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EFFECTS OF PEAT AND PEAT-ZEOLITE SUBSTRATES ON QUALITY, GROWTH INDICES OF CUCUMBER SEEDLINGS AND CROP PRODUCTIVITY

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ABSTRACT

The objective of this study was to evaluate the peat and zeolite mixtures substrates performance on cucumber seedling quality and crop yield. The research was carried out in a greenhouse covered with double polymeric film at the Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry. Cucumber seedlings were grown in different substrates: peat, peat + zeolite 1 : 1, peat + zeolite 2 : 1, peat + zeolite 3 : 1 and peat + zeolite 4 : 1. Cucumber seedlings grown in peat and zeolite substrates are shorter; the leaf area is smaller than that of the seedlings grown in peat alone. The dry mass of the aboveground part of these seedlings is lower (insignificant difference), however, the root mass is higher than those grown in peat alone. The addition of zeolite to peat substrate does not have any positive effect on the photosynthesis pigment content in cucumber seedling leaves. The physiological growth indices of the seedlings grown in peat-zeolite substrates were lower compared to those grown in peat. When zeolite is added to peat substrate, net assimilation rate is higher compared to those grown in peat. Higher yields (significant difference) were demonstrated by cucumbers, the seedlings of which had been grown in peat-zeolite substrates.

Key words: *Cucumis sativus* L., mixtures of growing media, seedling, yield

INTRODUCTION

The goal in vegetable seedling production is to produce a sturdy, compact plant, which will establish and grow quickly, and produce an optimum yield when transplanted [Vavrina 2002]. Many factors determine seedling quality, including leaf area, root to shoot ratio, root volume, fertilisation, transplant age, air temperature, substrate and growth stage [Cantliffe 1993, Schrader 2000, Brown et al. 2002, Vavrina 2002, Brigard et al. 2006, Jankauskienė et al. 2013]. Young plants are particularly sensitive to various environmental factors during early growth stages, therefore, one of the key factors to grow sturdy and healthy seedlings is the selection of a suitable substrate. A growing medium for seedlings affects the quality and growth parameters of seedlings as well as their total yield [Gruda and Schnitzler 1997, Babaj et al. 2009, Nichols and Savidov 2009, Gao et al. 2010, Bozorgi et al. 2012]. Peat, pine bark, sawdust, coco-fibre, vermicomposts, etc., alone or in mixtures are used as substrates for seedling growing. Peat moss has long been the primary component of seedling media for vegetable plants [Gruda and Schnitzler 2004].

The standard vegetable seedling medium in Lithuania is peat. In order to improve physical, chemical

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and biological properties of substrates, scientists recommend mixing peat with other natural materials in different proportions [Cattivello 1995, Sawan et al. 1999, Castillo et al. 2004]. One of such material is zeolite. Zeolites are crystalline, alkaline or alkaline-earth hydrated aluminosilicates, characterised by high cation exchange capacity and the ability to absorb ammonium ions and plant available nutrient elements [Ilsidar 1999, Mumpton 1999]. Many researchers have investigated the possibilities of using zeolite as substrate for hydroponic cultivation of vegetables in greenhouses, as well as its mixtures with other substrates (peat, perlite) [Kanazirska et al. 1997, Harland et al. 1999, Mumpton 1999, Stamatakis et al. 2001, Manolov et al. 2005, Nichols and Savidov 2009, Berar and Poşta 2011]. Zeolite as substrate has been successfully used for containerised production system [Yilmaz et al. 2014]. Some research results show that zeolite and its mixtures with other substrates have a positive effect on vegetable seedling growing [Markovic et al.1995]. Others argue that zeolite does not affect the quality of lettuce, melon and tomato seedlings and total yield [Cattivello 1995]. According to other researchers, addition of zeolite to peat substrate resulted in a higher yield of sweet peppers and tomatoes [Markovic et al. 2000, Traka-Mavrona et al. 2001]. It has been determined that the effectiveness of zeolite depends on its amount in substrate and the size of particles [Urbina-Sánchez et al. 2006, Anicua-Sánchez et al. 2008, Trinchera et al. 2010]. Tomato seedlings grown in zeolite of the largest particle size were shorter than in the zeolites with fine and medium particle sizes [Urbina-Sánchez et al. 2006].

Many studies have been carried out in which zeolite has been mixed with other substrates. Different substrates can be mixed in different proportion relationships in order to create the best possible conditions media for plant growth. However, there is a difference in the data for which the ratio of zeolite to the substrate is most appropriate for plants. The needs of each plant for substrates and their mixtures are different. The aim of this study was to determine the effect of peat and zeolite mixtures on cucumbers seedling quality, physiological growth indices and yield.

MATERIALS AND METHODS

The investigations were carried out at the Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry in the Multi Rovero 640 TR ("Rovero", the Netherlands) greenhouse covered with a double polymer film in the period of 2015–2017. The cucumbers were sown at the beginning of March and the seedlings were grown in polymer pots filled with substrate on the shelvings in a heated nursery. They were watered manually each cup individually, as needed. The seedlings were cultivated for 30 days. During seedling cultivation the day/night temperature was 20–23/15–18°C and the relative air humidity was 50–60%. The investigation object was hybrid 'Mandy'. Different substrates were investigated: peat (N 100–120, P_2O_5 30–80, K_2O 120–200 mg L^{-1}; microelements Fe, Mn, Cu, S, Mo, Zn; pH 5.5–6.5) (Profi 1, Durpeta, Lithuania), peat + zeolite 1 : 1, peat + zeolite 2 : 1, peat + zeolite 3 : 1, peat + zeolite 4 : 1. In the midle of April the seedlings were transplanted in the greenhouse and were cultivated in 20 l peat bags (1 bag – 2 plants). The plant density in the greenhouse was 2.5 plants per m^2.

In greenhouse the cucumbers were grown in open soilless system using drip irrigation. Plants were fertilized with "Nutrifol" (green and brown), magnesium sulphate, calcium and ammonium nitrate fertilizers. Nitric acid was used for water acidification. There was prepared solution, which was diluted with water in a ratio of 1 : 100, and plants were fertilized taking into the account the growth stage (each plant had a needle, the solution was watered 4−15 times a day through it). The amount of solution aranged from 0.3 to 1.5 liter per plant. The salt concentration in feeding solution was EC 2.8–3.0, acidity – pH 5.5–5.8.

The end of cucumber vegetation was 30 June. During plant cultivation the day/night temperature was 19–26/15–19°C and the relative air humidity was 60–80%. The plot area – 4.8 m^2. Three replications were done in a randomised block design.

The biometrical observations were carried out and the content of photosynthetic pigments in leaves was established at the end of the seedling growth. The seedling height was measured to the tip of the youngest leaf. The leaf area of seedlings was measured by

"WinDias" leaf area meter (Delta-T Devices Ltd., UK). To determine the dry weight of seedling shoots and roots they were dried in a drying oven at 105°C for 24 h. Photosynthetic pigment content per one gram of fresh foliage weight was measured in 100% acetone extract according to D. Wettstein method [Gavrilenko and Zigalova, 2003] using "Genesys 6" spectrophotometer (ThermoSpectronic, USA). The measurements were performed in four replicates ($n = 4$). The fully formed leaves were analysed.

The mineral element content was determined in plant leaves. The total nitrogen in plant leaves was determined by the Kjeldahl, phosphorus – calorimetrically, potassium – by the flame photometric, calcium and magnesium – by atomic absorption spectrometric methods.

Physiological growth indices were determined following Hunt et. al. [2002]. They were calculated as follows:
relative growth rate (RGR) is the

$$RGR = (\ln W_2 - \ln W_1)/(t_2 - t_1),$$

where W_2 and W_1 are total plant dry weights at times t_2 and t_1, respectively.

The net assimilation rate (NAR) of a plant is defined as its growth rate per unit leaf area for any given time period (day). It can be calculated as:

$$NAR\ (g\ cm^{-2}\ d^{-1}) = (1/LA)\ (dW/dt),$$

where LA is leaf area (cm^2) and dW/dt is the change in plant dry mass per unit time.

Leaf area ratio (LAR) is the total surface area of a plant's leaves (cm^2) divided by the dry weight of the plant (g).

Specific leaf area (SLA) is the ratio of leaf area (cm^2) per plant to leaf dry weight (g).

Leaf weight ratio (LWR) is the ratio of total leaf weight (g) to total plant weight (g).

Shoot root ratio (SRR) is the ratio of shoot dry mass to root dry mass.

The cucumber yield was recorded at every harvest. Cucumber fruits were harvested three times a week, and then they were separated into marketable and non-marketable ones. The total yield was calculated by aggregating each harvest. Nitrate concentration in cucumber fruits was measured by a potentiometric method [Geniatakis et al. 2003] using ion meter (Oakton, USA) and combined nitrate ion selective electrode HI4113 (HANNA instruments, USA).

The data was analysed by the ANOVA statistical package. The Fisher's LSD test was used to determine significant treatment effects. Statistical significance was evaluated at $p \leq 0.05$.

RESULTS

The cucumber seedlings grown in peat alone were 2.3–20.7% taller compared to those grown in peat and zeolite substrates (difference insignificant) (Tab. 1). Incorporating the highest proportion of zeolite (peat and zeolite 1 : 1) resulted in the shortest seedlings. The height of the seedlings grown in peat and peat and zeolite substrates 3 : 1 was almost identical. The stem diameter of the seedlings grown in peat-zeolite substrates was slightly smaller compared to the ones grown in peat alone. The seedlings grown in peat alone demonstrated the largest leaf area. It was 11.9–30.1% higher compared to that of seedlings grown in peat and zeolite substrates (difference insignificant). Among the seedlings grown in peat and zeolite substrates, the largest leaf area was demonstrated by the seedlings grown in peat and zeolite substrate 3 : 1. The highest dry mass of the aboveground plant part (leaf and stem) was observed in the seedlings grown in peat alone. It amounted to 4.83 g, and that of the seedlings grown in peat-zeolite substrates ranged from 3.69 to 4.37 g. The cucumber seedlings grown in peat and zeolite substrates had higher dry root mass. The highest root mass was recorded in the seedlings grown in peat and zeolite substrate 2 : 1. It was 3.9 times higher compared to the dry root mass of the seedlings grown in peat alone (difference insignificant). The dry root mass of the cucumber seedlings grown in other peat and zeolite substrates was 1.2–2.4 times higher than that of the seedlings grown in peat alone.

LAR, SLA, LWR and SRR of the cucumber seedlings grown in peat, were higher compared to those grown in peat-zeolite substrates (Tab. 2). Among the seedlings grown in peat-zeolite substrates, higher LAR, SLA, LWR and SRR were found in those grown in peat-zeolite substrate (4 : 1), while the lowest values of these growth indices were observed in the seed-

Table 1. Some morphological characteristics of cucumber seedlings grown in different substrates

Treatments	Plant height (cm)	Stem diameter (cm)	Number of leaves (unit)	Leaf area (cm^2)	Dry weight (g)		
					leaf	stem	root
Peat	40.8	0.65	5.2	800.99	3.21	1.62	0.80
Peat + zeolite 1 : 1	33.8	0.61	4.8	654.01	2.68	1.15	1.84
Peat + zeolite 2 : 1	36.0	0.60	4.9	658.11	2.87	1.20	3.15
Peat + zeolite 3 : 1	39.9	0.62	5.3	715.94	3.06	1.31	1.89
Peat + zeolite 4 : 1	38.0	0.62	4.7	615.58	2.49	1.20	0.98
LSD_{05}	14.73	1.18	0.73	261.57	1.41	0.70	3.23

Table 2. Some physiological growth indices of cucumber seedlings grown in different substrates

Treatments	RGR ($g\ d^{-1}$)	NAR ($g\ cm^2\ d^{-1}$)	LAR ($cm^2\ g^{-1}$)	SLA ($cm^2\ g^{-1}$)	LWR ($g\ g^{-1}$)	SRR
Peat	0.17	0.34	167.05	253.20	0.57	6.47
Peat + zeolite 1 : 1	0.16	0.42	138.50	231.60	0.50	2.89
Peat + zeolite 2 : 1	0.18	0.38	130.81	230.74	0.43	2.53
Peat + zeolite 3 : 1	0.17	0.38	144.99	235.60	0.50	2.64
Peat + zeolite 4 : 1	0.16	0.40	160.16	242.13	0.53	4.51
LSD_{05}	0.04	0.11	34.57	31.68	0.13	2.16

Table 3. Mineral element content in the leaves of cucumber seedlings grown in different substrates

Treatments	Mineral element content (% DM)				
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Peat	3.26	0.88	3.35	2.87	0.64
Peat + zeolite 1 : 1	2.87	0.79	2.65	2.53	0.60
Peat + zeolite 2 : 1	3.33	0.87	2.80	3.06	0.69
Peat + zeolite 3 : 1	3.52	0.95	2.50	3.12	0.72
Peat + zeolite 4 : 1	3.69	1.38	4.05	2.86	0.64
LSD_{05}	0.31	0.22	0.11	0.34	0.15

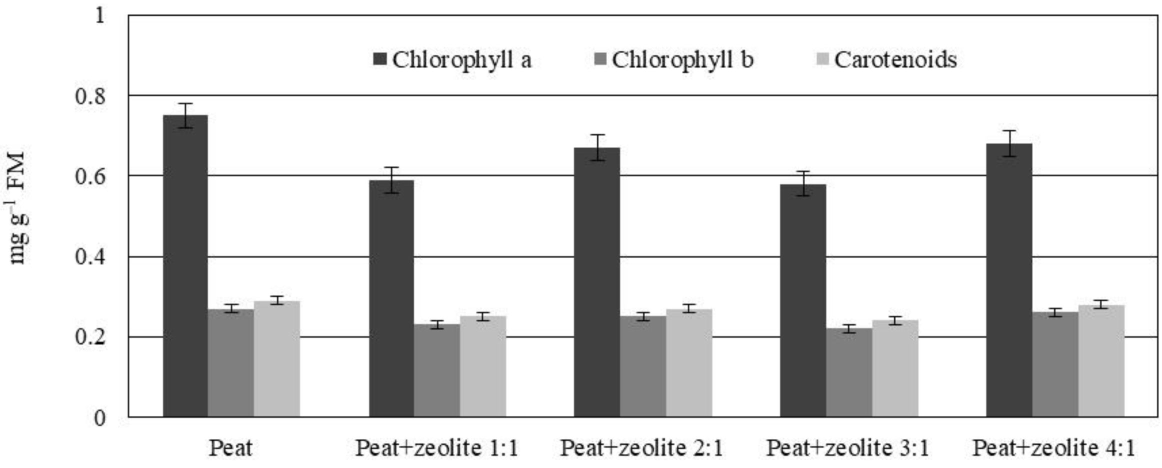

Fig. 1. The content of photosynthetic pigments in the leaves of cucumber seedlings grown in different substrates

lings grown in peat-zeolite substrate 2 : 1. The addition of zeolite in peat substrate had a positive effect on the net assimilation rate of the seedlings. The net assimilation rate of the seedlings grown in peat and zeolite substrates was 11.8–23.5% higher compared to those grown in peat alone (difference insignificant). The highest net assimilation rate was of the seedlings grown in peat and zeolite substrate 1 : 1. The net assimilation rate was the same for seedlings grown in peat and zeolite substrates 2:1 and 3 : 1.

The cucumber seedlings, grown in peat alone, accumulated more photosynthetic pigments in leaves compared to the seedlings grown in peat and zeolite substrates (Fig. 1). Chlorophyll content in their leaves was 8.5–24.4% higher compared to the leaves of seedlings grown in peat and zeolite substrates. Of the seedlings grown in peat and zeolite substrates, the highest chlorophyll content was observed in those grown in peat and zeolite substrates 2 : 1 and 4 : 1. The leaves of seedlings grown in peat and zeolite substrate 3 : 1 accumulated the lowest chlorophyll content. The highest carotenoid content was found in the leaves of seedlings grown in peat. It was by 3.6–20.8% higher respectively, compared to the seedlings grown in peat-zeolite substrates. The smallest carotenoid content as well as that of chlorophyll was accumulated in the leaves of seedlings grown in peat and zeolite substrate 3 : 1. The carotenoid content in the leaves of seedlings grown in peat and zeolite substrates 2 : 1 and 4 : 1 was the same.

Statistically more nitrogen, potassium and phosphorus were accumulated by the leaves of cucumber seedlings grown in peat-zeolite substrate 4 : 1 compared to those grown in peat alone (Tab. 3). The seedlings grown in peat-zeolite substrate 3 : 1 accumulated higher levels of nitrogen, phosphorus, calcium and magnesium compared to those grown in peat, but this difference was not significant. The seedlings grown in peat-zeolite substrate 1 : 1 contained the lowest amounts of nitrogen, phosphorus, calcium and magnesium in the leaves.

Zeolite added to peat substrate influenced cucumber productivity (Fig. 2). The highest early yield (i.e. the two yielding weeks) was obtained from the cucumbers, which had been grown in peat-zeolite substrates 2 : 1 and 3 : 1. In the first yielding month, it was 17.7% to 24.1% larger (difference insignificant) compared to the cucumbers, the seedlings of which had been grown in peat substrate alone. The total yield was higher in those treatments where cucumber seedlings had been grown in peat-zeolite substrates. The largest total yield was obtained from those cucumbers, the seedlings of which had been grown in peat-zeolite substrate 1 : 1. It was 31.9% (significant difference) higher than that of cucumbers, seedlings of which had been grown in peat substrate alone.

According to our research, the substrate in which the seedlings were grown affected the nitrate content in cucumber fruits (Fig. 3). The highest nitrate content was accumulated in those cucumber fruits, the seedlings of which had been grown in peat-zeolite substrate 3 : 1. They had a significant difference of 16.9% compared to those cucumber fruits, the seedlings of which had been grown in peat substrate. The least significant nitrate difference was observed in cucumber fruits, the seedlings of which had been grown in peat-zeolite substrate 2 : 1.

DISCUSSION

The selection of substrate influences biometric parameters of seedlings, their dry and fresh mass [Markovc et al. 2000, Arenas et al. 2002, Wang et al. 2004, Babaj et al. 2009]. The data by Markovic and other researchers [2000] showed that peppers of better quality were grown in peat (2/3) and zeolite (1/3) substrates. They were taller, had more leaves and more dry matter. Rydenheim [2007] proposes that cucumber seedlings are more developed and lush, when 20% of zeolite are incorporated into a substrate. According to Gül's data [2007], cucumbers grown in perlite + clinoptilolite substrate 3 : 1 were taller. Cattivello's [1995] notices that 3–7% of zeolite added to substrate for growing lettuce, tomato, melon, and some flower seedlings produced better results compared to the addition of 15% of zeolite. Xiuhua et al. [2004] argue that as the amount of zeolite in substrate increases, the stem diameter, leaf area and plant dry mass increase as well. Our research data showed that different peat and zeolite ratios had different effects on biometric and photosynthetic parameters of seedlings. Contrary to Rydenheim, Song and other data, our studies revealed that cucumber seedlings grown in peat and zeolite substrates were shorter; leaf area was also lower compared to those grown in peat alone (Tab. 1). Cucumber seedlings were the shortest, when the amount of zeolite in peat was the highest 1 : 1 and the root mass was the largest when zeolite was incorporated into the peat substrate at a ratio of 2 : 1.

The incorporation of zeolite into substrate has a positive effect on photosynthesis parameters, pigment content in plant leaves, root growth and mass [Xiuhua et al. 2004, Abdi et al. 2006]. Harb and Mahmoud [2009] found that with zeolite added to soil, plant fresh and dry mass as well as chlorophyll content in plants increase. Contrary to the data by Harb and Mahmoud, in our study cucumber seedlings grown in peat–zeolite substrates accumulated lower pigment content in leaves compared to those grown in peat alone. The dry mass of the aboveground part of the plant was also lower in the seedlings grown in peat and zeolite substrates. Krutilina et al. [2000] indicated that zeolite increased biomass production and photosynthetic rate in maize and barley. According to our research, the addition of zeolite to peat substrate had a positive effect on the net assimilation rate of seedlings. The higher the amount of zeolite in peat 1 : 1, the greater the net assimilation rate of cucumber seedlings (Tab. 2).

Not much literature can be found on the influence of substrates on the physiological growth indices of seedlings. SLA index helps to evaluate the resistance of the plant to stress during transplantation. When SLA decreases, resistance to stress is increasing. The LAR index is also used to evaluate seedling resistance at transplant [Herrera et al. 2008]. Herera and other researchers [2008] established that no significant differences were found for specific leaf area (SLA) or leaf area ratio (LAR) between the substrates studied. According to Babaj and others [2009], a sgnificantly higher relative growth rate (RGR) was found in cucumber seedlings grown in vermicompost compared to the seedlings grown in peat substrate. Our research data showed that the physiological growth indices of the seedlings grown in peat were higher compared to those grown in peat-zeolite substrates. Decreased shoot-to-root ratio and SLA showed (Tab. 2) that cucumber seedlings grown in peat-zeolite substrates, produced less leaves but accumulated more assimilative products in roots.

According to the data by Yilmaz and others [2014] the nutrient content in the leaves of cucumber seedlings depended on different growing media. The maximum amount of P and K was found in the leaves of seedlings grown in turf substrate; the addition of zeolite to this substrate reduced the content of these substances. The highest N content was observed in the leaves of seedlings grown in zeolite alone. Other

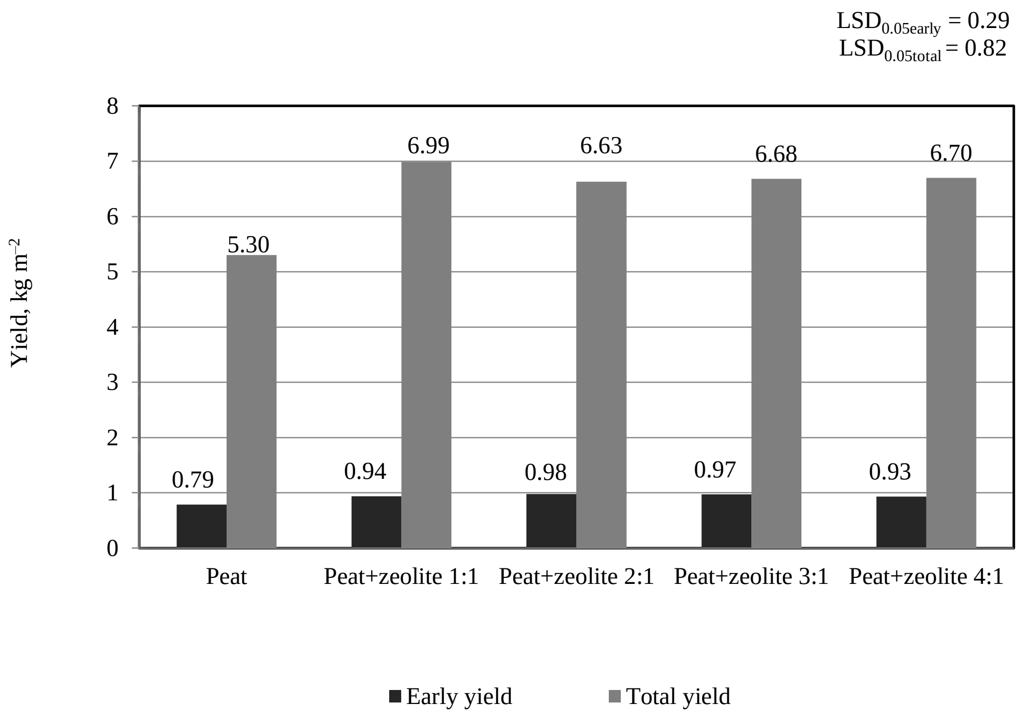

Fig. 2. The effect of substrates on early and total cucumber yield

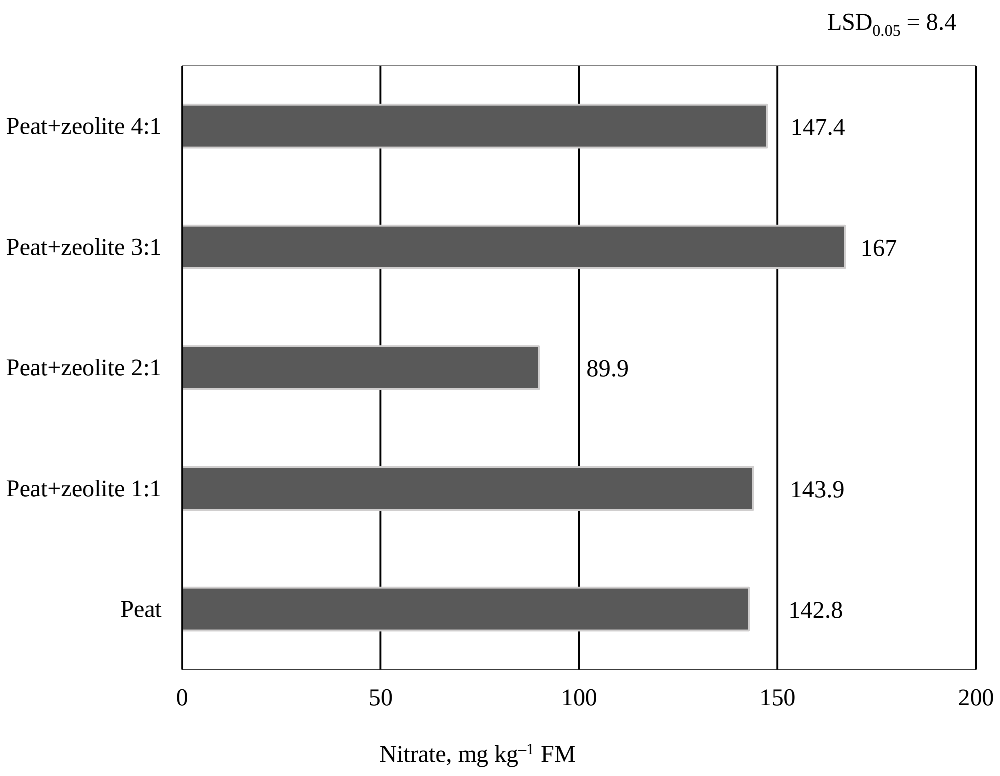

Fig. 3. The effect of substrates on nitrate content in the fruit of cucumber

authors argue that the zeolites are very effective in increasing N and K in plant tissues [Sönmez et al. 2010]. Gül and others provide the data [2007] revealing that the addition of zeolite to perlite substrate increased K, Fe, Cu and Mn, while Mg content in lettuce leaves decreased. According to our research, the content of mineral elements in the leaves of cucumber seedlings depended on the amount of zeolite in peat substrate. Statistically more nitrogen, potassium and phosphorus in leaves were accumulated by the cucumber seedlings grown in peat-zeolite substrate 4 : 1 compared to those grown in peat alone (Tab. 3).

Many authors found that the type of growing media (organic or mineral) did not affect productivity in cucumbers [Cantliffe et al. 2003, Schroeder and Sell 2009]. Peyvast et al. [2008] argue that substrate had a significant effect on cucumber growth and total yield. According to Leggo [2000] zeolites may be used in growth media to improve plant yields. Mixtures of zeolite and fertilisers also had positive effects on tomato [Ashraf 2011] and cucumber [Bozorgi et al. 2012] yields. Berar and others [2011] argue that the yield of tomatoes was increased by adding 25% zeolite to substrate. According to other researchers, higher yields of cucumbers were obtained by growing them in zeolite and perlite substrate for hydroponic cultivation [Kanazirska et al. 1997]. Adding zeolite (10 and 20%) into sawdust and, in some cases, perlite substrate results in a higher yield of greenhouse cucumbers [Nichols and Savidov 2009]. Pursuant to the data by many authors, the results of our study showed that the yield of cucumbers, the seedlings of which had been grown in peat-zeolite substrate, was higher. The most significant total yield was that of cucumbers the seedlings of which had been grown in peat-zeolite substrate 1 : 1 (Fig. 2).

According to the data of Gül and other researchers [2007], the addition of zeolite into perlite had a positive effect on the growth of lettuce and reduced the nitrate and nitrite content in their leaves. According to our research, the nitrate content in cucumber fruits depended on the amount of zeolite in peat. The least significant difference in terms of nitrates in cucumber fruits was attributed to cucumbers, the seedlings of which had been grown in peat-zeolite substrate 2 : 1 (Fig. 3). More detailed research are needed to determine the effect of zeolite on the accumulation of nitrate in cucumber fruits.

CONCLUSIONS

The admixture of zeolite into peat substrate had influence on biometric parameters of cucumber seedlings: they were shorter, the leaf area and the dry aboveground mass of the plant were smaller, but the root mass was higher. Thus, the positive effect of the admixture of zeolite into peat substrate on net assimilation rate in the leaves of cucumber seedlings was observed. The admixture of zeolite into peat substrate affected the yield quantity. The yield of cucumbers, the seedlings of which had been grown in peat-zeolite substrates was significantly larger compared to that of cucumbers, the seedlings of which had been grown in peat alone. The cucumbers with their seedlings grown in peat-zeolite substrate 1 : 1 recorded the highest yield (significant difference).

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