrate C (JZT : BGZ = 1:1)	Substrate C (JZT : BGZ = 1:1) +TW
Substrate D (JZT : BGZ = 3:1)	Substrate D (JZT : BGZ = 3:1) +TW
Substrate E (JZT : Org* = 7:3)	

* Organic product obtained from vital activity of "Californian earthworms - earthworm humus"

The whole plants were taken away from the pots at the end of the experiment. The volume of the root system was measured by its submerging in cylinder filled with water. The above surface plant biomass for cucumbers and whole biomass for tomatoes (including roots) was dried at 70 ^{o}C, weighed, grounded and analyzed for content N (Kjeldahl method) [14] after wet digestion, P (colorimetrically) [15], K (photometrically), Ca and Mg (complexometrically) [5] after dry digestion.

RESULTS AND DISCUSSION

Changing of chemical properties of substrates during their exploitation

The pH of all the substrates is slight alkaline – about 7.5. There was not considerable changing of this substrate parameter after cultivation of vegetable seedlings (table 1).

The considerable decreasing of the conductivity of substrates was founded after growing of seedlings (table 1). The conductivity was decreased from 34 % for substrate A to 71 % for substrate B in comparison with initial values before sowing of the seeds. The decreasing of conductivity was due to leaching of salts with irrigation water – process, which create better conditions for plant growth.

All the substrates have had a similar content of NH_4^+ - N at the beginning of the experiment (table 2). Therefore the growing plants have grown at the same conditions of nitrogen nutrition. The observed differences in their growth did not due to unequal supply of nitrogen. The cation exchange capacity (CEC determined by ammonium acetate method) of the both zeolites used for production of substrates was as follow:

- Jordanian zeolite (JZT) – 73.9 meq/100 g
- Bulgarian zeolite (BGZ) – 116.1 meq/100 g.

The absorbed NH_4^+ - N from substrates after their production (table 2 - column before sowing) was only about 5 meq/100 g substrate (calculation of NH_4^+ meq/100 g: value for NH_4^+ mg/100g was divided to coefficient 18.04).

The amount of NH_4^+ - N in substrates decreased considerably during the plant growing (table 2). This process was due to nitrification and NO_3^- - N and its leaching from the pots, as well as the taken up nitrogen from the growing plants. The decreasing was the highest at substrates A and E (substrates produced on the base of Jordanian JZT) - 82 and 95 % decreasing in comparison with initial content. The weakest decreasing of this nitrogen form (NH_4^+) was observed at substrate B (BGZ) - 58 % decreasing. Obviously the JZT has weaker ability to keep adsorbed NH_4^+. The Zaid [19] also reported for comparatively quick desorption and leaching of adsorbed ammonium nitrogen from JZT with tap water.

The irrigation of the substrates after sowing the seeds created suitable condition for the starting of process of nitrification of adsorbed ammonium nitrogen. The amount of nitrates in substrates after seedling cultivation varied from 44 to 63 mg/1000 g (table 2). The positive effect of this is that nitrogen in the form of NO_3^- is more

Table 1 Changing of pH and conductivity of substrates during growing of cucumber and tomato seedlings

Numeration	Substrate	Before sowing		After plant cultivation	
		pH	Conductivity µS	pH	Conductivity µS
A	JZT	7.66	1090	7.60	719
B	BGZ	7.78	469	7.60	135
C	JZT : BGZ = 1:1	7.39	729	7.75	358
D	JZT : BGZ = 3:1	7.50	782	7.51	421
E	JZT : Org = 7:3	7.32	1089	7.37	708

Table 2 Changing of NH_4^+, NO_3^+ and P_2O_5 of substrates during plant cultivation (mg/100 g)

Numeration	Substrate	NH_4^+ - N (mg/1000 g)		NO_3^- - N (mg/1000 g)		P_2O_5 (mg/100 g)	
		Before sowing	After plant cultivation	Before sowing	After plant cultivation	Before sowing	After plant cultivation
A	JZT	904.0	163.4	0	63.4	50.1	20.7
B	BGZ	979.4	414.3	0	44.2	62.7	19.7
C	JZT : BGZ = 1:1	960.2	225.6	0	50.5	53.2	22.9
D	JZT : BGZ = 3:1	985.7	186.5	0	45.0	48.1	23.4
E	JZT : Org = 7:3	866.4	47.0	0	53.7	42.3	28.9

Table 3 Changing of exchangeable K and Na of substrates during plant cultivation

Numeration	Substrate	K (mg/100 g)		Na (mg/100 g)	
		Before sowing	After plant cultivation	Before sowing	After plant cultivation
A	JZT	490	441	680	603
B	BGZ	1902	2209	601	666
C	JZT : BGZ = 1:1	1311	1398	631	669
D	JZT : BGZ = 3:1	984	1127	735	850
E	JZT : Org = 7:3	481	404	620	559

Table 4 Changing of exchangeable Ca and Mg of substrates during plant cultivation

Numer ation	Substrate	Ca (mg/100 g)		Mg (mg/100 g)	
		Before sowing	After plant cultivation	Before sowing	After plant cultivation
A	JZT	489	477	89	144
B	BGZ	682	588	57	74
C	JZT : BGZ = 1:1	616	505	109	102
D	JZT : BGZ = 3:1	545	552	68	95
E	JZT : Org = 7:3	639	582	108	137

Table 5 Dynamics of cucumber growth (height of plants in cm)

Substrates	Date of measurements			
	5.08.04	10.08.04	20.08.04	1.09.04
A (JZT)	3,3 a *	6,3 a	13,0 a	30,2 a
B (BGZ)	4,8 ab	8,7 bc	18,4 cd	39,4 bc
C (JZT : BGZ = 1:1)	5,2 bc	9,8 cd	18,6 cd	44,6 cd
D (JZT : BGZ = 3:1)	3,8 ab	7,5 ab	17,2 bc	43,6cd
E (JZT : Org = 7:3)	4,1ab	7,0 ab	14,8 abc	47,8 d
A (JZT) +TW	3,1 a	6,4 a	14,2 ab	35,6 ab
B (BGZ) +TW	7,0 d	12,2 c	22,2 d	49,2 d
C (JZT : BGZ = 1:1) +TW	6,7 cd	10,8 dc	22,2 d	45,4 cd
D (JZT : BGZ = 3:1) +TW	4,3 ab	8,2 abc	18,2 c	48,0 d

* The figures followed from the same letter are not significantly different according to DMRT analysis.

available for the plants. The negative effect is increased nitrogen loses due to NO_3^- leaching at more abundant irrigation.

Content of available phosphorus in substrates also decreased during their exploitation from 31 to 68 % in comparison with initial content (table 2).

The substrate B (BGZ) contained from 4 to 5 times more available potassium for the plants in comparison with substrate A and E (produced on the base of JZT) (table 3). The substrates C and D (mixture between JZT and BGZ) had considerable amounts of available potassium. Positive element for all substrates was that there was no considerable changing of amount of available potassium during their exploitation.

The content of exchangeable sodium in substrates was almost the same without considerable changing during plant growth (table 3).

The substrates produced by the two zeolites contained approximately the same amounts of exchangeable Ca. There was little changing of the available calcium during plant growing (table 4).

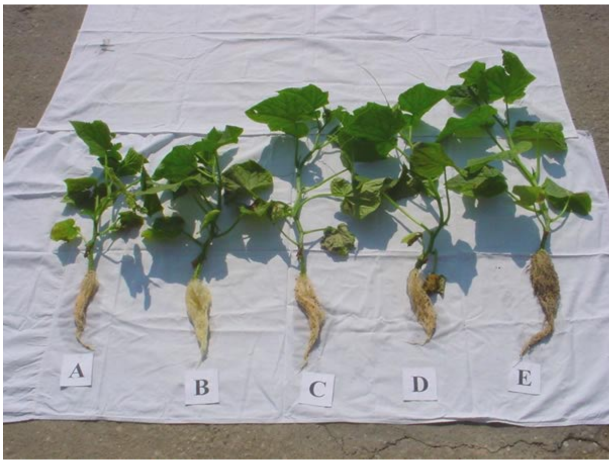
The content of available Mg in substrates even increased during the period of their exploitation (table 4).

Plant growth

The substrates showed considerably differences at the assessment of the main parameter of plant growth (height, cm). Nevertheless it was proved that seedlings could be grown in all of the studied zeolite substrates.

Cucumbers. The difference in cucumber growth on the

Picture 1 Cucumber plants before harvest



Picture 2 Cucumber plants after harvest

studied substrates is present on table 5, pictures 1 and 2.

Relatively weak growth of cucumber seedlings was observed on substrate A (JZT). The plants from substrate B (BGZ) were 30 % higher in comparison with plants from A substrate. The mixture from the both substrates (A and B) in ratio 1:1 and 1:3 improved the growth of the seedlings and it was respectively 48 and 44 % higher in comparison with the plants from substrate A (JZT).

The seedlings grown on organic-mineral substrate E were 58 % higher than these from substrates A (JZT). Obviously the presence of highly active organic matter from "Californian earthworms" accelerates development of the plants. There was a significant difference of height of plants grown on this substrate in comparison with the other mineral substrates.

The addition of small amount of the compound TERAWET (0.1%) to the mineral substrates increased the growth of cucumber seedlings (table 5). This compound improve water supply of the plants. The highest increase was achieved on substrate B (BGZ+TW).

Tomato. The results for tomato growth (table 6, picture 3 and 4) showed the same tendency like cucumber – best growth on substrate E (28.6 cm), followed by substrates C and D (26.2 and 25.8 cm), B (24 cm) and substrate A (19.8 cm).

The addition of the compound TW increased growth of the plants (table 6). The height of the plants from these substrates was similar with plants from substrate E. The difference between the plants growth on this substrate in comparison with the others was statistically proved. The highest plants from substrates E and B (BGZ) +TW were 44 % higher than seedlings from substrate A (JZT) at the end of the experiment.

Table 5 Dynamics of cucumber growth (height of plants in cm)

Substrates	Date of measurements			
	5.08.04	10.08.04	20.08.04	1.09.04
A (JZT)	3,3 a *	6,3 a	13,0 a	30,2 a
B (BGZ)	4,8 ab	8,7 bc	18,4 cd	39,4 bc
C (JZT : BGZ = 1:1)	5,2 bc	9,8 cd	18,6 cd	44,6 cd
D (JZT : BGZ = 3:1)	3,8 ab	7,5 ab	17,2 bc	43,6cd
E (JZT : Org = 7:3)	4,1ab	7,0 ab	14,8 abc	47,8 d
A (JZT) +TW	3,1 a	6,4 a	14,2 ab	35,6 ab
B (BGZ) +TW	7,0 d	12,2 c	22,2 d	49,2 d
C (JZT : BGZ = 1:1) +TW	6,7 cd	10,8 dc	22,2 d	45,4 cd
D (JZT : BGZ = 3:1) +TW	4,3 ab	8,2 abc	18,2 c	48,0 d

* The figures followed from the same letter are not significantly different according to DMRT analysis.

Table 6 Dynamics of tomato growth (height of plants in cm)

Substrates	Date of measurements		
	12.08.04	23.08.04	3.09.04
A (JZT)	3,1 a*	8 a	19,8 a
B (BGZ)	5,2 c	12,8 de	24 b
C (JZT : BGZ = 1:1)	4,7 bc	11,8 cde	26,2 bc
D (JZT : BGZ = 3:1)	4,3 abc	9 ab	25,8 bc
E (JZT : Org = 7:3)	4,9 c	12 cde	28,6 c
A (JZT) +TW	3,5 ab	9 ab	19,2 a
B (BGZ) +TW	5,3 c	13 e	28,6 c
C (JZT : BGZ = 1:1) +TW	5,3 c	11 cd	28,2 c
D (JZT : BGZ = 3:1) +TW	4,6 bc	10,6 bc	23,8 c

* The figures followed from the same letter are not significantly different according to DMRT analysis.

Picture 3 Tomato plants before harvest

Picture 4 Tomato plants after harvest

Volume of root system

The volume of root system was the highest at substrate E (26 cm^3 and 12.8 cm^3, respectively for cucumbers and tomatoes) – table 7. The smallest volume for cucumbers was observeded at substrate A (14.8 cm^3), while this volume for the plants from substrates B, C and D was the same. There was no significant difference between the results from these substrates.

The compound TW improved the growth of rooting systems, especially at cucumbers (table 7). The roots were ticker with more root heirs in comparison with the roots from substrate A, B, C and D.

The tendencies in tomatoes plants were the same like the cucumbers. Exception was that there was not significant positive effect of compound TW on growth of the root system.

All plants developed good root system, which spreads in whole volume of the pots (pictures 5)

a) substrate A (JZT)

b) substrate B (BGZ)

c) substrate C (JZT : BGZ = 1:1)

Number of leaves

There was no significant difference of number of leaves per plant especially at tomato seedlings during the plant growth (data not shown). At the end of the experiment the differences were comparatively small. This showed that the type of substrate had a little effect on this parameter.

Amount of formed dry matter

The cucumber and tomatoes seedlings from substrates A (JZT) and A (JZT) +TW formed the least dry matter of all substrates (table 8). The plants grown on the substrate B (Bulgarian zeolite) and other substrate mixtures have formed higher amount of dry matter, but there was not any dependence between substrates.

Picture 5 Tomatoes grown in different mineral substrates

Table 7 Volume of the root systems at the end of experiment (cm^3)

Substrates	Cucumbers	Tomato
A (JZT)	14,8 a*	9,6 b
B (BGZ)	19 ab	10 bc
C (JZT : BGZ = 1:1)	16,4 ab	10 bc
D (JZT : BGZ = 3:1)	16,6 ab	9 b
E (JZT : Org = 7:3)	26 cd	12,8 d
A (JZT) +TW	22 bc	6,6 a
B (BGZ) +TW	32 d	14 d
C (JZT : BGZ = 1:1) +TW	25,6 cd	10,2 bc
D (JZT : BGZ = 3:1) +TW	26 cd	7,8 ab

* The figures followed from the same letter are not significantly different according to DMRT analysis.

Dzhabarov, [2] studied growing of tomato seedlings on Bulgarian zeolite substrate, perlite + nutritional solution and two standard substrates (turf and turf substrate on "super seedling" system) for production of such seedlings. The dry mass of seedlings from BGZ was 40 % higher than seedlings from standard tuft substrates.

The dry mass of the tomato seedlings from this experiment grown on substrate A (JZT) formed 35 % lower dry mass than seedlings from substrate B (BGZ). Therefore the production capacity of substrate A (JZT) can be compared with standard turf substrates.

Concentration of nutritional elements in seedlings

All the studied substrates were good source of nitrogen for the grown cucumber seedlings (table 9). According Jones at al [4] and Bergmann [1] the optimum concentration of nitrogen in cucumber is in the range 4.0 – 5.5 % N. Therefore plants from all the substrates had sufficient nitrogen content. The differences among variants were small.

The optimum content of phosphorus in cucumbers is in the range 0.25 – 1.0 % P (Jones at al, [4]; Bergmann, [1]). The cucumber seedlings had optimum P content for their growth. The concentration of P was the highest in substrates E (JZT : Org = 7:3) and B (BGZ).

The optimum content of potassium in cucumbers is in the range 3.50 – 4.5 % K (Jones at al, [4]). The K content of plants grown on substrate A (Jordanian zeolite) was less then optimum concentration. This could be in result of lower content of exchangeable K in this substrate (table 3).

Content of Ca and Mg in grown cucumber seedlings were in optimum range of values for these elements according Jones at al [4] – respectively 1.50 – 4.0 for the Ca and 0.30 – 1.0 for the Mg. The cucumber seedlings grown on substrate A (JZT) had higher content of Ca and Mg in comparison with the other substrates (table 9).

The comparison of the content of nutritional elements in tomatoes seedlings (table 10) with optimal range of the elements in tomatoes according Jones at al [4] and Bergmann [1] showed that the plants were well supplied with the main nutritional elements.

The data received at this experiment for the mineral composition of tomato seedlings were similar with the data reported from Stoilov and Gorbanov [16], who have grown tomato seedlings on mineral zeolite substrate and nine other organic, mineral and organic-mineral nutritional media. The results were close especially for the N, P and Mg concentration in the seedlings. The authors found out best biometrics indices (weight of plants, height, number

Table 8 Dry matter per plant (g)

Substrates	Cucumbers	Tomato
A (JZT)	3,0	2,6
B (BGZ)	3,5	4,0
C (JZT : BGZ = 1:1)	4,3	4,1
D (JZT : BGZ = 3:1)	3,7	3,7
E (JZT : Org = 7:3)	3,9	5,6
A (JZT) +TW	3,1	2,3
B (BGZ) +TW	5,2	4,2
C (JZT : BGZ = 1:1) +TW	4,4	3,7
D (JZT : BGZ = 3:1) +TW	4,5	3,3

Table 9 Concentration of nutritional elements in cucumbers (%)

Substrates	N	P	K	Ca	Mg
A (JZT)	5,01	0,76	3,16	2,01	0,96
B (BGZ)	5,02	0,94	4,83	1,80	0,61
C (JZT : BGZ = 1:1)	5,19	0,59	4,35	1,75	0,85
D (JZT : BGZ = 3:1)	5,22	0,59	4,50	1,76	0,84
E (JZT : Org = 7:3)	4,28	1,02	4,11	1,92	1,07
A (JZT) +TW	5,39	0,66	3,29	2,25	1,01
B (BGZ) +TW	5,25	0,72	4,43	1,64	0,53
C (JZT : BGZ = 1:1) +TW	5,13	0,55	5,08	1,69	0,78
D (JZT : BGZ = 3:1) +TW	5,10	0,57	5,79	1,85	0,91

Table 10 Concentration of nutritional elements in tomatoes (%)

Substrates	N	P	K	Ca	Mg
A (JZT)	2,53	0,49	2,22	1,56	0,72
B (BGZ)	3,95	0,54	2,67	1,11	0,51
C (JZT : BGZ = 1:1)	3,97	0,36	3,06	1,18	0,59
D (JZT : BGZ = 3:1)	3,83	0,42	2,69	1,27	0,81
E (JZT : Org = 7:3)	3,93	0,41	2,05	1,36	1,05
A (JZT) +TW	4,03	0,44	2,21	1,32	1,00
B (BGZ) +TW	4,14	0,45	3,13	1,31	0,52
C (JZT : BGZ = 1:1) +TW	3,78	0,29	3,52	1,78	0,84
D (JZT : BGZ = 3:1) +TW	4,25	0,28	3,76	1,29	0,80

of leaves) and largest reserve of nutrients for the plants grown on the zeolite substrate.

CONCLUSIONS

1. The row material JZT from Jordan with its sorption properties and content of nutritional elements for the plants (K, Ca, Mg, P) can be use for production of substrates for growing of vegetable plants seedlings.
2. At comparison of growth strength of cucumber and tomato seedlings JZT showed low quality as a row material for substrates production in comparison with Bulgarian zeolites (BGZ). This could be explaining with no good balance between exchangeable cations.
3. Addition to the substrate of 0,1 % from the compound TERAWET improve plant growth but this amount was not sufficient and it is recommended to be increased. TERAWET decreased drought risk and could be eliminated if drip irrigation system is used.
4. The plant analyses demonstrate that substrates based on the JZT and BGZ ensure favorable nutritional conditions for seedling's growth. The content of the main nutritional elements in the plants was in the optimum range for their growth.

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