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Original Research

Organic Substrates for Intensive Horticultural Cultures: Yield and Nutrient Status of Plants, Microbiological Parameters of Substrates

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Abstract

The aim of our studies was to determine the suitability of organic substrate: peat, coconut fiber with a 20% admixture of chips, and coconut fiber with a 40% admixture of chips (as alternative substrates in relation to rockwool) in intensive horticultural cultures with fertigation adopted as the fertilization method. Tomato was the model plant in this study. Evaluations comprised yielding of plants, contents of macro- and microelements in leaves and fruits, plus changes in the counts of different groups of microorganisms: bacteria, fungi, Actinomycetes, and dehydrogenase activity in the root medium of plants during their vegetation. The significantly highest total yield of plants was found in the case of plants grown in peat and in coconut fiber with a higher (40%) content of chips (9.28 kg·m^{-2} each) in relation to rockwool (8.35 kg·m^{-2}). A similar trend was recorded in the case of commercial yield. Applied substrates significantly modified yielding fruit of grades I-VI. Despite the recorded significant modifying effect of the substrate on nutrient contents in leaves and fruits of plants grown in it, no visual symptoms of their deficiencies were observed, which indicates an adequate plant nutrition in both rockwool and organic substrates. Analyzed organic substrates are perfectly suitable for application in intensive culture of vegetables under cover. After the completion of the plants' cultivation cycle they become valuable organic fertilizer, exhibiting advantageous microbiological parameters, i.e. relatively high counts of fungi, bacteria, and Actinomycetes, as well as dehydrogenase activity, which may improve the fertility of the soil on which they have been utilized.

Keywords: soilless cultures, organic substrates, microbiological composition, tomato, yield, nutrient plant status

Introduction

The most efficient method of plant nutrition is fertigation, consisting of the combined application of fertilization and irrigation in the form of the so-called nutrient solution (water with dissolved fertilizers). Most intensive cultures presently run in Poland use this type of plant nutrition system. However, in most cases they are open fertigation systems, in which excess nutrient solution, the so-called spillway (20-40%), leach from the root zone of plants (from beds or culture mats) directly to soil under greenhouses, causing its physical or chemical degradation [1].

Rockwool is the inert substrate used most typically in intensive cultures under cover (especially greenhouses).

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This substrate provides advantageous air and soil conditions to plants: at 52% water, 45% air, and 3% the solid phase, which has a positive effect on plant yield [2, 3]. However, there are serious ecological concerns connected with its application, one of which concerns the spillway. It is estimated that the amount of nutrients released in this way from 1 hectare of greenhouse culture amounts to (in $kg \cdot ha^{-1}$ per year): $N\text{-}NO_3$ 231, K 413, Ca 220, and S 101 [1], which results in a significant scale of the problem considering the area cropped, to e.g., tomato, as high as approx. 2,500 ha. A serious drawback of the use of rockwool is also connected with problems with its management after the completion of the culture cycle, due to it being non-biodegradable. So far, despite repeated attempts, complete disposal of production waste of culture mats has not been possible.

From the point of view of ecology, it is more advantageous to use organic substrates, in which case it is not necessary to use a spillway; moreover, they are more readily biodegradable, e.g. by having substrates spread in the field after the culture cycle and mixing it with soil. Several recent studies have been conducted on the application of organic substrates, alternative to rockwool, in intensive horticulture systems, such as, e.g., wood fiber [4-9], sawdust [3], and coconut fiber [10-13]. It is important for the used substrates for a maximally long culture period to exhibit advantageous air and water relations. A considerable problem connected with the use of organic substrates in intensive cultures in greenhouses may be related to biological sorption of nutrients. This may pertain particularly to nitrogen and it is caused by microorganisms colonizing them [5, 7, 14-16]. This has been an incentive to conduct studies to provide insight into groups of microorganisms colonizing the root medium of plants and their potential effect on plant yield.

The aim of the conducted studies was to determine the suitability of organic substrates: peat, coconut fiber with a 20% admixture of chips, and coconut fiber with a 40% admixture of chips – as alternative substrates in relation to rockwool in intensive horticultural cultures. Evaluated parameters included quantitative and qualitative yielding of plants, contents of macro- and microelements in leaves and fruits, as well as changes in counts of bacteria, fungi, Actinomycetes, and dehydrogenase activity occurring during plant vegetation.

Material and Methods

Vegetation Experiment

Vegetation experiments were run in specialist culture greenhouses equipped with a modern climate control system. Climate parameters (temperature, CO_2 content, % RH) were recorded using Synopta software (Fig. 1). The facilities were equipped with a modern, computer-controlled fertigation system and energy-conservation curtains. Plants were grown at a density of 2.5 $plants \cdot m^{-2}$.

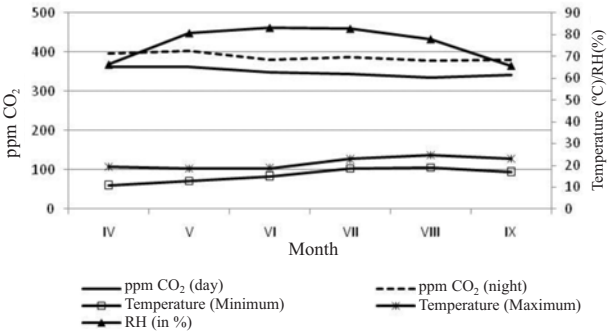

Fig. 1. Parameters of greenhouse climate: mean minimum and maximum temperatures (ºC), mean content of CO_2 during the day and at night (ppm CO_2), relative humidity (RH %).

The aim of the conducted experiments was to determine suitability of organic substrates: peat, coconut fiber with a 20% admixture of chips, and coconut fiber with a 40% admixture of chips – as alternative substrates in relation to rockwool in intensive horticulture systems run in a greenhouse. Analyzed organic substrates are characterized by varied air and water properties (% air – % water): Peat (60-34), coconut fiber (62-29), and coconut fiber II (47-41). Quantitative and qualitative plant yielding, contents of macro- and microelements in leaves and fruits, as well as changes in counts of bacteria, fungi, Actinomycetes and dehydrogenase activity occurring during the vegetation period were evaluated. Experiments were established in a random block design in 6 replications.

All cultivation measures were performed in accordance with the current recommendations for tomato growing. A tomato (*Lycopersicon esculentum* Mill.) cv. 'Caronte' (ISI Sementi, Italy) was used in the experiments.

Fertigation Water and Nutrient Solution

Plants were grown on culture mats using fertigation in the closed system, without circulation of nutrient solution, but the spillway was collected to special containers and next used in the nutrition of green areas. Two plants were grown per 1 mat. Water, on the basis of which nutrient solutions were prepared, contained (in $mg \cdot dm^{-3}$): $N\text{-}NH_4$ traces, $N\text{-}NO_3$ 3.7, $P\text{-}PO_4$ 0.3, K 1.8, Ca 57.3, Mg 13.4, $S\text{-}SO_4$ 58.3, Fe 0.080, Mn 0.080, Zn 1.648, B 0.011, Cu traces, Mo traces, HCO_3 277.5, pH 7.05, and EC 0.737 $mS \cdot cm^{-1}$. In the experiment a standard nutrient solution was used with the following nutrient contents (in $mg \cdot dm^{-3}$): $N\text{-}NO_3$ 225, P 50, K 445, Ca 150, Mg 60, Fe 4.7, Mn 0.3, Zn 0.5, Cu 0.05, pH 5.50, and EC 3.0 $mS \cdot cm^{-1}$.

Yielding of Plants

In the vegetation period, plant yield was recorded in terms of the following classes: I fruit diameter >10.2 cm, II 10.2 – 8.2 cm, III 8.2 – 6.7 cm, IV 6.7 – 5.7 cm, V 5.7 – 4.7

cm, and VI < 4.7 cm, as well as unclassified fruits and fruits with disease symptoms. Commercial yield comprised fruits of classes I-V.

Sampling

During the culture period leaf samples (8th-9th leaf from the top) were collected 3 times at monthly intervals (June, July, August) in order to determine nutrient status of plants. Samples of fruits at the consumption stage were harvested twice (August, September). Collected fruit samples were included in the recorded yields of plants.

Chemical Analyses

Collected plant material was subjected to chemical analyses. Samples of leaves and fruits were dried at 45-50ºC and then ground. In order to assay total forms of nitrogen, phosphorus, potassium, calcium, and magnesium plant material was mineralized in concentrated sulfuric acid. Mineralization for assays of iron, manganese, zinc and copper was run using the wet method in a mixture of nitric and perchloric acids (3:1, v/v). After mineralization of plant material the following determinations were performed: N – total nitrogen using the distillation method according to Kjeldahl in a Parnas–Wagner apparatus; P – colorimetrically with ammonia molybdate; and K, Ca, Mg, Fe, Mn, Zn, and Cu – using atomic absorption spectroscopy (AAS) (AAS3; Carl Zeiss Jena; Thornwood, NY, USA).

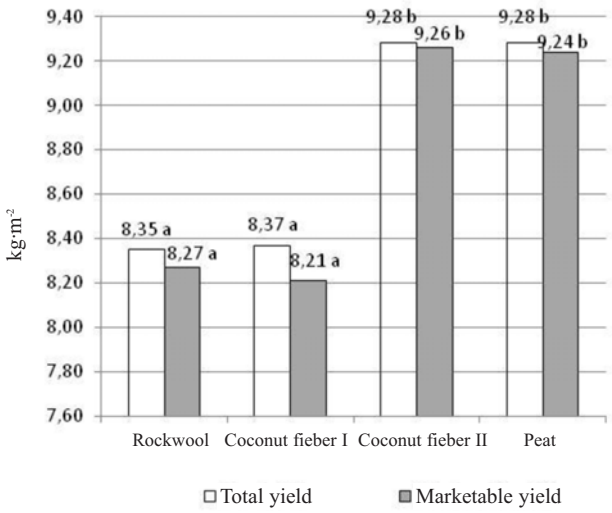

Fig. 2. The effect of substrates on total and marketable yields of plants.

Microbiological Analyses

Dynamics of development of selected microbial groups and enzymatic activity of dehydrogenases, depending on the used substrate (coconut fiber I, coconut fiber II, rockwool, peat), were determined at four dates, depending on the development phase of tomato:

- date I – planting of tomato seedlings (15.04)
- date II – beginning of fruiting (04.06)
- date III – full fruiting (17.08)
- date IV – last harvest and removal of plants (30.09)

In bulk samples collected from under the plants grown on respective substrates, the counts of microorganisms were determined using the plate method on selective agar media (in five replications). Mean number of colonies were converted per dry matter of a given substrate:

- total bacterial count was determined on a commercial Merck-Standard count agar medium after 5 days of incubation at 25ºC
- fungi were determined on the substrate according to [17] after 5 days of incubation at 24ºC
- Actinomycetes were determined on a medium according to Pochon after 5 days of culture at 25ºC

Analyses of enzymatic activity were based on the determination of dehydrogenase activity by colorimetry, using 1% TTC (triphenyltetrazolium chloride) as a medium, after 24-h incubation at 30ºC at a wavelength of 485 nm, and it was expressed in mmol TPF·kg^{-1}·24h^{-1}.

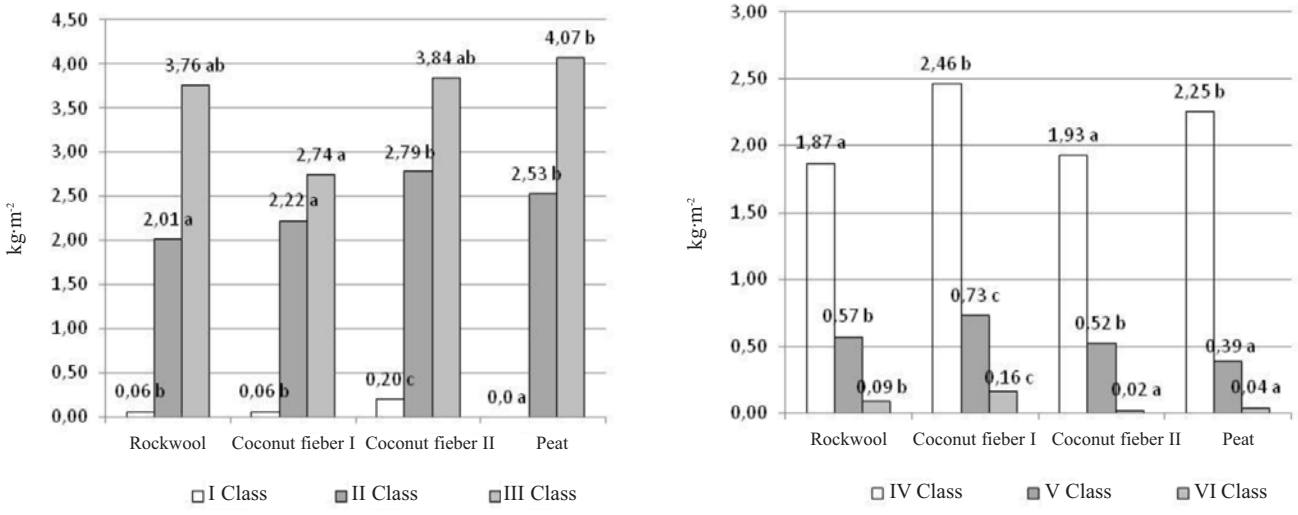

Fig. 3. The effect of substrates on yield of grades I-VI (mean from 6 replications).

Statistical Analyses

Results of plant yield, in terms of classes and analyzed substrates as well as nutrient status of plants and nutrient contents in fruits, were analyzed statistically by analysis of variance at significance level α=0.05.

Results and Discussion

Yielding

A significant variation in yielding was shown between analyzed substrates (Figs. 2 and 3). Yield was the lowest in the case of rockwool and coconut fiber I (8.35 and 8.37 kg·m^{-2}, respectively), while it was the highest in the case of coconut fiber II and peat (with 9.28 kg·m^{-2} each). Identical dependencies were found for commercial yield, being the total of yields in classes I-V.

Significantly, the highest yield of grade I was recorded in the case of coconut fiber II, grade II for coconut fiber, grade III for peat, grade IV for coconut fiber I and peat, grades V and VI for coconut fiber I. The lowest yielding for the analyzed quality grades was recorded in the case of peat (I), rockwool and coconut fiber I (II), coconut fiber I (III), rockwool and coconut fiber I and II (IV), peat (V), and coconut fiber II and peat (VI).

Nutrient Contents in Leaves

Despite significant differences in contents of macro- and microelements in leaves between substrates, during culture no symptoms of deficiency or excess of individual nutrients were observed on plants. Analyzed substrates, despite standard fertilization, had a significant effect on nutrient status of plants for nitrogen, potassium, and magnesium, while they did not modify contents of phosphorus or calcium in leaves. The greatest amounts of N were recorded in the case of plants growing in coconut fiber I, while the lowest for those growing in peat (Fig. 4) although the difference was not significant in comparing to plants growing in rockwool and coconut fibre II. Nitrogen content recorded in the analyses conducted by the authors fell within the optimal range for this nutrient (2.8-4.2% N) [18]. Nitrogen content in indicator parts of tomato plants, depending on the applied inert substrate, ranges from 3.64 to 3.69% N [19]. Some authors also cited higher contents of this nutrient in leaves of tomato [20-22]. The optimal range of nitrogen content in tomato leaves should range from 3.5 to 5.0% [23], which is higher than the contents recorded in our studies. Different tomato cultivars grown in coconut fiber ranged from 3.57 to 4.33% N [24].

No differentiating effect of substrate on nutrient status of plants was observed in our studies for phosphorus (Fig. 4). Slightly lower contents of this macroelement were recorded in earlier studies concerning nutrition of tomato [21]. Standard content of phosphorus in leaves of tomato should fall within the range of 0.40-0.65% P [18] or 0.30-0.65% P [23]. Slightly higher contents in case of tomato grown on coir were reported in an earlier study [24]. Mean content of phosphorus in tomato leaves was 0.41% P [19]. Markedly lower contents of phosphorus were reported earlier too [22, 25].

In the case of potassium, lower contents of this nutrient were recorded in plants grown in rockwool and coconut fiber II, being significantly greater in coconut fiber I and peat (Fig. 4). Similar potassium contents were recorded in the case of tomato grown in different inert substrates [19]. Literature sources reported also lower contents of this nutrient in leaves of tomato [20-22, 25, 26]. Optimal content of potassium in leaves should range from 3.5 to 4.5% K [23]. In earlier studies on small-fruited tomato the range of 4.59-5.87% K was recorded [24].

No modifying effect of substrate was found on calcium content in leaves of tomato (Fig. 4). It ranged from 4.32 to 4.30% Ca. Determined calcium contents in leaves were almost 1.5 times lower than those reported in earlier studies [19]. According to those authors high contents of calcium in leaves could have resulted from the application of nutrient solution with high calcium content (190-230 mg Ca·dm^{-3}). Markedly lower calcium contents in indicator parts of tomatoes were recorded in earlier studies [20-22, 25, 27]. Extremely low content of this nutrient (<1.0% Ca) was reported, too [28]. In the case of tomato grown in coir, they

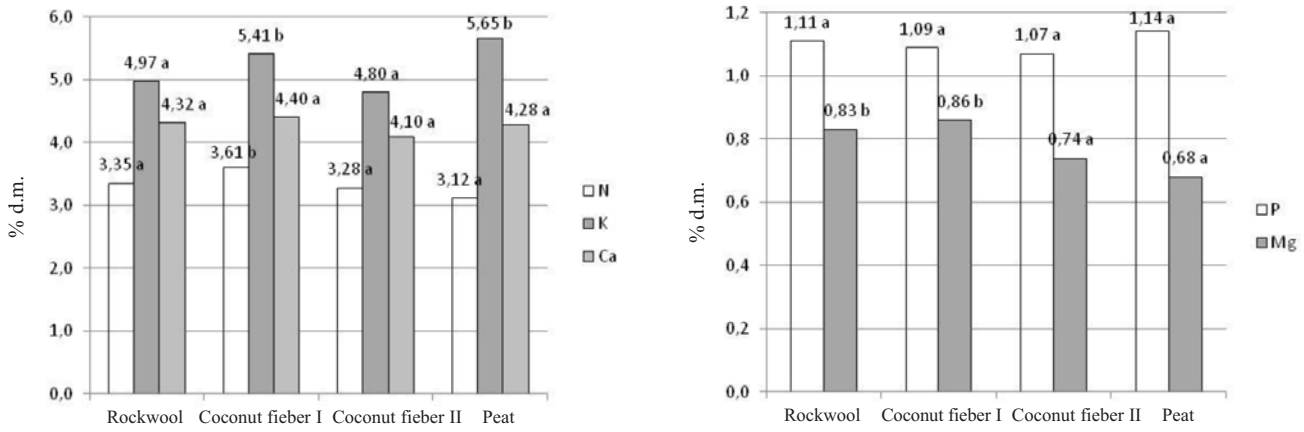

Fig. 4. The effect of substrates on contents of macroelements in leaves.

were recorded 2.64-3.13% Ca [24]. Calcium content determined in this study in leaves markedly exceeded the range of 1.0 to 3.0% Ca [23].

Significantly lower amounts of magnesium were determined in indicator parts of plants growing in coconut fiber II and peat, while they were higher for those grown in rockwool and coconut fiber I (Fig. 4). The nutrient status of tomato (0.73-1.10% Mg), similar to that found in this study, was determined in the case of cultures grown in coir [24]. Some authors in their studies determined markedly lower contents of this macroelement [19, 25]. Optimal content of this nutrient in leaves should fall within the range of 0.35-1.0% Mg [23]. Symptoms of magnesium deficiency are found on leaves of tomato when the content of this nutrient is <0.35% Mg [29].

A significant effect of substrate was observed on the nutrient status of plants for metallic microelements (apart from copper; Fig. 5). The significantly highest iron status of plants was found in the case of coconut fiber I, while for the other substrates they did not differ significantly. The content of this microelement recorded in this study in the case of all substrates were close to the range of 117.8-119.5 mg·Fe·kg^{-1} d.m. reported in earlier studies [30]. Depending on the form of this nutrient, the content of iron in tomato leaves was 127.8-161.1 mg·Fe·kg^{-1} [31]. In tomato culture in coir the detected range was 80.0-133.9 mg·Fe·kg^{-1} s.m [24]. Literature sources also recommend a much wider range of this microelement in leaves, i.e. 50-300 mg·Fe·kg^{-1} d.m., [21, 23] and 45-300 mg·Fe·kg^{-1} d.m. [22]. In the case of manganese a significant improvement of the nutrition status was observed for this nutrient in plants grown in organic substrates (153.3-162.7 mg·Mn·kg^{-1} d.m.) in comparison to rockwool (136.2 mg·Mn·kg^{-1} d.m.). Similarly, as in the case of zinc, the content of manganese recorded in earlier studies and amounting to 262.1-281.3 mg·Mn·kg^{-1} [30] were almost 2 times higher than those recorded in this study. Literature sources give a much wider range of optimal contents of this nutrient amounting to 25.0-1000.0 mg·Mn·kg^{-1} d.m. [18] and 25-200 mg·Mn·kg^{-1} d.m. [23]. In the case of small-fruited tomato grown in coir, the recorded content of manganese was 70.6-190.9 mg·Mn·kg^{-1} d.m. [24].

The highest amounts of zinc in leaves were found in the case of plants grown in rockwool and peat, while they were lower for coconut fiber I and II (Fig. 5). The nutrient status of plants for this microelement fell within the recommended range of this nutrient, amounting to 18-80 mg·Zn·kg^{-1} d.m. [23]. Much higher contents of this nutrient (46.0-56.1 mg Zn) were recorded in the case of tomato cultures in inert substrates [30]. In leaves of tomatoes grown in coconut fiber the content of zinc was found to be 66.9-133.5 ·Zn·kg^{-1} d.m. [24]. Literature sources also gave wider ranges of contents for this nutrient, amounting to 25.0-250.0 mg·Zn·kg^{-1} [18], 54-76 mg·Zn·kg^{-1} d.m. [25], and 20-100 mg·Zn·kg^{-1} d.m. [21].

No significant differences were shown between substrates in terms of the nutrient status of plants with copper. In the case of all the tested substrates it fell within the recommended range of 5 - 35 mg·Cu·kg^{-1} d.m. [23]. Lower mean contents of this nutrient (10.97-11.97 mg Cu) were recorded in the case of cultures in inert substrates [30]. The optimal range of copper contents in leaves is >4 mg Cu [18]. Other authors reported the following contents of this nutrient: 8-20 mg·Cu·kg^{-1} d.m. [21] and 5-30 mg·Cu·kg^{-1} d.m. [22]. Copper levels found in this study fell within the range of contents of this nutrient given for tomatoes grown in coir [24].

Nutrient Contents in Fruits

Literature comprises very few sources on the contents of nutrients (nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, zinc, and copper) in tomato fruits. In the conducted studies a varied and significant effect of substrates was shown on the nutritive value of fruits and their determined contents of nutrients (Figs. 6 and 7). This was found for all nutrients except copper. A general trend was observed, indicating higher contents of nitrogen, phosphorus, potassium, calcium, and magnesium in case of fruits harvested from plants grown in organic substrates (particularly peat) in relation to rockwool. In turn, fruits of plants grown in rockwool contained the highest amount of iron (87.5 mg·Fe·kg^{-1} d.m.), while in the case of coconut fiber I they contained the highest level of zinc (26.6 mg·Zn·kg^{-1} d.m.).

Nitrogen contents determined in fruits ranged from 1.47 to 2.59% N (for coconut fiber II and peat, respectively).

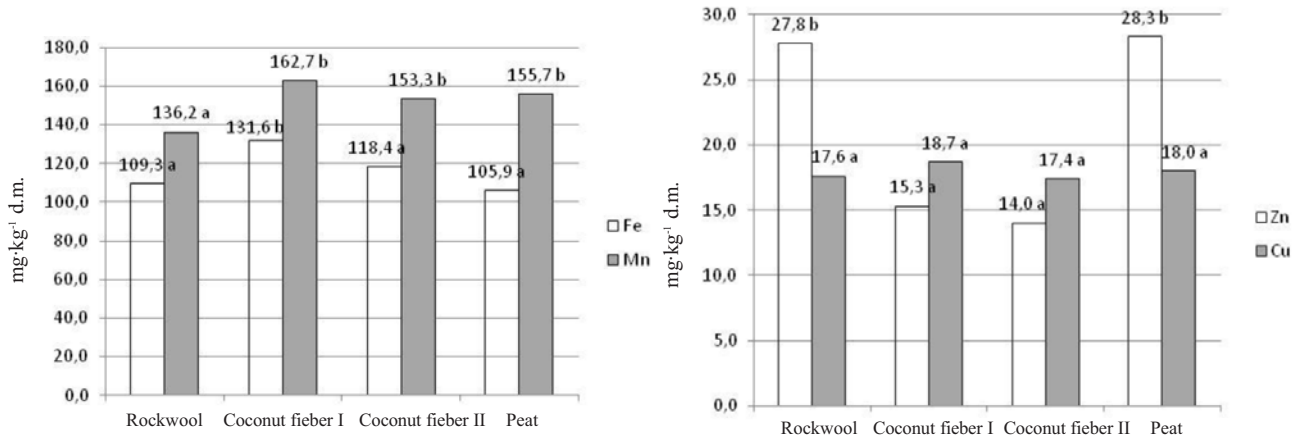

Fig. 5. The effect of substrates on contents of microelements in leaves.

Only in the case of peat were they were positively consistent with the contents cited in literature [2]. The abovementioned author also recorded significantly higher amounts of total nitrogen in fruits harvested from plants grown in peat. Depending on the varied K and Mg fertilization, mean content of nitrogen in fruits fell within the range of 2.28-2.39% N [32]. Substrates significantly modified the content of phosphorus in fruits, ranging from 0.46 to 0.55% P (for rockwool and peat, respectively), which is comparable to the data reported in literature [32]. The lowest content of potassium was determined in fruits of plants grown in coconut fiber II and rockwool (4.35 and 4.61% K, respectively), while it was highest for those grown in peat (5.09% K). Literature sources also confirmed the fact of the significant effect of substrates on potassium content in fruits [2]. In earlier studies [32] lower contents of potassium (3.29-3.30% K) were determined than for those recorded in analyses conducted by the authors of this study. In our studies a significant effect of substrates on calcium content in fruits was found. The content was highest in the case of coconut fiber II and peat (0.19-0.20% Ca), and lower (0.15-0.16% Ca) for the other substrates. A comparable content of this macroelement in fruits was recorded for different substrates, i.e. rockwool (0.15% Ca), peat (0.16% Ca), and sand (0.14% Ca) [2]. The applied substrates – in the case of peat – significantly increased the content of magnesium in fruits. For the other substrates the content of this nutrient did not differ significantly. No significant differences were shown in earlier studies in terms of the content of magnesium between culture run in peat, sand, and rockwool [2].

Microbiological Activity of Substrates

Substrates used in our studies were free from pathogens, pests, and diseases, which results from their production technologies. In the course of culture they are colonized by the root microflora of plants. Microorganisms develop in a close interdependence with plants from the moment of seed germination until plants reach maturity. Rhizosphere microorganisms may be neutral to plants or they may have a positive or adverse effect on their growth [33]. For this reason it is important to ensure an appropriate growth of these microorganisms, which have a positive effect on health status of plants, since in such a case pathogenic microorganisms appearing in crop culture usually remain in a state of equilibrium with the rhizosphere microflora and do not cause diseases in plants.

In the experiment the level of dehydrogenase activity was measured in selected substrates. Total activity of this enzyme is an indicator of the redox system and a measure of respiratory activity of microorganisms. It reflects the physiologically active microbial biomass in a given environment [34]. It is also a sensitive indicator of changes in their viability under the influence of different factors.

In the conducted experiments the highest dehydrogenase activity was observed in organic substrates – at the

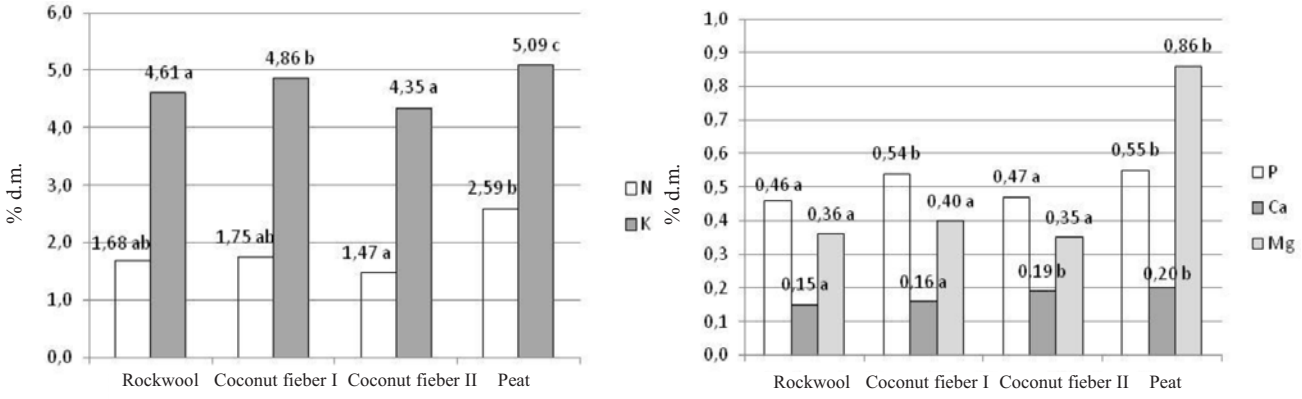

Fig. 6. The effect of substrates on contents of macroelements in fruits.

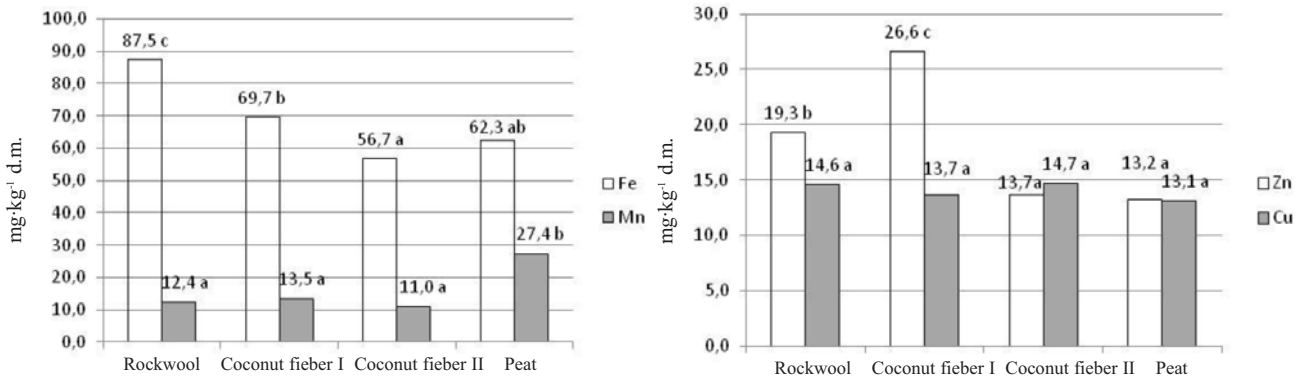

Fig. 7. The effect of substrates on contents of microelements in fruits.

beginning of culture on coconut substrates and at the completion of culture on the peat substrate (Fig. 8).

Enzymatic activity, similarly to microbial counts, depends on the environmental conditions, which include the type of substrate, moisture content, season of the year, temperature, crop species, and pH [35, 36].

Dehydrogenase activity decreases as a consequence of an increase in temperature and an insufficient moisture content, which is frequently observed in the hot summer months, thus frequently the highest values are recorded in the spring and/or autumn [37]. This is confirmed by the results recorded in this study. It is indicated that the highest enzyme activity is found in the spring or in the period of intensive plant growth [38]. On coconut substrates I and II the highest level of dehydrogenase activity was recorded on the 1st date (April). In turn, in case of peat substrate and rockwool the highest level of enzyme activity was recorded on the last date (September).

The highest activity of the analyzed enzyme was observed for organic substrates – at the beginning of culture on coconut substrates and at the end of culture on the peat substrate. Dehydrogenase activity is higher in organic soils in comparison to mineral soils [39]. Using this analogy we may explain the higher activity of the enzyme on the organic substrates used in this experiment.

It is reported in literature that dehydrogenase activity is a good indicator of activity in peat-muck soils. Peat soils characterize higher dehydrogenase activity in comparison to mineral soils [40, 41], which is connected with the fertility of the peat environment that has a high content of organic carbon, influencing enzymatic activity of soils. We may also state on the basis of recorded results that the higher level of the enzyme is found in the peat substrates than in the mineral substrate, i.e. rockwool.

The aim of the conducted investigations was to determine the dynamics of development for selected groups of microorganisms and enzymatic activity of dehydrogenase depending on the used substrate and the development phase of plants.

Another parameter in the evaluation of microbiological activity in the applied substrates was connected with the dynamics of changes in the population size of selected groups of microorganisms. The population size of soil microorganisms is one of the parameters indicating microbiological activity of the colonized environment. Their count depends, e.g., on the content of organic matter, pH, and temperature [42, 43]. Even the cultivar and its development phase determine the species composition and population size of microorganisms [44].

Fig. 9 presents results concerning changes in the total bacterial counts, which show that the highest number of

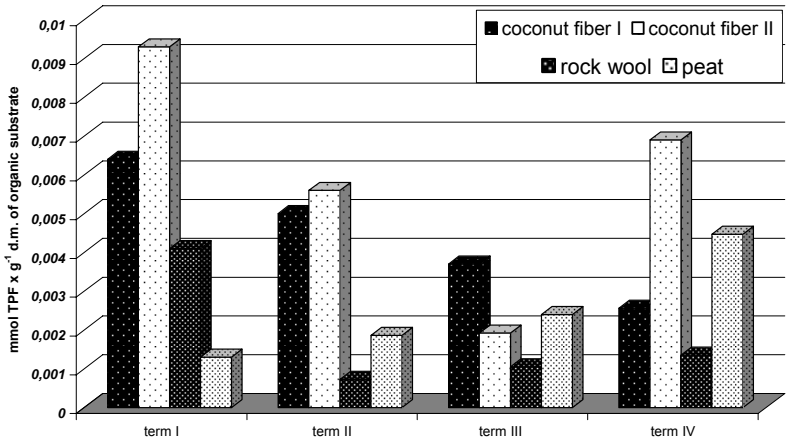

Fig. 8. Impact of the organic substrate on dehydrogenases activity.

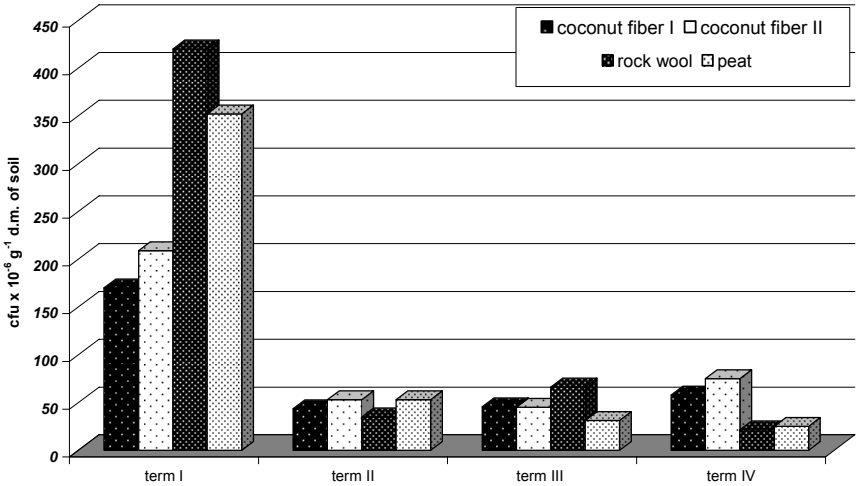

Fig. 9. Impact of organic substrate on total number bacteria.

colonies of the analyzed group of bacteria was recorded for all substrates on the first date, the number being highest on rockwool and amounting to 420 cfu × 1 g^{-1} d.m. substrate × 10^6. In turn, in the successive dates the number of colony forming units of the total bacteria count decreased considerably and was relatively uniform on all substrates. The lowest number, i.e. 21.6 cfu × 1 g^{-1} d.m. substrate × 10^6 was recorded on date IV on rockwool.

In turn, Fig. 10 presents results concerning the development of Actinomycetes on different growing substrates. The highest number of colonies of Actinomycetes was observed on date I on all substrates, except for rockwool. The discussed group of bacteria was growing best on coconut substrate I at all dates of analyses. A positive effect on the development of this group was also found for coconut substrate II and peat, particularly on the first two dates of analyses. On dates III and IV the number of Actinomycete colonies dropped considerably and the lowest number of 12 cfu × 1 g^{-1} d.m. substrate × 10^6 was recorded at the fruit bearing stage of tomato plants grown on peat.

It needs to be stressed that the substrates used in this experiment contained very high amounts of nutrients – organic substrates (coconut fiber I, coconut fiber II, and peat), thus at the beginning of culture a considerable growth of these microorganisms was recorded on organic substrates. In turn, due to the gradual depletion of the readily available nutrients in these substrates, the number of microorganisms decreased systematically.

We may find a statement in literature sources that Actinomycetes are found in particularly high numbers in peat soil [45], which is also confirmed by our studies. In the experiment, also a high count of Actinomycetes was recorded on organic coconut substrates. Throughout the entire growing period of tomato, Actinomycetes were the most numerous group of microorganisms.

In fertile soils we also take into consideration the ratio of bacteria to Actinomycetes, which amounts to 6:4. Using an analogy between soil and the applied substrates it may be stated that the number of bacterial colony units should be higher than the number of colonies of Actinomycetes. However, the results recorded in this experiment show that, particularly on the first two dates of analyses, the number of Actinomycete units was higher than the number of colony forming units for bacteria. An advantageous effect on this date on the highest count of these microorganisms could also have been exercised by optimal temperature.

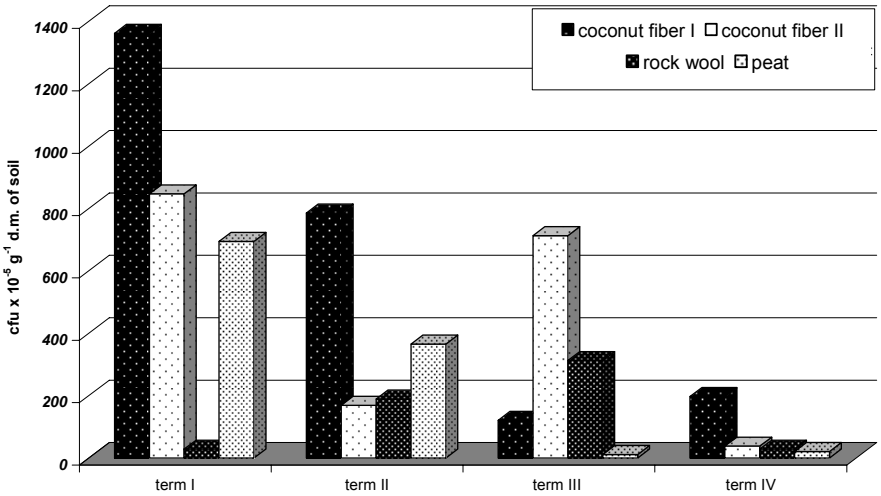

Fig. 10. Impact of the substrate on the number of *Actinomyces*.

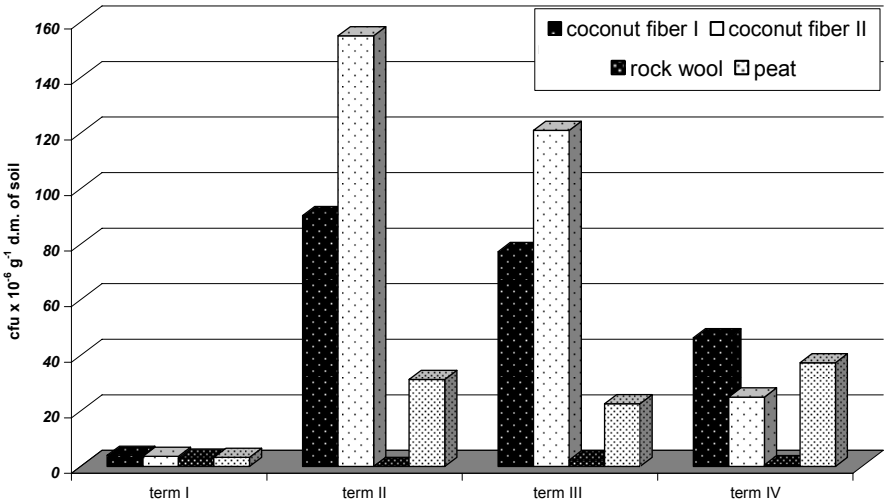

Fig. 11. Impact of the organic substrate on the number of fungi.

Table 1. Values of correlation coefficients between individual groups of microorganisms and dehydrogenase activity depending on applied substrate.

Values of correlation coefficients			
	Total number bacteria	Actinomycetes	Fungi
Coconut fiber I	0.731	0.937	-0.413
Coconut fiber II	0.817	0.724	-0.738
Rockwool	-0.789	-0.252	-0.448
Peat	-0.402	-0.445	0.686

The reaction of substrates is another basic physic-chemical parameter that determined the development conditions for microorganisms. We know that bacteria and Actinomycetes develop most effectively at pH 6.5-7.5, and fungi at pH 4-6. The applied optimal reaction for the development of tomato (pH of nutrient solution at 5.5) most probably had an advantageous effect on the growth of the analyzed groups of microorganisms and the potential fluctuations in pH of substrates during culture contributed to the stronger development of individual groups.

In our studies throughout the entire culture period a very low count of fungi was recorded, particularly on the first date, which could have been caused by the intensive growth of Actinomycetes and bacteria, as well as high pH of substrates (Fig. 11). The very low number of fungi was recorded on rockwool throughout the entire growing period. The highest values were observed for fungi growing on coconut substrates. This may have been caused by the presence of fungi from the genus *Trichoderma* in those substrates. It needs to be stressed that these fungi have a positive effect on the health status of plant roots.

The greatest growth of microorganisms in the tested substrates was found on organic substrates. Thus it may be concluded that these substrates are most advantageous for the development of microorganisms in comparison to mineral substrates.

In the conducted analyses Pearson's linear correlation coefficients also were determined. This coefficient was positive and highly significant between the total count of bacteria and dehydrogenase activity on coconut substrates I and II (Table 1). A strong dependence was also recorded between the count of Actinomycetes and dehydrogenase activity, where the value of the coefficient for coconut substrates was $\rho = 0.937$ and $\rho = 0.724$. In case of fungi a strong positive correlation with dehydrogenase activity was recorded only in the case of peat substrate. In the other samples the value of this coefficient was negative.

Many authors reported that the activity of soil enzymes is positively correlated with the count of soil microorganisms [46-48]. It was stated that a significant positive correlation between dehydrogenase activity and the count of soil microflora, and between the microbial count and the activity of enzymes, and the content of organic matter, sorption capacity, and reaction of soils [49]. It is a close relationship between enzyme activity and the content of organic carbon (C_{org}) and the content of total nitrogen (N_{og}). It results from the recorded data that there is a positive correlation between the counts of bacteria and Actinomycetes, and enzyme activity on coconut substrates and between the population size of fungi and enzyme activity on peat substrate [50]. The other negative correlation coefficients between the analyzed parameters may have resulted from the insufficient amounts of organic matter, inadequate pH, or other environmental factors.

Conclusions

Rockwool as a growing substrate has been used for over 30 years. In Poland it was first used on a broader scale in intensive horticultural cultures almost 20 years ago. However, there are ecological concerns promoting the use of organic substrates as alternative substrates to rockwool. From economic and practical point of view it is important to reach comparable and sometimes even better yields in terms of their quantity and quality than those in the case of rockwool, which was proven in the studies conducted by these authors. What is most important, despite the existence of significant differences in nutrient contents in leaves and fruits, is that no symptoms of their deficiencies were found on plants, which indicates proper plant nutrition both in the case of rockwool and the tested organic substrates. In all the analyzed combinations, which is a subjective impression, no differences were found in terms of fruit taste.

Taking into consideration the progressing degradation of the natural environment as a result of spillway of drainage waters from rockwool mats directly to soil (and ground waters), it is worth using organic substrates in intensive cultures in grenhouse. In organic substrates, in contrast to inert ones, when applying controlled plant nutrition based on cyclical chemical analyses, it is not necessary to use the so-called spillway. This would reduce the adverse fertilizer emissions to soil and ground waters. The microbiological aspect of the use of organic substrates in intensive cultures also is significant. It is crucial in view of the possibility of their complete utilization after the completed culture cycle. Organic substrates, including the analyzed peat and coir with a varied content of chips used in order to improve physical properties of substrates re biodegradable substrates. In essence, after the completion of the culture cycle they become a valuable organic fertilizer, rich in nutrients with positive microbiological parameters, i.e. relatively high counts of fungi, bacteria and Actinomycetes, as well as dehydrogenase activity, which may improve the fertility of soils on which they were utilized. In Poland, soils are to a considerable degree light soils with low organic matter content, thus taking into consideration the considerable cropped area (in case of tomato alone it is approximately 2,500 ha), the application of organic substrates managed after their use would considerably improve physicochemical properties of soils.

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