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DEVELOPMENT AND PHYSIOLOGICAL PERFORMANCE OF HYDROPONICALLY-GROWN ORNAMENTAL INDOOR PLANTS IN RELATION TO THEIR POTENTIAL USE IN BOTANICAL BIOFILTERS: EFFECT OF MINERAL NUTRIENT AVAILABILITY

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*The aim of the present study was to evaluate the effect of different levels of mineral nutrient availability on development and physiological performance of several common indoor ornamental plant species (*Anthurium *sp.,* Chlorophytum comosum, Epipremnum aureum, Plectranthus fruticosus, Spathiphyllum *sp., and* Tradescantia pallida*) cultivated in hydroponics with potential use in active botanical biofilter systems. Plants were grown in expanded clay granules at four levels of mineral nutrient availability provided by two types of commercial mineral fertiliser. The growth stimulative effect of increased mineral nutrient availability depended on plant growth rate, with a lower effect on slower growing species. The need for nutrients increased in the order* Anthurium < Spathiphyllum < Epipremnum < Chlorophytum < Tradescantia < Plectranthus*. Tissue water content showed pronounced differences between various plant species as well as between plant organs. For several species, increase in mineral nutrient availability resulted in a significant increase in tissue water content. Chlorophyll fluorescence analysis showed that indoor plants can successfully adapt to low and moderate mineral fertiliser levels with balanced individual nutrient rates, without negative consequences to photochemistry of photosynthesis. Consequently, indoor plants can be cultivated at a relatively low concentration of mineral nutrients for optimum utilisation in active botanical biofilter systems.*

Keywords: *chlorophyll* a *fluorescence, chlorophyll concentration, morphological parameters, Performance Index, water content.*

INTRODUCTION

Indoor air quality is one of the major concerns of human well-being in urban environments, including workplaces, living space, and public space. The removal of gaseous compounds by biological filtration is usually less expensive and more efficient than by other types of filters, such as adsorption, photocatalytic, gas-phase filters, and ozone generators (Soreanu *et al*., 2013). Plant ability to remove volatile organic compounds (VOC) in air has been studied to assess their use in different botanical air biofiltration systems that utilise both the ability of foliar uptake as well as plant-assisted microbial degradation in the rhizosphere (Kim *et al*., 2008; Wenzel, 2009; Teiri *et al*., 2018). In the last decade, special attention has been drawn to active botanical biofilters, in contrast to the previously used passive systems, due to their higher efficiency (Soreanu *et al*., 2013; Pettit *et al*., 2018). In these systems, polluted air is passed through the medium of the biofilter, which is humidified by increasing the inlet air humidity. This can be achieved in two ways: either water trickles down from the top (biotrickling) or the air is washed with water, which is then remediated in a bioreactor (bioscrubbing) (Iranpour *et al*., 2005). The biofilter itself consists of porous medium where plant roots are located, and root-assisted microbial-dependent VOC remediation occurs on the surface of medium parti-

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cles. In spite of recent practical progress in designing and construction of different types of active botanical biofilter systems, the scientific basis aimed at understanding of biological processes in botanical biofilters, as related to functioning of both microbial and plant components of the system and their interaction, remains limited.

Plant growth and physiological status is ultimately dependent on the availability of essential mineral nutrients (McDonald, 1994). Concentration of particular elements in the root-zone medium is of critical importance among all abiotic factors with respect to plant growth and development. Surprisingly, plant mineral nutrition is the least addressed aspect in studies of indoor air purification by plants. Usually, when describing experimental conditions, details related to plant fertilisation are either omitted (Liu *et al*., 2007; Yang *et al*., 2009; Kim *et al*., 2011; Dela Cruz *et al*., 2014; Mosaddegh *et al*., 2014; Hörman *et al*., 2018; Torpy *et al*., 2018; Panyametheekul *et al*., 2019) or it is noted that a commercially-available or any other substrate was used without indication of amounts of plant-available mineral nutrients (Yoo *et al*., 2006; Gawrońska and Bakera, 2015; Teiri *et al*., 2018). In some studies, slow-release fertilisers were used (Orwell *et al*., 2006). In addition, in studies using hydroponic systems, standard commercial liquid fertilisers have been used without special control of electrical conductivity (EC) in the system (Chun *et al*., 2010; Aydogan and Montoya, 2011; Irga *et al*., 2013; Torpy *et al*., 2018). Only in some cases, the approximate amounts of total nutrients in the hydroponic system were estimated by means of EC measurements to maintain the EC range within 1.3 to 1.6 $dS \cdot m^{-1}$, as corresponding to the optimum level of mineral nutrient availability (Zhang *et al*., 2013).

Nondestructive methods of physiological analysis are of special importance in relatively long-term studies with intact plants as means for monitoring their overall performance and condition (Andersone *et al*., 2011; Kalaji *et al*., 2016). Thus, chlorophyll fluorescence analysis has been used in nutrient deficiency diagnostics (Horaczek *et al*., 2020). Relationship between status of mineral nutrition and photochemistry of photosynthesis has been assessed previously in several studies with different plant species (Strand, 1997; Kastori *et al*., 2000; Wang *et al*., 2009; Ievinsh *et al*., 2020). Therefore, photosynthesis-related parameters — leaf chlorophyll concentration and chlorophyll *a* fluorescence — were selected for nondestructive physiological measurements in the present study.

The aim of the present study was to evaluate the effect of different levels of mineral nutrient availability on the development and physiological performance of several common indoor ornamental plant species cultivated in hydroponics as models. As a result, an approach has been developed of how to experimentally solve a problem on providing optimum mineral nutrition in botanical biofilters.

MATERIALS AND METHODS

Plant material. Model species (*Anthurium* sp., *Chlorophytum comosum, Epipremnum aureum, Plectranthus fruticosus, Spathiphyllum* sp., and *Tradescantia pallida*) were selected based on preliminary analysis of suitability for use in hydroponics-based botanical biofilters, as well as on information on possible uptake of volatile organic compounds (VOC). Stock plant material was obtained from the Botanical Garden of the University of Latvia (Rīga, Latvia) and was propagated vegetatively in vermiculite to obtain uniform planting material of high quality.

Cultivation system. Lightweight expanded clay aggregates (granules) were used as a growth medium. Being inert, homogenous and durable material with relatively small resistance for air movement, this type of granule is commonly used in microbial biofiltration (Rene *et al*., 2009; Dordio and Carvalho, 2013), but can be utilised also as a substrate in hydroponic systems for plant cultivation. Expanded clay granules produced in Belarus (Keramzit, fraction size 10–16 mm) were obtained from "Kano P" (Latvia).

Uniform planting material was carefully removed from substrate and washed with deionised water to remove vermiculite particles. Plastic containers with a square surface (1.2 l volume) were used for planting, placing the plant roots in an empty container in approximately the required position and adding the granules up to 1 cm from the edge. Containers with plants were placed on individual plastic base plates (0.4 l volume). Granules in each container were moistened with 200 ml of the selected fertiliser solution.

Plants were cultivated in a temperature- and humidity-controlled greenhouse with a natural light source during an autumn-winter period for 7 to 9 weeks after the start of the treatment. Relative humidity was 60 to 70% and day/night temperature 22/16 °C.

Fertilisation. For each plant species, eight treatments were used with two types of commercial soluble low ammonium fertiliser Kristalon Red and Kristalon Orange (Yara, Norway) in a mixture with Calcinit (Yara, Norway) at four concentrations each (Table 1). Both of the fertilisers have identical concentration of macronutrients phosphorus and potassium, as well as micronutrients, but Kristalon Orange has twice lower nitrogen, three times higher magnesium and eight times higher concentration of sulphur compared to Kristalon Red. For hydroponics, Kristalon fertilisers are

Table 1. Mineral nutrient composition of fertilisers used in the present study (% w/w)

Type	Kristalon Red	Kristalon Orange	Calcinit
N (total)	12	6	15.5
$N\text{-}NH_4$	1.9	1.5	1.1
$N\text{-}NO_3$	10.1	4.5	14.4
P_2O_5	12	12	–
K_2O	36	36	–
MgO	1	3	–
S	1	8	–
CaO	–	–	26.2
Micronutrients	B, Cu, Fe, Mn, Mo, Zn	B, Cu, Fe, Mn, Mo, Zn	–

used in a mixture with Calcinit (1:1, v/v) to provide calcium and additional nitrogen. The common concentration of mineral nutrients in hydroponic systems is 0.5 to 2.0 $g \cdot l^{-1}$; therefore, three concentrations within this range were chosen for this study (0.5, 1.0 and 2.0 $g \cdot l^{-1}$). A suboptimal concentration of 0.1 $g \cdot l^{-1}$ was used as a control. Fertiliser solutions were prepared using deionised water. Five replicate individuals were used for each fertiliser/concentration/plant species combination.

Special care was paid to the control of the liquid level and the EC value in individual containers, which changed due to evapotranspiration, to avoid buildup of excessive salt concentration in the granule environment. Watering/fertilisation regime was provided so that there was a visible amount of liquid continuously present in the base plates (at least 100 ml). The EC of fertiliser solution in base plates was checked by a LAQUAtwin compact conductivity meter B-771 (Horiba Scientific, Japan) periodically. If the level of EC in a container was similar or higher than the level of EC in the particular fertiliser mix at the respective concentration, the plant was watered with the necessary amount of deionised water. If the level of EC in a container was more than 10% lower than the level of EC in the particular fertiliser mix at the respective concentration, the plant was fertilised with the necessary amount of the respective fertiliser solution.

Analysis of physiological parameters. During plant growth, their physiological status was monitored weekly by means of measurement of chlorophyll *a* fluorescence. A continuous fast induced fluorescence measurement technique was employed using a Handy PEA (Hansatech Instruments, UK) fluorometer as described previously (Andersone *et al*., 2011). For each plant, one photosynthetically active fully-grown leaf was selected and dark adapted for at least 20 min using appropriate leaf clips, after which measurement of induced fluorescence was made. The data were analysed by PEA Plus software (Hansatech Instruments, UK). For characterisation of photochemical efficiency-dependent plant physiological status, a complex parameter Performance Index Total (PI) was used. PI is calculated from temporal changes in fluorescence signal emission as a cumulative activity of individual parameters: number of antenna chlorophylls per number of reaction center chlorophylls, efficiency of trapping of absorbed exciton, intensity of reduction of end electron acceptors, and rate of electron transport between photosystems (Tsimilli-Michael, 2020).

At the end of each experiment, leaf chlorophyll concentration was measured using a CCM-300 (OptiSciences, USA) chlorophyll meter. Two fully grown active photosynthesising leaves were selected for each individual plant, and the total number of individual measurements was 10 for each fertiliser/concentration/plant species combination.

Analysis of morphological parameters. At the end of the cultivation period, individual plants were separated from substrate and divided into parts according to morphological structure of the particular species. Each part of the individual plant was weighed separately to measure fresh mass and dry mass (after drying in an oven at 60 °C for at least 72 h until constant mass). The number of leaves and flowers (only for *Anthurium*) was recorded. Tissue water content was calculated for all plant parts as mass of water in g per g of tissue dry mass.

Data analysis. Comparative average stimulative effect of increasing concentration of different fertiliser types on morphological parameters was calculated as a mean value of relative changes of morphological measurements for each plant species. At each fertiliser concentration above 0.1 $g \cdot l^{-1}$, relative changes were calculated against control plants, which received suboptimal concentration of the fertiliser and therefore had a lower control value of the respective parameter.

Results were analysed and graphs were produced by KaleidaGraph (v. 4.1, Synergy Software, USA). Statistical significance of differences between all treatments was evaluated by one-way ANOVA using Microsoft Excel (www.biostathandbook.com/anova.xls) (McDonald, 2014).

RESULTS

Anthurium sp. Growth of *Anthurium* plants was relatively slow, and no visual signs of any effect of type of fertiliser and concentration during seven weeks of cultivation were seen. Morphology of vegetative parts was relatively less affected by the treatment in contrast to reproductive parts (Table 2). As an example, the number of leaves was not affected by increasing fertiliser concentration in the case of Kristalon Orange, but it was significantly affected by Kristalon Red. However, the number of inflorescences significantly increased from 0.1 to 0.5 $g \cdot l^{-1}$ treatment for both fertilisers with no further increase at higher concentrations, and the differences were not statistically significant due to large individual variability of this parameter. The type and concentration of the fertiliser showed no significant effect on biomass of all vegetative aboveground parts (leaf petioles, leaf blades, stem, root). Biomass of reproductive parts (flower stalk, spadix, spathe) significantly increased from 0.1 to 0.5 $g \cdot l^{-1}$ for both fertilisers, with no further increase at 1.0 $g \cdot l^{-1}$, followed by a tendency to decrease at 2.0 $g \cdot l^{-1}$ to the level found for plants grown at lower concentration.

Tissue water content in different parts of *Anthurium* plants increased in the order stem/leaf blades < spadix/spathes/leaf petioles < inflorescence stalks < roots (Fig. 1 A, B). Water content tended to continuously decrease with increase in fertiliser concentration in inflorescence stalks, with significant differences only at 2.0 $g \cdot l^{-1}$. In addition, there was a significant decrease in spadix water content with increasing fertiliser concentration.

Values of the chlorophyll *a* fluorescence parameter PI during plant cultivation were more affected by individual variation of the parameter between plants in comparison to different treatments (Fig. 1 C, D). Only six weeks after the start of the experiment, there was a tendency that plants at

Table 2. Effect of fertiliser type and concentration (in $g \cdot l^{-1}$) on morphological parameters and leaf chlorophyll concentration of hydroponically-grown indoor plants

	Kristalon Red + Calcinit				Kristalon Orange + Calcinit			
	0.1	0.5	1.0	2.0	0.1	0.5	1.0	2.0
Anthurium								
Number of leaves	5.6 ± 0.3 a	7.3 ± 0.5 b	6.8 ± 0.7 b	7.7 ± 0.7 b	6.5 ± 0.7 ab	6.3 ± 0.9 ab	6.2 ± 0.2 ab	5.7 ± 0.3 a
Inflorescence No.	1.4 ± 0.4 ab	2.3 ± 0.3 c	2.0 ± 0.0 bc	1.3 ± 0.3 ab	1.3 ± 0.3 a	2.0 ± 0.4 bc	2.0 ± 0.5 bc	1.3 ± 0.3 ab
Root DM (g)	1.6 ± 0.1 a	2.1 ± 0.3 b	2.0 ± 0.4 ab	1.7 ± 0.2 ab	1.8 ± 0.2 ab	1.6 ± 0.2 a	1.8 ± 0.1 ab	2.3 ± 0.3 b
Stem DM (g)	1.3 ± 0.1 a	1.5 ± 0.2 ab	1.5 ± 0.1 a	1.4 ± 0.2 a	1.5 ± 0.2 ab	1.4 ± 0.1 a	1.5 ± 0.1 a	1.7 ± 0.1 b
Leaf petiole DM (g)	1.3 ± 0.1 a	1.7 ± 0.2 b	1.5 ± 0.1 ab	1.5 ± 0.1 ab	1.4 ± 0.2 ab	1.3 ± 0.1 a	1.4 ± 0.1 ab	1.5 ± 0.1 ab
Leaf blade DM (g)	2.2 ± 0.2 a	2.9 ± 0.3 a	2.6 ± 0.1 a	2.5 ± 0.2 a	2.5 ± 0.4 a	2.4 ± 0.3 a	2.6 ± 0.2 a	2.8 ± 0.2 a
Inflorescence stalk DM (g)	0.43 ± 0.11 a	0.75 ± 0.11 b	0.71 ± 0.07 ab	0.47 ± 0.11 a	0.43 ± 0.10 a	0.69 ± 0.14 ab	0.73 ± 0.16 ab	0.53 ± 0.12 a
Spadix DM (g)	0.18 ± 0.03 a	0.43 ± 0.05 b	0.32 ± 0.08 ab	0.28 ± 0.10 ab	0.24 ± 0.05 a	0.43 ± 0.09 b	0.43 ± 0.11 b	0.33 ± 0.09 ab
Spathe DM (g)	0.38 ± 0.09 a	0.79 ± 0.07 b	0.72 ± 0.10 b	0.47 ± 0.10 ab	0.45 ± 0.11 ab	0.67 ± 0.14 b	0.76 ± 0.18 b	0.63 ± 0.15 b
Leaf chlorophyll ($mg \cdot m^{-2}$)	860 ± 30 ab	890 ± 21 b	882 ± 31 b	865 ± 25 ab	817 ± 24 a	834 ± 25 ab	868 ± 21 b	780 ± 32 a
Chlorophytum								
Number of leaves	18.3 ± 1.5 ab	22.6 ± 2.3 c	23.5 ± 3.9 bc	17.3 ± 0.5 a	16.0 ± 1.5 a	19.5 ± 1.2 ab	22.0 ± 2.1 bc	19.6 ± 0.7 b
Root DM (g)	1.4 ± 0.2 b	1.9 ± 0.3 c	2.0 ± 0.1 c	1.0 ± 0.2 a	1.1 ± 0.0 a	1.1 ± 0.2 a	1.4 ± 0.3 ab	1.0 ± 0.2 a
Leaf DM (g)	1.1 ± 0.1 b	1.6 ± 0.2 c	2.3 ± 0.2 d	1.7 ± 0.2 c	0.8 ± 0.0 a	1.3 ± 0.1 b	1.8 ± 0.2 c	1.7 ± 0.2 c
Leaf chlorophyll ($mg \cdot m^{-2}$)	795 ± 13 a	862 ± 14 cd	865 ± 10 d	835 ± 18 bc	785 ± 20 a	796 ± 17 a	829 ± 16 b	872 ± 19 d
Epipremnum								
Leaf No.	5.5 ± 0.5 a	9.0 ± 0.7 b	9.0 ± 0.6 b	9.5 ± 0.5 b	6.0 ± 0.0 a	8.3 ± 0.5 b	9.3 ± 0.6 b	8.5 ± 0.5 b
Stem length (cm)	28.2 ± 3.1 b	55.1 ± 4.2 c	51.4 ± 3.1 de	54.8 ± 1.8 cd	36.4 ± 2.2 a	47.0 ± 1.4 de	54.2 ± 4.6 cde	45.8 ± 4.3 e
Root DM (g)	1.7 ± 0.5 ab	2.0 ± 0.2 ab	2.1 ± 0.2 b	1.6 ± 0.4 ab	1.8 ± 0.0 a	1.9 ± 0.1 ab	1.9 ± 0.2 ab	1.4 ± 0.3 a
Stem DM (g)	1.2 ± 0.2 a	2.1 ± 0.1 c	2.2 ± 0.2 c	2.2 ± 0.3 c	1.4 ± 0.2 a	1.7 ± 0.3 ab	2.1 ± 0.2 bc	2.4 ± 0.4 c
Leaf DM (g)	0.9 ± 0.1 a	1.8 ± 0.1 c	2.2 ± 0.1 d	2.2 ± 0.3 d	1.1 ± 0.1 a	1.4 ± 0.2 b	2.0 ± 0.1 cd	2.3 ± 0.3 d
Leaf chlorophyll ($mg \cdot m^{-2}$)	856 ± 33 a	1024 ± 23 b	1055 ± 28 b	1181 ± 12 c	844 ± 27 a	1070 ± 26 b	1189 ± 23 c	1185 ± 19 c
Plectranthus								
Number of leaves	40 ± 6 b	69 ± 4 c	79 ± 6 c	78 ± 9 c	25 ± 2 a	71 ± 3 c	74 ± 10 c	103 ± 3 d
Root DM (g)	0.93 ± 0.10 ab	0.83 ± 0.10 ab	1.26 ± 0.28 c	1.26 ± 0.28 c	0.76 ± 0.05 a	0.94 ± 0.09 b	0.094 ± 0.10 b	1.03 ± 0.15 bc
Stem DM (g)	0.59 ± 0.06 a	0.61 ± 0.11 a	0.82 ± 0.12 ab	0.85 ± 0.11 b	0.48 ± 0.06 a	0.84 ± 0.09 b	0.89 ± 0.12 b	1.20 ± 0.09 c
Leaf DM (g)	1.2 ± 0.2 b	1.5 ± 0.3 b	2.6 ± 0.2 d	2.5 ± 0.3 cd	0.8 ± 0.01 a	2.1 ± 0.2 c	2.3 ± 0.3 cd	3.3 ± 0.5 e
Leaf chlorophyll ($mg \cdot m^{-2}$)	612 ± 33 ab	593 ± 20 a	661 ± 40 b	865 ± 26 d	559 ± 22 a	746 ± 34 c	785 ± 24 c	899 ± 20 d
Spathyphyllum								
Leaf No.	12.5 ± 1.2 b	22.0 ± 1.0 c	24.5 ± 0.2 d	23.0 ± 1.0 cd	7.5 ± 0.2 a	13.0 ± 1.0 b	12.5 ± 0.8 b	28.5 ± 0.8 e
Root DM (g)	1.7 ± 0.1 ab	1.6 ± 0.2 ab	2.2 ± 0.2 c	1.8 ± 0.1 ab	1.9 ± 0.1 b	1.6 ± 0.1 a	1.7 ± 0.1 a	1.9 ± 0.1 ab
Stem DM (g)	2.5 ± 0.2 b	3.0 ± 0.1 c	3.8 ± 0.1 d	2.4 ± 0.3 ab	1.8 ± 0.3 a	4.0 ± 0.3 d	3.5 ± 0.4 d	2.5 ± 0.5 ab
Leaf blade DM (g)	1.2 ± 0.2 ab	1.3 ± 0.1 b	2.1 ± 0.3 d	1.8 ± 0.1 d	1.4 ± 0.1 b	1.1 ± 0.0 a	1.9 ± 0.1 d	1.6 ± 0.1 c
Leaf petiole DM (g)	0.54 ± 0.11 a	0.72 ± 0.07 b	1.02 ± 0.19 cd	1.10 ± 0.07 d	0.58 ± 0.04 a	0.60 ± 0.05 a	1.10 ± 0.06 cd	0.93 ± 0.05 c
Leaf chlorophyll ($mg \cdot m^{-2}$)	693 ± 16 a	723 ± 24 a	805 ± 20 b	764 ± 37 ab	720 ± 10 a	711 ± 14 a	708 ± 17 a	707 ± 31 a
Tradescantia								
Number of leaves	22 ± 2 a	32 ± 5 b	47 ± 2 c	48 ± 3 c	23 ± 1 a	29 ± 3 b	44 ± 1 c	61 ± 7 d
Root DM (g)	2.8 ± 0.7 ab	1.9 ± 0.5 a	3.4 ± 0.3 c	3.0 ± 0.5 abc	5.3 ± 1.5 de	3.4 ± 0.3 bcd	2.6 ± 0.3 ab	7.3 ± 1.9 e
Stem DM (g)	1.1 ± 0.3 a	1.3 ± 0.2 a	2.2 ± 0.2 b	2.0 ± 0.2 ab	1.2 ± 0.2 a	1.5 ± 0.3 a	2.0 ± 0.1 b	2.7 ± 0.5 b
Leaf DM (g)	1.4 ± 0.2 a	2.2 ± 0.3 bc	3.3 ± 0.2 d	2.9 ± 0.2 c	1.6 ± 0.1 a	1.9 ± 0.2 ab	2.9 ± 0.1 c	3.9 ± 0.7 d
Leaf chlorophyll ($mg \cdot m^{-2}$)	789 ± 11 b	805 ± 11 b	818 ± 16 b	749 ± 16 a	754 ± 21 a	803 ± 14 b	790 ± 16 b	769 ± 17 ab

The same letter indicates not statistically significant differences between treatments for a particular parameter ($p < 0.05$). DM, dry mass

$0.1\ g \cdot l^{-1}$ fertiliser concentration had significantly lower values of PI. Plants cultivated with Kristalon Orange tended to have lower leaf chlorophyll concentration, but the effect was not statistically significant (Table 2). Moreover, in Kristalon Orange-treated plants, chlorophyll concentration continuously increased from 0.1 to $1.0\ g \cdot l^{-1}$ fertiliser concentration.

Chlorophytum comosum. The number of leaves per plant was relatively little affected by increasing fertiliser concentration in *Chlorophytum* plants (Table 2). For both fertilisers, leaf number increased from 0.1 to $1.0\ g \cdot l^{-1}$, with further decrease at $2.0\ g \cdot l^{-1}$. Leaf biomass linearly increased from 0.1 to $1.0\ g \cdot l^{-1}$, and values for Kristalon Orange were smaller than these for Kristalon Red. Root growth was less

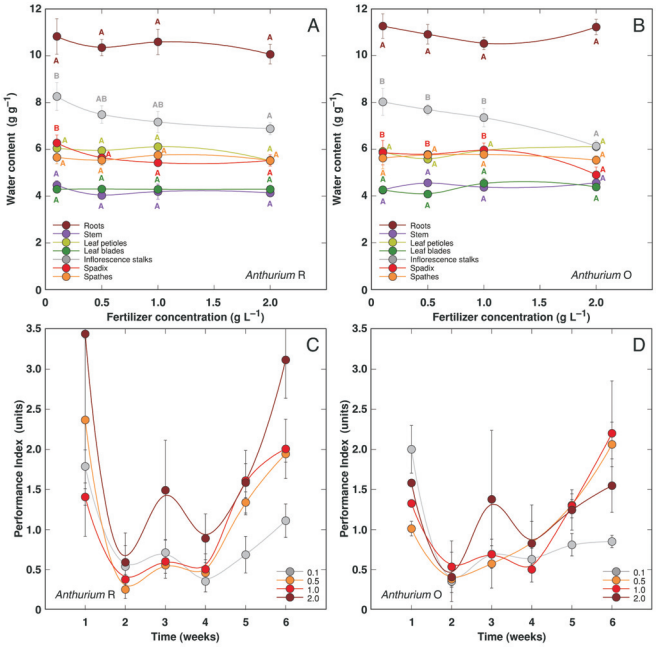


Fig. 1. Changes in tissue water content in different parts of *Anthurium* plants (A, B) and time course of chlorophyll *a* fluorescence parameter Performance Index in leaves of *Anthurium* plants (C, D) as affected by concentration of Kristalon Red with Calcinit (A, C) and Kristalon Orange with Calcinit (B, D) fertiliser. Data are means ± SE from 5 individual plants for each concentration or time point. The same letter indicates not statistically significant differences between treatments for a particular plant part ($p < 0.05$).

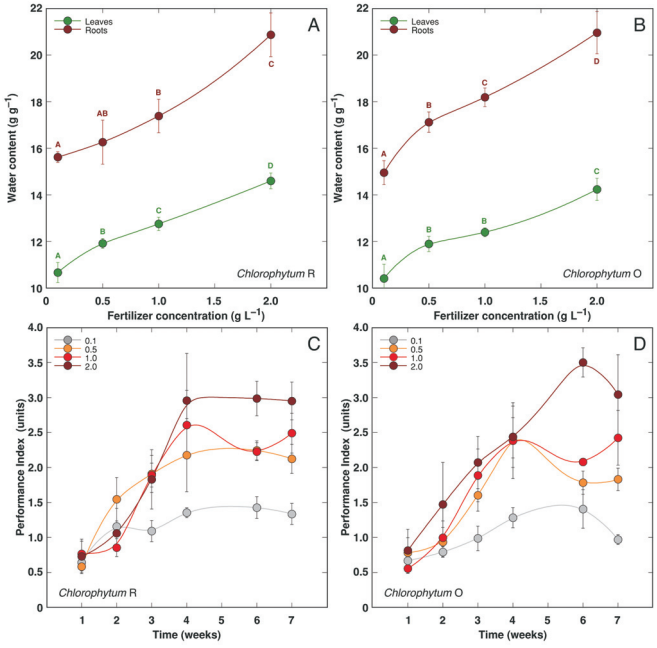


Fig. 2. Changes in tissue water content in different parts of *Chlorophytum* plants (A, B) and time course of chlorophyll *a* fluorescence parameter Performance Index in leaves of *Chlorophytum* plants (C, D) as affected by concentration of Kristalon Red with Calcinit (A, C) and Kristalon Orange with Calcinit (B, D) fertiliser. Data are means ± SE from 5 individual plants for each concentration or time point. The same letter indicates not statistically significant differences between treatments for a particular plant part ($p < 0.05$).

responsive to increase in fertiliser concentration, but Kristalon Red had relatively higher effect. For both fertiliser types, root mass significantly decreased with concentration increase from 1.0 to 2.0 g·l^{-1}, and for Kristalon Red, the root mass at 2.0 g·l^{-1} was significantly lower than at 0.1 g·l^{-1}.

Roots of *Chlorophytum* plants had higher water content than leaves (Fig. 2 A, B). Increase in tissue water content was a characteristic response of both leaves and roots to increasing fertiliser concentration.

Starting from week 3, PI in *Chlorophytum* plants cultivated in the presence of 0.1 g·l^{-1} was significantly lower than in other treatments (Fig. 2 C, D). During week 7, PI values were directly proportional to the concentration of fertiliser applied. Chlorophyll concentration in leaves of *Chlorophytum* plants were lowest for both fertilisers at 0.1 g·l^{-1} and increased linearly was increasing concentration of Kristalon Orange, while for Kristalon Red there was a sharp increase to 0.5 g·l^{-1} with no further gain with increasing concentration (Table 2).

Epipremnum aureum. The number of leaves of *Epipremnum* plants was significantly lower in the 0.1 g·l^{-1} fertiliser treatment, with no significant differences between other treatments (Table 2). Similar effect of fertiliser concentration was evident for stem length, but there was also a significant difference for Kristalon Red-treated plants between 0.5 and 1.0 g·l^{-1}. Leaf biomass increased with higher fertiliser concentration up to 1.0 g·l^{-1} for both fertilisers. A similar increase was seen for stem mass in the case of Kristalon Orange, but for Kristalon Red there was a sharp growth of stem mass from 0.1 to 0.5 g·l^{-1}, with no differences with further increase of concentration. In contrast, root mass of *Epipremnum* plants was relatively little affected by fertiliser type and concentration.

Tissue water content of *Epipremnum* plants at 0.1 g·l^{-1} was similarly low in leaves and stems in comparison to higher values in roots, but increase in fertiliser concentration resulted in pronounced significant increase in water content of stems (Fig. 3 A, B). Water content in leaves increased to a lesser extent, but root water content continuously increased only in the case of Kristalon Orange.

Cultivation of *Epipremnum* plants at fertiliser concentrations above 0.1 g·l^{-1} resulted in a sharp significant increase of PI already on week 2, but further there was a more or less pronounced concentration dependence of the parameter (Fig. 3 C, D). Leaf chlorophyll concentration of *Epipremnum* plants at the end of the experiment increased in dependence of concentration of Kristalon Red, but a more pronounced effect was evident for plants treated with Kristalon Orange at 1.0 g·l^{-1} (Table 2).

Plectranthus fruticosus. The number of leaves for *Plectranthus* plants was the lowest for both fertilisers at 0.1 g·l^{-1}, but there was no dependence of leaf number on increasing concentration from 0.5 to 2.0 g·l^{-1} in the case of Kristalon Red, and for Kristalon Orange from 0.5 to 1.0 g·l^{-1}, but a significant increase was evident at 2.0 g·l^{-1} (Table 2). Biomass of both leaves and stems increased with increasing fertiliser concentration, but the effect was less pro-

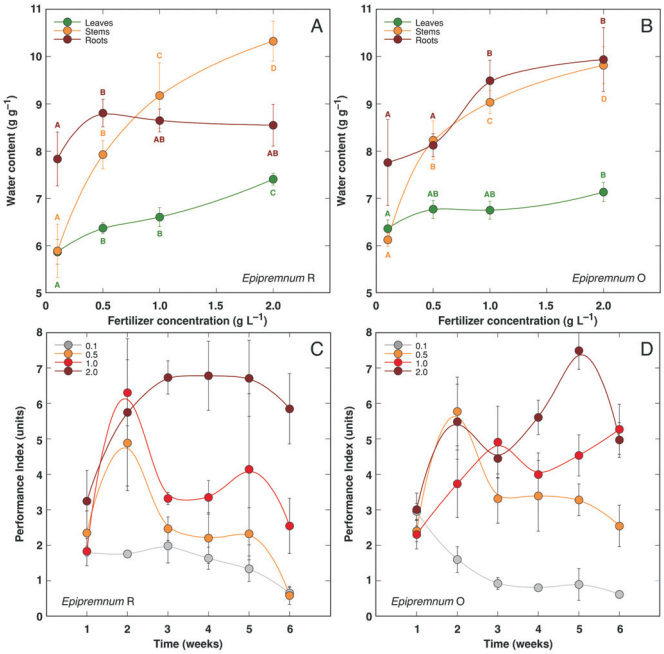


Fig. 3. Changes in tissue water content in different parts of *Epipremnum* plants (A, B) and time course of chlorophyll *a* fluorescence parameter Performance Index in leaves of *Epipremnum* plants (C, D) as affected by concentration of Kristalon Red with Calcinit (A, C) and Kristalon Orange with Calcinit (B, D) fertiliser. Data are means ± SE from 5 individual plants for each concentration or time point. The same letter indicates not statistically significant differences between treatments for a particular plant part ($p <$ 0.05).

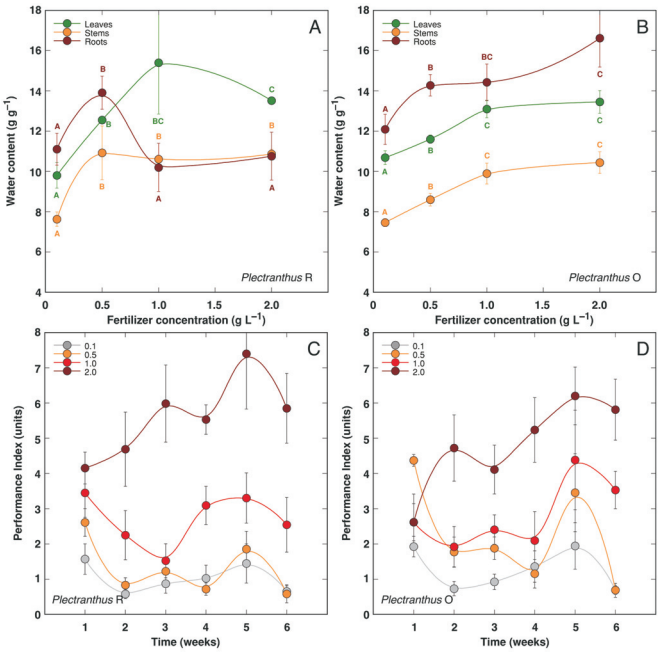


Fig. 4. Changes in tissue water content in different parts of *Plectranthus* plants (A, B) and time course of chlorophyll *a* fluorescence parameter Performance Index in leaves of *Plectranthus* plants (C, D) as affected by concentration of Kristalon Red with Calcinit (A, C) and Kristalon Orange with Calcinit (B, D) fertiliser. Data are means ± SE from 5 individual plants for each concentration or time point. The same letter indicates not statistically significant differences between treatments for a particular plant part ($p <$ 0.05).

nounced for Kristalon Red, especially, for stems. Root mass was higher for plants cultivated in presence of Kristalon Orange at 1.0 and 2.0 g·l^{-1} than in 0.1 g·l^{-1}, but without any concentration-dependent changes. For Kristalon Red-treated plants, root mass was similar at 0.1 and 0.5 g·l^{-1}, but was significantly higher at 1.0 and 2.0 g·l^{-1}.

Water content in control *Plectranthus* plants grown with 0.1 g·l^{-1} fertiliser concentration was lowest in stems and increased in leaves and further in roots (Fig. 4 A, B). In the case of fertilisation with Kristalon Orange, water content in all plant parts increased with increasing concentration (Fig. 4 B), but in the case of Kristalon Red this effect was less pronounced (Fig. 4 A).

Changes in the chlorophyll *a* fluorescence parameter PI showed positive dependence on fertiliser concentration, especially for Kristalon Red at early stages, but this effect varied with time (Fig. 4 C, D). Leaf chlorophyll concentration increased with increase in fertiliser concentration, and the most pronounced increase for Kristalon Red treatment was between 1.0 and 2.0 g·l^{-1}, but for Kristalon Orange treatment between 0.1 and 0.5 g·l^{-1} (Table 2).

Spathiphyllum sp. Similar to *Anthurium*, also *Spathiphyllum* plants were relatively slow growing. The number of leaves increased for Kristalon Red at all concentrations, and for Kristalon Orange at 2.0 g·l^{-1} (Table 2). Leaf growth did not depend on the type of fertiliser, and biomass of both leaf blades and leaf petioles significantly differed between 0.1 vs. 0.5 and 1.0 vs. 2.0 g·l^{-1}, and also between 0.1 vs. 0.5 g·l^{-1} for leaf petioles in the case of Kristalon Red. In contrast, root mass was relatively little affected by fertiliser type and concentration.

There was a very strong gradient of tissue water content between various parts of *Spathiphyllum* plants, with increase in the order stems < leaf blades < leaf petioles < roots (Fig. 5 A, B). Significant increase in water content was evident only for leaf petioles at 2.0 g·l^{-1} Kristalon Orange treatment and leaf blades for 2.0 g·l^{-1} Kristalon Red and 1.0 and 2.0 g·l^{-1} Kristalon Orange.

The time course of PI of Kristalon Red-treated plants showed differences between 0.1 g·l^{-1} treatment and all other concentrations (Fig. 5 C). In contrast, for Kristalon Orange-treated plants, only the highest concentration showed significantly higher PI (Fig. 5 D). Pronounced differences between fertilisers were evident also for leaf chlorophyll concentration: while there were no significant changes in Kristalon Orange-treated plants, chlorophyll concentration tended to increase in Kristalon Red-treated plants, with the highest value at 1.0 g·l^{-1} (Table 2).

Tradescantia pallida. For *Tradescantia* plants, number of leaves as well as leaf and stem biomass near-linearly increased with increasing concentration of Kristalon Orange (Table 2). A similar effect was evident for Kristalon Red, but there was no further increase of these morphological parameters at 2.0 g·l^{-1}. Root growth did not show much change in relation to concentration in the case of Kristalon Red, but it initially decreased for Kristalon Orange-treated plants up to 1.0 g·l^{-1}, and then increased.

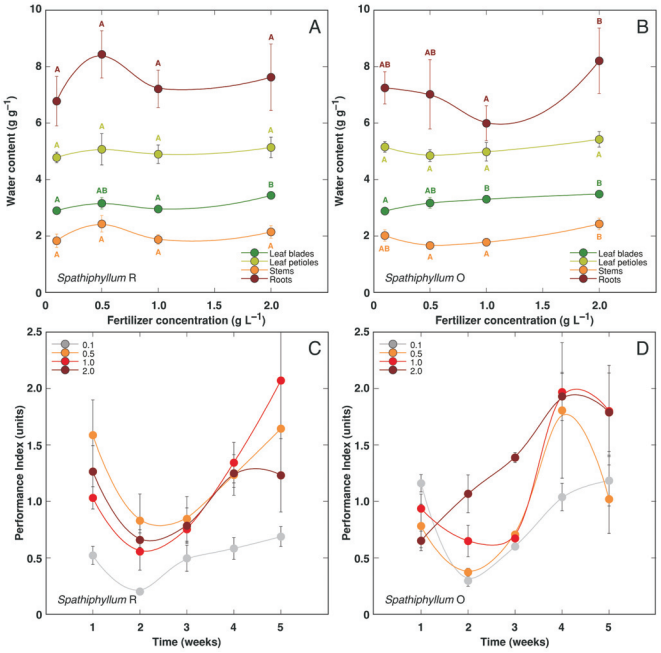


Fig. 5. Changes in tissue water content in different parts of *Spathiphyllum* plants (A, B) and time course of chlorophyll *a* fluorescence parameter Performance Index in leaves of *Plectranthus* plants (C, D) as affected by concentration of Kristalon Red with Calcinit (A, C) and Kristalon Orange with Calcinit (B, D) fertiliser. Data are means ± SE from 5 individual plants for each concentration or time point. The same letter indicates not statistically significant differences between treatments for a particular plant part (p < 0.05).

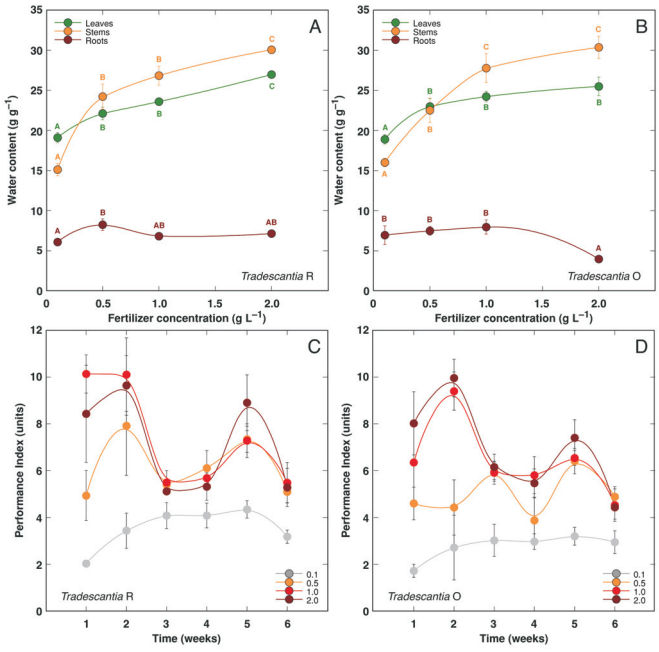


Fig. 6. Changes in tissue water content in different parts of *Tradescantia* plants (A, B) and time course of chlorophyll *a* fluorescence parameter Performance Index in leaves of *Tradescantia* plants (C, D) as affected by concentration of Kristalon Red with Calcinit (A, C) and Kristalon Orange with Calcinit (B, D) fertiliser. Data are means ± SE from 5 individual plants for each concentration or time point. The same letter indicates not statistically significant differences between treatments for a particular plant part (p < 0.05).

In contrast to other species, roots of *Tradescantia* had the lowest amount of water and it did not respond much to increase in fertiliser concentration (Fig. 6 A, B). In contrast, water content in leaves and stems continuously increased with increased fertiliser concentration. Water content in stems doubled from 0.1 g·l^{-1} to the highest concentration 2.0 g·l^{-1}, reaching 30 g·g^{-1} for both fertilisers, which was associated with extreme fragility of stems.

During early response to fertiliser treatment there was a pronounced effect of fertiliser concentration of PI, but at later stages only plants at the lowest concentration showed pronounced differences in PI values (Fig. 6 C, D). At the end of the experiment, leaf chlorophyll concentration tended to be higher in plants treated with Kristalon Red at 0.1 and 1.0 g·l^{-1}, but overall changes of chlorophyll in relation to the concentration of fertiliser were little pronounced (Table 2).

Comparative average stimulative effect of fertilisers on plant growth. Dependence of morphological parameters on fertiliser concentration (average stimulative effect) was used to compare both responses of different model species as well as the effect of two fertilisers (Fig. 7). Plants significantly differed in their general response to increasing fertiliser concentration, with effect increasing in the order *Anthurium* < *Spathiphyllum* < *Epipremnum* < *Chloro-*

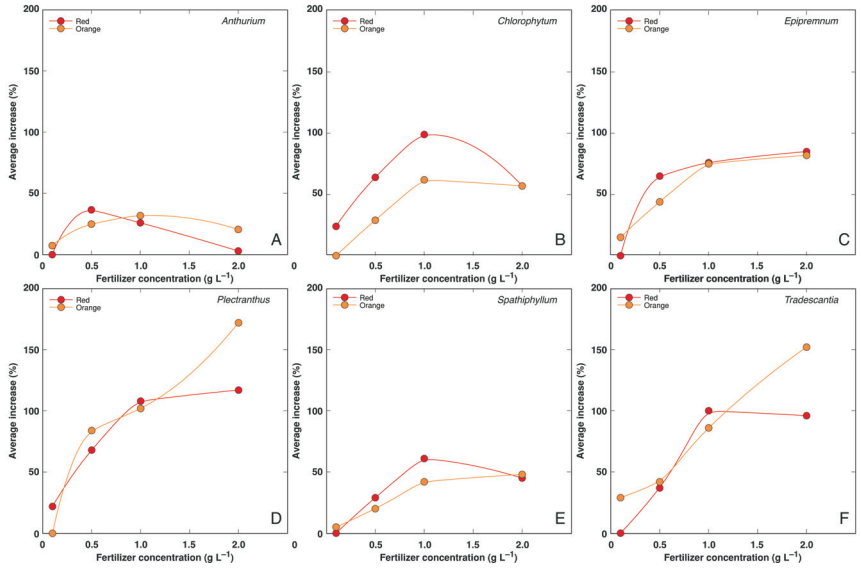


Fig. 7. Comparative average stimulative effect of increasing concentration of different fertiliser types on morphological parameters of indoor plants. (A), *Anthurium*; (B), *Chlorophytum*; (C), *Epipremnum*; (D), *Plectranthus*; E, *Spathiphyllum*; F, *Tradescantia*. Treatment showing the lowest average value for all morphological parameters was used for comparison (control, 0% increase). Data are means from all measured morphological parameters.

phytum < *Tradescantia* < *Plectranthus*. As the main difference between the two types of fertilisers was related to N concentration, it is evident that *Anthurium, Epipremnum,* and *Spathiphyllum* can be characterised as N-neutral plants, but *Plectranthus* and *Tradescantia* as N-neutral plants with some N sensitivity, due to lack of further growth stimulation from 1.0 to 2.0 $g \cdot l^{-1}$ in the case of N-rich fertiliser Kristalon Red. *Anthurium* plants also showed pronounced N sensitivity. Only *Chlorophytum* can be characterised as a nitrophilic species, as Kristalon Red showed better growth stimulation in comparison to Kristalon Orange, but with pronounced signs of N sensitivity.

DISCUSSION

Changes of growth. Generalised dose response curves of changes in plant growth with increasing concentration of essential nutrients predict growth stimulation by boosting nutrients during the suboptimal phase, followed by no growth changes during the optimal phase, with probable growth decrease due to toxicity during the surplus phase (Berry and Wallace, 1981). Consequently, both nutrient deficiency as well as excess can negatively affect growth and physiological status of plants. In hydroponic cultivation systems, both depletion of nutrients and evapotranspiration affect the concentration of fertiliser components; therefore, special attention needs to be paid to keeping both total concentration and balance of individual elements near optimum (Resh, 2013). The mineral nutrient concentration range for optimum growth tended to differ between the studied species in the present experiments, and relative increase in growth with increased nutrient concentration varied as well. Plant leaves and roots of the most slowly growing species *Anthurium* did not positively respond to increased mineral nutrient availability, but the optimum growth of generative organs was attained already at 0.5 $g \cdot l^{-1}$ (Table 2). In contrast, for faster growing species, as *Tradescantia*, optimum shoot growth was reached at 1.0 $g \cdot l^{-1}$, but root growth did not respond positively to increase in nutrient concentration. In general, the need for nutrients increased in the order *Anthurium* < *Spathiphyllum* < *Epipremnum* < *Chlorophytum* < *Tradescantia* < *Plectranthus* (Fig. 7).

None of the plant species grew better with Kristalon Orange, but some morphological or physiological aspects in several plant species were affected differentially. For example, chlorophyll concentration tended to be higher in Kristalon Orange-grown *Epipremnum* and *Plecranthus* plants (Table 2). While it is commonly considered that leaf chlorophyll concentration reflects plant supply with N (Ziadi *et al*., 2010), in the present cases it seems that elevated Mg concentration was important, as Mg is a structural component of chlorophyll (Willows, 2003).

Another situation where Kristalon Orange performed better was general morphological response of *Plectranthus* and *Tradescantia* plants at 2.0 $g \cdot l^{-1}$ fertiliser concentration, which clearly indicated N sensitivity of these species (Table 2, Fig. 7). Plant N sensitivity can be a reflection of ammonium toxicity (Bittssanszky *et al*., 2015), but the ammonium concentration in both fertilisers was low and N was mainly in the form of nitrate. It seems that inability of *Plectranthus* and *Tradescantia* plants to respond positively to maximum N concentration is associated with physiological peculiarities of tissue N metabolism, possibly related to dependence of nitrate assimilation on photorespiration (Rachmilevitch *et al*., 2004), and as a result, decreasing both net rate of photosynthesis and growth through negative feedback control.

In contrast to other species used in the present study, mineral nutrition of *Anthurium* sp. has gained relatively much scientific attention due to its major use in cut flower production (Paull *et al*., 1992; Chang *et al*., 2010). *Anthurium andraeanum* plants developed an identical number of inflorescences (flowers) per plant within six months of cultivation, irrespective of nitrogen concentration provided, but there was a significant increase of flower number at optimum N supply during longer cultivation (Chang *et al*., 2012). In contrast to the present study, leaf area per plant also increased at optimum N supply for *A. andraeanum* (Chang *et al*., 2012). It was observed that the number of flowers is positively affected equally by N, P, and K, but flower size depends only on N and K rate (Higaki *et al*., 1992). Similar to the present study, decrease in plant and flower development and growth at supraoptimal N availability was noted in previous studies (Higaki *et al*., 1992; Dufour and Guérin, 2005; Chang *et al*., 2012). It is most likely that, for extremely slow growing species like *Anthurium*, a period of six weeks of cultivation at different nutrient availability is too short for any effects of leaf development and growth to appear, but flower development is more sensitive in this respect.

Another aspect of N nutrition is related to nitrophily, a need of a plant species for a relatively high root-zone nitrogen level (Fichtner and Schulze, 1992). In this respect, only *Chlorophytum* can be characterised as a nitrophilous species, as both leaf and root growth was significantly increased in Kristalon Red with higher nitrogen concentration in comparison to Kristalon Orange (Table 2). Slightly nitrophilous characteristics were evident also for *Spathiphyllum*, especially with respect to leaf development.

Tissue water content. A water-related parameter, relative tissue water content, has been most often used for characterisation of the degree of plant tissue water saturation as an indication of possible water shortage and drought resistance (Matin *et al*., 1989). Absolute tissue water content on a dry mass basis has been rarely assessed and usually related to the phenomenon of succulence (Males, 2017). In the present study, measurement of tissue water content on a dry mass basis seemed to be an important physiological indicator of status of indoor plants. Firstly, tissue water content appeared to be a genetically determined parameter, with pronounced differences between various plant species as well as between plant organs, with possible physiological consequences. Secondly, for several species, increase in mineral nutrient availability resulted in significant increase in tissue water content.

Plants of specific ecological groups have evolved to possess leaf and stem succulence, a phenomenon that includes also high tissue water content. The most commonly used examples are drought tolerant water-conserving plants of arid lands from Crassulaceae, Cactaceae etc. families (Males, 2017). In addition, rainforest epiphytes are known to have developed succulence as a means to conserve water in conditions of absence of soil-related water acquisition (Gotsch *et al*., 2015). However, in contrast, succulence in halophyte species is thought to have evolved concomitantly to massive vacuolar development as a result of ionic accumulation (Ogburn and Edwards, 2010). The latter seems also to be the case in the present study, where several plant species showed pronounced increase in tissue water content due to increase in mineral nutrient availability. It appears that *Chlorophytum comosum*, which had the most pronounced increase of tissue water content (leaves and roots, Fig. 2), *Epipremnum aureum* (stems, Fig. 3), and *Tradescantia pallida* (stems, Fig. 6) use this strategy to efficiently decrease ionic strength and/or osmotic potential in cellular environments in conditions of increased mineral nutrient availability.

Plants with lower leaf water content are suggested to have slower growth rates and more efficient use of nutrients (Saura-Mas and Lloret, 2007). Plants of both of the slower growing species, *Anthurium* (leaf water content about 4 $g \cdot g^{-1}$) and *Spathiphyllum* (leaf water content 3 $g \cdot g^{-1}$), were the least responsive to increasing concentration of fertilisers, indicating that the above phenomenon indeed had general importance. It is also interesting that roots in general contained higher water content in comparison to other parts for all plant species except *Tradescantia*.

The studied indoor plant species can be characterised as having relatively high water content. The lowest water content was in leaves of *Spathiphyllum* (about 3 $g \cdot g^{-1}$) and the highest in leaves of *Tradescantia* (20 to 25 $g \cdot g^{-1}$). In comparison, typical herb species from Lamiaceae, *Melissa officinalis, Nepeta cataria, Dracocephalum moldavica* and *Thymus vulgaris*, had respective water content of 2.4 to 3.0, 2.2 to 2.4, 2.5 to 3.7 and 1.5 to 2.0 $g \cdot g^{-1}$, at various doses of organic fertiliser (Ievinsh *et al*., 2020).

Physiological status. Physiological status of plants used for VOC remediation studies has typically not been assessed. However, it is clear that conditions of plant growth in prior experiments could have greatly affected plant characteristics related to possible phytoremediation efficiency. Thus, chlorophyll *a* fluorescence measurements have been used also in studies of phytoremediation ability of indoor plant species, and it was concluded that physiological status can affect plant ability to remove VOC (Hörman *et al*., 2018). So far, the physiological status has been studied in *Anthurium* plants in regard to use of growth regulators for improving flower production (de Moura *et al*., 2018). Therefore, during the present study, mineral nutrient-related changes in physiological status of plants were monitored.

While it can be logically expected that increase of mineral nutrient availability towards optimality could lead to improvement of physiological status in plants, and, as a result, their efficiency in air purification systems, it seems that growth and physiological status may be affected differently by increased nutrient availability.

The absolute level of chlorophyll concentration in leaf tissues is clearly a genotype-specific characteristic, in general being significantly higher in plants adapted to low light conditions to capture more light, such as for many rainforest understory species that are used as indoor plant species (Walters, 2005). In the present study, the highest chlorophyll concentration and the widest range of changes (850 to 1200 $mg \cdot m^{-2}$) was found for *Epipremnum*, a climbing plant species from tropical rainforest, and the second widest range of changes in chlorophyll concentration (600 to 900 $mg \cdot m^{-2}$) was in *Plectranthus* (Table 2), a species from relatively dry open or partly shaded habitats (Van Jaarsveld, 2006). In contrast, other model species showed a less pronounced range of changes in chlorophyll concentration due to fertiliser treatment, possibly indicating their lower adaptation potential. *Spathiphyllum* plants showed significant increase of leaf chlorophyll concentration for Kristalon Red treated plants (both at 1.0 and 2.0 $g \cdot l^{-1}$), in comparison to that in Kristalon Orange treated plants (Table 2), which could be the effect of increased N availability (Yeh *et al*., 2000).

It is important to note that, even more so than for chlorophyll concentration, any fluorescence analysis-derived parameter, especially, such as the Performance Index, can be evaluated only for the respective model species as changes in time or between different treatments (Tsimilli-Michael, 2020). Thus, in the present study, the particular levels of PI between the species cannot be compared, but rather the changes of PI in time due to the effect of fertiliser treatments.

Plant species significantly differed in respect to ability of PI to discriminate between various levels of mineral nutrient availability. For *Epipremnum* and *Plectranthus* plants, the level of PI was largely positively dependent on fertiliser concentration, but for *Spathiphyllum* and *Tradescantia* plants, PI was relatively stable over a concentration range and was lower only at the lowest fertiliser level (0.1 $g \cdot l^{-1}$). In *Anthurium*, a positive relationship between nutrient availability and PI was evident only at the end of the experiment. Average response was characteristic for *Chlorophytum* plants. These results also indicate that for the majority of indoor plant species with potential use in botanical biofilters, optimum intensity of photochemical reactions of photosynthesis can be achieved at relatively low mineral nutrient availability (0.5 $g \cdot l^{-1}$), irrespective of effects on growth.

Based on these results, it seems that indoor plants can successfully adapt to low and moderate mineral fertiliser levels with balanced individual nutrient rates, without negative consequences to photochemistry of photosynthesis. In contrast, it has been shown that deficiency in a single mineral nutrient results in the most pronounced decrease of PI, suggesting decrease in leaf electron transport capacity or

photoinhibitory damage to photosystem II (Horaczek *et al*., 2020).

Suitability for use in botanical biofilters. There are no clear criteria available for evaluation of suitability of particular plant species for use in hydroponics-based botanical biofilter systems (Brilli *et al*., 2018). Apart from the most crucial features such as ability to take up VOC in the aboveground plant parts (Kim *et al*., 2008; Teiri *et al*., 2018) or capacity to stimulate microbial VOC detoxification activity in the rhizosphere (Wenzel, 2009), other plant characteristics could be important in view of operation and maintenance of the biofilter systems. In this context, the role of mineral nutrient availability assessed in the present study can be related to effects on both growth rate and physiological status of plants. For relatively slow-growing indoor plants of epiphytic origin, such as *Anthurium* and *Spathiphyllum*, fertiliser concentration up to 0.5 $g \cdot l^{-1}$ was sufficient for sustaining growth and optimum physiological status. Faster growing species clearly required fertiliser concentration at least 1.0 $g \cdot l^{-1}$ for optimum growth and even lower than that for maintenance of vigorous physiological status. For the latter group of species, use of low fertiliser concentration resulting in slower growth can be even beneficial for more easy maintenance of botanical biofilters.

CONCLUSIONS

The results of the present study clearly indicate the need for evaluation of mineral fertiliser effects at morphological and physiological levels in plant species to be potentially used in botanical biofilters, as species-specific responses to changes in nutrient availability were found. The proposed system was both efficient and simple, using commercially available fertilisers and other components with the possibility of practical utilisation in active plant biofilter systems.

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HIDROPONISKI AUDZĒTU DEKORATĪVO TELPAUGU ATTĪSTĪBA UN FIZIOLOĢISKĀ VEIKTSPĒJA SAISTĪBĀ AR TO IESPĒJAMO IZMANTOŠANU BOTĀNISKAJOS BIOFILTROS: MINERĀLVIELU PIEEJAMĪBAS IETEKME

Šī pētījuma mērķis bija novērtēt dažādu minerālvielu pieejamības līmeņu ietekmi uz vairāku plaši izplatītu iekštelpu dekoratīvo augu sugu (*Anthurium* sp., *Chlorophytum comosum, Epipremnum aureum, Plectranthus fruticosus, Spathiphyllum* sp. un *Tradescantia pallida*) attīstību un fizioloģisko veiktspēju hidroponikā, saistībā ar to potenciālo izmantošanu aktīvo botānisko biofiltru sistēmās. Augus audzēja keramzīta granulās četros minerālo barības vielu pieejamības līmeņos, ko nodrošināja divu veidu komerciālais minerālmēslojums. Paaugstinātas minerālo barības vielu pieejamības augšanu stimulējošā iedarbība bija atkarīga no augu augšanas ātruma, ar mazāku ietekmi lēnāk augošām sugām. Vajadzība pēc minerālvielām palielinājās secībā *Anthurium* < *Spathiphyllum* < *Epipremnum* < *Chlorophytum* < *Tradescantia* < *Plectranthus*. Audu ūdens saturs uzrādīja izteiktas atšķirības starp dažādām augu sugām, kā arī starp augu orgāniem. Vairākām sugām barības vielu pieejamības palielināšanās izraisīja ievērojamu ūdens satura pieaugumu audos. Hlorofila fluorescences analīze parādīja, ka telpaugi var veiksmīgi pielāgoties zemam un mērenam minerālnodrošinājuma līmenim ar līdzsvarotu individuālo minerālvielu daudzumu, bez negatīvām sekām uz fotosintēzes fotoķīmiju. Līdz ar to telpaugus var kultivēt salīdzinoši zemā minerālvielu koncentrācijā, lai tos optimāli izmantotu aktīvajās botānisko biofiltru sistēmās.