Załącznik 3

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SUMMARY OF SCIENTIFIC AND PROFESSIONAL ACCOMPLISHMENTS

Poznań 2019

TABLE OF CONTENS

First name and family name **ANITA BARBARA SCHROETER-ZAKRZEWSKA**

1. Diplomas and scientific degrees

1993-1998- studies at the Faculty of Horticulture, the Agricultural University of Poznań

Master's degree

1998 - Master's degree and Engineer's degree in horticulture;

Master's thesis entitled "Assessment of yielding in 13 rose varieties grown in a greenhouse"

Scientific supervisor dr hab. Anna Lisiecka

Ph.D. degree

2005 - Ph.D. degree in agricultural sciences in the field of horticulture

the August Cieszkowski Agricultural University of Poznań, the Faculty of Horticulture

Ph.D. thesis entitled "The effect of retardants on growth and flowering of selected flower bed plants"

Scientific supervisor: prof. dr hab. Marek Jerzy

Reviewers:

dr hab. Anna Lisiecka (the August Cieszkowski Agricultural University of Poznań)

prof. dr hab. Małgorzata Zalewska (the University of Science and Technology in Bydgoszcz)

Other education forms

1995 a training course for camp counselors

1999-2003 Ph.D. studies at the Faculty of Horticulture, the August Cieszkowski Agricultural University of Poznań

2004 - a teaching qualification course

16-17.03.2011 – training "Methods to acquire fuds for research projects (including EU funds)", the Maritime University of Szczecin

2. Information on employment history in scientific institutions

1999-2005 - senior technical worker at the Department of Ornamental Plants, the Faculty of Horticulture and Landscape Architecture, the Poznań University of Life Sciences

1.10.2005 - present - Assistant Professor at the Department of Ornamental Plants, the Faculty of Horticulture and Landscape Architecture, the Poznań University of Life Sciences

November 2004 - February 2005 – maternal leave

January 2012 - June 2012 – maternal leave

3. Indication of the scientific accomplishment 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 Laws 2016, item 882 with later amendments in the Journal of Laws 2016, item 1311)

3.1. Title of scientific accomplishment

The scientific accomplishment as indicated above comprises a monographic series of 7 scientific publications entitled **Quality of light as a factor determining growth and development of selected species of horticultural plants**

3.2. Author/authors, title/titles of publications, year, name of publisher

A.1. Schroeter-Zakrzewska A. 2009. Wpływ barwy światła na jakość rozsady szałwii błyszczącej (*Salvia splendens* Buc'hoz Ex Etl.). Zeszyty Problemowe Postępów Nauk Rolniczych 539: 633-640. [4 points in the classification of the Ministry of Science and Higher Education]

A.2. Jerzy M., Zakrzewski P., **Schroeter-Zakrzewska A**. 2011. Effect of colour of light on the opening of inflorescence buds and post-harvest longevity of pot chrysanthemums (*Chrysanthemum* x *grandiflorum* (Ramat.) Kitam). Acta Agrobotanica 64(3): 13-18. [7 points in the classification of the Ministry of Science and Higher Education]

A.3. **Schroeter-Zakrzewska A**., Kleiber T. 2014. The effect of light colour and type of lamps on rooting and nutrient status in cuttings of Michaelmas daisy. Bulgarian Journal of Agricultural Science 20(6): 1426-1434. [10 points in the classification of the Ministry of Science and Higher Education]

A.4. Schroeter-Zakrzewska A. 2015. Influence of the light colour on the seedling quality of French marigold and Scarlet sage. Bulgarian Journal of Agricultural Science 21(5): 951-956. [5 points in the classification of the Ministry of Science and Higher Education]

A.5. Schroeter-Zakrzewska A., Borowiak K., Wolna-Maruwka A. 2016. Effect of light quality and microbiological inoculum on geranium (*Pelargonium zonale*) gas exchange parameters. Notuale Botanicae Horti Agrobotanici Cluj Napoca 44(1): 25-33. [IF= 0,547; 15 points in the classification of the Ministry of Science and Higher Education]

A.6. Schroeter-Zakrzewska A., Kleiber T., Zakrzewski P. 2017. The response of chrysanthemum (*Chrysanthemum* x *grandiflorum* (Ramat.)Kitam) cv. Covington to a different

range of fluorescent and LED light. Journal of Elementology 22(3): 1015-1026. [IF= 0,641; 15 points in the classification of the Ministry of Science and Higher Education]

A.7. Kleiber T., Borowiak K., **Schroeter-Zakrzewska A**., Budka A., Osiecki Sz. 2017. Effect of ozone treatment and light colour on photosynthesis and yield of lettuce. Scientia Horticulturae 217:130-136. [IF= 1,624; 35 points in the classification of the Ministry of Science and Higher Education]

Total score of points = 91

Total IF= 2,812

The declarations of the co-authors of the papers concerning their individual contributions to these publications are given in Attachment 5. None of the studies listed above have been a part of a monographic series in another postdoctoral degree conferral procedure.

3.3. Discussion of the scientific aim of the above-mentioned studies and results along with the presentation of their potential applicability

Light is one of the most important environmental factors affecting plant growth. Light intensity and its variability fluctuate as a result of diurnal changes. The quantity and quality of light are also influenced by the angle of irradiating sun rays. Light intensity in Poland on a cloudless day is 100 thousand lux. In the period from November to mid-February we experience adverse light conditions. In this period the duration of actual insolation is 40-50 h, while in the summer it is 200-250 h a month (Jerzy 2000). In comparison to outdoor cultivation the amount of light reaching plants grown in tunnels is by 20-40% lower (Woźny 2015). Initial material for cultivation, such as rooted cuttings or seedlings, is produced in winter or early spring months. Thus growing plants in the period of insolation deficit is connected with the need to provide additional lighting for plants, which as a result leads to increased production costs. Supplementary lighting is required to provide quality plants.

Observed climate change caused by greenhouse gas emissions is a major problem of environmental protection in the 21st century. For this reason new solutions are being searched for in order to mitigate the adverse consequences of this phenomenon. At present we may observe a global trend to replace greenhouses and plastic tunnels with facilities with no access of natural light, in which plants are grown under strictly controlled conditions. In such facilities temperature, light intensity and quality, day length, carbon dioxide supplementation as well as consumption of water and fertilizers may be closely controlled. It is also indicated that in the nearest future we will face water shortages. For this reason cultivation in closed, hydroponic systems will be an advantageous solution promoting water conservation. In literature on the subject they are referred to as Plant Factory with Artificial Lighting (PFAL) (Kang et al. 2014, Kozai 2018, Sakhonwasse et al. 2017). Typically they are large climate chambers or rooms equipped with racks of shelves for growing plants. The shelves are equipped with lamps lighting the plants. Growing plants on several levels increases the efficiency of production per unit area, while at the same time reducing production costs in comparison to greenhouse cultivation. It also facilitates several cycles of cultivation regardless of the season of the year or external conditions (Heming 2011, Watanabe 2011, Wolagen and Runkle 2014). Intensive development of such facilities has been observed since 2010 in Asia (Japan, Taiwan, Korea, China), in the United States and in Holland (Goto 2011, 2012, Kozai et al. 2004, 2006, Kozai 2018, Kozai and Ohyama 2006). In 2018 there were 200 such commercial facilities in Japan, with 100 in Taiwan and approx. 500 in other regions worldwide. Plant factories and recently established vertical farms, which may use both natural and artificial light, are in line with the global trend towards state-of-the-art horticulture (Gang and Boldi 2014).

Lighting may be provided by fluorescent lamps and increasingly often Light Emitting Diode (LED) lamps, characterized by a long service life and adaptability of the spectrum to specific plant requirements (Brown et al. 1995, Morrow 2008, Reinders 2008). Moreover, they are energy-efficient, as they may reduce energy consumption by as much as 80%. In contrast to other light sources they do not emit heat energy, thus they may be placed directly over plants. An additional advantage is also connected with the fact that no mercury is required to produce them (Woźny 2015).

Photosynthetically Active Radiation (PAR) falls within the range of visible radiation in the wavelength of 380-760 nm. It is composed of the following light colours: purple, blue, green, yellow, orange and red. Primarily orange-red and purple-blue light is photosynthetically active. Purple-blue light (400-480 nm) is absorbed by chlorophylls *a* and *b*. In turn, blue and

purple light is also absorbed by carotenes and xanthophylls and cryptochrome. Green and yellow light (500-600 nm) reduces photosynthesis and organ formation, while it also participates in the synthesis of anthocyanins. When far red to red colours predominate in the spectrum of light reaching plants, intensive shoot elongation is observed (Takachi et al. 2000). Such a situation is probably connected with the contents of gibberellins responsible for elongation growth, which levels increase under the influence of far red (King 2006). An opposite effect may be obtained by lighting plants with blue light (Parks et al. 2001).

Plant quality is affected by the course of photosynthesis. Factors having the greatest effect on the photosynthetic activity of plants next to light include also temperature, availability of water and carbon dioxide. Both a deficit and excess of any of these factors may have an adverse influence on plants by disturbing the intensity of photosynthesis. Standard parameters used in studies on the effect of stressors on plants include the intensity of photosynthesis, intensity of transpiration, stomatal conductivity, carbon dioxide exchange and chlorophyll fluorescence. A study by Kim et al. (2004) showed that stomatal conductivity increases gradually in the early morning hours at plant cultivation under fluorescent lamps emitting white light and decreases towards the end of the day. This trend is less evident under LED lamps emitting red+blue light, under LED lamps emitting red+blue light with an addition of green light emitted by fluorescent lamps, as well as under fluorescent lamps emitting green light. Stomatal conductivity is probably dependent not only on the colour of light, but also on the type of lamps used to light plants (Yorio et al. 2001, Goins 2002, Kim et al. 2004). There is a close dependence between quality of light and photosynthetic activity, as well as stomatal conductivity. Greater photosynthetic activity in poinsettia, Plecranthus ad lettuce was recorded in plants grown under LED lamps in comparison to sodium lamps (Domurath et al. 2012). A higher level of photosynthesis was also reported in tomato seedlings grown under LED lamps emitting red+blue and red+blue+green light, as well as orchids growing under blue and red+green+blue light (Liu et al. 2011, Xiaoying et al. 2012, Lee et al. 2011).

Plant quality is also determined by their habit. Growth retardants are commonly used in order to ensure an appropriate habit in the cultivation of flower bed and balcony plants under plastic tunnels. At ecological restrictions the replacement of growth retardants using first of all blue-coloured light seems to be a reasonable solution. In order to obtain quality seedlings it is also necessary to ensure optimal amounts of nutrients.

The aim of the research presented here as the scientific accomplishment was to assess the potential to grow selected plant species of considerable importance in horticultural

production under artificial light as well as storage to extend their vase life or the duration of decorative value.

Evaluation of the effect of light colour and lamp type on seed germination and seedling quality in scarlet sage and French marigold (A.1., A.4.)

Seeds of scarlet sage (*Salvia splendens*) were sown to multitrays, which were next placed in a growth chamber on racks equipped with TLD Philips fluorescence lamps of 36 W. Lamps emitted the following light colours: daylight, white, blue, yellow, green and red. Quantum radiation intensity was 35 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Additionally seeds were sown onto Petri dishes. It was found that light colour had a significant effect on seed germination and further seedling growth. The greatest percentage of sage seeds germinated under lamps emitting white and blue light, followed by red, green and yellow light. In contrast, the smallest percentage, as low as 33%, germinated under daylight lamps. Seedlings exposed to red light were growing the fastest. In comparison to the other light colours the seedlings were tallest and at the same time of lowest quality. Plants had creeping, limp shoots of smallest diameters as well as the smallest fresh and dry weight. A similar growth rate and quality were found in seedlings grown under yellow-coloured light.

In the case of white, daylight and green light the growth rate of plants was similar. In the first weeks of cultivation the slowest growth was observed in seedlings placed under lamps emitting blue light. Eventually plant height was comparable to that of plants grown under white, daylight and green light.

The longest hypocotyl was formed by seedlings grown under lamps emitting yellow and red light. It was by over 2 cm longer in comparison to the other seedlings. In contrast, no significant effect of light colour was observed on epicotyl length, except for seedlings growing under daylight and red light. They differed significantly. Dark green leaves with the highest SPAD index were found in plants grown under red and blue light. Seedlings growing under lamps emitting white and blue light produced high fresh and dry mass. In turn, the lowest mass was recorded for plants growing under yellow and red light.

In the second experiment seeds of scarlet sage (*Salvia splendens*) and French marigold (*Tagetes patula*) were sown onto Petri dishes and to multitrays and placed on racks equipped with Leuchtek LED Tube lamps emitting white, green, blue, red as well as white + blue (50:50) and red + blue light (75:25).

Both in French marigold and sage the highest percentage of germinating seeds was recorded for blue light, followed by mixtures of red + blue and white + blue light. In both species the lowest percentage of germinating seeds was reported for white light colour.

In the case of scarlet sage the highest quality of seedlings was obtained under the influence of blue coloured light as well as combinations of red + blue and white + blue coloured light. In turn, in French marigold it was under the influence of white coloured light as well as mixtures of red + blue and white + blue light.

In comparison to plants grown under the other light colours they were characterised by stiffer shoots, larger and darker leaves as well as their greater number.

Summing up it may be stated that both light colour and the type of lamps used had a significant effect on germination and quality of seedlings. The response to light colour was also be dependent on the species.

Assessment of the effect of light colour and lamp type on rooting and status of nutrition in New York aster cuttings (A.3.)

New York aster (*Aster novi-belgii*) is a very popular species grown both on flower beds and for cut flowers cultivated in plastic tunnels. Recently low varieties of a compact habit, recommended for flower box growing, have been developed. Thanks to controlled cultivation flowering plants are available for sale outside the autumn season. Rooted cuttings are products for further cultivation.

Multitrays with cuttings were placed in a growth chamber on racks equipped with Leuchtek LED Tube lamps as well as fluorescent TLD Philips lamps emitting white, green, blue, red, red+blue (75:25) and blue+white lamps (50:50). The day length was 12 h and quantum radiation intensity was 35µmol·m^{-2}·s^{-1}.

Cuttings rooting was dependent on the type of lamps and colour of light. In the case of LED lamps the largest number of rooted cuttings was produced under blue (77.5%) and green light (70%). In the case of fluorescent lamps it was 47.5% and 20%, respectively. Under fluorescent lamps the largest number of cuttings was rooted in the case of red+blue light (60%), while for LED lamps it was 17.5%. Light colour and the type of lamps had no effect on the elongation increment of cuttings, except for the red colour of light emitted by fluorescent lamps. The longest roots, irrespective of the type of lamps, were formed on cuttings rooted under blue coloured light. In the case of LED lamps it was also under white+blue and white light, while for fluorescent lamps it was also under red coloured light.

The type of lamps had a significant effect on contents of calcium and sodium. Rooting of cuttings under fluorescent lamps contributed to an increase in the contents of calcium, while under LED lamps it was for sodium levels. The type of lamps had no effect on the contents of nitrogen, phosphorus, potassium and magnesium. In the case of microelements the type of lamps affected the content of iron. Higher contents were detected under the influence of fluorescent lamps. Light colour significantly modified contents of nitrogen, sodium, iron and manganese.

Evaluation of the effect of light colour on the development of inflorescence buds and vase life of chrysanthemums (A.2.)

Potted chrysanthemum are extremely popular, particularly in the autumn when they are used not only to decorate graves, but also balconies and terraces. These plants are increasingly often sold in large retail chain supermarkets or discount stores. In order to determine whether it is possible to store and extend decorative value of chrysanthemums using artificial light experiments were conducted aiming at the evaluation of the effect of light colour on the development of inflorescence buds and extension of vase life in a medium variety of chrysanthemum (*Chrysanthemum* x *grandiflorum*)'Leticia Time Yellow'.

The experiments were conducted in a growth chamber, in which racks were equipped with TLD Philips fluorescent lamps emitting white, blue, green, yellow and red light. Quantum radiation intensity was 30 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and day length was 10 hours. The experiment involving the opening of inflorescence buds was started at the stage of their macroscopic development,

on a day when they were still green and closed, but ready to colour and develop further. At such a stage plants were transferred from a plastic tunnel to a growth chamber. Next the duration of the colouring phase of inflorescence buds and their blooming time were determined. At anthesis when half of all heads were fully opened, their diameters were measured and heads in full bloom were counted.

In the first year of the experiment inflorescence buds coloured fastest in plants grown under blue and white light, while it took longest under the influence of green coloured light. Light colour had no significant effect on the number of developing flower heads or on their size. An exception was observed for plants grown under blue coloured light, which produced heads with a larger diameter.

In turn, in the second year the development was fastest also under blue coloured light, while buds developing under red light took longest to colour and develop. The number and size of flower heads was significantly dependent on light colour. A greater number and larger-sized heads developed under the influence of white and blue coloured light. Larger heads were also found in plants growing under green coloured light.

Observations concerning vase life were started at anthesis. After flowers were overblown their vase life was determined based on the number of days, which had passed from anthesis of plants to the loss of their decorative value (i.e. at the time when a half of apical flower heads were overblown) and overblown heads (only apical ones) were counted.

Light colour had no effect on the number of overblown flower heads. In turn, plants stored under white, blue and green light retained decorative value, on average for 26-31 days. Under red and yellow light plants lost their decorative value after 20-22 days.

Summing up it may be stated that light colour may regulate the development of inflorescence buds. Blue and white colour causes earlier development and extends vase life of stored plants.

Evaluation of the effect of light colour and the type of lamps on growth, flowering and nutritional status of chrysanthemums (A.6.)

The aim of the experiments conducted in two cycles was to verify whether chrysanthemums may be grown under artificial lighting with no access of natural light. For this purpose rooted cuttings of a medium garden mum variety 'Covington' were planted with five cuttings per pot and placed on racks in a growth chamber. Plants were grown on racks equipped with TLD Philips fluorescent lamps and LED Tube lamps emitting white, blue and green light as well as a combination of white + blue colour (1:1) as well as red + blue colour (3:1). Quantum radiation intensity was 35 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and day length was 10 h. Air temperature was 20^0 C and humidity was 70%.

Plants were grown until a half of flower heads in a pot developed. Then plant height and diameter, the number of buds and inflorescences, the diameter of flower heads as well leaf SPAD index values were recorded. Leaves were also collected to determine contents of macro- and microelements.

Earlier blooming was recorded in plants growing under LED lamps emitting white and blue coloured light. Irrespective of the type of lamps, larger flower heads were formed by plants under the influence of blue light, while they were smallest when grown under a mixture of red+ blue light. The differences in size amounted to approx. 1 cm. Red light emitted both by fluorescent and LED lamps had an adverse effect on plant quality, primarily flower abundance and colouring of leaves, which were characterized by the lowest SPAD values.

Both light colour and type of lamps affected the nutritional status of plants. Greater contents of analyzed macro- and micronutrients (nitrogen, phosphorus, calcium, magnesium, sulphur as well as iron, manganese, zinc and copper) were recorded in leaves of plants grown on racks equipped in LED lamps compared to fluorescent lamps. The type of lamps had no effect only on the content of potassium in mum leaves. Analyses of light colour showed that the lowest contents of phosphorus, potassium, calcium, magnesium, sulphur, iron and zinc are found in leaves of plants grown when exposed to a mixture of red + blue light. Red light had a negative effect on contents of manganese and copper, green light - on the levels of zinc and copper, while blue light had a negative effect on potassium contents and white light - on calcium contents.

Evaluation of the effect of light colour, type of lamps and microbiological inoculants on photosynthetic activity of garden geranium (A. 5.)

An alternative for the application of artificial fertilisers may be provided by the use of microbiological inoculants, containing selected strains of bacteria, Actinobacteria and fungi affecting the health status of plants, chlorophyll content as well as acceleration of flowering (Boelens et al. 1994). An inoculant increasingly gaining in popularity is EM (Effective Microorganizms) containing bacteria *Streptomyces albus*, *Propionibacterium freudenreichil* and *Streptococcus lactis*, moulds *Aspergilius oryzae* and *Mucor hiemalis*, yeast *Saccharomyces cerevisiae* and *Candida utilis* as well as unspecified counts of bacteria *Lactobacillus* spp., *Rhodopseudomonas* spp. and Actinobacteria *Streptomyces griseus* (Formowitz et al., 2007).

Effective microorganisms secrete to the substrate both vitamins, organic acids, amino acids, antibiotics, hormones, growth stimulators as well as antioxidant substances. Moreover, substrates treated with EM exhibit a greater capacity to retain water. In turn, plants grown in substrates inoculated with a microbiological inoculant are characterised by greater contents of dry matter and thus greater amounts of nutrients (Daly and Stewart 1999). Also Stielow (2003) was of an opinion that introduction of the EM inoculant to the substrate provides several positive effects, e.g. limitation of putrefaction processes, improved plant rooting, enhanced drought resistance, accelerated metabolism, increased effects of photosynthesis, inhibition of plant pathogen growth as well as more abundant plant flowering.

There is a close relationship between plants and microorganisms. The primary role of microorganisms in the substrate is connected with the continuous metabolism of organic and mineral compounds while making nutrients available to plants. Microorganisms are closely associated with plants and their root systems and thus root exudates. They participate in the degradation and promotion of nutrient availability as well as decomposition of toxic substances. They are also responsible for the synthesis of secondary metabolites stimulating plant growth (growth phytohormones, phytochelatins, organic acids, vitamins B). Microorganisms may also secrete substances exhibiting a toxic effect on plant pathogens or animal organisms (antibiotics, H_2S) thus improving the condition and health status of plants (Marschner 2007). Inoculation of plants with inoculants composed of selected microorganisms facilitates biological control of roots against penetration by pathogens, promotes nutrient availability to plants and improves rooting of cuttings (Barea et al. 2002).

Rooted cuttings of zonal pelargonium (*Pelargonium zonale*) 'Tamara' were planted to pots of 12 cm in diameter and grown in a greenhouse. One week after planting the plants were treated with microbiological inoculants used in foliar and soil applications at a concentration of 1:100. Two inoculants were applied: the commercially available EM (Effective Microorganisms) preparation and the BAF_1 inoculant developed at the Department of General and Environmental Microbiology PULS in Poznań. When plants reached a height of approx. 30 cm and formed inflorescence buds, they were transferred to a growth chamber, in which temperature was maintained at 20 ^{O}C and day length was 12 h. Quantum radiation intensity was calibrated to 35 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for all light colours and lamp types.

Photosynthetic parameters were measured when the first inflorescences developed on the plants. Using a Ci 340 aa CID system by BIOSCIENCE Inc. Camas, USA the following measurements were recorded: net photosynthetic activity, stomatal conductance, transpiration coefficient and intracellular CO_2 concentration.

In the case of the mixture of white + blue light the type of lamps had no significant effect on net photosynthetic activity and CO_2 accumulation in intercellular spaces. In contrast, it had a significant effect on stomatal conductance and transpiration. Higher values of these indexes were recorded after the application of the BAF_1 inoculant.

Similarly as in the case of the above-mentioned light colour, also analyses of the white light showed no effect of the type of lamp or the type of the applied inoculant on net photosynthetic activity. A significant effect of this factor was shown for the other evaluated parameters. Increased stomatal conductance was recorded in plants treated with BAF_1 and grown under LED lamps, while in the case of transpiration it was also the application of EM. In plants treated with BAF_1 and grown on racks equipped with fluorescent lamps an increased CO_2 accumulation was detected in intercellular spaces.

Red light had no effect on CO_2 accumulation in intercellular spaces in plants lighted using LED or fluorescent lamps. Similarly, the application of inoculants was found to have no significant effect on that parameter. Significantly higher levels of net photosynthetic values, stomatal conductance and transpiration were recorded in plants exposed to the light of LED lamps and treated with EM.

Higher net photosynthetic values were obtained in plants subjected to treatment with microbiological inoculants and growing under fluorescent lamps emitting red + blue light. In comparison to the control the plants grown under fluorescent lamps and those subjected to foliar

and soil EM application showed higher values of the other indexes (transpiration, stomatal conductance, CO_2 concentration).

The type of lamps in the case of blue light emission had no significant effect on net photosynthetic activity. Higher values of stomatal conductance and transpiration coefficient were recorded in the control plants lighted with LED lamps. Only in plants subjected to the effect of BAF_1 and growing under LED lamps an increase was observed in CO_2 concentration in intercellular spaces.

Under green light a marked effect of the type of lamp on the parameters of photosynthesis was found. Higher values of net photosynthetic activity, stomatal conductance and transpiration coefficient were recorded for plants grown under LED lamps, irrespective of inoculation with microbiological preparations.

Evaluation of the effect of light colour and ozone on yield, nutritional status and photosynthetic activity of lettuce (A.7.)

The natural process of formation of trioxygen molecules during electrostatic discharges in the atmosphere is applied in portable ozone generators for modern agriculture and horticulture. Ozone is one of the strongest disinfectants. It exhibits efficacy in the elimination of bacteria, fungi, spores or microorganisms resistant to chlorine. By acting on the seed surface it disinfects the seed coat, decomposes pesticide residue and secondary metabolites of mould fungi (Skrobacz et al. 2016).

Seeds of lettuce *Lactuca sativa* 'Subyana F_1' and seedlings at the stage of 3 - 4 leaves were subjected to a 30-minute ozone treatment at 14 g O_3 h^{-1} produced by a Biosphera 14 ozone generator. Plants were grown in a growth chamber in rockwool cubes of 10 x 10 x 10 cm placed in drainless containers of 3.45 dm^3. Racks in the growth chamber were equipped with LED lamps emitting light at an intensity of 70 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and using the following colours: white, blue as well as white + blue (50:50). The day length was 12 h and the temperature was maintained at 22^0 C at 65-70% humidity. Plants were watered with a nutrient solution at 150-300 ml per plant, maintaining its level constant at a height of 2 cm.

A combined ozone treatment of seeds and seedlings significantly reduced plant yielding. A lower weight (30.3 g· $plant^{-1}$) was reported for plants grown under white light, while it was

greater (50.2 g· plant^{-1}) for plants subjected to the effect of blue light. Ozone treatment of seeds alone had no significant effect on the mean yield of fresh mass of lettuce heads.

Light colour had no effect on the mean number of leaves formed by plants. Irrespective of the used light colour the lowest number of leaves was produced by plants subjected to ozone treatment as seeds and seedlings.

In turn, lettuce, in which only seeds were exposed to ozone, showed significantly greater SPAD values. A lower value of this index was recorded in all plants grown under white light in comparison to the other colours.

Light colour and ozone treatment affected contents of macro- and microelements in lettuce leaves.

Cultivation under blue light had a negative effect on contents of nitrogen and potassium in comparison to the application of the other colours. In the case of phosphorus a marked increase in the contents of this nutrient was recorded in plants growing under white + blue light. A lower level of calcium and a higher level of sodium were detected in plants growing under blue coloured light and a mixture of white + blue light. In the case of microelements the lowest mean contents in lettuce leaves were reported in plants exposed to white + blue light. In contrast, they were highest under the influence of blue light, except for manganese, for which the highest mean content was found in leaves of plants exposed to white light.

Exposure to ozone, irrespective of light colour, significantly increased nitrogen contents in leaves compared to the control. A combined ozone treatment of seeds and seedlings led to a decrease in mean contents of the other macroelements in leaves. In the case of microelements ozone treatment contributed to a reduction of mean contents in leaves.

Both light colour and ozone treatment influenced investigated photosynthetic parameters. Ozone treatment of seeds and growing plants under white + blue light had a positive effect on the investigated photosynthetic parameters.

Concluding remarks

- Light colour and the type of lamps have a significant effect on germination and development of plants
- Blue light may be recommended for the production of seedlings in Scarlet sage and French marigold as well as rooting of cuttings in New York aster
- Earlier development of inflorescence buds in chrysanthemums and extended vase life of stored plants may be provided by the effect of blue and white coloured light
- Better nutrition of mums may be obtained using LED lamps in their lighting
- A greater net photosynthesis level in garden geranium was observed in the case of LED lamps. In the control plants under the influence of blue as well as red coloured light, while in plants treated with the BAF_1 inoculant an increased level of photosynthesis was recorded under the influence of white+blue coloured light
- A beneficial effect on the analyzed parameters of photosynthesis is found for seed ozone treatment and growing of lettuce under white+blue light emitted by LED lamps

Conducted experiments showed that it is feasible to grow plants under completely artificial light with a relatively low intensity of quantum radiation. Quality of light may significantly modify biometric parameters, the intensity of photosynthesis as well as contents of macro- and micronutrients in plants. Knowledge on the response of individual plant species to the tested factors may be used in horticultural practice to optimize cultivation or it may be useful in plant storage. For this purpose LED lamps are particularly recommended and tests conducted with their use are of great value, since in the nearest future they will obviously replace fluorescent lamps currently used in laboratories and sodium lamps used in greenhouses.

3.5. References

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4. Discussion of other major research results

4.1. Application of growth retardants in cultivation of ornamental plants

Growth retardants are commonly used in growing of ornamental plants. They are mainly applied to regulate plant habit. As a result lower and more compact plants may be produced. Response of individual species or even varieties may vary, for this reason it is advisable to test a wide range of growth retardants. Despite increasingly strict environmental restrictions on their use, these chemicals are still commonly used by plant producers. However, due to high prices of growth retardants cheaper alternatives are being searched for.

I have been involved in research on growth retardants since the beginning of my scientific career. My studies have concerned many aspects related with the application of this group of growth regulators and have been conducted on several taxa of bedding and patio/balcony garden plants.

Foliar application is the most common method used for growth retardants. However, to ensure uniform plant growth plants need to be evenly covered with their solution. An alternative option for growth retardant application is to water plants with their solution. In my research I have also tested seed soaking or spraying of the substrate, to which seeds were sown.

In the conducted experiments I have tested growth retardants registered in Poland for use in cultivation of ornamental plants, i.e. daminozide, which is an active substance of several commercially available preparations such as B-Nine 85 SP or Dazide Enchance 85 SG, and flurprimidol contained in Topflor. Since the above-mentioned preparations are costly, producers are searching for their cheaper substitutes, which would exhibit a similar action. For this reason studies have been undertaken to evaluate the effect of growth inhibiting preparations such as chlormequat contained in Cycocel 460 SL and metconazole contained in Caramba 60 SL.

I tested daminozide, flurprimidol and chlormequat used in foliar application and broadcasting in the cultivation of buzzy lizzy (*Impatiens walleriana*) and wax begonia (*Begonia semperflorens*). In those experiments, apart from evaluating the effect of retardants on plant quality the dynamics of plant growth and flowering were also analyzed. Based on the recorded results I stated that flurprimidol - both in foliar application and broadcasting - exhibited an excessively strong inhibitory effect on growth and flowering of wax begonia. In contrast, in

Impatiens walleriana a positive residual effect on flowering was observed for broadcasting of flurprimidol (C.10, C.13).

When broadcasting chlormequat, daminozide and flurprimidol in the cultivation of two varieties of wax begonia and petunia (*Petunia atkinsiana*) I stated that the effect of retardants on plant quality was significantly dependent on the variety as well as the applied preparation. In the case of wax begonia 'Eureka Bronze Rose' daminozide and chlormequat stimulated plant growth. In contrast, in another variety 'Eureka Scarlet' these retardants inhibited plant growth. Flurprimidol significantly reduced plant growth, particularly in wax begonia. Depending on the variety it was by as much as 66.7-79.3%. Watering with a daminozide solution stimulated more abundant flowering in wax begonia 'Eureka Scarlet' and petunia 'Prism Sunshine' (C.11).

For the first time in Poland I used foliar application of metconazole from the triazole group, contained in Caramba 60 SL in the cultivation of garden geranium and garden mum, while in cultivation of French marigold I used it to soak seeds and spray the substrate. In the case of most garden geranium varieties growth retardants could not be successfully eliminated from horticultural practice. Chlormequat is commonly used in cultivation of this species. Studies have also been conducted on the effect of other retardants such as flurprimidol and daminozide. In my experiments chlormequat and metconazole effectively inhibited growth and length of peduncles in zonal geranium 'Aida' and promoted its more abundant flowering. These plants also produced a greater number of darker leaves compared to the control plants. In cooperation with the Department of Plant Nutrition PULS the effect of tested substances (chlormequat and metconazole) on the state of plant nutrition with macro- and microelements was also evaluated. The tested substances resulted in an increase in phosphorus contents at a simultaneous reduction of potassium contents. In contrast, the applied substances were found to have no effect on the contents of calcium and magnesium. In the case of nitrogen the use of chlormequat caused an increase in the contents of this element in leaves. Foliar treatment of plants with chlormequat and metconazole increased copper content in upper and lower leaves, the level of iron in upper leaves at the same reducing its content in lower leaves. In the case of sodium and manganese opposite trends were observed (C. 22, C.23, C.24).

Chrysanthemums is a species of considerable importance both as a cut flower and a pot plant. In both cases preparations modifying plant habit are applied, mainly growth retardants such as e.g. daminozide. Based on experiments in three cycles: spring, summer and autumn I showed that in the cultivation of chrysanthemum 'Leticia Time Yellow' daminozide may be successfully replaced with a much cheaper metconazole. However, its efficacy depends on the

concentration and application rate of the preparation, the number of treatments and date of cultivation.

In the summer cultivation season the action of metconazole applied once at a concentration of 300 mg· dm^3 was comparable with the efficacy of daminozide applied twice at a concentration of 2550 mg· dm^3, while in autumn growing it was even higher. It needs to be stressed that no delay was observed in plat flowering (C.27).

In the case of French marigold 'Boy Golden' I used three application methods (seed soaking before sowing, substrate spraying after sowing, seedling spraying) for metconazole contained in Caramba 60 SL and daminozide in B-Nine 85 SP. Seed soaking in a metconazole solution and spraying of plants with a daminozide solution effectively inhibited plant growth. However, metconazole had an adverse effect on seed germination (C.19).

4.2. Application of growth regulators in cultivation and extension of vase life of ornamental plants

In the years 2007-2012 I participated in research concerning the effect of growth regulators: gibberellic acid and benzyladenine on growth, flowering and extension of vase life in selected ornamental plant species. Based on the research it was stated that gibberellic acid accelerated flowering of poppy anemone 'Sylphide' by 11-16 days, while benzyladenine - by 3-7 days. Both growth regulators caused an increase in contents of chlorophyll and carotenoids as well as accumulation of sugars in leaves of this species (C.20, C.29).

In the case of two busy Lizzie cultivars 'Spellbound Lilac' and 'Spellbound Pink Imtrarepu' gibberellic acid was applied in foliar treatments at five concentrations: 10, 30, 50, 100 and 150 mg ·dm^{-3}. Irrespective of the applied concentration and plant variety gibberellic acid stimulated plant growth. Under its influence plants produced by 57.4-87.8 % more inflorescence buds when compared to the control plants. However, gibberellic acid had an adverse effect on plant appearance and leaf colour (C.14).

Extension of vase life in cut flowers is essential first of all in the species, which rapidly lose their decorative value, such as e.g. lisianthus. In that experiment it was shown that

conditioning of cut lisianthus flowers in aqueous solutions of gibberellic acid extended their post-harvest life. Flowers with the longest vase life were produced by conditioning in a solution of gibberellic acid at a concentration of 50 mg $\cdot dm^{-3}$ and storage in an aqueous solution of 8-hydroxycholine at a concentration of 200 mg $\cdot dm^{-3}$ supplemented with 2% sucrose addition (C.15).

I also assessed the effect of growth regulators on post-harvest life of florist green. In the case of Italian arum conditioning in a solution of gibberellic acid at a concentration of 100 mg $\cdot dm^{-3}$ followed by storage in a solution of benzyladenine at 50 mg $\cdot dm^{-3}$ prolonged leaf vase life by 1-2 weeks (C.16).

In turn, in sea lavender conditioning of leaves in gibberellic acid at a concentration of 25 and 50 mg $\cdot dm^{-3}$ or their storage in a solution of benzyladenine at a concentration of 25 and 50 mg $\cdot dm^{-3}$ without conditioning extended post-harvest life of their leaves (C.21).

4.3. Applicability of composts in ornamental plant growing

Highmoor peat thanks to its good air-water relations, sorption and potential to regulate its reaction, as well as contents of macro- and micronutrients is a commonly used substrate in cultivation of ornamental plants. In view of its intensive exploitation other components of gardening substrates are being searched for, which could at least partly replace it.

Properties comparable to those of peat are found in compost, which is produced in an aerobic decomposition of organic waste. All plant origin residue and waste, including also wood waste, may be managed using biological methods such as composting. Wood waste may be composted thanks to its high lignin contents.

In cooperation with the Environmental Protection and Wood Chemistry Department, the Wood Technology Institute in Poznań and the Department of General and Environmental Microbiology and the Department of Plant Nutrition PULS I conducted experiments aiming at the evaluation of the effect of composts produced from wood waste and post-consumer wood waste on growth and development of garden geranium and canna lily.

Post-consumer wood waste includes used and dilapidated furniture, construction joinery and carpentry elements (windows, doors, floors, structures) as well as other wood products, which completed their life cycle and are deposited in landfills. This research was based on two compost variants denoted as OPA and OPB. Plants were grown in substrates composed of composts and highmoor peat mixed in various volumetric variants.

In the case of zonal geranium higher doses of compost (100% and 75%) inhibited plant growth. In contrast, a 25% compost addition to the substrate may be successfully applied in geranium growing (C.30).

Similar results were obtained for canna lily, in which analyses included additionally plant nutrition status and microbial counts as well as their enzymatic activity in the substrates, in which the plants were grown.

Analyses of the results showed that the type of the substrate had an effect on vegetative characteristics of canna lily such as plant height, the number of leaves and their green colour intensity. High doses (100% and 75%) of composts inhibited plant growth. In contrast, plants grown in substrates supplemented with 50% and 25% compost were characterized by quality comparable to that of the control. The type and dose of applied compost turned out to be a factor determining changes in the counts and activity of microorganisms in the tested substrates, as well as plant nutrition status (B.4, C.31).

Introduction of advanced sewage treatment technologies has resulted in the production of greater amounts of sewage sludge. Until the present they have been deposited in landfills, with very small amounts used as fertilizer. In accordance with the EU regulations it is recommended to apply either thermal disposal through combustion or sewage sludge management in agriculture. In view of the above I undertook studies in cooperation with the Department of General and Environmental Microbiology, the Institute of Agricultural Engineering and the Department of Ecology and Environmental Protection. Aims of these studies were to determine the effect of composts produced based on sewage sludge on growth and flowering of garden verbena, scarlet sage and French marigold, as well as evaluate the microbiological and biochemical status of substrates.

As a rule sewage sludge is composted with an addition of structural components, such as straw, sawdust, wood chips and municipal green waste. In those experiments sewage sludge was composted in a bioreactor with a 20% addition of sawdust and a 30 % addition of wheat, maize and lupine straw.

Plant quality was dependent on the species, applied substrate (the composition and percentage shares of components). In garden verbena applied composts stimulated plant growth and formation of inflorescence buds. It was observed that admixtures of composts contributed to the development of mould fungi and Actinobacteria, which was not recorded in the case of Eubacteria. It was also observed that composts irrespective of the applied dose stimulated dehydrogenase activity. The primary factors influencing enzymatic activity in the substrates and changes in counts of analysed microroganisms included substrate pH and the development stage of plants (B.1).

In the case of scarlet sage applied composts stimulated plant growth except for the treatment with compost alone. Plants grown in compost supplemented with fresh maize straw produced longer inflorescences. Analyses of the results showed that composts produced from municipal sewage sludge may be used in the cultivation of scarlet sage, but only as an addition to peat substrate, since application of compost alone had an adverse effect on the recorded traits. Substrates containing composts were characterized by higher counts of heterotrophic bacteria and acid phosphatase activity compared to the control substrate. Stronger proliferation of mould fungi and Actinobacteria in relation to the control was recorded in substrates containing compost K3 (50% sewage sludge +20% sawdust + 30% lupine straw) and compost K4 (50% sewage sludge +20% sawdust + 30% fresh maize straw). In turn, the highest urease activity was detected in the substrate containing compost K1 (50% sewage sludge +20% sawdust + 30% wheat straw) (B.7).

In the cultivation of French marigold compost supplemented with lupine straw had a negative effect on plant quality, in which flowering was inhibited and shoots were deformed. Stronger growth of bacteria and fungi was observed in the compost with an addition of lupine straw, while proliferation in compost K1, composed of 50% sewage sludge + 20% sawdust and 30% wheat straw (B.8).

4.4. Application of microbiological inoculants in cultivation of ornamental plants

This preparation was not used to date in commercial cultivation of ornamental plants. For this reason together with the Department of General and Environmental Microbiology, the Poznań University of Life Sciences I started studies on the effect of this preparation on growth and flowering in ornamental plants. In the case of garden geranium 'Andria' plants were grown in two types of substrate: deacidified highmoor peat and peat supplemented with an addition of clay. Plants were treated once with the EM preparation diluted in water at varying proportions (1:10, 1:50, 1:100). The inoculant was used in foliar application by spraying plants with a dose of 10 cm^3 per plant and the preparation was applied to the soil at 50 cm^3 per pot. Foliar and soil applications had a positive effect on plant flowering. In contrast, no influence was found on plant height or the number of leaves. The SPAD index and contents of chlorophyll *a*+*b* in leaves depended on the type of substrate, in which geranium was grown, as well as the manner of application and the concentration of the EM preparation. Irrespective of EM concentration and the type of substrate both foliar and soil application contributed to increased dehydrogenase levels (C.32).

The aim of the second experiment was to determine growth dynamics for selected microbial groups and dehydrogenase activity in the substrate, in which garden geranium 'Trend Lavender' was grown; additionally, another aim was also to evaluate plant quality. Similarly as in the first experiment the plants were grown in two types of substrate, i.e. deacidified highmoor peat and peat supplemented with an addition of clay. After planting geranium plants were treated with the EM preparation diluted in water at 1:10, 1:50 and 1:100. The preparation was used in foliar application and to the soil at 10 cm^3 per plant or per pot. Substrate samples were collected in three stages: after planting, at the vegetative growth phase and at flowering. Based on the results it was stated that the introduction of the EM inoculant to the peat substrate inhibited growth of mould fungi, promoted an increase in counts of bacteria and Actinobacteria, as well as increased dehydrogenase activity. These experiments showed that foliar EM application at 1:10 inhibits growth of these microorganisms. The greatest counts of bacteria and Actinobacteria as well as the highest dehydrogenase activity were recorded at the stage of plant flowering. Application of the EM inoculant had no effect on plant height, the number of leaves and SPAD value as well as the length of inflorescence sheaths. Nevertheless, a beneficial effect of this preparation was observed on the number of flowers and buds as well as acceleration of flowering. Moreover, analyses showed decreased contents of chlorophyll *a*+*b* in leaves in the

case of plants grown in peat substrate supplemented with clay, as well as their increase in plants grown in deacidified peat (C.26).

I also conducted experiments in cultivation of French marigold using EM in foliar application, applied to the soil and in both application methods jointly by watering and spraying plants at varying proportions of 1:10, 1:50 and 1:100. Based on the obtained results I stated that the combined application of an EM solution at 1:100 contributed to the formation of a larger number of darker leaves as well as a greater number of inflorescences. It was also shown that the plant development stage was the primary factor determining levels of enzymatic activity. The EM preparation had a beneficial effect on acid phosphatase activity, while it showed a stimulating effect on the activity of urease or dehydrogenases (C.33).

Bacteria are a major group of microorganisms promoting increased availability of nutrients and protecting plants against pathogen attack. In terms of their counts, Actinobacteria rank second, after Eubacteria, among microorganisms involved in important metabolism pathways of complex carbon compounds in the substrate. Moreover, they exhibit phytosanitary properties by producing antibiotics. The primary role in the cycle of nutrients and energy flow is played by mould fungi. In view of the above, in my next experiments I tested a microbial inoculant BAF_1, developed at the Department of General and Environmental Microbiology, which contained 30 strains of bacteria, 10 strains of Actinobacteria and 4 strains of fungi *Trichoderma atroviride*.

In the cultivation of French marigold a joint foliar and soil application of the inoculant used at 1:100 contributed to the formation of a greater number of darker leaves and a higher number of inflorescences. Greater chlorophyll contents in leaves were detected in plants, which were sprayed with a BAF_1 solution at 1:10. The inoculant had no effect on the counts of the analysed microbial groups or the activity of urease, phosphatase and dehydrogenase (B.6).

In the cultivation of scarlet sage a modified composition of the BAF_1 inoculant was used, containing 15 strains of bacteria, 5 strains of Actinobacteria and 4 strains of the fungus *Trichoderma harzianum* coming from the collection of the Institute of Plant Genetics PAS in Poznań.

In cv. ‘Saluti Red’ foliar application of BAF_1 at 1:10 promoted microbial growth. In turn, the highest dehydrogenase activity was recorded when the inoculant was applied at a 1:50 ratio. The plant growth stage was also important, since greater proliferation of bacteria and Actinobacteria as well as higher dehydrogenase activity were observed at the flowering stage

of plants, while analogous growth of fungi was recorded at the vegetative growth stage. Higher chlorophyll content in leaves was detected in plants watered with an inoculant solution at 1:50 and sprayed with the solution at 1:100. Spraying as well as a combined foliar and soil application of the preparation, irrespective of the application rate, stimulated inflorescence growth. The height of leaf canopy was significantly dependent on the applied inoculant dose and the method of its application. Leaves were formed markedly higher in plants sprayed with the inoculant solution, irrespective of the application rate. The inoculant had no significant effect on the other morphological characteristics such as the number, width and length of leaves as well as their greenness (B.2).

In the case of cv. 'Salvano' the BAF_1 inoculant stimulated growth of bacteria and fungi after planting and at the flowering stage. In turn, the preparation inhibited growth of Actinobacteria, while also reducing the activity of dehydrogenase, phosphatase and urease. In contrast, it had no significant effect on plant quality except for the length and fresh mass of inflorescences. Similarly, the inoculant had to significant effect on vegetative characteristics of plants (B.5).

Concluding remarks

Summing up, my research interests are connected with regulation of plant habit and optimization of plant cultivation applying environmentally-friendly methods.

My scientific publications, including papers comprising the monographic series presented above and constituting the original scientific accomplishment, consist of 49 original research papers, of which I was an author or co-author (after receiving the Ph.D. degree when I was appointed to the post-doctoral position - 41), 16 summaries in conference proceedings, 4 chapters in monographs and 142 popular-science articles. I received a total score of 417 points according to the Ministry of Science and Higher Education classification based on the year of publication.

The body of my published works may be summed up using the following indexes. The total Impact Factor according to the Journal Citation Reports (JCR) database according to the year of publication is 8.95. The number of citations according to the Web of Science database

is 29 (23 excluding auto-citations). The Hirsch Index according to the Web of Science database is 3.

My scientific activity was connected with 2 research projects financed by the National Science Centre, of which I was the head of one project and the main contractor in the other. Moreover, I participated in a project financed by the Polish Agency of Enterprise Development as the main contractor.

I participated actively in 16 international and national conferences. I co-organized two national conferences concerning horticultural therapy.

I have taught courses (classes and lectures) at 1- and 2-cycle studies at the Faculty of Horticulture and Landscape Architecture for students of Horticulture, Landscape Architecture and Plant Medicine, as well as a course in Commercial production of ornamental plants within the English language studies for international students in the field of Horticulture. Moreover, I give classes and lectures in the Postgraduate Programme in Horticultural therapy organized at the Faculty of Horticulture and Landscape Architecture.

I have been a scientific supervisor for 46 students preparing their diploma theses. A total of 20 Master's theses and 26 Engineer's theses were prepared under my supervision by students of Horticulture and Landscape Architecture.

I am a member of two Committees for Quality of Teaching at the Faculty of Horticulture and Landscape Architecture for the fields of study Horticulture and Landscape Architecture. Moreover, I am the faculty coordinator for the University Depository of Diploma Theses.

I have reviewed scientific papers for international journals such as Scientia Horticulturae, the Journal of Animal and Plant Sciences, the Canadian Journal of Plant Science, the African Journal of Biotechnology, as well as Polish journals: Folia Horticulturae, Folia Pomeranae Universitatis Technologiae Stetinensis Agricultura, Alimentaria, Piscaria et Zootechnica, Nauka Przyroda Technologie.

I actively participate in the promotion of the Faculty of Horticulture and Landscape Architecture.

Detailed bibliometric data along with a list of scientific publications and information on teaching accomplishments, scientific cooperation and popularization of science are given in the Attachment 4.

No man is an island. The scientific accomplishment submitted for evaluation would probably never have been possible without the invaluable help of an exceptional Mentor, the late Prof. dr hab. Marek Jerzy, as well as my husband and all the kind co-workers, with whom joint research projects and publication have been prepared.

Table 1. The statement of the total scientific acquis, including publications of scientific achievement

publikacje	number	IF according to the year of publishing	MNiSW points according to the year of publishing	MNiSW points in 2016
Original research papers included in Journal Citation Reports (JCR) database				
Acta Scientiarum Polonorum- Hortorum Cultus	12	8,03	185	205
Archives of Environmental Protection				
Drewno				
Fresenius Environmental Bulletin				
Folia Horticulture				
Horticultural Science				
Journal of Elementology				
Notuale Botanicae Horti Agrobotanici Cluj Napoca				
Polish Journal of Environmental Study				
Other original research publications				
Acta Agrobotanica	37		181	378
Aparatura badawcza i Rozwojowa				
Bulgarian Journal of Agricultural Science				
Ecological Chemistry and Engineering A				
EJPAU (Electronic Journal of Polish Agricultural Universities)				
Journal of Fruit and Ornamental Plant Research				
Science Nature Technologies				
Zeszyty Problemowe Postępów Nauk Rolniczych				
Zeszyty Naukowe Akademii Rolniczej w Krakowie				
Roczniki Akademii Rolniczej w Poznaniu				
Other publications				
Chapter in monography	4			
Conference abstracts	17			
Popular-science articles	144			
Total	**214**	**8,03**	**406**	**603**

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