ZAŁĄCZNIK III

Dr inż. Bartosz Markiewicz
The Poznan University of Life Sciences
The Faculty of Horticulture and Landscape Architecture
The Department of Plan Nutrition

SUMMARY OF POST-DOCTORAL DISSERTATION

Scientific achievements and publications

Poznan 2019

1. **First name and surname** Bartosz Markiewicz

2. **Diplomas and scientific degrees**

   25 June 2001 – the title of Master of Sciences, Engineer in horticulture, M.Sc. thesis entiled 'Effect of nitrogen fertilization on herbal yield and oil content in basil (*Ocimum basilicum* L.), Scientific supervisor: prof. dr hab. Anna Golcz, The Faculty of Horticulture, the August Cieszkowski Agricultural University of Poznan

   - **16 Mai 2006** – the doctoral degree in agricultural sciences in the field of horticulture. Ph.D. dissertation entitled 'Effect of substrate type and nitrogen, phosphorus and potassium fertilization on eggplant yielding (*Solanum melongena* L.)'
     Scientific supervisor: prof. dr hab. Anna Golcz, The Faculty of Horticulture, the August Cieszkowski Agricultural University of Poznan
     Reviewers: prof. dr hab. Andrzej Komosa (AU in Poznan),
     prof. dr hab. Stanisław Cebula (AU in Krakow).

3. **Information on employment history**

since 2008	**Assistant professor**, the Department of Plant Nutrition (formely the Department of Horticultural Plant Fertilization), Poznan University of Life Sciences,
2007 – 2008	**Research assistant** with the doctoral degree, the Department of Horticultural Plant Fertilization, August Cieszkowski Agricultural University of Poznan,
2005 – 2007	**instructor**, the Department of Horticultural Plant Fertilization, August Cieszkowski Agricultural University of Poznan,

4. **Descrpition of the scientific achievement**

In accordance with art. 16 item 2 of the Act of 14 March 2003 on scientific degrees and scientific titles and on degrees and title in the field of art (the Journal of Law 2016 item 882 with later amendments in the Journal of Law 2016 item 1311):

a) **Title of scientific achievement**

Response of tomato (*Lycopersicon esculentum* Mill.) grown in rockwool to diverse boron and titanium contents in nutrient solutions

The scientific achievement documented by a series of 7 research papers, of which I am the only author (2 papers) or the first author (6 papers), including 4 publications with *Impact Factor*. The total score for these papers (calculated based on the classifications of Ministry of Science and Higher Education) for the year of publication is **86**, and the total **IF score** is **2.404.**

b) The list of publications comprising the scientific achievement constituting the basis for the application for the conferral of scientific of postdoctoral-degree:

No.[1]	Research papers	Sc.[2]	IF[3]
B.1.	**Markiewicz B.** 2017. Wpływ stężenia i formy boru na skład chemiczny strefy korzeniowej pomidora (*Lycopersicon esculentum* Mill.) uprawianego w wełnie mineralnej. Aparatura Badawcza i Dydaktyczna. 22 (3), 174-182.	10	
B.2.	**Markiewicz B.** 2019. Effect concentration and forms of boron on the nutritional status of tomato (*Lycopersicon esculentum* Mill.) grown on rockwool. J. Elem., 24(2): 829-841. DOI: 10.5601/jelem.2018.23.4.1686.	15	0.684
B.3.	**Markiewicz B.,** Kleiber T., Bosiacki M. 2016. Hydroponic Cultivation of Tomato; Alternative Crops and Cropping Systems, book edited by Petr Konvalina, ISBN 978-953-51-2279-1. 105-129.	5	
B.4.	**Markiewicz B.,** Muzolf-Panek M., Kaczmarek A. 2019. The effect of deficit and over-standard boron content in nutrient solution on the biological value of tomato fruit. J. Elem., 24(3): 961-976. DOI: 10.5601/jelem.2019.24.1.1796.	15	0.684
B.5.	**Markiewicz B.,** Kleiber T. 2014. Wpływ stosowania Tytanitu na skład chemiczny strefy korzeniowej pomidora uprawianego w wełnie mineralnej. Nauka Przyr. Technol. 8.3 #34. 1-11.	6	
B.6.	Kleiber T., **Markiewicz B.** 2013. Aplication of 'Tytanit' in greenhouse tomato growing. Acta Sci. Pol., Hortorum Cultus. 12 (3), 117- 126.	20	0.393
B.7.	**Markiewicz B.,** Kleiber T. 2014. The effect of Tytanit application on the content of selected microelements and the biological value of tomato fruits. J. Elem., 19(4): 1065-1072. DOI: 10.5601/jelem.2014.19.3.486.	15	0.643
Suma		**86**	**2.404**

[1] numbers of original research papers corresponds to the order, in which they are discussed
[2] point score for the year of publication, in the case of papers from 2019 the applied score is the number of points for 2018
[3] in the year of publication, in the case of papers from 2019 the IF value of 2018 was applied

The declarations of co-authors of the above mentioned papers concerning their individual contributions to these publications are given in attachment VI. None of the above mentioned papers has been a part of monographic series in another post-doctoral degree conferral procedure.

Discussion of the scientific aim and the results of the work, together with a discussion of their possible use

Tomato (*Lycopersicon esculentum* Mill) is a species of greatest economic importance in Poland. The area of tomato cultivation in plastic tunnels is 2150 ha (GUS 2018). In reaching optimal quality of yield a major role is played not only by macro-, but also micronutrients (Fe, Mn, Zn, Cu, B, Mo, Cl) (BREŚ ET AL. 2012). At the end of the 20^{th} century hydroponic concentrations of micronutrients were developed for tomato growing in rockwool. Polish studies concerning tomato culture in hydroponic systems provide only boron levels or concentrations in the nutrient solution. However, no information is available on the form of the applied micronutrient, assays of its contents in nutrient solutions as well as indicator parts and fruit of tomato. In view of the very small range of values between boron deficiency and excess as well as interactions of this micronutrient with other nutrients it is essential to verify our knowledge in terms of the effect of boron on yielding of currently grown heterotic varieties. In view of increasing requirements of consumers expecting products of the best possible quality researchers search for nutrients having a positive effect on plant growth and yield quality. Titanium (Ti) is another trace element exhibiting biostimulatory activity.

Boron (B) is a micronutrient essential for plant growth and development. It is classified as a biophilic non-metallic element (TOMASZEWSKA 2010). Sources of boron in underground waters are connected with natural and anthropogenic factors. Natural concentrations of boron in fresh water result from contents of borates in soils and rocks, mixing of waters from different aquifers and the effect of marine intrusions. In the course of rock weathering boron penetrates to the soil solution forming the following anion series: BO_2^-, $B_4O_7^{-2}$, BO_3^{-3}, $H_2BO_3^-$, $H_4BO_4^-$. (KABATA-PENDIAS, PENDIAS 2001). Most frequently boron is found in water in the form of boric acid (ITAKURA ET AL. 2005), less often in the form of anions and organic complexes (KABATA-PENDIAS, PENDIAS 1999). Boron content in surface and underground waters may be 5-100 mg· dm^{-3} (MELNYK ET AL. 2005). Natural boron content in underground waters in Poland amounts to 0.01-0.5 mg·dm^{-3} (RMS, Dz.Uz 2008, no. 143 item 896). Plants take up boron through their root system (FOTYMA AND MERCIK 1995) or leaves (LITYŃSKI AND JURKOWSKA 1982).

Boron participates in the formation of cell wall structures and cell divisions (BROWN ET AL. 2002, O'NEIL ET AL. 2004). Boron deficiency inhibits cell wall synthesis and influences cell elasticity (BIERNAT AND PIECZYŃSKA 2000), resulting in an increase of pore size, which in turn leads to cell wall rupture (BROWN ET AL. 2002). Boron was found to influence pollen tube growth (LITYŃSKI AND JURKOWSKA 1982). Boron content has an effect on nitrogen metabolism of plants, while deficiency of this micronutrient results in increased contents of nitrates in plants. Boron also plays a role in the metabolism of saccharides (SHOL'NIK 1965) and phenols (RUIZ ET AL. 1998) as well as the ascorbate–glutathione metabolic pathway (BROWN ET AL. 2002). Boron may form complex compounds with sugars, phenols, organic acids and polymers (HU AND BROWN 1997). Most typically boron is found in complexes with mannitol, sorbitol, glucose and fructose (HU AND BROWN 1997). Boron may also form complex compounds with a polysaccharide, RG-II (KOBAYASHI ET AL. 1996, O'NEIL ET AL. 1996, O'NEIL ET AL. 2001, GOLDBACH ET AL. 2002) stabilised with calcium ions (BROWN ET AL. 2002, GOLDBACH ET AL. 2002) and being the most important compound binding boron in the cell wall. The complex is found in mono- and dicotyledonous plants (ISHII AND MATSUNAGA 1996, KANEKO ET AL. 1997).

To date the role of boron in the human organism has not been fully clarified. This micronutrient affects physiological bone development by preventing osteoporosis. An adequate boron content in the human diet prevents arthritis (GOLDBACH ET AL. 2002). Boron was shown to affect the activity of brain cells, calcium and magnesium metabolism as well as the immune system (MURRAY 1995, NIELSEN 2000). According to KORTOGLU ET AL. (2001) and LI AND ZHANG (2007), the interaction of boron and calcium has an effect on hormone functions in the human. The daily dose of boron taken up by humans - inhaled, ingested and absorbed through the skin - varies and ranges from 0.25 to 20 mg a day (MOORE ET AL. 1997, RAINEY ET AL. 1998, KABATA-PENDIAS, PENDIAS 1999). Boron is not accumulated in tissues and it is excreted with urine (MOORE ET AL. 1997), but its excess is dangerous for human health (SAHIN AND NAKIBOGLU 2006). The most important sources of boron for humans include beverages, vegetables and fruit (BIEGO ET AL. 1998). According to CASTILLO ET AL. (1985), the greatest amounts of boron are contained in beets (250 $mg \cdot kg^{-1}$), lemons (150 $mg \cdot kg^{-1}$) and apples (110 $mg \cdot kg^{-1}$).

According to BREŚ ET AL. (2010), the content of boron in water used in horticulture does not exceed 0.1 mg·dm^{-3}; however, in regions with intensive horticultural production the content of boron may exceed 0.6 mg·dm^{-3} (KOWALCZYK ET AL. 2010). Many authors (WYSOCKA–OWCZAREK 1998, JAROSZ AND DZIDA 2011, KOWALCZYK AND GAJC-WOLSKA 2011, JAROSZ ET AL. 2012) recommends the optimal content of boron in the nutrient solution for fertigation of tomato at 0.3 mg·dm^{-3}. In studies by other authors the recommended boron content in the nutrient solution in tomato growing ranges from 0.2 to 0.7 mg·dm^{-3} [(ZEKKI ET AL. 1996) 0.2 mg·dm^{-3}, (KOMOSA AND GÓRNIAK 2012) 0.35 mg·dm^{-3}, (KOMOSA ET AL. 2010) 0.4 mg·dm^{-3}, (ADAMS 1994) 0.4-0.5, (REVILLA ET AL. 1985) 0.5 mg·dm^{-3}, (BOROWSKI AND NURZYŃSKI 2011) 0.54 mg· dm^{-3}, (HOCHMUTH AND HOCHMUTH 2012) 0.7 mg·dm^{-3}].

Boron is a micronutrient determining yield volume and quality. The effect of boron applied to the soil and as foliar application is particularly well known in pomiculture. According to WÓJCIKA ET AL. (1999), the use of boron in apple orchards significantly increased the yield of fruit, contents of boron and calcium in fruit, while it also determined keeping quality and resistance to disease. Boron spraying of apple trees after flowering reduced fruit softening during their storage and the incidence of bitter pit, internal breakdown and bitter rot of apples (WÓJCIK ET AL. 1997). Foliar application of boron in the culture of stone fruits (cherries and plums) may increase the yield of fruit. Foliar application of boron is recommended even if plants show no signs of deficiency of this micronutrient (HANSON 1991). Spring boron spraying of blueberry cv. Jersey had a significant effect on an increase in the content of soluble solids in fruit (WÓJCIK 2004). Analyses showed the effect of combined nutrition with boron, humic acids and soluble solids from *Vitis vinifera* seeds on yield, contents of chlorophyll and carotenoids in fruit of three tomato varieties. The variety had a significant effect on yield and carotenoid contents in fruit of tomato cv. Antalya, Cemil and Lorely under the influence of boron fertilisation in combination with organic compounds (DINU ET AL. 2015).

Titanium is another tested trace element exhibiting biostimulatory activity (MICHALSKI 2008). Titanium is a chemical element from the group of transition metals. It accounts for approx. 0.57% Earth's crust (BUETTNER AND VALENTINE 2012). A marked majority of titanium is found mainly in the form of water insoluble minerals (as TiO_2 or $FeTiO_3$) (DUMON AND ERNST 1988). It is found in the form of minerals: anatase, rutile and brookite at approx. 95% TiO_2 content, leucoxene (Fe_2O_3 $nTiO_3$) containing over 65% TiO_2 as well as ilmenite

($FeOTiO_3$) containing 40-65% TiO_2 (ZHANG ET AL. 2011). Titanium is relatively mobile in the soil, it is found in the soil solution and is available to plants. In most plants it is found at relatively low concentrations (0.1-10 ppm) (LYU ET AL. 2017). The role of titanium (Ti) in plant metabolism has not been thoroughly clarified.

Literature sources provide several theories explaining the positive action of titanium as a nutrient having an advantageous effect on plants. Contemporary research conducted worldwide have supported only some of these theories. Analyses have confirmed the effect of titanium on an increase in Fe and Mg uptake (DUMON AND ERNST 1988, SIMON ET AL. 1988), their participation in the redox reactions (Ti^{4+}/Ti^{3+} z Fe^{3+}/Fe^{2+}) in this way improving iron activity in plant tissues (CARVAJAL ET AL. 1995) or its interaction with iron in the electron transport chain and a reduction of photosystem II efficiency at a high Ti concentration (CIGLER ET AL. 2010), stimulation of enzymatic activity and photosynthesis (CARVAJAL AND ALCARAZ 1998). The effect of titanium on plant yielding is also associated with an increase in chlorophyll biosynthesis, increased photosynthesis and nutrient uptake (DUMON AND ERNST 1988, CIGLER ET AL. 2010). In studies by RAM ET AL. (1983) and KOVACIK ET AL. (2014) greater concentrations of total chlorophyll as well as its a and b fractions were detected in common bean (*Phaseolus vulgaris* L.) and wheat (*Triticum aestivum* L.) under the influence of titanium application.

A positive effect of titanium application on plants depends mainly on its interaction with iron (SIMON ET AL. 1988, CARVAJAL AND ALCARAZ 1998, CIGLER ET AL. 2010). Plants take up titanium by roots or leaves. According to LYU ET AL. (2017), both antagonistic and synergistic dependencies may be observed between titanium and iron depending on their concentrations. Titanium may induce expression of genes related with iron uptake in the case of its deficiency. Interactions of plants with Ti and Fe may result in the formation of proteins binding Ti in plants, which either specifically bind Ti, or non-specifically share with Fe or other elements. High concentrations of titanium in plants may cause its phytotoxicity. According to CARVAJAL ET AL. (1995), leaves of capsicum (*Capsicum annuum* L.) sprayed with Ti-ascorbate showed a considerable increase in the concentrations of iron and titanium. Moreover, the effect of Ti was also observed on an increase in the activity of certain enzymes: peroxidase, catalase and nitrate reductase (PAIS 1983) and lipoxygenase (DAOOD ET AL. 1988). Titanium stimulates the activity of nitrate reductase in common bean (NAUTSCH-LAUFER 1974). Application of titanium in plant growing also determines the quality of produced yield. According to BIACS ET AL. (1997), the application of titanium in the form of spraying results in increased contents of β-carotene, xanthophylls and capsanthin in fruit of capsicum. Foliar Ti application increased biosynthesis of vitamin C in capsicum fruit (MARTINEZ-SANCHEZ ET AL. 1993). Moreover, the positive effect of titanium was also confirmed on yielding and quality of orchard plants. Application of titanium caused an increase of vitamin C contents in six varieties of strawberry (*Fragaria x ananassa* Duch.) and that of anthocyanins in three varieties (SKUPIEŃ AND OSZMIAŃSKI 2007). Titanium nutrition increases yielding over a very wide range depending on culture (PAIS 1983, CARVAJAL AND ALCARAZ 1998). The weight of peach fruit and their firmness are increased, while weight loss during storage is significantly limited after the application of Ti or a mixture of Ti with Ca or Mg before harvest (ALCARAZ-LOPEZ ET AL. 2004). Titanite application resulted in an increase in soluble solids contents and reduction of nitrate contents in raspberry fruit (GRAJKOWSKI AND OCHMIAN 2007). According to HAGHIGHI ET AL. (2012), Ti nutrition in tomato growing shows a positive effect on plant growth at reduced nitrogen contents in the nutrient solution. Foliar titanium application causes an increase in the weight of tomato fruit by 11 up to 25% (PAIS 1983).

Contents of Ti in plants range from 1 to 578 mg kg^{-1}, at the mean value of 33.4 mg kg^{-1} (LYU ET AL. 2017). According to KABATA-PENDIAS AND PENDIAS (2001), Ti content in leaves ranging from 50 to 200 $mg \cdot kg^{-1}$ may be considered toxic.

In the years 2009-2014 based on research conducted by the author comprising vegetation experiments the response of tomato response was presented in the multi-aspect system to increasing concentrations of boron and titanium in nutrient solutions.

Boron concentrations were presented in the range from insufficient to excessive/toxic. The studies documented chemical changes taking place in the root zone of plants and in leaves under the influence of increasing boron and titanium concentrations, as well as yields of fruit and their quality, determined based on nutrient contents and parameters characterizing the biological value of their fruit.

Based on research I determined the range of boron concentrations in nutrient solutions used in fertigation of tomato, at which plants exhibit toxicity of this micronutrient. As a result of my research I verified - and confirmed using scientific evidence - hydroponic concentrations of boron for tomato grown in rockwool, indicating at the same time an important and novel practical aspect, i.e. potential varietal differences within this range. I also showed a positive effect of Ti application in the form of titanite as a biostimulator affecting the effect on the yield of plants and their biological quality.

In cultivation of tomato (*Lycopersicon esculentum* Mill.) cv. Alboney F_1 (*Enza Zaden*) and cv. Emotion F_1 (*S&G)* (Experiments I and II), and ISI 68294 (Experiment III) the standard nutrient solution was used in tomato growing, differentiating the following contents:

1. Boron

a) Experiment I: 0.011 (natural content in water), 0.40, 0.80, 1.60 mg $B \cdot dm^{-3}$ in the form of borax $Na_2B_4O_7 \cdot 10H_2O$, 11.3% B, (denoted as B-I, B-II, B-III, B-IV), papers B.1., B.2., B.3., B.4.

b) Experiment II: 0.011 (natural content in water), 0.40, 0.80, 1.60 mg $B \cdot dm^{-3}$ in the form of boric acid H_3BO_3, (denoted as B-I, B-II, B-III, B-IV), papers B.1., B.2., B.3.

2. Titanium

   a) Experiment III: control (no titanium application), 80, 240, 480, 960 g $Ti \cdot ha^{-1}$ /year, which is equivalent to the annual dose: Ti-I 2.01 mg $Ti \cdot plant^{-1}$, Ti-II 6.04 mg $Ti \cdot plant^{-1}$, Ti-III 12.08 mg $Ti \cdot plant^{-1}$, Ti-IV 24.16 mg $Ti \cdot plant^{-1}$ (denoted as the control, Ti-I, Ti-II, Ti-III, Ti-IV.), papers B.5., B.6., B.7.

Wpływ stężenia i formy boru na skład chemiczny strefy korzeniowej pomidora (*Lycopersicon esculentum* Mill.) uprawianego w wełnie mineralnej (B.1.)

Changes taking place in the root zone of tomato grown in rockwool are caused e.g. by water uptake predominating over nutrient uptake. As a result of this process nutrient levels were increasing in the mats, as manifested in an increased EC in the nutrient solution. The phenomenon accompanying growing nutrient concentrations are connected with alkalization of the nutrient solution in relation to the nutrient solution applied to plants. Greater concentrations of alkaline character (calcium, magnesium, potassium and sodium) cause an increase in pH of the nutrient solution.

The aim of the research was to assess the effect of boron fertigation on changes in the concentrations of nutrients in the root zone using borax compared to boric acid in the cultivation of two tomato varieties (Alboney F_1 and Emotion F_1) in rockwool.

Based on vegetation experiments a significant increase was observed in contents of nitrate nitrogen, potassium, calcium, magnesium, sulphide sulphur and zinc, sodium and chlorides in nutrient solutions in the root medium compared to the nutrient solution applied to plants. Changes in the root medium may be considered typical of hydroponic cultures.

Moreover, a significant reduction was shown for phosphorus contents in mats at the application of 1.60 mg B·dm^{-3} in the nutrient solution applied to plants. Using borax and boric acid significantly the lowest content of P-PO_4 was recorded in combination B-IV compared to B-I (Alboney F_1) as well as B-I and B-II (Emotion F_1). It was observed that the interaction between boron and phosphorus takes place at the application of both borax and boric acid.

Borax most often used in hydroponic cultures did not modify manganese contents in the root medium. Boric acid as a source of boron increased the concentration of manganese in the nutrient solution taken up from cultivation mats compared to the nutrient solution applied to plants. Significantly the greatest content of manganese in nutrient solutions in the root medium was recorded for cv. Alboney F_1 at a boron concentration of 1.60 mg·dm^{-3}.

Application of boric acid as a source of boron had no effect on pH of the nutrient solution taken up from drip lines. I showed a significant effect of 0.80 and 1.60 mg·dm^{-3} boron concentrations on an increase in EC of nutrient solutions in the root medium compared to the concentrations of 0.011 and 0.40 mg B·dm^{-3}. This dependence was observed at the use of both borax and boric acid. I showed that variation in tomato nutrition with boron in the form of borax and boric acid does not necessitate changes in the composition of nutrient solutions in rockwool cultivation systems.

Effect concentration and forms of boron on the nutritional status of tomato (*Lycopersicon esculentum* Mill.) grown on rockwool (B.2.)

Boron is a micronutrient, for which the range between deficiency and excess is relatively small. All deviations from hydroponic concentrations in that nutrient may cause disturbances in many physiological and metabolic processes in plants.

The aim of the research was to assess the effect of increasing concentrations of two boron forms in nutrient solutions on the nutrient status of tomato cv. Alboney F_1 and Emotion F_1 grown in rockwool.

As a consequence of changes taking place in the root zone (**B.1. and B.3.**) the effect of boron on contents of macro- and micronutrients was shown in indicator parts of tomato plants.

I showed in my research that varied (increasing) boron concentrations in nutrient solutions have a significant effect on changes in contents of selected nutrients in leaves of tomato plants. The mean nitrogen content in tomato leaves was changed only in combination B-III using boric acid compared to combination B-I. Application of increasing boron levels within the range of 0.011-1.60 mg·dm^{-3} (B-I to B-IV) using borax had no effect on the nitrogen nutrient status of plants.

In my studies I showed a varied reaction of cultivars applied in the nutrient solution with the boron form. Significantly the greatest mean content of phosphorus in indicator parts was recorded in combination B-I (0.82 %P) compared to B-II, B-III and B-IV (Experiment I), as well as B-I (0.83 %P) compared to B-IV (Experiment II). Using borax in the nutrient solution a greater (statistically unconfirmed) mean content of phosphorus was detected in indicator parts of cv. Emotion F_1 in comparison with cv. Alboney F_1. In turn, a significantly greater mean content of phosphorus was recorded in leaves of cv. Alboney F_1 at the application of boric acid. In the conducted experiments I showed a varietal reaction to mean contents of calcium, magnesium, iron, manganese and copper in both conducted experiments as well as potassium and zinc (in Experiment II).

As a result of the research I stated that increasing boron levels in the nutrient solution within the range from 0.011 to 1.60 mg·dm^{-3} supplied in the form of borax and boric acid do not change nutrient contents in leaves to a degree causing an insufficient or toxic nutrition status of plants.

Hydroponic Cultivation of Tomato (B.3.)

Recorded changes occurring in the root medium (**B.1.**), as well as the nutrition status of macro- and micronutrients in plants (**B.2.**) provided the basis for the conclusion that the direct cause for reduced yielding is boron concentration in the nutrient solution used in fertigation causing a toxic/excessive nutrient status of plants in the case of this micronutrient.

The aim of this study was to determine the effect of increasing concentrations of the two boron forms in the nutrient solution used in fertigation on marketable yield, as well as boron content in the nutrient solutions, indicator parts and fruit of two tomato varieties grown in rockwool.

I obtained the greatest marketable yield of fruit in cv. Alboney F_1 in the range of boron concentrations in the nutrient solution of 0.011 – 0.40 mg·dm^{-3}; 5.55 and 5.52 kg·plant^{-1}

(Experiment I) as well as 5.73 and 5.87 kg·plant^{-1} (Experiment II). Recorded results indicate lower nutrient requirements of that variety in relation to boron. Both a reduction and an increase in boron contents in the nutrient solution outside the range of hydroponic concentration (0.40 mg·dm^{-3}) caused a decrease in the marketable yield of fruit in cv. Emotion F_1. The greatest marketable yield of fruit in cv. Emotion F_1 was obtained in both experiments at the concentration of boron in the nutrient solution amounting to 0.40 mg·dm^{-3}. When analysing the obtained marketable yield I stated that the optimal range of boron concentration in the nutrient solution is broader for cv. Alboney F_1 in comparison with cv. Emotion F_1. This dependence was confirmed in both experiments.

In that study I showed that boron concentration in the nutrient solutions of the root medium amounting to 0.93 mg·dm^{-3} for cv. Alboney F_1 and 0.96 mg·dm^{-3} for cv. Emotion F_1, at the application of borax causing a reduction of marketable yield of fruit. An increase in boron concentration in the root medium up to 1.87 mg·dm^{-3} for cv. Alboney F_1 and 2.00 mg·dm^{-3} for cv. Emotion F_1 does not cause any further reduction in fruit yield. Using boric acid as a source of boron in the nutrient solution I showed identical dependencies in the case of the volume of marketable yield; however, the content of boron in cultivation mats close to 2.00 mg·dm^{-3} resulted in a significant decrease in yielding compared to combination B-III (± 1,00 mg·dm^{-3}).

In my studies the greatest yield of cv. Alboney F_1 (Experiment I) (5.55 and 5.52 kg·plant^{-1}) was obtained at boron contents in indicator parts within the range of 33.24-78.58 mg·kg^{-1} and B contents in fruit at 11.66-13.10 mg·kg^{-1}, while for cv. Emotion F_1 (5.57 kg·plant^{-1}) at boron contents in leaves at 79.44 mg·kg^{-1} and in fruit at 14.26 mg·kg^{-1}.

In an experiment with boric acid cv. Alboney F_1 yielded best at boron contents in indicator parts within the range of 32.80 – 80.62 mg·kg^{-1}, (5.73 and 5.87 kg·plant^{-1}) and boron contents in fruit at 11.66 mg·kg^{-1} to 16.70 mg·kg^{-1}. In turn, cv. Emotion F_1 at boron contents in indicator parts of 83.89 mg·kg^{-1} (5.85 kg·plant^{-1}) and 19.56 mg·kg^{-1} in fruit.

A significant decrease in marketable yield of fruit in combinations B-III and B-IV was the result of the toxic/excessive nutrient status of plants in the case of boron. In both experiments applying the concentration of boron at 0.80 and 1.60 mg·dm^{-3} in the nutrient solution boron contents recorded in leaves exceeding 100 mg B·kg^{-1}, which is considered toxic for plants.

In both experiments I showed that the content of boron in nutrient solutions used in fertigation has a significant effect on the mean content of this micronutrient in fruit. In the experiment with the application of borax the values recorded in tomato fruit ranging from

11.61 mg·kg^{-1} (B-I) to 16.86 mg·kg^{-1} (B-IV). Using boric acid in the nutrient solution greater mean boron contents were detected in fruit (13.49-26.50 mg·kg^{-1}). It was shown that variety differentiates mean contents of boron in fruit (Experiment II).

When comparing the recorded results I obtained for boron contents in fruit with those reported in literature sources I stated that they are contents below the mean contents of this nutrient specified at 30 mg B· kg^{-1}, as posing no health hazard to humans.

The effect of deficit and over-standard boron content in nutrient solution on the biological value of tomato fruit (B.4.)

The next stage in the research was connected with the determination of the effect of varied boron concentrations in nutrient solutions on the biological value of tomato fruit.

The aim of the research was to determine the effect of hydroponic boron concentrations for tomato growing (**B.3.**) on contents of the macro- and micronutrients, vitamin C, lycopene, total contents of polyphenols as well as antioxidant activity.

It was shown that boron concentration in nutrient solution modifies mean contents of nitrogen, phosphorus, magnesium (significantly the lowest content was recorded in combination B-IV), as well as potassium (the lowest content in B-I and B-IV). Within the range of boron concentrations at 0.011-1.60 mg·dm^{-3} a reduction was found in mean contents of iron as well as an increase in contents of manganese and zinc in tomato fruit. Variety differentiated mean contents of calcium, magnesium, iron, manganese and copper. Varietal differences were observed also within ranges of boron concentrations for B-I and B-II (iron), B-II (magnesium, manganese and copper), B-II and B-III (potassium). In human diet tomatoes and their processed products are main sources of lycopene. Lycopene is an antioxidant with a high biological activity, accounting for approx. 80-90% total contents of carotenoids determining the red colour of tomatoes. In my research I decided to focus on dependencies between the composition of nutrient solution, the nutrient status of plants, yield of fruit (**B.1., B.2. B.3.**) and lycopene contents in fruit. No dependencies were observed between boron concentration in the nutrient solution and lycopene contents and fruit colour. In turn, variety is the main factor differentiating the content of lycopene in fruit. A significantly greater content of lycopene was recorded in fruit of cv. Alboney F_1 compared to cv. Emotoin F_1. It was shown that the greatest significantly content of lycopene in fruit of Emotion F_1 was recorded at boron concentration in the nutrient solution at 0.40 mg B· dm^{-3}, which was established as the hydroponic concentration for this variety (**B.3.**). No effect of boron concentration was found on fruit colour (except for B-II; Emotion F_1).

It was shown that boron concentration and variety influence content of vitamin C in fruit. Increased boron contents in the nutrient solution within the range of 0.011-1.60 caused a significant reduction of vitamin C contents in fruit of both varieties. For cv. Emotion F_1 8.40 mg·kg FW vitamin C was recorded at the hydroponic concentration of boron (**B.3.**) established at 0.40 $mg \cdot dm^{-3}$. It was shown that plants grown at the natural boron contents in water (0.011 $mg \cdot dm^{-3}$) contain lower contents of vitamin C than in the case of exceeded hydroponic concentration, as indicated by a decrease in contents of vitamin C by 1.8% (Emotion F_1) and by 8.0% in Alboney F_1 at a concentration of 0.80 mg $B \cdot dm^{-3}$.

Increase in the concentration of boron in the nutrient solution caused an increase in the total contents of polyphenols in fruit of Emotion F_1 and a reduction of contents of these compounds in fruit of Alboney F_1. Selection of a variety with greater contents of polyphenols plays a significant role due to their health-promoting properties. Polyphenols inhibit dangerous free radical reactions both in living organisms and in food. These compounds exhibit strong anti-cancer properties, they have a beneficial effect on the cardiovascular system, while they also inhibit inflammatory processes in blood vessels, facilitate blood circulation and reduce formation of clots.

Wpływ stosowania Tytanitu na skład chemiczny strefy korzeniowej pomidora uprawianego w wełnie mineralnej (B.5.)

Increasing requirements of consumers expecting products of highest possible quality motivate producers to search for nutrients having a positive effect on plant growth and yield quality **(B.1., B.2., B.3., B.4.**).

Titanium is one of the trace elements acting as biostimulators. The commercially available fertiliser containing this component is titanite (0.8% Ti; Intermag Olkusz).

The aim of the research was to assess the effect of side dressing with titanium in the form of fertigation on changes taking place in the root zone of tomato grown in rockwool.

I showed that the application of titanium at the annual dose of 80 g $Ti \cdot ha^{-1}$ (Ti-I) significantly reduced the content of ammonia nitrogen in the nutrient solutions in the root medium compared to the control and doses from 240 to 960 g $Ti \cdot ha^{-1}$. I stated that titanium at a dose of 480 g $Ti \cdot ha^{-1}$ causes a significant increase in $P\text{-}PO_4$ contents in cultivation mats in comparison with the dose of 80 g Ti·ha^{-1}. Increasing titanium doses had a significant effect on contents of potassium in nutrient solutions in the root medium. Significantly lower contents of potassium were recorded in combinations Ti-I and Ti-II when compared to the control and combinations Ti-III and Ti-IV.

In my studies I reported a significant increase in the contents of nitrate nitrogen, calcium and magnesium, zinc, sodium and chlorides in the nutrient solutions of the root medium compared to the nutrient solution applied to plants, at the simultaneous trend towards a decrease in the contents of phosphorus, iron, manganese and copper. I showed changes in the nutrient solutions in the root medium resulting from the increasing concentrations as well as a decrease in nutrient contents in cultivation mats. On this basis the following series of concentrations was developed for nutrients in the nutrient solutions in the root medium (in % for means of the tested combinations): Ca (+58.2) > Na (+49.2) > Cl (+38.3) > N-NO_3 (+35.8) > Zn (+24.3) > Mg (+10.7) > S-SO_4 (+8.4) > K (+2.3) compared to the nutrient solutions applied to plants, as well as a series for the reduction in nutrient contents (in %): Mn (-63.3) < N-NH_4 (-22.2) < Cu (-20) < P-PO_4 (-10.7) < Fe (-9.9).

It was shown that EC of the nutrient solution in the root zone of plants increased by 18% in comparison with the nutrient solution applied to plants.

In terms of the practical aspect it was stated that in the cultivation of tomato in rockwool using fertigation with an addition of titanium to the nutrient solution there is no need to modify the chemical composition of the standard nutrient solution recommended in culture of this crop.

Aplication of 'Tytanit' in greenhouse tomato growing (B.6.)

Based on conducted studies (**B.5.**) it was shown that changes taking place in the root medium are typical of tomato cultivation in rockwool. The efficacy of compounds exhibiting biostimulatory activity is confirmed by their effect on the level of yield as well as quality parameters of fruit. The positive effect of titanium was shown only in combination Ti-IV at the application of the greatest titanium dose (960 g Ti·ha^{-1}). In this combination the total yield of fruit obtained amounted to 19.19 kg·m^{-2}, at the greatest share of marketable yield, which accounted for 98.9% total yield. No significant differences were observed in the total yield of fruit between the control and the doses of titanium ranging from 80 to 480 g Ti·ha^{-1}. Application of the greatest dose of titanium in the nutrient solution had a significant effect on an increase in the share of fruit grades I, II and III in the total yield compared to the other combinations. At the greatest concentration of titanium applied in the nutrient solution the indicator parts of plants contained the greatest levels of nitrogen, phosphorus, calcium and magnesium. In relation to the control combination the application of titanite caused an increase in the contents of nitrogen (in Ti-I, Ti-III, Ti-IV), phosphorus (Ti-III, Ti-IV), potassium (Ti-I), calcium and magnesium (Ti-IV).

Summing up it may be stated that in all the analysed combinations, despite the differences in nutrient contents in leaves, no symptoms of their deficiency/excess were observed.

Application of increasing titanium doses in the nutrient solution caused no significant differences in the contents of phosphorus and potassium in tomato fruit. Titanium influenced contents of nitrogen (Ti-I, Ti-III, Ti-IV) and magnesium (Ti-I, Ti-IV) compared to the control. Analyses of quality parameters in fruit showed no effect of titanium on contents of dry matter, sugars and total acidity. Significantly greater contents of vitamins compared to the control were recorded at the application of 80 g $Ti \cdot ha^{-1}$ and 480 g $Ti \cdot ha^{-1}$.

Based on these studies it may be stated that the application of titanium as a biostimulator in nutrition of tomato has an effect on better nutrition with nitrogen, phosphorus, calcium, magnesium, as well as a decrease in the contents of potassium. The greatest (statistically unconfirmed) contents of potassium in fruit in the case of Ti-IV may cause a decrease in the contents of this nutrient in leaves. Increased levels of magnesium in leaves, as an element being the main component of chlorophyll, may explain the yield-promoting action of titanium at a dose of 960 g $Ti \cdot ha^{-1}$.

In terms of practical applicability aiming at an improvement of yielding it is recommended to apply titanium as a biostimulator in the cultivation of tomato in rockwool at a dose of 960 g $Ti \cdot ha^{-1}$.

The effect of Tytanit application on the content of selected microelements and the biological value of tomato fruits (B.7.)

The further stage in research was to determine the effect of titanium on contents of metallic micronutrients as well as parameters of biological value of fruits, such as total acidity, contents of nitrates and lycopene.

A significant effect was shown for titanium used at a dose of 80 g $Ti \cdot ha^{-1}$ (Ti-I) on contents of iron and manganese in indicator parts of plants. Based on my studies the theory concerning an interaction between titanium and iron was confirmed. This dependence was confirmed only at a dose of 80 g Ti·ha^{-1}. Greater doses of titanium caused a decrease in iron contents in indicator parts compared to the dose of Ti-I. In turn, no statistically significant differences were found in the contents of iron and manganese in leaves within the range of titanium dose from 240 to 960 g Ti·ha^{-1}. A significant effect of titanium on zinc content was observed in indicator parts of plants in combination Ti-II compared to the control and the other combinations. Application of titanium had no significant effect on copper contents in indicator parts except for combination Ti-IV (960 g Ti·ha^{-1}). In turn, increasing doses of titanium had a significant effect on a reduction of copper contents in fruit. Significantly the lowest contents of copper in leaves and fruit were recorded in combination (Ti-IV). No significant differences were recorded in copper contents in fruit between the control and combinations Ti-II and Ti-III.

Titanium was found to affect total acidity of tomato fruit. The greatest content of nitrates was detected in combination Ti-III (30.03 mg·kg^{-1}). No effect of titanium was observed on the contents of nitrates in the other combinations. A significant increase in lycopene contents was reported in fruit in the case of 80 g Ti·ha^{-1} (46.11 mg·kg-^{1}) in relation to the other combinations. Lycopene content was the greatest in the case of Ti-I (46.11 mg·kg^{-1}), whereas application of titanium at 960 g Ti·ha^{-1} (Ti-IV) induced a significant increase in total acidity of fruit. In turn, application of titanium was found to have no effect on contents of nitrates in fruit compared to the control, except for the dose of 480 g Ti·ha^{-1} (Ti-III).

Summing up it may be stated that the conducted research showed a significant effect of the Tytanit preparation on the biological value of tomato fruit.

Summary of the most important results documenting the scientific accomplishment, constituting the basis for the application to confer the postdoctoral degree [doktor habilitowany]:

Based on the conducted 6-year vegetation experiments I showed a diverse cultivar-specific response to increasing boron concentrations in the nutrient solution in tomato grown in rockwool applying drip fertigation.

I showed that tomato can be grown at a natural abundance of boron in water (0.011 mg·dm^{-3}). The natural boron content in water is sufficient to grown tomato cv.

Alboney F_1 in rockwool. No symptoms of the micronutrient deficiency were observed in plants, while fruit were characterised by the best biological value.

Tomato cv. Emotion F_1 should be considered less tolerant to boron deficiency/excess in the nutrient solution.

Boron concentration in the nutrient solution within the range of 0.80-1.60 $mg \cdot dm^{-3}$ is excessive for cultivation of both tomato cultivars in rockwool. Observed toxicity occurs both at the application of boron in the form of borax and boric acid.

In my studies the greatest yields of cv. Alboney F_1 (Experiment I) (5.55 and 5.52 $kg \cdot plant^{-1}$) were recorded at boron contents in indicator parts within the range of 33.24 – 78.58 $mg \cdot kg^{-1}$ and boron contents in fruit at 11.66-13.10 $mg \cdot kg^{-1}$. In turn, for cv. Emotion F_1 (5.57 $kg \cdot plant^{-1}$) it was at boron contents in leaves amounting to 79.44 $mg \cdot kg^{-1}$ and in fruit at 14.26 $mg \cdot kg^{-1}$. In the experiment with boric acid (Experiment II) cv. Alboney F_1 yielded best at boron contents in indicator parts within the range of 32.80-80.62 $mg \cdot kg^{-1}$, (5.73 and 5.87 $kg \cdot plant^{-1}$) and boron contents in fruit at 11.66 $mg \cdot kg^{-1}$ up to 16.70 $mg \cdot kg^{-1}$. In turn, in cv. Emotion F_1 it was at boron contents in indicator parts of 83.89 $mg \cdot kg^{-1}$ (5.85 $kg \cdot plant^{-1}$) and 19.56 $mg \cdot kg^{-1}$ in fruit. When analysing the recorded boron contents in fruit I stated that excessive boron concentrations in nutrient solutions used in fertigation pose no health hazard to humans.

Varietal differences were reported in terms of contents of macro- and micronutrients in indicator parts as well as fruit of tomato at the application of the two boron forms. At the application of boric acid (Experiment II) a significantly greater content of phosphorus was recorded in indicator parts of cv. Alboney F_1; in turn, using borax a greater, statistically non-significant content of phosphorus was detected in leaves of cv. Emotion $F_{1.}$ I showed that in contrast to borax, boric acid does not modify calcium contents in indicator parts.

I stated a significant effect of titanium application at a dose of 960 g $Ti \cdot ha^{-1}$ on the total and marketable yield of tomato fruit as well as an increase in the yield of fruit with the greatest diameters (grades I, II and III) compared to the other tested combinations.

Under the influence of titanium application in hydroponic cultivation of tomato the produced yield was of a better biological quality. I showed that tomato fruit at a dose of 80 g $Ti \cdot ha^{-1}$ contained significantly the highest content of lycopene and vitamin C.

In my own research, I confirmed that there may be antagonistic and synergistic relationships between titanium and iron depending on the titanium dose. I also showed that titanium at 80 and 960 $Ti \cdot ha^{-1}$ significantly affect the magnesium content in tomato leaves.

In contrast, I found no effect of titanite application on the other quality parameters of fruit. Application of Ti in fertigation does not require changes in the chemical composition of standard nutrient solution for tomato growing in rockwool and plants show no signs of insufficient/excessive nutrient status for any of the nutrients.

Taking into consideration the scientific and practical aspects of this research it needs to be stressed that it is advisable to verify presently binding and commonly applied hydroponic concentrations of nutrients in nutrient solutions for tomato cultivation in rockwool, as well as search for elements having a positive effect on plant yielding, focusing particularly on improvement of the biological quality of fruit.

In my studies I confirmed high toxicity of boron; however, particularly important and novel outcomes are related with the results obtained for plant growing at a natural boron content in water. In view of the practical aspect, especially improvement of plant yielding, it also seems highly recommendable to apply titanium as a biostimulant in tomato growing in rockwool.

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5. Discussion of the other scientific and research accomplishments

Main directions of my research concern the following scientific problems:

1. Nutrition of selected herb and vegetable species
2. Optimisation of nutrition for aubergine (*Solanum melongena* L.)
3. Optimisation of soilless cultures of tomato (*Lycopersicon esculentum* Mill.)
4. Hydroponic cultivation of butterhead lettuce (*Lactuca sativa* L.)
5. Anthropogenic soil contamination in urban areas.

5.1. Nutrition of selected herb and vegetable species

5.1.1. Basil (*Ocimum basilicum* L.)

Nitrogen is the nutrient having the greatest effect on yield volume in that plant. In experiments on the nutrition of basil (*Ocimum basilicum* L.) cv. Wala 5 doses of nitrogen were tested. (0.0, 0.3+0.15, 0.6+0.3, 0.9+0.45, 1.2+0.6 g N·plant^{-1}). The greatest yields of the herb, leaves as well as stems were obtained at the application of the total dose of 1.8 g N·plant^{-1}. Significantly greater mean yields were produced in the second harvest period (**D.2.**). Contents of dry herb matter in basil were on average 20% fresh plant matter. In the growing period contents of nitrogen and potassium in the substrate were decreasing, while magnesium content in leaves and stems was increasing (**D.9.**). The characteristic determining the quality of great basil is its content of essential oils (**D.3.**). The greatest contents of essential oils were recorded when growing basil applying fertilisation at 0.6+0.3 g N·plant^{-1} (1st harvest). Plants grown at the application of nitrogen doses of 0.9 and 1.2 g N·plant^{-1} were characterised by the most desirable aroma attributes: basil, pungent, spicy and herb. The experiments were continued in the cultivation of two basil cv. Wala and Dark Opal at a varied nitrogen fertilisation in two pre-vegetation doses of 0.9 and 1.2 g N · plant^{-1} and top-dressing doses of 0.45 and 0.6 g N · plant^{-1} (**D.1.**). A varied variety-dependent response to the applied nitrogen doses was shown. Significantly greater contents of essential oils were recorded in the herb of cv. Wala.

5.1.2. Common onion (*Allium cepa* L.)

Consumption of onion in Poland is estimated at 5.67 kg/person/year. It is an important and valuable source of minerals in the human diet. I participated in studies on the effect of controlled nutrition of onion and its storage on the nutritional value expressed in the contents of macro- (**D.16.**) and micronutrients (**D.17.**) in the storage part. Experiments were conducted in a private horticultural farm. Analyses were conducted on 21 most popular onion cultivars grown in Poland. It was shown that during storage of onions contents of N, P and S decreased. Storage of onion storage organs had no effect on dry matter content or contents of K, Ca, Na, Fe and Zn in onions. A significant effect of storage on magnesium content in onion was observed.

5.1.3. Peppers (*Capsicum annuum* L.)

I was one of the participants in studies on the effect of nitrogen and potassium fertilisation of chili peppers on the nutrient status of plants and substrate salinity (**A.2.**). Experiments were conducted in an unheated greenhouse on chili peppers cv. Wulkan. Analyses were conducted on the effect of varied nitrogen and potassium fertilisation on changes in the contents of these nutrients resulting in an increase in salinity (EC) in the substrate as well as the nutrient status of plants. Increasing doses of nitrogen and potassium (N 350, K 400 $mg \cdot dm^{-3}$) were found to influence an increase in substrate salinity. The level of nitrogen fertilisation did not have a significant effect on the contents of this macronutrient in indicator parts of plants. I also participated in studies on the effect of the type of potassium fertiliser on yielding of annual peppers cv. Cyklon (**A.7.**). In that experiment identical levels of nitrogen and potassium fertilisation as those in the earlier studies, i.e. N-250, K-300 and N-350, K-400 $mg \cdot dm^{-3}$ substrate. Potassium fertilisation was varied in three forms: nitrate, chloride and sulphate. The type of potassium fertiliser at two levels of nitrogen and potassium had no significant effect on yielding and biometric parameters of peppers. Recorded results are pioneering on the international scale and are of considerable practical importance. Our findings critically refer to the previous classification of peppers as a sulphur-loving plant.

5.1.4. Cucumber (*Cucumis sativus* L.)

In cooperation with the Department of Vegetable Crops, the Poznań University of Life Sciences I participated in studies on applicability of wood fibre as an alternative organic substrate in cucumber growing (**D.15.**) The aim of the studies was to determine changes in the chemical composition of the nutrient solution in cultivation of cucumber cv. Onyks $F_{1.}$ In the experiments the use of wood fibre of varying density (60, 80 and 100 g·dm^{-3}) was compared with rockwool. It was found that in wood fibre mats of 80-100 g·dm^{-3} density an increase is observed in the contents of ammonia nitrogen, manganese, copper, boron and sodium. At wood fibre density of 100 g·dm^{-3} a considerable increase in EC was observed in the nutrient solutions of the root medium, while no significant changes were found in pH levels. A series of increasing concentrations was determined for nutrients in the case of wood fibre: Cu> Na> Zn> Ca> Cl> K> B> S-SO4> Mg. No increasing concentrations of N-NH_4 and N-NO_3 were detected in the wood fibre as a result of biological sorption due to the high C : N ratio in this substrate.

5.2. Optimisation of nutrition for aubergine (*Solanum melongena* L.)

Aubergine, also referred to as eggplant (*Solanum melongena L.*), has been grown for many centuries in south-eastern Asia and Turkey (**D.4.**). In studies on the optimisation of nutrition in aubergine growing experiments tested three substrates, two cultivars and three levels of fertilisation (NPK). The basic fertilisation - pre-vegetation and top-dressing with macronutrients was established for the assumed levels (N - low, S - standard, W - high, maintaining the macronutrient ratios N : P : K = 1 : 0.9 : 1.7) for organic substrates: N (N-300, P-265, K-500 mg·dm^{-3}), S (N- 400, P-350, K-665 mg·dm^{-3}), W (N-500, P-440, K-830 mg · dm^{-3}), for mineral soil - N (N-200, P-175, K-330 mg·dm^{-3}), S (N-300, P-265, K-500 mg·dm^{-3}), W (N-400, P-350, K-665 mg·dm^{-3}).

I stated that the mean marketable yield in terms of the number of fruit and single fruit weight in both aubergine cultivars in highmoor peat did not differ significantly (**D.7.**) The level of fertilisation was shown to have an effect on the marketable yield of fruit. Differences between the greatest and the lowest fertilisation levels amounted to ±22% in the mean marketable yield and ±24% in the mean number of fruit.

At the standard fertilisation level in both cultivars a comparable single fruit weight was obtained (mean 339.4 g). When growing plants in a mixture of mineral soil and highmoor peat (v:v – 4:1) the fertilisation level and cultivar were found to have a significant effect on the total yield, mean number of fruit, as well as single fruit weight in aubergine (**A.3.**).

Fruit od aubergine cv. Epic F_1 contained more vitamin C than fruit of cv. Solara F_1. In fruit of both aubergine cultivars in all the years of the study the solids content ranged from 4.0 to 5.5 %. A greater mean dry matter content in aubergine fruit was recorded in the case of cv. Solara F_1.

In the cultivation of aubergine in rings filled with mineral soil mixed with highmoor peat (v:v – 4:1) it is recommended to apply pre-vegetation supplementation of nitrogen, phosphorus and potassium contents in the substrate to the levels (mg·dm^{-3}): N-250, P-220, K-415, while in top-dressing (from the 3rd week of culture nutrient contents in the substrate were maintained at N-400, P-350, K-665).

The nutrient status of plants was the factor determining yielding (**A.1.**) In indicator parts of plants grown in organic substrates the following levels were recorded: in cv. Epic F_1: 1.12-3.40% N, 0.42-1.14% P, 1.80-4.81% K, while in cv. Solara F_1 it was 1.17-3.50% N, 0.53-1.27% P, 1.96-4.00% K depending on the substrate and fertilisation level.

The effect of fertilisation level on yielding and nutrient status of plants was shown. Contents of nitrogen, phosphorus and potassium in indicator parts of plants grown in highmoor peat decreased during cultivation. Greater contents of nitrogen and phosphorus were recorded in indicator parts of cv. Solara F_1, whereas indicator parts of cv. Epic F_1 contained more potassium.

Aubergine fruits were harvested several times from July to October in each year of the study. Dynamics of yielding was determined for aubergine grown in various substrates following the application of three fertilisation levels (**D.14.**) In organic substrates the greatest yielding dynamics was observed at the standard and high fertilisation levels, while in mineral soil supplemented with peat at the application of high fertilisation levels. It was shown that the highmoor substrate is most suitable for aubergine growing.

Aubergine is a termophilous plant. I stated that air temperature during the vegetation period of aubergine as well as the type of the applied substrate had a significant effect on the total yield and the number of fruit (**D.11.**). The difference between years in the mean diurnal temperature in the cultivation period of 2°C caused a significant reduction of yield as well as the number of fruit. The obtained total yield in 2004 was by 36% lower and single fruit weight was by 24% lower compared to 2003.

Due to the varied cultivar-dependent response I undertook studies on the effect of cultivar and type of substrate on the early yield as well as biometric parameters and biological value of fruit in selected aubergine cultivars (**D.13.**). The greatest early yield was obtained in cv. Arrow F_1 and Black Bell F_1.

The type of organic substrate had a significant effect on yielding in aubergine. Significantly greater mean early yields were recorded in the bark-peat substrate in the case of all cultivars, except for cv. Solara F_1.

No effect of the type of substrate was observed on the solids contents in fruit. The greatest content of vitamin C was recorded in fruit of cv. Solara F_1 (18.7 mg%), while it was lowest in fruit of cv. Impuls F_1 (10.1 mg%) grown in peat substrate. The type of substrate had no effect on the content of vitamin C in fruit of cv. Arrow F_1 and Black Bell F_1. Based on the shape coefficient it was found that this is a solely varietal characteristic.
In aubergine fruit contents of glucose, fructose and sucrose were also determined **(D.5.**) It was shown that glucose is the dominant sugar in aubergine fruit, while the content of sucrose in 19-fold lower than in carrot roots. Aubergine fruits are also valued for their low calorie content and for their contents of minerals, including potassium.

I showed significant differences in the mean content of potassium in fruit depending on the cultivar (Epic F_1 - 26.65 g K·kg d.m, Solara F_1 – 29.72 g K·kg d.m) (**A.4.**). The greatest content of potassium was recorded in fruit of cv. Epic F_1 grown in peat at the low fertilisation level (28.47 g K·kg d.m.) as well as in fruit of cv. Solara F_1 grown in the mixed substrate composed of low peat + bark at a high fertilisation level (32.07 g K·kg d.m.).

The type of substrate had a significant effect on mean contents of nitrogen and calcium in fruit. The level of fertilisation was found to have no effect on the mean contents of nitrogen, phosphorus, potassium, magnesium and sulphur in aubergine fruit. Greater mean contents of manganese were recorded in fruit of plants grown in highmoor peat compared to fruit of plants grown in the mixed substrate, with an opposite dependence observed in the case of iron. No effect was found for the level of fertilisation on mean contents of iron, manganese, zinc and copper in aubergine fruit (**D.23.**).

The next stage in research concerning aubergine cultivation in organic substrates was connected with the determination of substrate suitability in terms of their re-use (**D.8.**). It was shown that substrate re-use caused a significant reduction of fruit yield (on average by 56%), the number of fruit on the plant (on average by 53%) as well as mean fruit weight.

In substrates during cultivation the EC level increased, while phytotoxic substances were accumulated. Repeated use of substrates had no significant effect on the contents of macronutrients in leaves and fruit of aubergine (**D.10.**). Greater contents of nitrogen, potassium and magnesium were recorded in leaves of plants grown in highmoor peat, while those of phosphorus and calcium in a mixture of bark with peat. A significant problem in aubergine growing is connected with the protection of plants against pests, particularly since aubrigine is used as a trapping and indicator plant in the cultivation of other species. Development of pest control methods is of practical importance. In these studies I showed that misting using a Mgła E Turbo cold mist generator and the Lannate 200 SL preparation were highly effective in the control of greenhouse whitefly (**D.6., D.12.**). In the vegetation period only three misting operations were performed and the population of that pest was maintained at a very low level, i.e. maximum 10.67 imagines were caught per 1 beating tray. A greater problem in aubergine cultivation is connected with the presence of the western flower thrips. I showed that regularly performed misting operations (on average once a week) using Winylofos 550 EC effectively protected the culture against the western flower thrips. In the vegetation period a low number of this pest was recorded. A maximum of 12.67 insects were caught per 1 trap. .

5.3. Optimisation of soilless cultures of tomato (*Lycopersicon esculentum* Mill.)

A major part of my scientific activity was connected with my participation in research aiming at the development of a plant cultivation system in technologies causing no environmental pollution. As an employee of the Department of Plant Nutrition I participated in the realisation of two research projects financed by the Ministry of Science and Higher Education. These studies resulted in scientific publications, in which I was a co-author.

In that research cultivation of plants in hydroponic systems was compared in the systems with and without recirculation of nutrient solutions (**A.5.**). No significant differences were observed in the total and marketable yields, as well as the dynamics of yielding in tomato grown in the systems with and without recirculation of nutrient solutions. Fruit of plants grown in the recirculation system contained greater contents of calcium, zinc and boron, while in the system without recirculation it was greater contents of phosphorus, potassium and manganese. It was shown that plants grown in the recirculation system show no signs of excessive accumulation of nitrates and nitrites in fruit compared to the system without recirculation. In the nutrient solutions collected from drip lines and the root medium only bacteria were detected, while no fungi were found. Among the bacteria there were no species pathogenic to plants. Bacterial counts in nutrient solutions sampled from drip lines in both systems were similar, while in drainage waters they were greater in the recirculation system. A high efficacy of UV radiation (253.7 nm) was confirmed by a reduction of bacterial counts in drainage waters in the recirculation system. A significant practical aspect is related with the statistically confirmed consumption of water and fertilisers in the system with nutrient solution recirculation. The recirculation system provided water conservation amounting to 42.5%, while in the case of nutrients it was (in %): 42.1 N-NH4, 56.0 N-NO3, 31.4 P, 52.1 K, 63.5 Ca, 47.9 Mg, 49.4 S-SO4, 51.9 Cl, 50.9 Fe, 47.9 Zn, 24.6 Mn, 53.3 Cu and 47.2 B.

These studies led to the experiments aiming at the determination of applicability of aeroponic cultivation of tomato compared to the hydroponic systems in the installations with and without recirculation of nutrient solutions (**A.8.**). In this study the tested nutrient solution included: A-2 - applied as a standard in soilless tomato growing (also in the systems with rockwool), A-1 – with nutrient contents lower by 30%, as well as A-3 with 30% greater nutrient contents than in A-2. Comparing the three hydroponic cultivation systems it was shown that the greatest total and marketable yields of tomato fruit were obtained in the rockwool cultivation system with recirculation of the nutrient solution. A 30% increase in nutrient contents in the nutrient solution caused a significant decrease in yielding. In turn, no significant differences were found in the yields in rockwool culture without recirculation of the nutrient solution, as well as aeroponics with the application of nutrient solutions A-1 and A-2. The diverse growing systems determined nutrient contents in indicator parts of plants. The greatest contents of nitrogen, phosphorus and potassium were recorded in leaves of plants grown in the aeroponic system with the application of nutrient solutions A-2 and A-3 compared to cultivation in rockwool with/without recirculation of nutrient solution as well as aeroponics with nutrient solution A-1. In own study obtained comparable yield and nutrient status in aeroponic cultivation with nutrient solution A-1 and in those of in rockwool without recirculation using standard nutrient solution A-2.

An important application aspect is connected with the conservation of nutrient solutions in aeroponic cultivation compared to culture in rockwool without recirculation (58.1%), as well as the recirculation system (18.8%). The results showed suitability of the aeroponic cultivation system in the intensive tomato production in polytunnels. Implementation of this cultivation system in horticultural practice has an important ecological aspect, eliminating cultivation mats, which disposal is an important environmental problem. Reduced consumption of water and mineral fertilisers will protect soils and groundwaters against uncontrolled leakage of drainage waters in hydroponic systems with an open fertigation system.

I continued experiments on the optimisation of nutrition for tomato in soilless cultivation in cooperation with the Department of General and Environmental Microbiology, the Poznań University of Life Sciences. I investigated the application of organic substrates in intensive tomato cultivation. Those experiments verified suitability of peat mats as well as coir mats with varied coconut chip contents (20% and 40%) compared to standard rockwool mats (**A.6.**). Growing substrate significantly modified contents of N, P, Mg, Fe, Mn, Zn in leaves. No changes were shown in the contents of K and Cu. Moreover, it had a significant effect on contents of all analysed macro- and micronutrients, except for Cu in fruit. These investigations indicate a potential to eliminate rockwool in tomato growing. I showed that in organic substrates yields may be comparable to those in systems with rockwool. Microbiological analyses of organic substrates showed large counts of microorganisms (bacteria, Actinobacteria and fungi), as well as enzyme activity, including dehydrogenases. These parameters indicate that such substrates upon the completion of the cultivation process may provide valuable organic fertiliser.

I participated in research concerning manganese nutrition in tomato. This experiment showed the effect of increasing manganese concentrations on the value of SPAD (**D.24**). Moreover, a correlation was found between SPAD reading and nutrient contents in tomato leaves.

5.4. Hydroponic cultivation of butterhead lettuce (*Lactuca sativa* L.)

An important problem in Polish horticulture is connected with uncontrolled discharge of drainage waters in hydroponic cultures. In regions with intensive horticultural production groundwater quality deteriorates, as expressed in the increased EC. I am a co-author of studies on the effect of salinity induced by the increase in the concentrations of macro- and micronutrients in nutrient solution on growth and yielding of lettuce grown in the stagnant hydroponic system. The research determined the effect of the chemical composition of the nutrient solution with varying EC: NS I (nutrient solution 50%, EC 1.60 $ms \cdot cm^{-1}$), NS II (nutrient solution 100%; EC 2.50 $ms \cdot cm^{-1}$), NS III (nutrient solution 150%, EC 3.50 $ms \cdot cm^{-1}$), NS IV (nutrient solution 200%, EC 5.10 $ms \cdot cm^{-1}$) on changes in nutrient contents in the root medium, yielding as well as nutrient contents in aboveground parts of plants.

Experiments were conducted using 2 butterhead lettuce cultivars (*Lactuca sativa* L.): ISI 42017 and Brigitta (ISI 42008) provided by ISI SEMENTI (Italy). As a result of increasing concentrations of most nutrients in all the experimental variants an upward trend was observed for salinity (EC) of nutrient solutions in the root medium in relation to the nutrient solution applied to plants (**D. 18.**). No negative response was shown in the analysed lettuce cultivars to salinity of the nutrient solution within the range from 1.60 to 5.10 $mS \cdot cm^{-1}$ as well as excessive content of nitrate nitrogen (392.0 mg $N\text{-}NO_3 \cdot dm^{-3}$), phosphorus (683.7 mg $P \cdot dm^{-3}$) and potassium (496.2 mg $K \cdot dm^{-3}$) in the nutrient solution. Salinity (expressed in EC) had a significant effect on the mean weight of lettuce heads, the number of leaves formed on plants as well as intensity of leaf blade colour (SPAD) (**D.19.**). The EC of nutrient solution was shown to influence contents of P, K, Mg, Fe, Mn, Zn, Cu and Na in lettuce heads and outer leaves, as well as Ca and Cu levels in outer leaves of plants (**D.19., D.20.**). Varietal differences were shown in contents of Fe, Mn and Na in outer leaves, while Zn level only in lettuce heads. Within the investigated range of salinity (up to EC=5.10 $mS \cdot cm^{-1}$) no symptoms of toxicity were observed on plants.

Based on the investigations the potential applicability was shown for water and nutrient solutions with greater salinity (EC) than currently recommended for lettuce growing in stagnant hydroponic systems.

Buuterhead lettuce is a plant with a short vegetation period, very often used as a test plant in studies on plant nutrition. I conducted studies on the effect of increasing boron nutrition levels on yielding and chemical composition of lettuce grown in the system with the recirculation of nutrient solution as well as stagnant hydroponic systems (**D.26., D.30.**) The aim of these studies was to verify the response of butterhead lettuce as a plant with a different edible part in boron concentrations used in tomato growing. In those experiments the applied nutrient solution had the following composition ($mg \cdot dm^{-3}$): $N\text{-}NH_4$<10, $N\text{-}NO_3$ 150, $P\text{-}PO_4$ 50, K 150, Ca 150, Mg 50, Fe 3.00, Mn 0.50, Zn 0.44, Cu 0.03. In the first experiment the aim was to investigate the effect of the chemical composition of the nutrient solution with varying boron contents: (B-I - without boron application, B-II - 0.4 mg $B \cdot dm^{-3}$, B-III - 0.8 mg $B \cdot dm^{-3}$, B-IV - 1.6 mg $B \cdot dm^{-3}$) on yielding and nutrient contents in aboveground parts of lettuce grown in a closed fertilisation system with the recirculation of nutrient solution using cultivation trays Wilma. (**D.26.**). A significant effect of boron level in the nutrient solution used in fertigation on the weight of produced lettuce heads. It was shown that in the case of butterhead lettuce boron is a yield-forming nutrient. The lowest weight was recorded for plants grown using nutrient solution B-I at the lowest boron content (yield of 163.55 g·plant^{-1}), while the heaviest plants - at B-IV (yield of 220.11 g·plant^{-1}). No significant differences in yielding were found between combinations B-II and B-III (193.33 and 206.44 g·plant^{-1}, respectively). The level of boron in the nutrient solution used in fertigation modified significantly the leaf blade colour intensity. The greatest SPAD value (32.7) was recorded at the application of the nutrient solution with the greatest boron content (B-IV), while significantly the lowest (24.5) at the application of the nutrient solution with the lowest boron content (B-I). No significant differences in SPAD values were found between B-II and B-III (28.3 and 29.2). An increase in SPAD values with an increase in boron level in the nutrient solution used in fertigation may indicate an increase in the contents of chlorophyll in lettuce leaves. An effect of an increasing boron nutrition was observed on the contents of nitrogen and phosphorus in leaves, whereas it was not found in the case of potassium, calcium or magnesium. The content of boron in the nutrient solution significantly modified contents of iron, manganese, copper and boron in lettuce heads. These experiments showed that plant tolerance to varying boron concentrations in the nutrient solution is a species-specific characteristic. Within the tested range of boron concentrations no symptoms of toxicity of that nutrient was observed in butterhead lettuce.

I continued studies on the effect of boron concentrations in the cultivation of butterhead lettuce cv. Sunny F_1 using the stagnant hydroponic system (**D.30.**). In stagnant hydroponic systems we observe the phenomenon of increasing concentrations of nutrients causing an increase in salt concentrations in the root zone of plants. This increase in nutrient concentrations is caused by the dominance of transpiration over selective uptake of ions by plants. The negative effect of salinity on plants may be a consequence of two mechanisms, i.e. the toxic individual action of the ion on plants (e.g. Na, B) or exceeding the tolerance limit of the plant to the total salt concentration. Boron toxicity may occur in the case of application of water with high contents of this microelement. A combination of the cultivation system, in which nutrient concentrations are strongly increased with the potentially simultaneous toxic effect of boron on plants may confirm the previously investigated high tolerance of butterhead lettuce to boron concentrations found toxic for tomato grown in rockwool. Application of stagnant hydroponic systems confirmed previously recorded results with the use of the system with recirculation of nutrient solution. The greatest total yield of aboveground parts was obtained when growing plants at boron concentration in the nutrient solution of 1.6 mg B · dm^{-3}. Similarly as in the case of cultivation in the closed system with recirculation, tolerance of high boron concentrations in nutrient solution was confirmed in butterhead lettuce. Summing up, based on two conducted experiments it may be stated that in the case of plants, which edible parts are leaves, boron is a yield-forming element. However, it should be stressed that in leaves of lettuce the boron content of 100 mg $B \cdot kg^{-1}$, considered toxic to plants, was not exceeded.

5.5. Anthropogenic soil contamination in urban areas

I also participated in joint studies on the effect of increasing doses of heavy metals (Cd,Pb, Ni, Cu and Zn) added to the substrate (mineral soil as well as its mixture with highmoor peat) on the green colour index in leaves of *Miscanthus x giganteus* Greef i Deu (**D.25**).

In the conducted studies light absorption by the leaf blade (the green colour index of leaves) was measured using the SPAD apparatus. The SPAD measurement is a rapid and non-invasive method facilitating determination of nutrient status of plants. The lowest leaf green colour index was recorded both in the first and second year of growth in plants grown in a w mixture of mineral soil with highmoor peat, which was contaminated with 600 mg $Ni \cdot dm^{-3}$. Varied correlations were found between contents of heavy metals and the green colour index of leaves. A very high negative correlation as well as the greatest coefficient of determination was observed for nickel (in plants growing in a mixture of mineral soil with highmoor peat).

I am also a co-author of a monograph concerning soil contamination with heavy metals in urban areas (**D.29.**) using phytoremediation techniques (**D.28.**) as well as characteristics and the role of heavy metals as essential micronutrients (**D.31.**) and soil contamination (**D.32.**). In the years 2012-2013 I conducted monitoring studies in the city of Poznań. The aim of the study was to determine the rate of soil contamination with heavy metals as well as select plants with the greatest capacity to accumulate heavy metals which may be used in plantings in urbanised areas. In 2012 monitoring studies were conducted along Polska street (**D.28.**) Based on the recorded results it was stated that the following species may be used in plantings in urban areas: *Physocarpus opulifolius* (L.), *Fraxinus excelsior* (L.), *Spiraea ×cinerea* 'Grefsheim' as well as *Cornus alba* (L.). Monitoring studies were continued in 2013. Samples of soil and leaves were collected from transportation routes characterised by a high intensity of vehicle traffic, i.e. Aleja Niepodległości, Aleja Solidarności and the Dąbrowskiego street (**D.29.**). Contents of zinc, cadmium, manganese, copper, nickel, lead and iron were determined in woody plants and in soil. It was shown that contents for Cu, Zn and Ni optimal for plants were exceeded in soils of all the transportation routes as well as that of iron in Aleja Niepodległości and Aleja Solidarności. Decreasing contents of heavy metals in soil were recorded with an increasing distance from the traffic lane. Based on the recorded results the tree species accumulating the greatest amounts of heavy metals were selected for plantings in urban areas: *Spiraea ×vanhouttei* ((Briot) Zabel), *Salix acutifolia* (Willd.), *Berberis thunbergii* (DC.) 'Athropurpurea', *Tilia cordata* (L.) as well as *Philadelphus coronarius* (L.).

6. Concluding remarks

My scientific activity concerns problems associated with plant nutrition in soilless cultivation, particularly tomato growing in hydroponic systems. I also participated in works concerning cultivation of selected herb species and vegetables, optimisation of aubergine nutrition as well as anthropogenic soil contamination in urban areas.

In the period of my employment on the post-doctoral position [adiunkt] I submitted applications for 5 research projects (KBN, NCN, NCBiR).

The body of my scientific publications includes 47 original research papers, of which I am the author or a co-author, including 7 chapters in monographs (a total of 345 points in the Ministry of Science and Higher Education classification for the year of publication), as well as 7 popular science papers. The total IF for the publications is 4.992, while the Hirsch Index according to the Web of Science = 3. The total number of citations according to the Web of Science is 40, while excluding autocitations it is 37.

I actively participated in 16 international and national scientific conferences delivering 5 papers, including one invited paper, while I also presented 20 abstracts and 11 posters. I was a member of the organising committee of two scientific conferences.

I have given classes in soil science and plant nutrition for full-time and part-time students of the Faculty of Horticulture and Landscape Architecture.

I have been a scientific supervisor for 8 M.Sc. papers and 8 B.Sc. papers. I am an auxiliary supervisor in the initiated Ph.D. degree conferral procedure.

Detailed information concerning a list of my scientific publications as well as information on my teaching accomplishments, scientific cooperation and popularisation of science are given in Attachment 4.

Table 1. A list of entire scientific activity, including the publications comprising the scientific accomplishment

Journal	Total score	Total IF[1]	Score MNiSW, KBN[2]
Original research papers placed in the base Journal Citation Reports (JCR)			
Acta Scientiarum Polonorum – Hortorum Cultus	12	4.992	178
Journal of Elementology			
Journal of Plant Nutrition			
Polish Journal of Environmental Sciences			
Other peer-reviewed journals			
Aparatura Badawcza i Dydaktyczna	28		134
Biuletyn Naukowy – Olsztyn University of Agriculture and Technology			
Ecological Chemistry and Engineering A			
Herba Polonica			
Folia Horticulture - Suplement			
Nauka Przyroda Technologie			
Roczniki Akademii Rolniczej w Poznaniu			
Progress in Plant Protection			
Zeszyty Problemowe Postępów Nauk Rolniczych			
Vegetable Crop Research Bulletin (Journal of Horticultural Research)			
Other journals			
Chapters in scientific monographs	7		33
Conference summaries	20		
Popular science publications	7		
Total	**74**	**4.992**	**345**

[1] point score for the year of publication, in the case of papers from 2019 the applied score is the number of points for 2018
[2] in the year of publication, in the case of papers from 2019 the IF value of 2018 was applied

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