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LIGNITE AS A NEW MEDIUM IN SOILLESS CULTIVATION OF TOMATO

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Abstract

Thus far, lignite has not been used as a growing medium in soilless cultivation. The aim of the research conducted in 2011-2013 was to develop a new growing medium made of lignite, and to determine the suitability of such a medium to prolonged soilless cultivation of tomato under greenhouse conditions. Lumps of lignite were crashed and sifted to obtain fractions of lignite particles 20, 10, 2.5 mm in diameter of and the earthy fraction. Cultivation mats measuring 100 x 20 x 7 cm were made of the particular fractions and a mixture of lignite fractions. These substrates were used in a prolonged cycle cultivation of the tomato cultivar Growdena, with the results compared to its cultivation in Grodan-Grotop rockwool. The crashing of lignite into small-grain fractions changed the substrate's pH, salinity and concentration of $S\text{-}SO_4$. Smaller lignite fractions resulted in the reduction of the medium's pH and an increase of the salt content, particularly sulphate. Together with the crashing of lignite, the bulk density and water capacity increased, while the air capacity decreased. The most preferred air and water properties at pF=1.0 occurred in the medium with the fraction of lignite particles 2.5 mm in diameter and in the media formed by mixing different lignite fractions. The pH of the solution taken from the cultivation mats made of lignite was similar to the pH of the nutrient from rockwool. The concentration of nutrients in the lignite media throughout the whole cultivation period was similar to the concentration in rockwool. There was no biological sorption of nitrogen in the initial period of tomato cultivation on lignite and rockwool. The highest early, marketable and total yields of tomato fruits from cv Growdena F_1 were obtained in the cultivation on mats made of the lignite fraction with particles 2.5 mm in diameter. These yields did not significantly differ from the marketable and total yields obtained in rockwool.

Keywords: soilless cultivation, medium, lignite, physical and chemical properties, tomato, yield.

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INTRODUCTION

In recent years, due to the problems caused by waste from used rockwool, biodegradable organic media have been implemented in the soilless cultivation of vegetables. The most popular is coconut fiber, while peat, sawdust, wood fiber and straw are less often used. Thus far, lignite has not been applied as a medium in soilless cultivation. Lignite is a combustible sedimentary rock formed by carbonization, mainly during the Miocene. The carbonizing process progressed through the biochemical (peat formation and rotting) and geochemical (diagenesis) stages. Lignite is formed by diagenesis of peat at an elevated temperature and pressure. It is composed of organic substances (humic acids, fulvic acids, hymatomelonic acide, humans, bitumins, fusite, lignin, cellulose), water and organic substances. According to its physical and chemical properties, lignite is divided into low-carboned (soft), including xylite and earthy coals, and highly-carboned (hard), such as matte and glossy coals (Kalembasa, Tengler 1992, Kwiatkowska 2007). Studies on the agricultural use of lignite in Poland commenced before the Second World War and have been continued by many researches to the present day (Musierowicz 1938, Jurkowska 1961, Berśniewicz, Nowosielski 1976, Kalembasa, Tengler 1992, Maciejewska, Kwiatkowska 2007, Kwiatkowska, Maciejewska 2013). Soft lignite is used in agriculture mainly to improve the properties of light soils. Lignite is a rich source of humic substances (humic acids and their salts) and therefore it helps to sustain soil fertility and supply plants with mineral nutrients. It improves the physical, chemical and biological properties of soils. Humic substances regulate the concentration of the soil solution by sorption and release elements to the solution, hence protecting the soil medium and ecosystems against the effects of heavy metal contamination. Lignite is highly condensed organic matter, which is why it has a stable, homogeneous and very slowly biodegradable structure. It is the most durable organic material used both in field and greenhouse conditions (Kwiatkowska 2007). Lignite is free of pathogens and does not contain the substances harmful to plants. It is porous and absorbs water (Kalembasa, Tengler 2004). According to Nowosielski (1995), lignite has a sufficiently stable chemical composition, where each portion has a slightly acidic pH 6-7 and very low salinity (0.2 g dm^{-3} NaCl).

The aim of the study was to develop a growing medium made of lignite, and to determine the suitability of such a medium for prolonged cultivation of tomato in greenhouse conditions.

MATERIAL AND METHODS

The study on the influence of media made of lignite on the growth and yield of the greenhouse tomato cultivar Growdena F_1 was conducted in 2011-

-2013. The lignite used in this experiment originated from the vicinity of Bełchatów (Table 1). It contained 61.5% of dry matter, 87.5% of organic matter, 12.5% of ash and 43.7% of carbon.

Table 1

The content of elements and heavy metals in lignite from the vicinity of Bełchatów (total content in mg kg^{-1} d.m.)

Macroelements		Microelements		Heavy metals	
N	55.5	Fe	3429.3	Pb	3.7
P	88.9	Mn	40.8	Cd	0.24
K	102.9	Cu	13.9	Cr	1.4
Mg	668.7	Zn	23.2	Ni	4.7
Ca	28851.7	B	41.5	Co	1.7
Na	133.2				
S	5926.2				

Lumps of lignite were crashed in a hammer mill and sifted through appropriate sieves to obtain the fractions of lignite particles of the diameter of 20, 10, 2.5 mm and the earthy fraction. Cultivation mats, 100 cm in length, 20 cm in width and 7 cm in height, wrapped up with two-layer, white-black foil, were made of the particular fractions and a mixture of lignite fractions.

The tested mats consisted of the following fractions of lignite:

1) fraction of lignite particles of the diameter of 20 mm (LØ 20 mm);
2) fraction of lignite particles of the diameter of 10 mm (LØ 10 mm);
3) fraction of lignite particles of the diameter of 2.5 mm (LØ 2.5 mm);
4) earthy fraction (L EF);
5) 1/2 of fraction of the diameter of 20 mm + 1/2 of the earthy fraction (1/2LØ 20 mm + 1/2EF);
6) 1/3 of fraction of the diameter of 2.5 mm + 1/3 of fraction of the diameter of 10 mm + 1/3 of the earthy fraction (1/3LØ 2.5 mm + 1/3LØ 10 mm + 1/3EF);
7) control – Grodan-Grotop Master rockwool (Grodan).

The experiment was conducted in a randomized block design with four replications. Three tomato plants were grown on each mat and twelve plants in one replication. Tomato seeds were sown in mid-February and after 45-50 days tomato transplants were planted onto the tested lignite mats. Tomato plants were grown in a prolonged cycle until 10^{th} of November. Nutrient solution with the standard concentration of nutrients (in mg dm^{-3}): N – 200-240, P – 40-60, K – 250-400, Mg – 60-80, Ca – 190-220, Fe – 2.0-2.5, Mn – 0.6-0.8, Cu –0.15, Zn – 0.10, B – 0.20, Mo – 0.05, was applied to fertigate all the plants. During the plant growing period, the composition of the nutrient solution was adjusted to the growth stage of plants and weather conditions. Analyses of the solutions received from the rhizosphere were taken into account when correcting the nutrient solution composition. The principles of integrated indoor cultivation of tomato were respected during the study. The trials were conducted in a greenhouse of the Research Institute of Horticulture in Skierniewice, equipped with a suspended trough, three circuit heating systems, a computer control system of microclimate conditions and an Ami Completa fertilizer feeder. Over the course of the tomato culture, analyses of nutrient solutions collected from growing mats were carried out at two-week intervals.The total salt content (salinity) was determined by a universal method (Nowosielski 1988). pH was determined with the potentiometric method, electrical conductivity (EC) was checked with the conductometric method and the nutrient content was analyzed in a nutrient solution taken from the growing mats. The total N content was determined with the Kjeldahl method in a Vapodest apparatus made by Gerhardt (Walinga et al. 1995). The content of $N-NO_3$ was tested with the colorimetric method using a Scan Plus flow analyzer, whereas the concentrations of P, K, Ca, Mg, Na, Fe, Mn, Cu, Zn and B were assayed with the plasma spectrometry method (ICP) on an 2000 DV spectrophotometer, model ICP, made by Perkin-Elmer. The physical properties were determined before the onset of cultivation, according to the methodology presented by Aendekerk et al. (2000). Moreover, the content of heavy metals such as Pb, Cd, Cr, Ni, Co in the media was determined with the plasma spectrometry method. Tomato fruits were harvested twice a week. The first six harvests were taken as an early yield. The total harvest time started at the beginning of June and ended on 10th of November.

The analysis of variance, which compared the means with the Newman -Keuls test at significance level of $\alpha = 0.05$, was performed for the nutrient content in the medium and the yield.

RESULTS AND DISCUSSION

Chemical composition of substrates

Table 2 shows the content of available forms of nutrients in the media made of lignite before the transplanting of tomato. The crashing of lignite caused a change of pH, salinity and the concentration of $S-SO_4$. Small-grain lignite fractions resulted in the lowering of pH. The lignite fraction with particles 20 mm in diameter resulted in higher pH (5.8), while the earthy fraction caused a more acidic pH (5.0). When lignite was crashed, its active surface increased and salt, primarily sulphate, was extracted.

Salinity was the basic factor that determined the concentration of all mineral nutrients in the media. The largest concentration of available mineral nutrients appeared in the medium made of the earthy lignite fractions, while the lowest concentrations were observed for the lignite fraction of the 20 mm diameter. The crashing of lignite did not influence the availability of

Table 2

Available content of nutrient elements in lignite media

Type of medium	pH	Salinity (g NaCl dm^{-3})	(mg dm^{-3})						
			$N-NO_3$	$N-NH_4$	P	K	Mg	Ca	$S-SO_4$
LØ 20 mm	5.8*a*	0.18*d*	<1.0*a*	2.2*a*	14*a*	9*a*	75*a*	1440*a*	220*c*
LØ 10 mm	5.4*b*	0.83*c*	<1.0*a*	2.3*a*	14*a*	9*a*	69*a*	1430*a*	267*c*
LØ 2.5 mm	5.2*c*	1.07*b*	<1.0*a*	2,1*a*	12*a*	12*a*	76*a*	1550*a*	373*b*
LEF	5.0*d*	1.18*a*	<1.0*a*	2.0*a*	10*a*	10*a*	76*a*	1470*a*	493*a*
1/2LØ 20 mm + 1/2EF	5.0*d*	0.79*c*	<1.0*a*	2.3*a*	8*a*	8*a*	75*a*	1430*a*	244*c*
1/3LØ 2.5 mm + 1/3LØ 10 mm + 1/3EF	5.0*d*	0.84*c*	<1.0*a*	2.0*a*	9*a*	9*a*	71*a*	1460*a*	357*b*

Means with the same letter are not significant at $a = 0.05$.

N, P, K, Mg and Ca, as the content of these nutrients in all the media made of lignite was similar.

The physical properties of media

Physical properties of organic media, particularly the air and water properties and the stability of the structure throughout the whole cultivation period, determined their suitability for soilless cultivation (Gruda, Schnitzler 2004). Organic media made of lignite were characterized by a 5.5-fold greater bulk density in comparison to rockwool (Figure 1). The greatest bulk density was found in the medium formed from the smallest lignite fraction, called the earthy one. Thicker fractions of lignite corresponded to lower bulk densities. The crashing of lignite increased its bulk density. Mixing the lignite

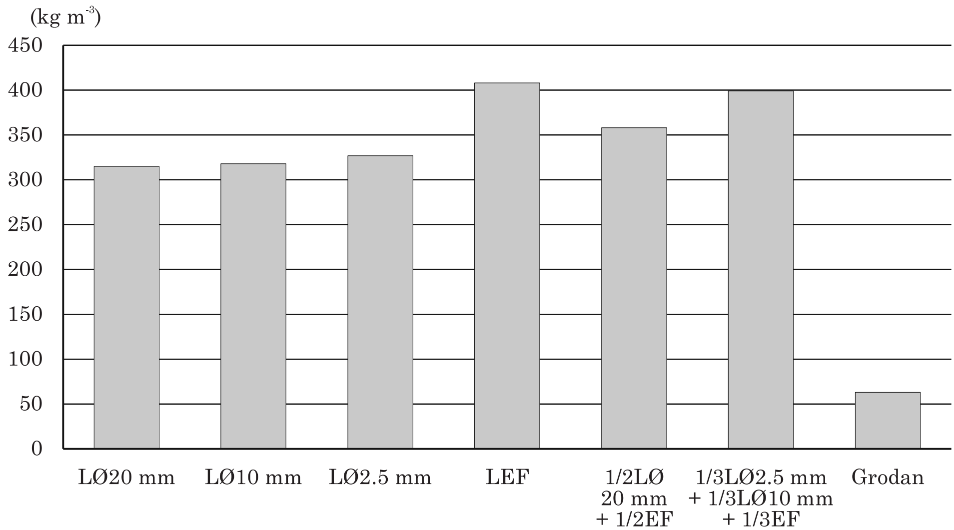

Fig. 1. Bulk density of media made of lignite and rockwool

fractions slightly reduced the bulk density in comparison to the earthy fraction.

The water and air capacity are the basic physical parameters informing about the water and air properties of medium. The requirements set for media intended for soilless cultivation are significantly stricter than in the case of a soil medium. The retention of water easily available for plants ranging from 0.5 pF to 1.5 pF is most important in soilless cultivation. The media made of lignite at the water potential pF 1.0 were shown to contain less water than rockwool, with the exception of the earthy fraction (Figure 2). The

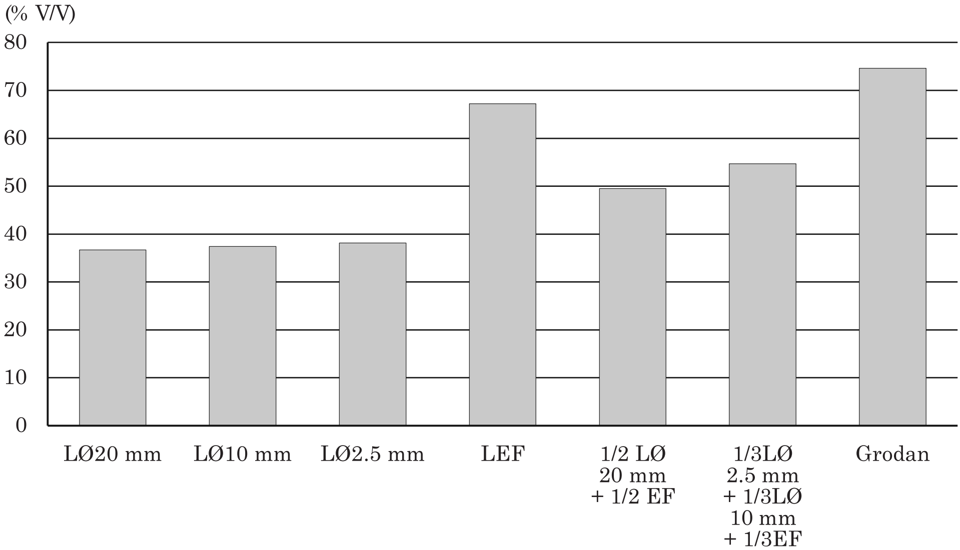

Fig. 2. The water capacity of media at pF 1.0

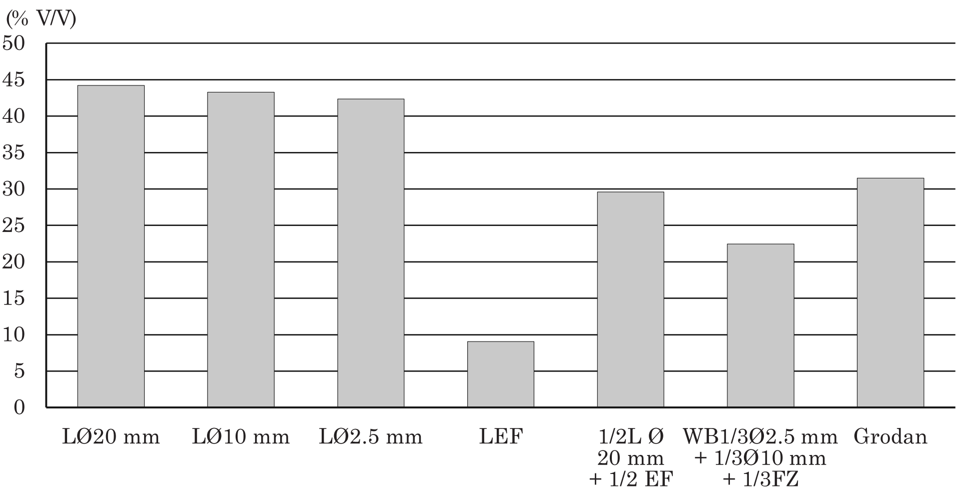

Fig. 3. The air capacity of media at pF 1.0

smallest fraction of lignite gathered an approximately same content of water as rockwool, but with evidently poorer air properties (Figure 3). According to GRUDA (2010), the water availability increased in an organic medium made of wood fiber parallel to the increase of its bulk density, but the air content was significantly reduced. The crashing of lignite improved the water properties of the media. The fraction composed of lignite particles of a diameter of 2.5 mm retained much more water than the 20 mm fraction. By mixing a coarser fraction of lignite with the earthy one, the content of easily available water in a medium was increased. The media made of lignite particles with particles of a diameter from 20 mm to 2.5 mm had a greater air capacity than the other lignite media or rockwool. The air and water relations can be freely adjusted for thicker fractions of lignite by using an appropriate size of lignite particles and adding some earthy fractions. NOWOSIELSKI (1995) suggested to mix thicker fractions of lignite with such substances as peat, granulated rockwool, supersorbents and bark of conifers in order to improve the air and water capacity.

The pH and content of mineral elements in the root zone of tomato plants

The right nutrient uptake depends on maintaining the proper pH of a nutrient solution in an inert and organic medium. The nutrient solution for fertigation of tomato should represent pH between 5.3-6.0. The chemical analyses performed every two weeks proved that the pH of the root zone was changing during the cultivation. The course of pH modifications is illustrated in Figure 4. During the cultivation, the pH of the solution received from rockwool cultivation mats was similar to the pH of lignite media. However, the pH of the solution from the rhizosphere of plants grown on Grodan mats was

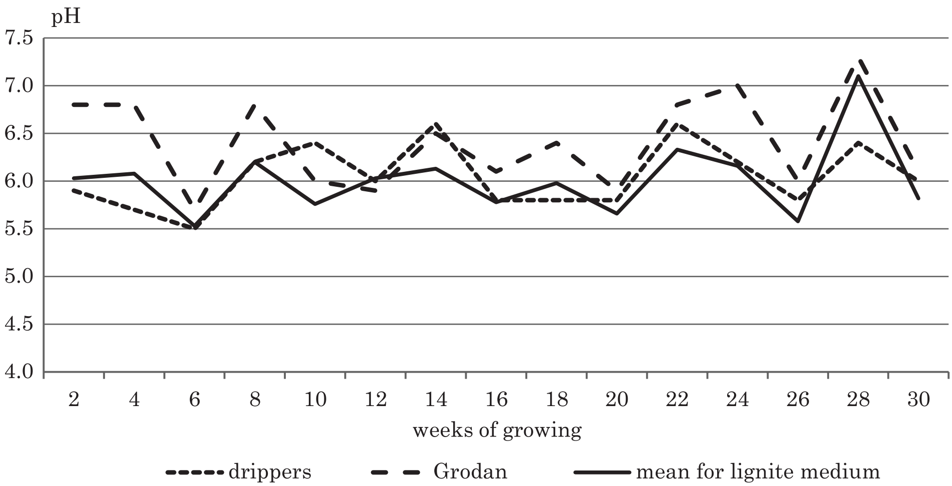

Fig. 4. Changes of the pH of nutrient solutions collected from drippers and the root zone located in rockwool and lignite medium

slightly higher (mean pH 6.4) than the pH of the solution obtained from lignite mats (mean pH 6.0). Lignite did not cause alkalinization of the fertilizer solution within the rhizosphere, which often occurs in tomato cultivation on other organic media. Alkalinization of nutrient solution within the root zone has been demonstrated in cultivation of tomato on wood fiber, coconut mats, sawdust and cereal straw (Kowalczyk, Dyśko 2006, Breś, Ruprik 2006, Komosa 2009).

Adequate electrical conductivity (EC) is a basic physical indicator of the concentration of all mineral nutrients in solution. The nutrient solution provided to tomato plants during the cultivation had a stable value of EC, from 2.2 to 3.3 mS cm^{-1} (Figure 5). A higher concentration of nutrients occurred in all the tested media. The value of EC in the lignite media was similar to EC in rockwool. An increase in the concentration of nutrients in the media was associated with more intensive water transpiration by plants during the su-

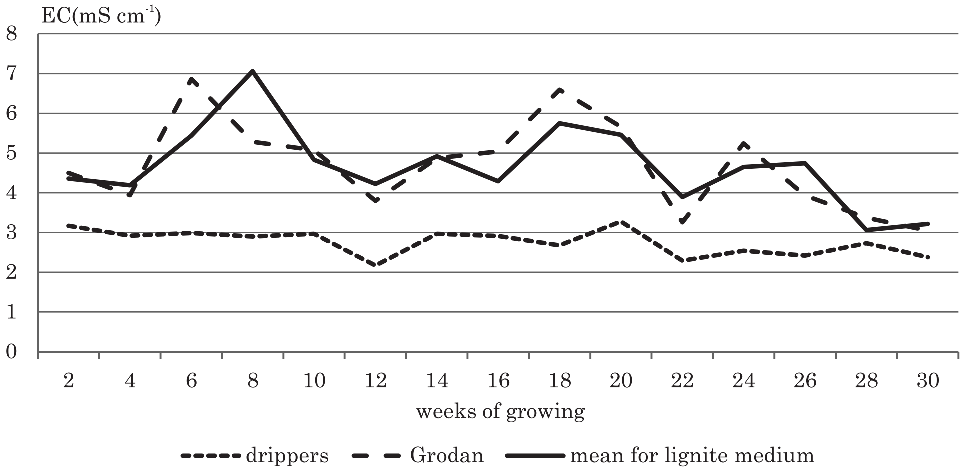

Fig. 5. Changes of the EC of nutrient solutions collected from drippers and the root zone located in rockwol and lignite medium

mmer months under good light and thermal conditions and with selective uptake of ions.

The fluctuations in the nitrate nitrogen content in nutrient solutions obtained from the capillary and root zone as the average for the media made of lignite and of rockwool during the whole cultivation can be seen in Figure 6. The $N\text{-}NO_3$ content in the root zone growing in lignite mats ranged from 200 to 675 mg dm^{-3}, in which it resembled that in rockwool. However, in lignite media there was no biological sorption of nitrogen, which occurred in the initial stage of cultivation on all organic media. The immobilization of nitrogen by microbial activity has been noted by many authors in cultivation of different organic media (Handreck 1993, Hardgrave, Harriman 1995,Gruda et al. 2000, Kowalczyk, Dyśko 2006, Jackson, Wright 2007, Kaniszewski et al. 2010).

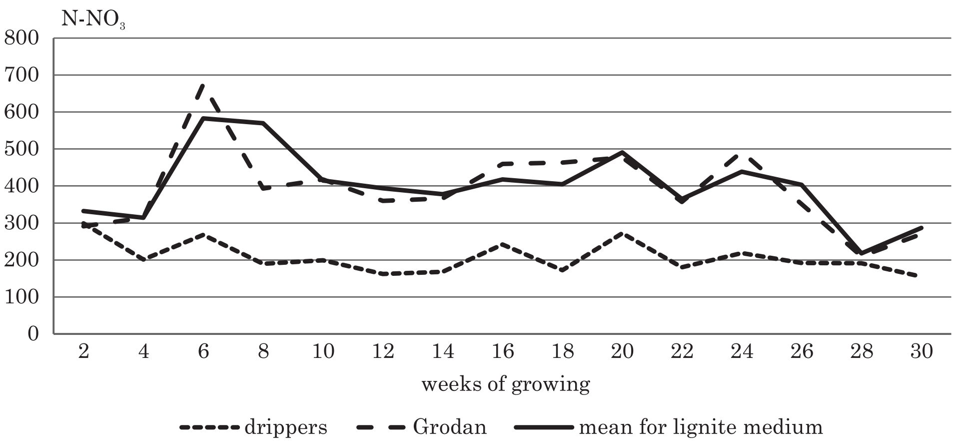

Fig. 6. Changes of $N\text{-}NO_3$ content in nutrient solutions collected from drippers and the root zone located in rockwool and lignite medium

Yield of tomato

The tested media significantly affected the yield of cv Growdena F_1 greenhouse tomato (Table 3). A significant influence of the medium was found in early, marketable and total yields. The highest early, marketable and total yields were obtained in tomato cultivation on mats with lignite particles 2.5 mm in diameter. Also, these high marketable and total yields did not statistically differ from the ones harvested from plants growing in rockwool. The lowest yield of tomato fruits was obtained from tomato culture in the earthy fraction of lignite. The yielding of tomato was similar on all the other lignite media. Good quality fruits, well-filled, firm and with good internal and external colouration were obtained from all the tested media. Any technology of soilless cultivation of tomato must include proper mechanical maintenance of the root system and ensure adequate air and water conditions. This creates many opportunities of using various materials as media. According to Nurzyński (2013), high yields of tomato fruits, comparable to or exceeding the ones from plants grown in rockwool, can be achieved on different organic media. Higher tomato yields than in rockwool culture were harvested from plants kept on on shredded oilseed rape straw mixed with bark of conifers, but the differences were not statistically proven. In contrast, Dyśko et al. (2008) reported a higher yield of tomato from plants grown in rockwool than in straw and peat substrates.

In conclusion, the above experiment implicates that lignite is a good medium and should be used in greenhouse soilless cultivation. The slightly acidic pH of lignite positively influenced the availability of most nutrients, while the lack of biological nitrogen sorption at the initial stage of growing and the ability to maintain the concentrations of mineral nutrients at almost identical level throughout the cultivation period are the properties in which lignite resembles rockwool. Lignite has an adequate water and air capacity once it has been crashed into suitably small particles. Lignite has a durable and homogeneous structure, which decomposes very slowly owing to the highly condensed organic matter it contains. Complete mineralization of cereal straw takes 16 months, whereas peat will decompose completely in 4 to 13 years, depending on its type. Apparently, lignite may undergo much slower mineralization. The low content of available forms of mineral nutrients and their very slow release in lignite mats mean that it is relatively easy to maintain certain concentrations of nutrients.

CONCLUSIONS

1. The crashing of lignite changed the substrate's pH, salinity and the concentration of $S\text{-}SO_4$. The smaller the particle size (from a fraction of 20 mm in diameter to the earthy fraction), the lower the pH of the medium and the higher extraction of salts, especially sulphate.

2. The crashing of lignite increased its bulk density and water capacity, while the air capacity decreased. The most preferred air and water properties at pF 1.0 occurred in the medium with lignite particles of a diameter of 2.5 mm and in media formed by mixing different fractions of lignite.

3. The pH of the solution taken from the lignite growing mats was similar to the pH of the nutrient solution from rockwool slabs.

4. The nutrient concentration in lignite media was similar to that in rockwool throughout the cultivation period.

5. There was no biological nitrogen sorption at the initial stage of tomato cultivation on the lignite media, in which they resembled rockwool.

6. The highest early, marketable and total yields of tomato fruits from cv. Growdena F_1 were obtained in cultivation on mats made of the fraction of lignite with particles 2.5 mm in diameter. These yields did not significantly differ from the marketable and total yields obtained from tomato plants grown in rockwool.

REFERENCES

Aendekerk Th.G.L., Cerat H., Dolmans N., van Elderen C., Kipp J.A., de Kreij C., Sonneveld C., Verhagen J.B.G.M., Wever G. 2000. *International substrate manual. Analysis, characteristics, recommendations*. Elsevier International Business Information, 2000, The Netherlands.

Bereśniewicz A., Nowosielski O. 1976. *Possible use of lignite for agriculture*. Post. Nauk. Rol., 1: 69-84. (in Polish)

Breś W., Ruprik B. 2006. *Growing of greenhouse cherry tomato in coconut fibre with differentiated nitrogen and potassium fertilization*. Part II. *Changes in chemical composition of nutrient solutions in root environment*. Acta Agroph., 7(3): 529-548.

DYŚKO J., KANISZEWSKI S., KOWALCZYK W. 2008. *The effect of nutrient solution pH on phosphorus availability in soilless culture of tomato*. J. Elementol., 13(2): 189-198.

GRUDA N., TUCHER S., SCHNITZLER W. H. 2000. *N- immobilization of wood fiber substrates in the production of tomato transplants (Lycopersicon esculentum* Mill (L.) Karst. Ex. Farw.). J. Appl. Bot., 74: 32-37.

GRUDA N. 2010. *Sustainable peat alternative growing media*. Acta Hort., 927: 973-979.

GRUDA N., SCHNITZLER W. H. 2004. *Suitability of wood fiber substrate for production of vegetable transplants*. I. *Physical properties of wood fiber substrates*. Sci. Hort., 100: 309-322.

HANDRECK K.A. 1993. *Immobilization of nitrogen in potting media*. Acta Hort., 342: 121- 126.

HARDGRAVE M., HARRIMAN M., 1995. *Development of organic substrates for hydroponic cucumber production*. Acta Hort., 401: 219-224.

JACKSON B.E., WRIGHT R.D. 2007. *Pine tree substrate: an alternative and renewable substrate for horticultural crop production*. Acta Hort., 819: 265-272.

JURKOWSKA H. 1961. *Lignite as a buffering indicator*. Zesz. Nauk. WSR Kraków, Ser. Rol., 12: 89-115. (in Polish)

KALEMBASA S., TENGLER SZ. 1992. *The use of brown coal in fertilization*. WSRP Siedlce, Monogr. 21, p. 136. (in Polish)

KALEMBASA S., TENGLER SZ. 2004. *The role of brown coal in fertilization and environmental protection*. Wyd. AP Siedlce, Monogr. 52, p. 174. (in Polish)

KANISZEWSKI S., DYŚKO J., KOWALCZYK W., WOJTYSIAK J., WROCŁAWSKI Z., DZIEDZICZAK K. 2010. *Effect of nitration of organic materials on nitrogen availability and yield of tomato in soilless culture*. Veget. Crops Res. Bull., 72: 71-83.

KOMOSA A., PIRÓG J., KLEIBER T. 2009. *Changes of macro and micronutrients contents in the root environment of greenhouse tomato grown in fiber wood*. Veget. Crops Res. Bull., 70: 71-80.

KOWALCZYK W., DYŚKO J. 2006. *Nitrogen status of greenhouse tomato plants grown in rye straw slabs*. Acta Agroph., 7(4): 959-967. (in Polish)

KWIATKOWSKA J. 2007. *Evaluation of brown coal as a effective source of organic matter in anthropologically transformed soil*. Inż. Ochr. Środ., 10(1): 71-85. (in Polish)

KWIATKOWSKA-MALINA J., MACIEJEWSKA A. 2013. *Uptake of heavy metals by darnel multifloral (Lolium multiflorum* Lam.*) at diverse soil reaction and organic matter content*. Soil Sci. Annual., 64(1): 19-23.

MACIEJEWSKA A., KWIATKOWSKA J. 2007. *Use of brown coal for soil fertilization*. Zesz. Probl. Post. Nauk Rol., 520: 339-343. (in Polish)

MUSIEROWICZ A. 1938. *Research on nutritional value of lignite dust*. Prz. Dośw. Rol., 1(6), 25. (in Polish)

NOWOSIELSKI O. 1988. *Rules for fertilizer recommendations in gardening*. Ed. II supplemented. PWRiL, Warsaw, pp. 310. (in Polish)

NOWOSIELSKI O. 1995. *Coal mine as the background, fertilizer and raw material for producing background materials and fertilizers*. Zesz. Probl. Post. Nauk Rol., 422: 87-92. (in Polish)

NURZYŃSKI J. 2013. *Yield and quality of greenhouse tomato fruit grown in rape straw substrates*. Acta Sci. Pol., Hort. Cult., 12(1): 3-11.

WALINGA J., VAN DER LEE J.J., HOUBA V.J.G., VAN VARAK W., NOWOZAMSKY I. 1995. *Plant analysis manual*. Kluver Academic Publishers, Dordrecht, The Netherlands.