THESIS OF DISSERTATION

Complex assesment of green roofs and of applied *Sedum* species

Andrea Szőke

Supervisors:

László Gerzson PhD, associate professor

Edit Forró PhD, associate professor

Corvinus University of Budapest
Faculty of Horticulture
Department of Dendrology and Ornamental Plants

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PhD School

name: PhD School of Horticultural Science

field: 4.1 Crop Sciences and Horticulture

head: Prof. Magdolna Tóth, DsC
Corvinus University of Budapesti
Faculty of Horticulture
Department of Pomology

Supervisors: László Gerzson PhD
associate professor
Corvinus University of Budapest
Faculty of Landscape Architecture
Department of Garden and Open Space Design

Edit Forró PhD
associate professor
Corvinus University of Budapesti
Faculty of Horticulture
Department of Soil Science and Water Managaement

Signatures:

The applicant met the requirement of the PhD regulations of the Corvinus University of Budapest and the thesis is accepted for the defence process.

Dr. Tóth Magdolna	Dr. Gerzson László	Dr. Forró Edit
Head of PhD School	Supervisors	

1. Introduction

Due to climate change, urbanization and population explosion, the traditional natural ecosystems are being replaced by artificial ones. The negative effects of the global tendencies are increasingly expressed in cities (heat island, dust dome, growing air pollution and airborne dust concentration, decreased transpiration, hectic climatic conditions etc.). Because of the high number of buildings, the different infrastructural developments and the ratio of artificial elements, the value of green areas has increased. Although decision-makers agree on the importance of green areas, in many cases the decisions cannot be implemented due to economic and social reasons (Láng, 2004).

Green roofs contribute to the improvement of local and urban climate; they accumulate water and by evaporation moderate the heat island effect. They serve as a habitat and have a recreational role for the urban population, not to mention the aesthetic value. Due to the demanding circumcisions, green area cannot live up to their full potential and functioning in moderating the climate and ecology, and their visual-aesthetic role (Li and Yeung, 2014).

Nowadays it is in the best interest of every city to moderate climatic parameters, especially the heat island effect and air pollution, which can be done by building green roofs. By utilizing the roof level, new green spaces, green roofs can be established, which is in agreement with the purposes of Lipcsei Charta and the regulations of the Integrated City Development Strategies (ICDS) (Mega, 2010). According to Somfai (2011) development of green roofs should not be done at the expense of the ground green areas. Green roofs serve as an alternative way to deal with the challenges the cities are facing.

Green roofs (dachbegrünung, toit vert) are structures where the building, the insulation layers and the horticultural elements are integrated in one system. In another way, green roofs are structurally and biologically stabile systems covered and protected by vegetation (FLL 2002; Hidy et al., 1995). Green roofs have multiple roles. From the aesthetic and ecological point of view they should fit into the surroundings, should have vegetation suitable for the local climate. They should also be suitable for recreation. From the horticultural point of view, the plant application is in the focus, by taking the suitable soil mixtures, substrate layers and climatic conditions into account.

Green roofs basically bring different fields and professions together, thus numerous types of these structures exist.

Extensive or eco roofs act as a biologically active, vegetative, protective layer with relatively undemanding plants. A minimal maintenance is necessary after planting. Intensive green roofs are gardens established on roofs with structure, utilization and requirements similar to that of ornamental gardens. A constant maintenance is necessary in intensive gardens. Another type of extensive green roofs is that with high diversity and nature-like structure, which places long-term animal and plant diversity in focus (Balogh et al., 2013; ÉMSZ, 2007; Hidy et al., 1995).

I studied extensive green roofs, which form an ecological layer with undemanding vegetation and natural processes. Green roofs usually have 10-15 cm layers. They are usually not suitable for human utilization; that is why special walkways or stepping stones have to be placed on the roof as well (Hidy et al., 1995). Extensive green roofs are the most economic ones among all types; both building and maintenance are easy (Li and Yeung, 2014).

In Hungary no extensive studies on green roofs have been conducted before with long-term monitoring and scientific statistical evaluation of the vegetation, substrates etc. Moreover, no data is available on the number and extension of these kinds of roofs. In Hungary the first green roof was built in 1991. Only a few attempts were made to organize and register the green roofs in the past two decades (Magyar, 1998; Szabó, 2010; Szőke et al., 2013). There is a rightful demand from the customers, the designers, the contractors and from the legislative authorities as well to see the current situation of the existing green roofs, since an effective regulation and incentive system can only be based on such database.

2. Aims

The main goal of my PhD thesis is to give an integrated and complex evaluation of the Sedum species applied on green roofs in Hungary, under Hungarian conditions. These structures integrate the vegetation, the substrate mixtures, water and climatic conditions. These elements were placed into the focus in my study.

Questions on the vegetation:

1. How do extensive circumcisions affect the tissue structure of *Sedum* species?
2. How do extensive circumcisions affect the antioxidant capacity of *Sedum* species? What are the characteristics of the pigmentation of the species?
3. How can the growth dynamics of the species be described?
4. When do the species reach full cover percentage?
5. Which factors (substrate mixture, layer thickness, species etc.) influence the growth and what interactions can be found?
6. Which weeds appear on the extensive green roofs? How do layer thickness and species influence the weed cover percentage?

Questions on water:

1. How can water retention be characterized by time?
2. Which factors influence water retention?
3. Which factors influence the quality of the percolation water?
4. How can water quality parameters be characterized in case of a newly built experimental green roof?
5. How can water quality parameters be characterized in case of a three year old experimental green roof?

Questions on the substrate:

1. How can the compaction rate of the substrates be characterized?
2. What statistical modelling can be applied?
3. What are the physical and chemical profiles of the substrate mixtures?
4. Which mixture proved to be more suitable for the species (ranking)?

Questions on green roof application:

1. How many green roofs have been built in Hungary?
2. What is ration of extensive and intensive green roofs?
3. What mathematical model is suitable for the characterization of green roof application in time?
4. What are the tendencies, which factors influence the ratio of newly built green roofs from one year to another?

The main motivation of my experiments and studies was to provide scientifically proven data to be used in the process of planning and building green roofs, hence enforcing the future of such structures.

3. Material and methods

3.1. Experiment design, species, substrates, leachet

According to the initial design of the experiment 32-32 parcels (1m x 1m) were assigned on two E-W situated experimental roofs. The different layer thickness, substrate mixtures and species were assigned to the parcels randomly. 4 repeats were applied in each case. In the experiment 4 substrate mixtures, 2 layer thicknesses and 4 *Sedum* **species** were tested. The 4 substrate mixtures and 2 layer thicknesses result in 8 combinations which were coded with different colors (*Table 1.*, **Figure 1.**).

Table 1. The design of the insulated control roof and parcels of the experimental roof (1=V1K1, 2=V1K2, 3=V1K3, 4=V1K4, 5=V2K1, 6=V2K2, 7=V2K3, 8=V2K4, V1=10cm thickness, V2=15cm thickness; K1-K4=substrate mixtures; A=*S. album*, B=*S. hybridum*, C=*S. reflexum*, D=*S. spurium)*

6A	6C	4A	4C		5D	5B	7A	7B
6D	6B	4B	4D		5C	5A	7C	7D
5B	5D	8D	8C		1C	1A	3B	3C
5C	5A	8A	8B		1B	1D	3A	3D
7D	7A	1C	1A		2B	2A	4C	4B
7C	7B	1D	1B		2D	2C	4A	4D
1D	1A	5B	5D		3A	3C	2D	2B
1B	1C	5C	5A		3D	3B	2A	2C
2A	2C	3C	3B		4D	4C	8B	8D
2B	2D	3D	3A		4B	4A	8C	8A
3D	3C	6B	6A		7C	7A	5B	5A
3A	3B	6C	6D		7D	7B	5D	5C
4B	4C	2A	2D		8B	8D	6C	6D
4D	4A	2B	2C		8A	8C	6A	6B
8C	8B	7D	7C		6A	6D	1D	1B
8D	8A	7A	7B		6C	6B	1C	1A

The following 4 **substrate mixtures** were used. K1 mixture: zeolite 25%, clay granule 10%, sand (0/4) 20%, soil 40%, peat 5%. K2 mixture: MKR-0-2 33%; MSQ-2-6 33%; MSQ-0-2 34 %. K3 mixture: ground brick 25%, ground ytong 25%, peat 15%, zeolite 20%, meliorite 15%. K4 mixture: soil 50%, peat 20%, sand 15%, meliorite 15%. The mixtures were applied in 2 thicknesses (V1 and V2), thus resulting in 8 combinations. The parcels were separated by plastic borders. The following species were tested: *S. album, S. hybridum, S. reflexum, S. spurium*, 9 db/0.25 m^2, 3x3 in each parcel. 1 year old plants were planted (originally grown in 7 cm pots). The water from the roof was collected by a vertical drain pipe, individually from each parcel, so the **percolation water** of each parcel was measured. A 5 cm border of pebbles was applied to prevent the substrate to wash away with the water and to clog the pipe. The control roof did not have any mixture on top (**Figure 1.**).

Figure 1. The two experimental roofs (a) Drainage pipes (b) Parcels with PVC insulations (c) Before planting (d) After planting (e) (Nyíregyháza, Ilona tanya)

3.2. Methods and equipment

3.2.1. Quality and quantity measurements of species

3.2.1.1. Tissue examinations of Sedum species

The tissues structure of the Sedum species were examined at the Department of Botany of the Corvinus University of Budapest. The samples were prepeared by a Leitz type microtome and than preserved by 1:1 glycerine and water solution. The samples were dyed by toulidine blue dye. Pictures were taken by using Zeiss Axio Imager. A2 type microscope and Axio Cam HRc, Zeiss camera. The examination mainly focused on the structure of the stem (general structure (10x), base and outer tissues (20x), central image (40x)). The results are presented in case of each species. In each case the plants collected from the roofs are compared to those grown on the ground as control.

Stoma numbers were determined at the Department of Vegetable and Mushroom Growing of the Corvinus University of Budapest. For the purposes of this study samples from the roof and from the ground were taken (3 samples from each combination with a total of 24 samples from the roof; 3 samples from each species from the control plants from the gorund). 5-5 pcs. of epidermis particulars were prepared from each sample and examined under Olympus CX-41 microscope (400x). Stoma number was given in the average of 10 leaflets (+SD) db/mm^2.

3.2.1.2. Determination of chlorophyll-a, chlorophyll-b, and total carotenoid contetnt od Sedum species

The methodology is based on the phenomenon that following to acetone extraction the plant pigments can be quantified in a certain wavelength according to formula. The extraction resulted by the clean acetone extraction are filled in to glass cuvettes and the absorbance is measured in (λ=661.6; λ=644.8; λ=470nm) against blank sample by Helios-alpha spectrophotometer. Calculation: Cl_a (µg/mg) = $11.24*A_{661.6} - 2.04*A_{644.8}$, Cl_b (µg/mg) = $20.13*A_{644.8} - 4.19*A_{661.6}$, $C_{(x+c)}$ (µg/mg) = $(1000*A_{470}-1.90*C_a-63.14*C_b)/214$. Measurements were carried out in 5 repeats. For statistical analysis Kruskal-Wallis test were used, by calculating the exact p-value on 95% significance level. If case of significant difference, Dunn's post-hoc test was applied as well, by using XL-Stat program (Addinsoft, 28 West 27th Street, Suite 503, New York, NY 10001, USA) (Lichtenthaler and Buschmann, 2001).

3.2.1.3. Determination of antoxidant capacity of Sedum species

The determination of *Total otal phenolic contents* (TPC) was measured by Folin-Ciocalteu reagent. The general charactereistics of polyphenols the good water solubility, the antioxidant charactereistics (reacted with an oxidizing agent), and phenolic hydroxil group or derivate of it. The original methodology was developed by Singleton and Rossi (1965) based on the Folin-Ciocalteu mixture. According to the theory of the method the phospho-wolfram acid ($H_3PW_{12}O_{40}$) and the phospho-molybden acid ($H_3PMo_{12}O_{40}$) oxidizes the phenolic components, which gives the colour change. The resulted blue colour can be followed spectrophotometrically (Abrankó et al., 2013). A mixture of 500mg/ml are prepared, and homogenized for 2 minutes with a homogenizator equipped teflon knifes with a speed of 24000 min^{-1}. The mixture is centrifuged for 20 minutes on 13500 rotation/minutes and the clear supernatant is used the measurement. The absorbation is monitored in λ=765 nm. All of the measurements were carried out in five replicate. The results are provided in gallic acid equivalence of the raw sample (mgGAAe/kg).

The methodology based on *Ferric Reducing Ability of Plasma* (FRAP)**.** For the determination of the total antioxidant activity of investigated plants the modified methodology of Benzie and Strain was used (Benzie and Strain, 1966). The element of FRAP methodology is the reaction where the ferri-(Fe3+) ions will reduced in to ferro-(Fe2+) ions due the effects of molecules with antioxidant activity which form blue complex in low 3.6 pH with tripyridil-tiazine (TPTZ); the reaction can be monitored photometrically. The samples are prepared similarly to that of the TPC and the clear supernatant will be used the measurements. The photometric detection is carried out in λ=517 nm in 5 replicates. The results are provided in ascorbic acid equivalence of the raw sample (mgAAe/100g).

CUPricion Reducing Antioxidant Capacity (CUPRAC) method. The methodology was developed by Apak et al. (2007). The methodology determines the antioxidant activity based on the reducing ability on pH 7, λ = 450 nm with the reaction time 30 minutes. In the mixture the oxidation number of $CuCl_2$(II) decreases according to reducing ability of antioxidants. The CU(I) dimerizates the neocuproine which becomes blue: $Cu(Nc)_2^{2+} \rightarrow$ + antioxidant $\rightarrow$ $Cu(Nc)^{2+}$ + ↑ λ= 450 nm. The samples are incubated for 30 minutes. The photometric detection is carried out in λ=450 nm in 5 replicates. The results are provided in trolox equivalence of the raw sample (mgTe/100g).

The antioxidant activity methodology based on the binding of the 1,1-difenil-2-pikrilhidrazil (DPPH) radical. The theory of the methodology that the antioxidant molecules react with the DPPH radical, which looses its dark purple colour. The more antioxidant molecules are in the given volume of sample, the colour change stronger is. A plant extraction of 200 mg/ml is prepared with cc. 96% ethanol (Blois, 1958). After 20 minutes of shaking of in 70°C the samples centrifuged (13500 rotation/minutes) and the supernatant is used thereafter. The neutralization of the DPPH radical is monitored in λ=517 nm. All of the measurements were carried out in five replicates, the results are provided in inhibition % (BRAND et al., 1995). All of the measurements were carried out in five replicates, based on the random selection *Sedum* species from the plots 10 cm substrate. For statistical analysis Kruskal-Wallis test were used, by calculating the exact p-value (α=0.05). If case of significant difference, Dunn's post-hoc test was applied as well. To determine correlation of methods Spearman rank correlation was applied by XL-Stat program (Addinsoft, 28 West 27th Street, Suite 503, New York, NY 10001, USA).

3.2.1.4. Determination of growth dynamics of Sedum species

The dimater of the plants were measured 4 times a year (in March, May, August and October). Each and every plant was measured in every occasion. This means that 1152 data (32 parcels x 36 plants) were collected at once, which resulted in a total of 4608 measurements by year (4 times x 32 parcels x 36 plants) and 13824 measurements in the course of the 3 year experiment (3 years x 4 times x 32 parcels x 36 plants). The data were given in mm accuracy. Multivariate Analysis of Variance (MANOVA) was applied to determine the factors (mixture, thickness or the combination of these) affecting the growth significantly (α=0.05). SPSS 20.0. for Windows was used for evaluation.

3.2.1.5. Weeds of the extensive greenroof

The spreading of the planted Sedum species and the appearing weeds on the parcels were constantly monitored. The following categories were applied to characterize the colonization strategies of the plants: ratio of planted Sedum species (%), ratio of weeds (%), cover of mixtures (%). A 1 m^2 (100x100 cm; divided to 100 pcs. of 10x10 cm parts) frame was used for ratio assessment. The data were registered twice (April and October) in each year (2012, 2013, 2014 and 2015).

3.2.2. Quality and quantity of the percolation water

3.2.2.1. Element analysis of the percolation water (ICP-OES, ICP-MS)

Analyses of the samples were done in an accredited laboratory (NAT-1-1462/2010) of the Corvinus University of Budapest. Samples were prepared based on MSZ 1484-3:2006, 4.2.1., and ICP/OES were done following the EPA Method 6010C:2007 (determined elements: Ba, B, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Si, Sr, V, Zn). ICP/OES analysis is usually used for determining macro components. Other elements were measured by ICP/OES method.

3.2.2.2. Multi criteria ranking of percolation waters

For element content comparison of the percolation waters ICP/OES and ICP/MS measurements provided the data. For statistical analysis *Sum of Rank-Difference, SRD* was applied (Héberger, 2010) and the SRDrep_V5_E10.xlsm free software (http://aki.ttk.mta.hu/srd/) was used (Héberger and Kollár-Hunek 2011).

3.2.2.3. Determination of percolation water production and precipitation retention capacity

Each parcel and control roof was equipped with a pipe (a total of 33 pipes) for drainage which collected the percolation water in individual tanks (10 l, closed). The percolation water was collected after each precipitation and the quantity was determined.

3.2.3. Quality and quantity assessment of substrate mixtures

3.2.3.1. General physical characterization

The measurements were done in an accredited laboratory (Laboratory of SGS Hungária Kft. (NAT-1-0992/2014)). The following features were determined: density (KA) (MSZ-08-0205:1978 Chapter 5), humus % (m/m) (MSZ 21470:1983 Chapter 2), dust and silt content % (m/m) (MSZ-08-0205:1978 Chapter 3), hygroscopy (hy1) (MSZ-08-0205:1978), capillary rise (5h) mm (MSZ-08-0480-2:1982). The mixtures were analyzed twice: first right after the roof was built, then 3 years later. Measurements were carried out in 5 repeats. For statistical analysis Kruskal-Wallis test were used, by calculating the exact p-value on 95% significance level. If case of significant difference, Dunn’s post-hoc test was applied as well, by using XL-Stat program (Addinsoft, 28 West 27th Street, Suite 503, New York, NY 10001, USA).

3.2.3.2. Specific physical characterization of substrate mixtures

Three groups of features were formed based on previous methodology (Szőke et al., 2013):

1. Density-related indicators: loose density, wet loose density, rock material density, wet density of the rock, crystal structure density, rock mass per unit rock volume; rock

volume per unit rock volume, rock mass per unit wet rock volume, rock mass per unit wet rock mass.

2. Water content related indicators: water content (porosity) per unit mass of wet rock, water content (porosity) per unit wet rock volume, water content per unit volume of wet granules, surface water per unit volume of granules, surface water per unit mass of granules.
3. Indicators related to space between particles: space between grains per unit volume of granules, space between grains per unit mass of granules.

Measurements were carried out in 5 repeats. For statistical analysis Kruskal-Wallis test were used, by calculating the exact p-value on 95% significance level. If case of significant difference, Dunn's post-hoc test was applied as well, by using XL-Stat program (Addinsoft, 28 West 27th Street, Suite 503, New York, NY 10001, USA).

3.2.3.3. General chemical characterization of substrate mixtures

Measurements were done by the accredited laboratory of the SGS Hungária Kft (NAT-1-0992/2014). The following features were determined: pH (KCl) (MSZ-08-0206-2:1978 2.1), pH (H_2O) (MSZ-08-0206-2:1987 2.1), total water soluble salinity % (m/m) (MSZ-08-0206-2:1978 2.4.), total carbonate content in $CaCO_3$ % (m/m) (MSZ-08-0206-2:1978 2.2.), soda lye % (m/m) (MSZ-08-0206-2:1978 2.3), (NO_2+NO_3)-N mg/kg (MSZ 20135:1999), P content in P_2O_5 mg/kg (MSZ 20135:1999), K content in K_2O mg/kg (MSZ 20135:1999), Mg content mg/kg (MSZ 20135:1999), Na content mg/kg (MSZ 20135:1999), Zn content mg/kg (MSZ 20135:1999), Cu content mg/kg (MSZ 20135:1999), Mn content mg/kg (MSZ 20135:1999).
Measurements were carried out in 5 repeats. For statistical analysis Kruskal-Wallis test were used, by calculating the exact p-value (α=0.05). If case of significant difference, Dunn's post-hoc test was applied as well, by using XL-Stat program.

3.2.3.4. Compaction of substrate mixtures

Measurements were done 4 times a year (March, June, September and December) between 2012.03 and 2015.03. In each parcel 10 data were registered every time. Samples were taken randomly by mm accuracy. The average values were than determined, which represents the rate of substrate compaction optimally. A model was fitted to the data based on Harnos and Ladányi (2005) by SPSS 20.0. for Windows program.

3.2.4. Statistical analysis of the green roof cadastral

A model was fitted to the input data of the green roof register based on Harnos and Ladányi (2005) by SPSS 20.0. for Windows program.

An approximation of the graph by plotting the data

1. Modelling
2. Estimation of modelling coefficients
3. Regressive diagnostics
    a. estimation of the deterministic coefficient (R^2) testing its significance (R^2=1–(Residual Sum of Squares)/(Corrected Sum of Squares)
    b. tests on estimation of parameters (decisions on what variables to use in the model)
    c. ANOVA of the model (how good the model is at explaining the deviation of data)
4. Condition assessment
    a. independence of residues (correlation)
    b. normality of residues $\varepsilon i \sim N(0;\sigma)$

4. Results

4.1. Quality and quantity measurements of species

4.1.1. Tissue examinations of *Sedum* species

Based on the data it can be concluded that the tissue structure of the *Sedum* species alter due to the extremities on the green roof. In case of *S. reflexum* the epidermis thickens. *S. spurium* forms a hypoderma, a line of cells with thick cell walls. The cortex tissue becomes more compact, the size of the intercellular space decreases, the tracheas of the xilem grow in diameter. The results show that under extreme conditions the stoma number of *S. hybridum, S. album* and *S. spurium* is significantly higher than those of the control plants grown on the ground.

4.1.2. Chlorophyll-a, chlorophyll-b and total carotenoid content of *Sedum* species

In case of each species and types of mixtures, chlorophyll-a was present in a highest rate, followed by chlorophyll-b and carotenoid content. The tendencies of the **species** were the following from highest to lowest: *S. hybridum, S. spurium, S. album, S. reflexum*. Based on the chlorophyll-a levels, control samples of *S. hybridum* had the highest pigment level (α=0,05), while *S. reflexum* (K3, K4, K2) had the significantly lowest. Every other combination was in between. Based on the chlorophyll-b and carotenoid content no significant difference occurred (**Figure 2.**) (*Table 2.*).

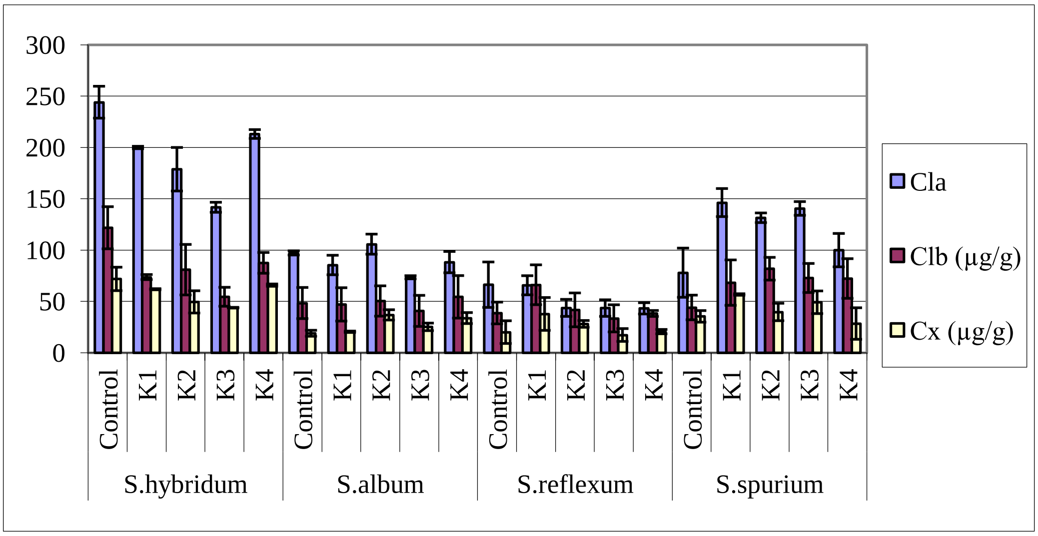


Figure 2. ***Chlorophyll-a, chlorophyll-b and total carotenoid content of Sedum species***

Table 2. Comparison of the chlorophyll-a, chlorophyll-b and carotenoid content of Sedum species by Dunn's post-hoc test (homogenous groups were marked by letters)

	Chlorophyll-a			Chlorophyll-b			Carotenoid		
	mean	st. dev	groups	mean	st. dev	group	mean	st. dev	groups
S.album K1	85.274	9.502	AB	46.907	16.244	A	20.248	0.698	A
S.album K2	105.611	9.789	AB	50.234	14.764	A	36.693	5.021	A
S.album K3	73.336	1.525	AB	40.603	15.136	A	25.020	3.682	A
S.album K4	88.098	10.362	AB	54.258	20.723	A	33.583	5.344	A
S.album Control	97.079	2.073	AB	48.239	15.169	A	18.799	2.907	A
S.hybridum K1	199.784	1.183	AB	73.532	2.451	A	61.677	0.549	A
S.hybridum K2	178.599	21.221	AB	80.739	24.612	A	49.362	10.843	A
S.hybridum K3	141.547	4.888	AB	54.348	9.226	A	43.680	0.366	A
S.hybridum K4	212.934	4.294	AB	87.380	10.128	A	65.682	1.131	A
***S.hybridum* Control**	243.930	15.548	**B**	121.584	20.523	A	71.730	11.427	A
S.reflexum K1	65.531	9.327	AB	66.053	19.421	A	37.615	16.001	A
***S.reflexum* K2**	43.509	8.295	**A**	41.572	16.508	A	27.924	3.314	A
***S.reflexum* K3**	43.323	8.066	**A**	33.328	13.229	A	17.106	6.231	A
***S.reflexum* K4**	43.061	5.502	**A**	38.098	2.894	A	20.390	2.106	A
S.reflexum Control	66.110	22.132	AB	38.532	10.605	A	19.904	11.066	A
S.spurium K1	146.114	13.671	AB	68.134	22.101	A	56.559	0.741	A
S.spurium K2	131.307	4.706	AB	81.664	11.087	A	39.528	8.503	A
S.spurium K3	140.389	6.673	AB	72.646	14.161	A	48.987	11.038	A
S.spurium K4	99.779	16.259	AB	72.134	19.318	A	28.255	15.369	A
S.spurium Control	77.815	23.968	AB	43.923	12.025	A	35.238	5.640	A

4.1.3. Antioxidant capacity of the *Sedum* species

Antioxidant capacity analysis suggests the following order (from highest to lowest): *S. hybridum, S. spurium, S. reflexum, S. album.* K3 and K4 mixtures gave better results than K1 and K2. The results of control samples varied in case of species and mixtures. The methods of determining antioxidant capacity showed significantly (α=0.05) strong correlations in case of: FRAP−CUPRAC (0.958), FRAP−TPC (0.881), CUPRAC−TPC (0.814). Moderate correlations: DPPH−FRAP (0.690), DPPH−CUPRAC (0.611), DPPH−TPC (0.594). We came by the same conclusion as Apak et al. (2007) and Huang et al. (2005), that the methods TPC−FRAP−CUPRAC are based on the same methodology, thus their results are likely to correlate.

4.1.4. Growth dynamics of *Sedum* species

A linear regression cannot be used to characterize the growth dynamics. General model: $p_1+p_2*(1-exp(-p_3*time))$, where p_1 is the starting value, p_2 growth until saturation, p_3 the speed of growth. While the plant diameters were very similar at the time the deployment (p_1), the species are different in growth until saturation (p_2) and the speed of growth (p_3). The following summarizing table shows the growth curves and characteristics of *Sedum* species *(Table 3.).*

Table 3. The growth curves and characteristics of Sedum species on the extensive experimental green roof

Thickness and substrate mixture	Statistical curves	Estimation of the deterministic coefficient	Diameter of the colony (cm) (at planting and at the end)	Final size (month)
***S. album* V1K1**	y = 9.061 + 10.243*(1-exp (-0.072*1095))	R² = 0.956	9.825→18.097cm	20
***S. album* V2K1**	y = 8.927+ 11.204*(1-exp (-0.070*1095))	R² = 0.954	9.836→18.702cm	20
***S. album* V1K2**	y = 9.195 + 13.000*(1-exp (-0.03*1095))	R² = 0.946	9.630→18.047cm	30
***S. album* V2K2**	y = 9.234 + 13.000*(1-exp (-0.028*1095))	R² = 0.915	9.736→18.127cm	30
***S. album* V1K3**	y = 9.388 + 13.000*(1-exp (-0.026*1095))	R² = 0.927	9.744→17.613cm	30
***S. album* V2K3**	y = 9.288 + 13.000*(1-exp (-0.027*1095))	R² = 0.930	9.647→17.752cm	30
***S. album* V1K4**	y = 9.098 + 10.303*(1-exp (-0.071*1095))	R² = 0.955	9.852→18.144cm	20
***S. album* V2K4**	y = 8.922 + 10.713*(1-exp (-0.076*1095))	R² = 0.953	9.858→18.438cm	20
***S. hybridum* V1K1**	y = 9.093 + 10.390 * (1-exp (-0.070*1095))	R² = 0.954	9.877→18.175cm	20
***S. hybridum* V2K1**	y = 8.926 + 11.235 * (1-exp (-0.071*1095))	R² = 0.954	9.861→18.758cm	20
***S. hybridum* V1K2**	y = 9.314 + 13.000 * (1-exp (-0.029*1095))	R² = 0.945	9.811→18.002cm	30
***S. hybridum* V2K2**	y = 9.266 + 13.000 * (1-exp (-0.028*1095))	R² = 0.923	9.758→18.05cm	30
***S. hybridum* V1K3**	y = 9.271 + 13.000 * (1-exp (-0.028*1095))	R² = 0.936	9.744→17.894cm	30
***S. hybridum* V2K3**	y = 9.158 + 13.000 * (1-exp (-0.030*1095))	R² = 0.938	9.663→18.125cm	30
***S. hybridum* V1K4**	y = 9.076 + 10.474 * (1-exp (-0.070*1095))	R² = 0.955	9.863→18.230cm	20
***S. hybridum* V2K4**	y = 8.986 + 10.623 * (1-exp (-0.074*1095))	R² = 0.957	9.858→18.388cm	20
***S. reflexum* V1K1**	y = 9.108 + 9.375 * (1-exp (-0.077*1095))	R² = 0.972	9.713→17.75cm	30
***S. reflexum* V2K1**	y = 9.169 + 9.808 * (1-exp (-0.074*1095))	R² = 0.973	9.836→18.130cm	30
***S. reflexum* V1K2**	y = 9.538 + 13.000 * (1-exp (-0.024*1095))	R² = 0.832	9.741→16.377cm	36
***S. reflexum* V2K2**	y = 9.711 + 13.000 * (1-exp (-0.021*1095))	R² = 0.956	9.736→16.747cm	36
***S. reflexum* V1K3**	y = 9.793 + 13.000 * (1-exp (-0.020*1095))	R² = 0.956	9.744→16.441cm	36
***S. reflexum* V2K3**	y = 9.641 + 13.000 * (1-exp (-0.022*1095))	R² = 0.955	9.661→16.802cm	36
***S. reflexum* V1K4**	y = 9.228 + 9.856 * (1-exp (-0.067*1095))	R² = 0.971	9.736→18.091cm	30
***S. reflexum* V2K4**	y = 9.195 + 10.146 * (1-exp (-0.068*1095))	R² = 0.971	9.811→18.355cm	30
***S. spurium* V1K1**	y = 9.176 + 9.176 * (1-exp (-0.078*1095))	R² = 0.970	9.825→17.686cm	30
***S. spurium* V2K1**	y = 9.170 + 10.180 * (1-exp (-0.070*1095))	R² = 0.973	9.836→18.333cm	30
***S. spurium* V1K2**	y = 9.600 + 8.546 * (1-exp (-0.037*1095))	R² = 0.965	9.630→15.769cm	36
***S. spurium* V2K2**	y = 9.683 + 9.105 * (1-exp (-0.033*1095))	R² = 0.966	9.736→15.830cm	36
***S. spurium* V1K3**	y = 9.657 + 8.486 * (1-exp (-0.036*1095))	R² = 0.965	9.744→15.677cm	36
***S. spurium* V2K3**	y = 9.731 + 13.000 * (1-exp (-0.020*1095))	R² = 0.958	9.663→16.588cm	36
***S. spurium* V1K4**	y = 9.122 + 9.558 * (1-exp (-0.077*1095))	R² = 0.969	9.825→17.808cm	30
***S. spurium* V2K4**	y = 9.022 + 9.720 * (1-exp (-0.082*1095))	R² = 0.968	9.836→17.947cm	30

The statistical model regressions describing the compaction, the estimation of model coefficients, the regression diagnostics and criteria investigations were accepted as satisfactory. *S. hybridum* and *S. album* can be characterized by the highest growth rate and size. On mixture K1 and K4 they achieved total coverage within 20 months (irrespective of the thickness), while on K2 and K3 only in 30 months. *S. hybridum* is a higher, more robust species with wide and flat leaves and bigger green mass than that of *S. album*. *S. album* is shorter; the leaves are more fleshy and round. *S. reflexum* and *S. spurium* can be characterized with a slower growth paste and diameter on each mixture and thickness. Irrespective of the thickness, they reached total coverage on K1 and K4 mixtures in 30 months, while on K2 and K3 they showed a slower growth rate and did not reach total coverage even by the end of the experiment **(Figure 3.).**

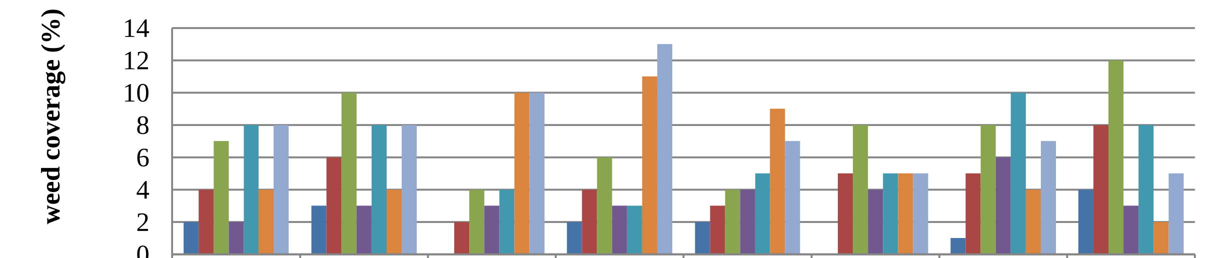
Figure 3. *S. hybridum* (top left), *S. album* (bottom right), *S. reflexum* (bottom left, top right), *S. spurium* (top right, bottom left) (V2K1, V2K4) (2013.05)

Multivariate Analysis of Variance (MANOVA) was applied to determine the factors (mixture, thickness or the combination of these) affecting the growth significantly (α=0.05). The results showed that the mixture have a significant (α=0.05) influence on the growth rate in case of each species. Substrate mixtures affect the size (diameter) of the species significantly (α=0.05), with the exception of *S. spurium*. The thickness of the mixtures does not influence the growth rate significantly (α=0.05).

4.1.5. Weeds on the extensive green roof

In spring the autumn germinating, early, annual (T_1) plants are typical, while in October the number of T_4 plants is higher. Moreover, T_2 (*Crepis rhoeadifolia, Vicia villosa),* G1 (*Agropyron repens, Poa angustifolia)* and H (*Artemisia vulgaris, Melandrium album, Oxalis corniculata, Plantago major*) weeds were registered as well.

Weed coverage were denser during the spring period than in the autumn. The only exception was in the first year, when the substrates were fresh and completely weed free. T1 plants strat to develop earlier than the *Sedum* species. Later on *Sedum* gain part of the area back, leaving less space for the autumn development of the weeds. It can be concluded that a thicker layer (15 cm) results in denser weed coverage (**Figure 4.**).



	V1K1	V2K1	V1K2	V2K2	V1K3	V2K3	V1K4	V2K4
2012_04	2	3	0	2	2	0	1	4
2012_10	4	6	2	4	3	5	5	8
2013_04	7	10	4	6	4	8	8	12
2013_10	2	3	3	3	4	4	6	3
2014_04	8	8	4	3	5	5	10	8
2014_10	4	4	10	11	9	5	4	2
2015_04	8	8	10	13	7	5	7	5

Figure 4. Weed coverage on the different substrate mixtures (%)

The results show that the mixtures/components have a stronger effect on the ratio of weeds. On substrates K1 and K4 (with higher organic matter content) the weed ratio was higher until the end of the second year. K4 had the most diverse weed flora, followed by K1. The weeds appeared on K2 and K3 later, which can be caused by the low organic matter rate. In the first two years the weed ratio was low.

4.2. Quality and quantity of the percolation water

4.2.1. Element analysis of the percolation water (ICP-OES, ICP-MS)

The element content of the first percolation water (right after the roof was built in 2012.03.) and the last percolation water (2015.03) was determined. The data were given in case of each mixture and thickness combination. Comparison of the 2012 and 2015 samples showed that the element content decreased, the filtering effect was stronger by the end. The highest change in data was registered in case of V2K3. The filtering increased (8→17) and the pollution decreased (17→9). The effect of the thickness can easily be proven since the same mixture resulted lower filtering rate on thinner layer (10 cm), the element content (12→11) and the pollution did not decrease (14→14). V2K2 had a steady performance (16→16), while the pollution decreased (13→9). The same was experienced in case of V1K4 and V2K4: (10→11) filtering (15→14) pollution and (11→11) filtering, (15→14) pollution.

4.2.2. Multi criteria ranking of percolation waters (SRD)

By SRD method the percolation waters were ranked. The rank was determined at the beginning, after the first precipitation (2012.03.) and in the end of the experiment (2015.03.). The first results (2012.03.) gave the following rank (from the most similar to percolation water collected from the control roof): V2K3 → V2K2 → V1K3 → V1K4 → V1K1→ V1K2 → V2K1 → V2K4 **(Figure 5.).**

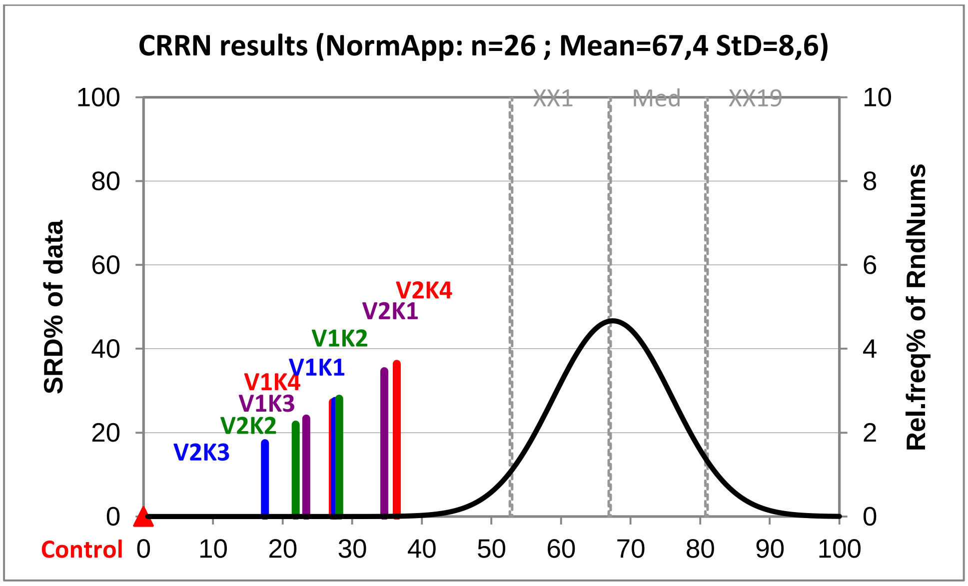


Figure 5. Ranked percolation waters according to SRD values (2012. 03)
Minimum values in the reference column. SRD values on the x axis and on the y axis on the left, relative frequencies on the y axis on the right (black line). Probability 5% (XX1), median (Med), and 95% (XX19)

The second results (2015.03.) gave the following rank (from the most similar to percolation water collected from the control roof): V2K4 → V2K1 → V1K2, V1K4 → V1K3 → V2K2 → V1K1 → V2K3 **(Figure 6).**

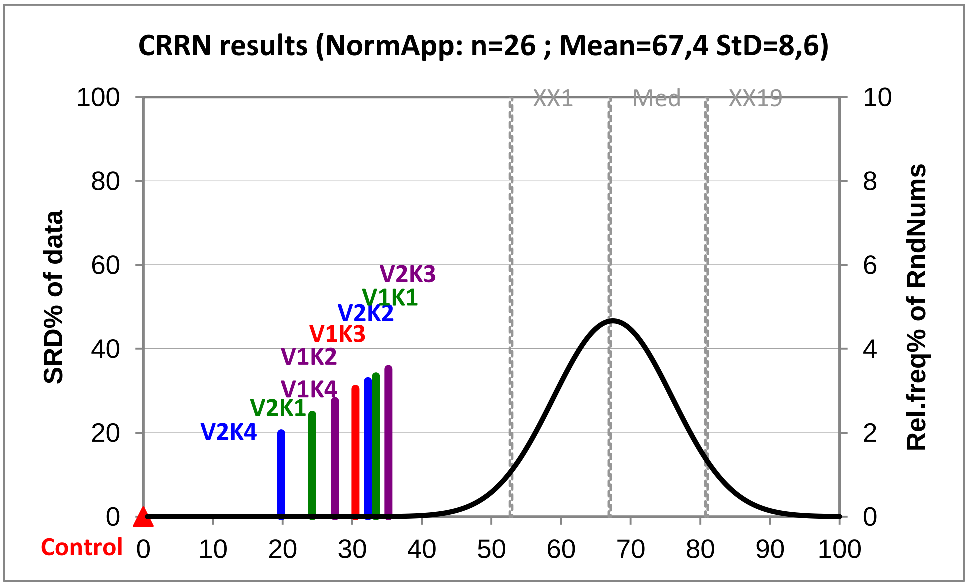


Figure 6. Ranked percolation waters according to SRD values (2015. 03)
Minimum values in the reference column. SRD values on the x axis and on the y axis on the left, relative frequencies on the y axis on the right (black line). Probability 5% (XX1), median (Med), and 95% (XX19)

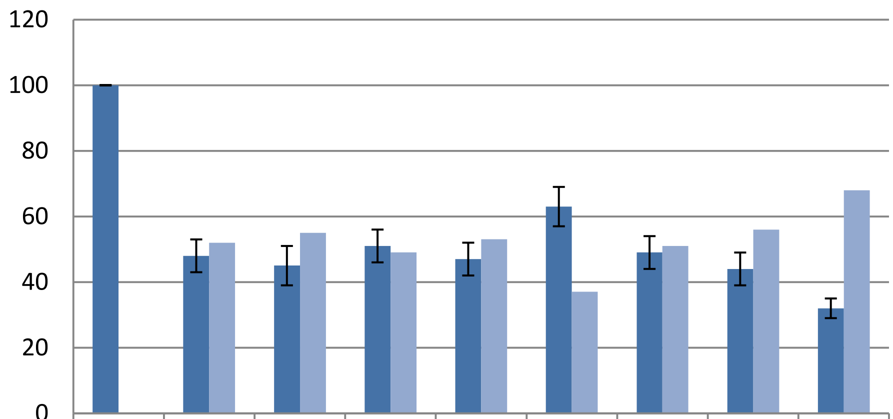
The results of both analysis proves that while at first the V2K3 and V2K2 combinations are the most similar to the quality of the control rainfall, but in the end these are the ones that give the most different results. This can be explained by the fact that these substrates contain slowly decaying and gradually soluble materials (K2 mixture: MKR-0-2 33%; MSQ-2-6 33%; MSQ-0-2 34 %. K3 mixture: ground brick 25%, ground ytong 25%, peat 15%, zeolite 20%, meliorite 15%). The same can be seen in case of other combinations as well. The most similar to natural precipitation is the high organic matter content V2K4 (K4 mixture: soil 50%, peat 20%, sand 15%, meliorite 15%) and V2K1 (K1 mixture: zeolite 25%, clay granule 10%, sand (0/4) 20%, soil 40%, peat 5%). The latter two had the higher filter effect at the end of the three years. In the other hand these were the most polluted samples at the beginning, in 2012.

4.2.3. Percolation water production and precipitation retention capacity

In the vegetation period (March-September) an average of 37-68%, outside the vegetation period 7-28% was the water retention capacity. This value is determined by mainly the ingredients of the substrate, the thickness of the substrate layer and the season. The more the organic matter content is, the higher the water retention capacity will be (in the vegetation period: V1K3→37%, V2K4→68%, outside the vegetation period: V1K3→7%, V2K4→28%).

A thinner layer (10 cm) of the same type of mixture is able to retain less water than the thicker layer (15 cm).

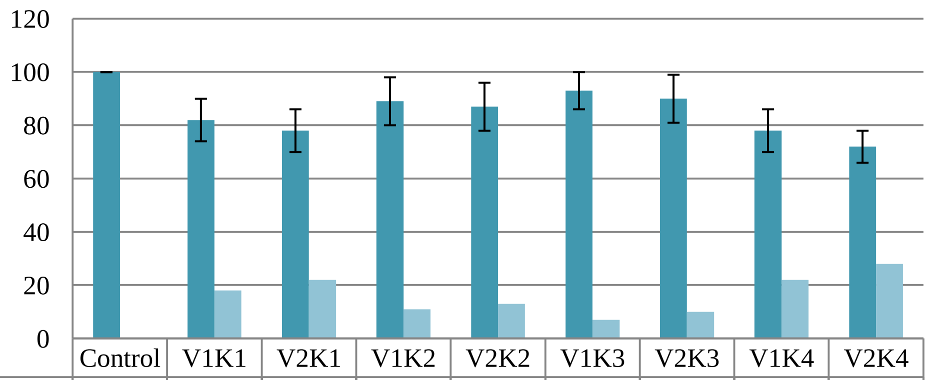
The following ranking was made (from higher water retention capacity to lower): V2K4 → V1K4 → V2K1 → V2K2 → V1K1 → V2K3 → V1K2 → V1K3. This value is influenced greatly by the physical characteristics of the soil. The highest values occurred in case of the substrates with higher soil content (K4 mixture: soil 50%, peat 20%, sand 15%, meliorite 15%; K1 mixture: zeolite 25%, clay granule 10%, sand (0/4) 20%, soil 40%, peat 5%). The substrate with lowest soil content had lower water retention capacity (K3 mixture: ground brick 25%, ground ytong 25%, peat 15%, zeolite 20%, meliorite 15%) **(Figure 7.).**



	Control	V1K1	V2K1	V1K2	V2K2	V1K3	V2K3	V1K4	V2K4
Water passing through (%)	100	48	45	51	47	63	49	44	32
Retained percolation water (%)	0	52	55	49	53	37	51	56	68

Figure 7. The average amount of water passing through (%) and retained percolation water (%) in the different combinations of substrate mixtures and layer thickness (vegetation period from March to September) (2012.03-2015.03)

Results of the samples taken after the vegetation period showed similar tendencies. The substrates with the higher soil content had higher, while those with the lower soil content and bigger fractions had lower water retention capacity. The following ranking was made (from higher water retention capacity to lower): V2K4 → V1K4, V2K1 → V1K1 → V2K2 → V1K2 → V2K3 → V1K3 **(Figure 8.)**



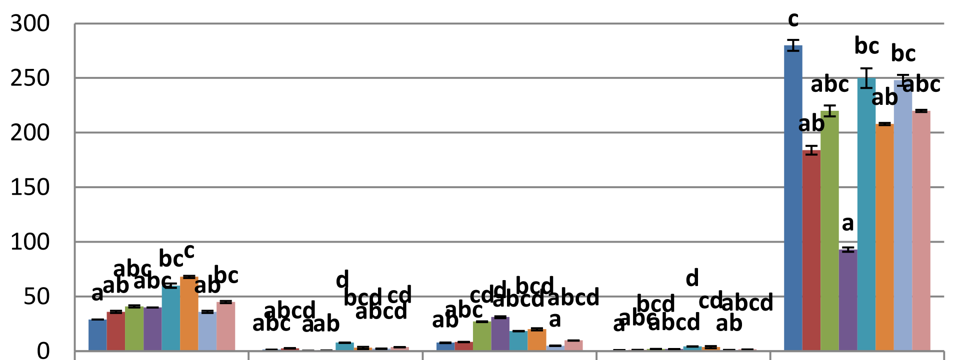
	Control	V1K1	V2K1	V1K2	V2K2	V1K3	V2K3	V1K4	V2K4
Water passing through (%)	100	82	78	89	87	93	90	78	72
Retained percolation water (%)	0	18	22	11	13	7	10	22	28

Figure 8. The average amount of water passing through (%) and retained percolation water (%) in the different combinations of substrate mixtures and layer thickness (outside the vegetation period) (2012.03-2015.03)

4.3. Results of the qualitative and quantitative measurements of substrate

4.3.1. Results of the general physical investigation of substrate mixtures

The general investigations of substrate mixtures were conducted two times, at the time of deployment and at the end of the experiment, three years later. The columns by each other shows the comparison of each substrate mixtures (K1, K2, K3, K4), respectively, in three different years (2012 and 2015) **(Figure 9).**



	Stiffness (KA)	Humus %(m/m)	Clay and silt %(m/m)	Hygroscopy (hy1)	Water capillary rise (5h) mm
K1_2012	29	1.28	7.68	0.935	280
K1_2015	36	2.67	8.4	1.176	184
K2_2012	41	0.36	26.99	2.055	220
K2_2015	40	0.68	31.1	1.845	93
K3_2012	60	7.74	18.38	4.3	250
K3_2015	68	2.99	20.03	3.693	208
K4_2012	36	2.26	4.97	1.142	248
K4_2015	45	3.66	9.75	1.591	220

Figure 9. Mean values, standard deviation, and homogenous and heterogeneous groups of physical parameters of substrate mixtures

As a tendency it was observed, that stiffness (KA) typically increased, clay and silt content (%(m/m)) increased, while water capillary rise (5h, mm) decreased in case of every substrate mixture in the examined time period. The rise of clay and silt content illustrates, that the mechanical composition of substrate mixtures change over years; the percentage of 0.02 mm and smaller particles will increase.

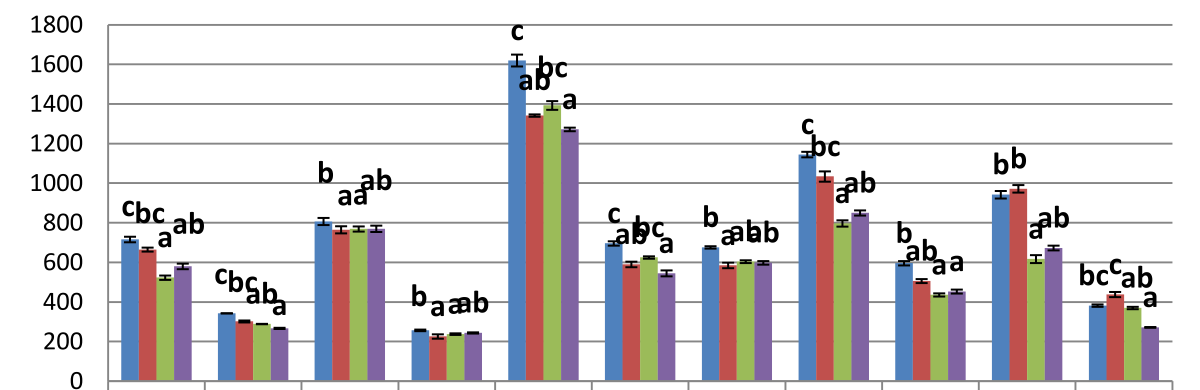
The decrease of **water capillary rise** (5h, mm), however indicates, that the changes in the capillary ruin the water regime and water uptake of media mixtures. This critical change causes that the plants on the extensive green roof can access less water. The average water capillary rise of K1 media mixture significantly decreased (280 mm→184 mm), which can be explained by the compaction of the substrate containing high amounts of soil. The substrate mixture K2 showed the same compaction phenomenon, its average water capillary rise (5h) decreased significantly (220 mm→93 mm). The zeolite fractions of K2 mixture are prone to compaction, which was justified by personal perceptions as well. In case of K3 and K4 no significant differences (α=0.05) were given between the investigated parameters. Stiffness (K_A) increased in every case, except that of K2 substrate mixture, which basically kept the initial level. The increase can be explained with the fact, that substrate mixtures containing organic matter (soil, peat) become more porous and dry, than the K2 substrate mixture containing only zeolite. The zeolite is able to keep water. (The Arany stiffness value shows the amount of water, which makes 100g of soil pulpy but not fluidal). In general, stiffness shows consistence rather with the clay content of the soil (the higher the clay content is, the higher the Arany stiffness value). In case of the investigated media the increase is in consistence with clay content rise, but with the compaction of substrate mixtures.

The **humus content** (m/m) characterizes the organic matter content of substrate mixtures; the increase in case of K1, K2, and K4 substrate mixtures can be explained by the dissolution of humus materials from the planting substrate of plants to the substrate mixtures. In case of K3 substrate mixture a large decrease was observed, which can be explained by the oxidation of the peat in the substrate mixture. **Clay and silt content** % (m/m) It decreases in case of K1 and K2, while it increases in K3 and K4 substrate mixtures, which indicates that higher number of components and smaller fraction size causes the increase of the percentage of 0.02 mm and smaller sized particles in the substrate mixture. **Hygroscopic** (h_y1) values shows, that it increases in case of those substrate mixtures (K1, K4), which have the best water keeping capacity. The hygroscopic value is in coherence with stiffness value.

When **comparing the years** the K1 substrate mixture showed the lowest stiffness value, K3 substrate mixture gave the highest humus percentage, K2 resulted the highest clay and silt content, and K1 reached the highest water capillary rise results. In contrast with this, the ranking has changed in 2015. The lowest stiffness value was given by K1 substrate mixture, the highest humus content was shown by K4 substrate mixture, the highest clay and silt content resulted by K2 substrate mixture, the highest hygroscopic value was given by K3 substrate mixture, while the highest water capillary rise was shown by K4 substrate mixture.

4.3.2. Specific physical investigation of substrate mixtures

The specific investigations of substrate mixtures were conducted two times, when the deployment happened and when the experiment has finished three years later. It is practical to review and evaluate the pairwise comparison of special physical parameters – loose/m, loose/v, dust/m, dust/v, mix/m, mix/v, water/m, water/v, susp/m, susp/v, wet/m, wet/v – by substrate mixtures **(Figure 10).**

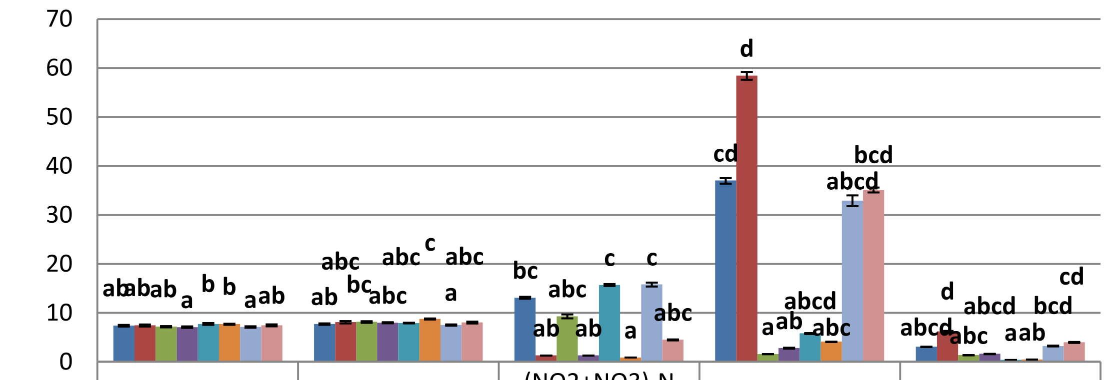


	loose/m	loose/v	dust/m	dust/v	mix/m	mix/v	water/m	susp/m	susp/v	wet/m	wet/v
K1	716	343	807	257	1620	696	676	1145	596	942	382
K2	665	302	765	226	1342	590	585	1034	506	972	438
K3	523	289	769	238	1393	625	604	797	436	617	370
K4	580	267	770	244	1272	545	598	850	453	673	272

Figure 10. Mean values, standard deviations, and homogeneous and heterogeneous groups of the specific physical parameters of substrate mixtures (2012.03)

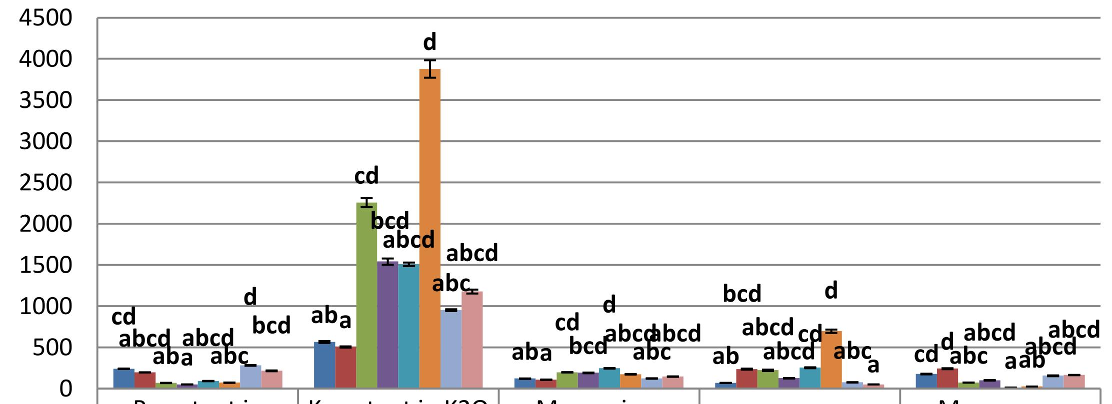
4.3.3. Results of the general chemical analysis of substrate mixtures

The special investigations of substrate mixtures were conducted two times, at the time of deployment and three years later at the end of the experiment. It is practical to review and evaluate the pairwise comparison of special physical parameters – pH (KCl), pH (H_2O), water soluble total salt % (m/m), total carbonate content in $CaCO_3$ equivalence % (m/m), sodium alkalinity % (m/m), (NO_2+NO_3)-N (mg/kg), P-content (in P_2O_5 equivalence (mg/kg)), K-content (K_2O-ben equivalence (mg/kg)), Mg-content (mg/kg), Na-content (mg/kg), Zn-content (mg/kg), Cu-content (mg/kg), Mn-content (mg/kg) – by substrate mixtures and by years as well **(Figure 11, Figure 12).**



	pH (KCl)	pH (H2O)	(NO2+NO3)-N mg/kg	Zink mg/kg	Coper mg/kg
K1_2012	7.39	7.72	13.1	37	3.08
K1_2015	7.44	8.1	1.3	58.4	6.21
K2_2012	7.19	8.15	9.3	1.6	1.38
K2_2015	7.1	8	1.3	2.8	1.62
K3_2012	7.75	7.94	15.7	5.8	0.4
K3_2015	7.69	8.77	0.9	4.1	0.47
K4_2012	7.13	7.53	15.8	32.9	3.25
K4_2015	7.47	8.04	4.5	35.1	3.98

Figure 11. Mean values, standard deviations, and homogeneous and heterogeneous groups of the general chemical investigations of substrate mixtures



	P content in P2O5 eq. mg/kg	K content in K2O eq. mg/kg	Magensium mg/kg	Natrium mg/kg	Manganese mg/kg
K1_2012	242	567	122	70.5	178
K1_2015	198	506	109	237.2	243
K2_2012	70	2258	199	223.1	74
K2_2015	52	1542	192	126.4	102
K3_2012	93	1509	247	254.5	12
K3_2015	73	3879	175	697.2	26
K4_2012	283	953	124	77.1	157
K4_2015	217	1179	147	52.1	166

Figure 12. Mean values, standard deviations, and homogeneous and heterogeneous groups of the general chemical investigations of substrate mixtures

With regards to pH (KCl) values an increase can be observed in case of those substrate mixtures (K1, K4), which contain soil, while those substrate mixtures containing mainly inorganic components show a decrease in pH values. The (NO_2+NO3)-N content was decreased in case of all four substrate mixtures due to the N utilization of plants. The zinc, copper, and manganese content is increasing in every case, which can be explained by the fact, that the common salts of these microelements belonging to cations are less soluble in soil solutions, therefore are inaccessible for plants; here the components of the substrate have importance in plant development. An exception is K3 substrate mixture, which shows a decrease in zinc content. The P-content decreased in case of all substrate mixtures, which can be explained by the P utilization of plants (e.g through photosynthesis) The K-content is decreasing in case of K1 and K2 substrate mixture, which can also be explained by the K utilization of plants (defines the osmotic potential of cells, the turgor of plant cells and tissues). However, in case of K3 and K4 the amount of K is increasing, which can be explained with the brick and ytong content in K3, and with the meliorite content in K4. The decrease of Mg in substrate mixtures is in correlation with the Mg usage of plants, as magnesium is the central component of chlorophyll (takes part in photosynthesis, in biosynthesis of amino acids and proteins). The magnesium content is decreasing in case of K1, K2, and K3, while it decreases in case of K4. The Na content is increasing in case of K1 and K3 substrate mixtures, and decrease in K2 and K4 substrate mixtures which can be explained by the differences of leaching.

4.3.4. The rate and curve of substrate mixture compaction

As a summary it can be concluded, that the compaction of investigated media can be explained by decomposition models. The general decomposition model of the investigated media is the following: $p_1+p_2*(1-exp(-p_3*time))$, where p_1 is the starting value (e.g 10 or 15 cm), p_1+p_2 is the compaction limit value, p_3 is the speed of compaction, and time is the number of days passed by from the first measurement. The compaction of the investigated substrate can be characterized by the initial thickness of the media, by the compaction limit values, and by the speed of compaction. The relatively faster compaction rate is indicated by higher p_3 values, while the relatively slower compaction rate is indicated by lower p_3 values. It can be concluded, that media with lower thickness (10cm) have lower decrease in value, while thicker media (15cm) have higher compaction in value. The statistical model regressions describing the compaction, the estimation of model coefficients, the regression diagnostics and criteria investigations were accepted as satisfactory *(Table 4).*

Table 4.Compaction curves and rates of substrate thickness on the investigated extensive experimental roof in combination with substrate mixtures

Thickness and substrate mixture combination	**Statistical curve**	**Estimation of the deterministic coefficient**	**Substrate tihickness (deployment and last measurement (cm))**
V1K1	y = 9.976 + (-0.646) * (1-exp (-0.001*1095))	$R^2 = 0.992$	10→9.500cm
V2K1	y = 15.014 + (-6.290) * (1-exp (-0.003*1095))	$R^2 = 0.996$	15→9.150cm
V1K2	y = 9.968 + (-2.571) * (1-exp (-0.001*1095))	$R^2 = 0.996$	10→8.075cm
V2K2	y = 15.063 + (-11.285) *(1-exp (-0.001*1095))	$R^2 = 0.996$	15→9.025cm
V1K3	y = 9.952 + (-2.490) * (1-exp (-0.001*1095))	$R^2 = 0.996$	10→8.500cm
V2K3	y = 15.483 + (-18.213) * (1-exp (-0.001*1095))	$R^2 = 0.981$	15→7.675cm
V1K4	y = 9.913 + (-2.390) * (1-exp (-0.003*1095))	$R^2 = 0.979$	10→7.500cm
V2K4	y = 14.881 + (-6.770) * (1-exp (-0.002*1095))	$R^2 = 0.997$	15→9.425cm

4.4. Results of the statistical analysis of green roof cadastral

As a results of the research, analyzing the data of the database it can be concluded, that in Hungary a **total of 395678.6 m^2** green roof has been built until 15 March 2015, from which 134251.9 m^2 (33.92%) was designed as extensive, while 261426.7 m^2 (66.08%) was designed as intensive green roof. Below the mathematical modelling of the quantitative changes of the three green roof types is demonstrated in the investigated period (1991-2015). By the illustration of the points I assumed, that the curve adjusted to the data has a bi-logistic character (Perrin, 1994). The adjustment of the model to the data was conducted by a bi-logistic model. The statistical model regressions describing the spreading of green roofs, the estimation of model coefficients, the regression diagnostics, and criteria investigations were accepted as satisfactory. I justified, that bi-logistic mathematical models are appropriate for describing the quantitative change of green roof deployment **(Figure 13, Figure 14, Figure 15**).

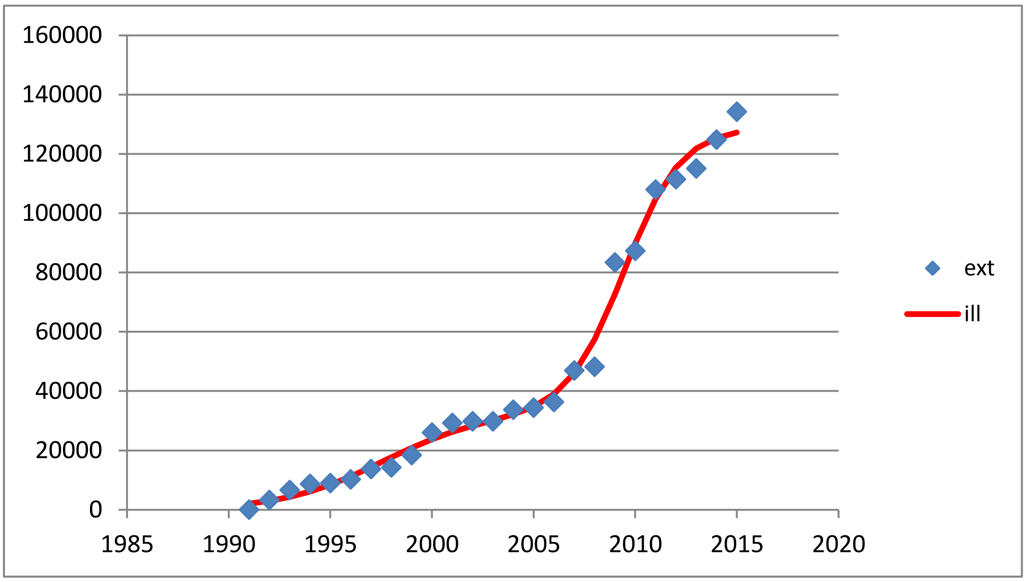


Fig.13. The size of established extensive green roofs (m²) and the bi-logistic mathematic model

The size of established extensive green roofs (m²) shows different levels of variation over the investigated period (1991-2015). The extensive green roofs increased relatively slowly between 1991 and 2006 in Hungary. In the last years of this period some kind of saturation can be observed. The signs of the change in development rate appeared in 2006, but the real breakthrough was brought by 2009 and 2011. With the analysis of incoming cadastral data, it is obvious that these outstanding growth values were given by major projects of Budapest funded by the European Union: Budapest Central Sewage Site (2009), Terminal station of metro M4 Kelenföld (2011).

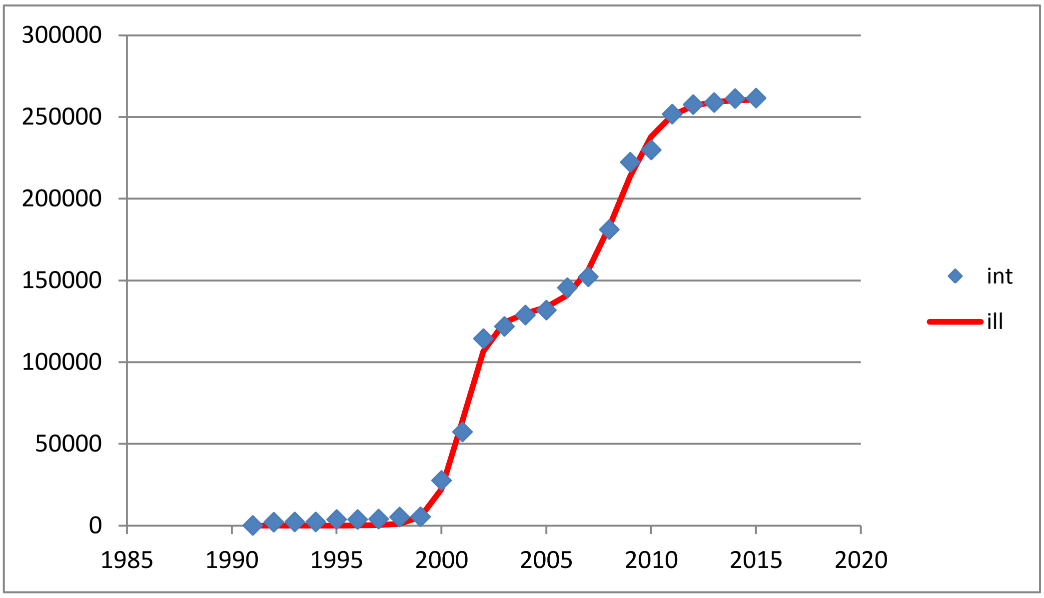


Fig.14. The size of established intensive green roofs (m²) and the bi-logistic mathematic model

The size of established intensive green roofs (m^2) shows different levels of variation over the investigated period (1991-2015). There was a minimal increase of intensive green roofs between 1991 and 1999. The growth rate was outstanding in 2000-2002, in 2008-2009, and in 2011, while between 2002 and 2005, in comparison with the preceding and subsequent period, the rise is rather slow, a kind of saturation can be observed in this period. In the first few years after the regime change, parallel with the introduction of market investors, the intensive green roofs of the first large shopping plazas were deployed between 2000 and 2002: Nyugati City Center (West End) (2000), MOM Park offices and residential buildings (2001), Ázsia Center (2002). Between 2008 and 2009 the intensive green roofs built onto the top of business centers, wellness hotels and modern residential facilities contributed to the increase of the area of intensive green roofs: Millennium Offices (2008), Egerszalók Wellness Hotel (2008), Sárvár Wellness Hotel (2008), Marina Part Residential Park (2009), Corvin Sétány Business Center (2009), Capitals Square (2009), Haller Gardens (2009), Oxygen Wellness (2009). In 2011 the rise in the size of intensive green roofs was obviously given by the intensive green roof of KöKi Terminal and Shopping Center. Another saturation process can be observed after 2011.

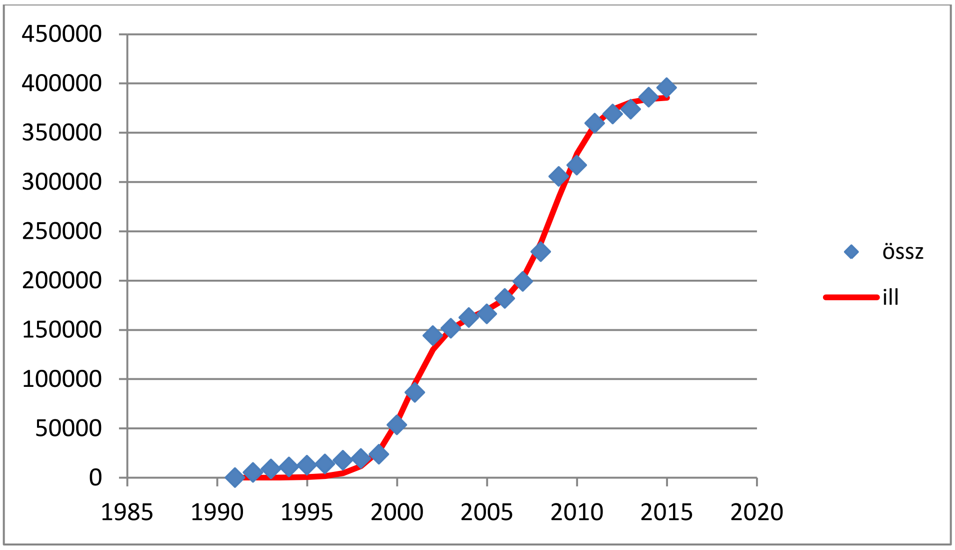


Fig.15. The total size of deployed green roofs (m^2) and the bi-logistic mathematic model

The bi-logistic mathematical model based on the incoming cadastral data provides a theoretical possibility to the prediction of values. However, it would be irresponsible to forecast based on the present tendencies, as the precise estimation of future cases is less possible, due to the highly variable characteristics of incoming parameters; furthermore, it cannot be justified, that the past tendencies will be valid in the future as well.

5. New scientific results

1. My investigations justified, that in extensive experimental conditions the species *S. album, S. hybridum,* and *S. spurium* develop significantly higher numbers of stomas, in contrast with the control species.

2. I characterized the antioxidant capacity of *Sedum* (*S. album, S. hybridum, S. reflexum, S. spurium)* species investigated on the extensive experimental roof with the parallel use of several analytical methods. By the consensus of the methods a clear ranking was idenitified: *S. hybridum, S. spurium, S. reflexum, S. album.* Among the antioxidant capacity measuring methods based on similar methodology a strong significant correlation was identified (FRAP−CUPRAC (0.958), FRAP−TPC (0.881), CUPRAC−TPC (0.814)).

3. At the first time, my experiment justified, that the growth of the investigated *Sedum* species (*S. album, S. hybridum, S. reflexum, S. spurium)* on the combination of the investigated substrate mixtures and thickness can be described by non-linear regression models. Every substrate mixtures have significant effect on the speed of the growth in case of all species. Substrate mixtures have significant effect on the growth size (diameter) of species, except in the case of *Sedum spurium*. Substrate mixture thickness have no significant effect on the speed of the growth.

4. I justified, that with the combination of element analytical investigation of percolation water and SRD methodology a significant ranking can be created, according to the extent of environmental impact. The percolation waters leaking through the newly established green roofs have a higher environmental impact, as three years later the filtering effects of substrate mixtures become dominant.

5. My experiment justified, that water holding capacity greatly depends on the constituents of the substrate mixtures, on the thickness, and on the seasonality. I justified, that the compaction of the investigated media can be described by decomposition models. The statistical model regressions describing the compactions, the estimation of model coefficients, the regression diagnostics and criteria investigations were accepted as satisfactory

6. With my research activity I created the cadastral of green roofs established in Hungary. Based on this, a total area of 395678.6 m^2 (extensive 134251.9 m^2, intensive 261426.7 m^2) green roof has been built within the investigated period of 1991-2015. I justified that bi-logistic mathematical models are appropriate for describing the quantitative tendencies of green roof establishment.

6. Conclusions and suggestions

Overall, it can be concluded that in extensive conditions the average number of the stomas of *Sedum hybridum, Sedum album, Sedum spurium* species were higher, than those of the control plants grown in open field conditions. In order to clarify, whether the tissue structure of the leaf or stem changes of a certain *Sedum* species in extensive conditions, more experimental locations should be involved, where sampling can be designed parallel, at the same time, following the good practice of statistical sampling.

By the measurement of color components I identified characteristic patterns of the identified *Sedum* species. The highest amount was reached by chlorophyll-a, followed by chlorophyll-b, and carotenoids. After investigating the tendencies characteristic to the species, the following ranking was created, starting from the highest: *S. hybridum, S. spurium, S. album, S. reflexum.* The chlorophyll-a value of *S. hybridum* control was significantly (α=0.05) the highest. My results are in agreement with international literature data; chlorophyll-a content, being characteristic to species, indicates the good physiological condition of the plant (Lichtenthaler, 1998). In comparison with the control sample of *S. hybridum*, the leaves of plants on the extensive roof, exposed to drought stress, typically have lower chlorophyll content (Gupta and Berkowitz, 1988). According to the measured values, the second highest chlorophyll-a content, the highest growth speed and diameter was reached by *S. hybridum* and K4 combination among different substrate mixture combinations.

Based on the consensus of antioxidant capacity measurements (TPC, FRAP, CUPRAC, DPPH), the following pattern was given with regards to the species, starting from the highest: *Sedum hybridum, Sedum spurium, Sedum reflexum, Sedum album.* The antioxidant capacity of *Sedum* species is presumably in strong correlation with the drought tolerance ability of species. For the objective answer of this scientific question, I suggest such an experimental design in the future, where the antioxidant capacity would be measured before and after a drought period, in several repetitions and with several methodologies. Where the change is the lowest in comparison with itself (relatively the lowest) the effect of drought stress is the lowest on that plant.

Based on my experiment, *Sedum album* has the best stress tolerance, having the lowest antioxidant capacity. In further studies it would be practical to compare the same species with antioxidant capacity measurements based on different mechanisms. It is suggested to prepare assays working with link analytical systems in a more detailed evaluation, especially with the application of HPLC-DAD-ESI-QTOF system, which provides an acceptable selectivity to the separation and identification of polyphenols, or of the application of standard compounds of polyphenols. It is also suggested to explore the enzymatic protection systems of the investigated plants in further studies.

In my work I justified, that the growth rate of investigated plants (*Sedum album*, *Sedum hybridum*, *Sedum reflexum*, *Sedum spurium*) are not linear, which data are provided for the combinations of substrate mixtures and thickness values. The *Sedum hybridum* and *Sedum album* species can be characterized with the highest growth rate and diameter. The total surface covering was reached in 20 months in case of K1 and K4 substrate mixtures. It is important to mention, that *Sedum hybridum* and *Sedum album* species had a strong weed suppressing ability on both four substrate mixtures. This result shows, that these two species are suggested to choose in a given substrate mixture. It obviously requires further studies to examine the performance of these two species in different climatic conditions of Hungary. It is instructive, that the rate of growth was not influenced by the thickness of the substrate mixtures significantly. A possible reason could be the fact that extensive green roofs are designed for more than 15 years lifetime, therefore the objective investigation of this question requires an experimental design planned for more than 3 years; the effect of substrate mixture thickness has to be re-examined with statistical methodology.

The element analytical identification of percolating waters has a key role in defining the contaminating/filtering effect of substrate mixtures on precipitation. Based on the first and last results of percolating water analyses, that the contamination was decreased almost in every cases, while the filtering effect mainly increased. However, the effect of substrate mixture thickness is well demonstrated on the results: in the same substrate mixture, with a thinner layer the amount of filtered elements is lower. Therefore it is advised to choose a thicker layer for an extensive green roof. I also justified, that the water holding capacity depends firstly on seasonality, secondly on the water uptake and holding capacity of substrate components, thirdly on the thickness of substrate mixtures. The more organic matter the substrate mixture contained, the highest the water holding capacity were. The role of species in water holding capacity cannot be investigated in this experimental design.

The nutrient uptake of plants on the extensive green roof is greatly influenced by the chemical and physical properties of the substrate mixture, and by the changes of them in time, which has to be taken into consideration when designing a green roof.

By summarizing the multi-aspect (growth, environmental impact of percolation waters, precipitation holding, etc.) evaluation of media, the following conclusions can be drawn: the growth rate and diameter of plants was the highest on K4 substrate mixture, regardless to substrate thickness. With regards to the environmental impact of percolation waters, until the end of the experiment V2K4 substrate thickness and substrate mixture combination gave the element analytical results most similar to that of the rainwater. From the point of water holding capacity, the combination of V2K2 with 15 cm thickness could hold the highest amount of water. In total, the best choice is the V2K4 substrate mixture, based on the parameters, environmental factors and in the time period of the experiment.

With my research activity I created the green roof cadastral of Hungary. Based on the evaluation of this, a total of 395678.6 m^2 green roof has been built, from which 134251.9 m^2 (33.92%) is an extensive, while 261426.7 m^2 (66.08%) is intensive green roof. Based on the results the amount of extensive green roofs is half as much as that of the intensive green roofs. This could have evolved mainly by the regulation of OTÉK, which defines that a *„the extensive, single floor green roofs with 8-20 cm soil layer or with light structured soil (substrate)"* can be included into green surface replacement only in 15%, in contrast with the 40-75% of intensive green roofs.

Currently the cadastral contains basic information about the existing green roofs (designer, constructor, investor, location, type, size, year of construction, irrigation, maintenance). The advantage of the database is the ability to expand according to further purposes and by professional consensus. The accuracy of cadastral information can further be improved by the integration of green roof construction permit data of the local governments and by the inspections of declarations on the spot. The energetic, water utilization, economic, ecological, and landscape effects of green roofs are known for professionals. For the extension in Hungary it is advised to integrate the experiences of national incentive systems, which are based mainly on indirect and direct subsidies, or on compulsory legal rules. Besides quantity, quality should also be highlighted, in which quality control has a key role. Unfortunately, the quality of existing green roofs is worsened by the fact, that, according to the regulation, quality controllers having a key role in final inspection should be qualified as architect. No knowledge on botanics, plant physiology, ornamental plants, horticulture or landscape ecology is required. As a solution I suggest the reform of the regulation and the initiation of the education specialized for green roof establishment.

Publications

Published in referred (IF) journals
A. Szőke, V. Losó, L. Sipos, A. Geösel, A. Gere, Z. Kókai (2012): The effect of brand/type/variety knowledge on the sensory perception. *Acta Alimentaria*, (Suppl. 1) pp. 197-204. (IF=0,379).
Published in other Hungarian journals (HAS listed)
A. Szabó, A. Geösel, Z. Kókai, Cs. Orbán, K. Töreki, **A. Szőke** (2016): Antioxidant activity as indicator of UV radiation and other abiotic stress factors on *Agaricus bisporus* (Lange/Imbach) and *Sedum hybridum* (L.) *Acta Universitatis Sapientiae*, (accepted: 08. 09. 2015). *In press*
Conference abstracts (Hungarian)
Szőke, A., Gerzson, L., Forró, E., Erdélyi, É. (2011): Extenzív zöldtetőn alkalmazott Sedum fajok teljesítményének értékelése Sedum-ex talajkeverékben. IX. Magyar Biometriai, Biomatematikai és Bioinformatikai Konferencia, 2011. július 1., Budapest. p. 71.
Szőke, A., Gerzson, L., Forró, E. (2012): Extenzív zöldtetők termesztő közegeinek kritikus paraméterei, Talajtani Vándorgyűlés Miskolc, 2012. augusztus 23-25. pp. 67-68.
Szőke, A., Gerzson, L., Forró, E. (2012): Közegkeverékek jellemzése csurgalékok vízparamétereinek monitorozásával, extenzív zöldtetőkön, Talajtani Vándorgyűlés Miskolc, 2012. augusztus 23-25. pp. 68.
Szőke, A., Gerzson, L., Forró, E. (2012): Kísérleti extenzív zöldtetők az energiahatékonyság növelésében. A Fenntarthatósági Innovációs Technológiai Centrum (FITC) a „Baross Gábor - Napház Középület Program az Észak-magyarországi régióban" című (KRNKP_09) projekt keretében „Az energiahatékonyság növelése az észak-magyarországi régió közintézményeiben” című tudományos konferencia Károly Róbert Főiskola, Gyöngyös, 2012. szeptember 25.

Conference abstracts (English)
A. Gere, A. Györey, V. Losó, **A. Szőke**, S. Kovács, Z. Kókai, L. Sipos (2013): Comparison of mapping methods: PARAFAC and PCA in horticultural and food sciences. 4th MoniQA International Conference, 26 February – 1 March, 2013, Budapest, Hungary. p. 115.
Conference proceedings ('full paper')
A. Szőke, T. Mátyás, D. Szabó, L. Gerzson, E. Forró (2013): Method for the rapid determination of soil physics parameters of extensive green roofs. 12th Wellmann International Scientific Conference. 25th April, 2013, Hódmezővásárhely. pp. 62-68.
A. Szőke, D. Szabó, E. Forró, L. Gerzson (2013): Developing Hungarian cadastral database of green roofs and the trends in green roof construction industry. 12th Wellmann International Scientific Conference. 25th April, 2013, Hódmezővásárhely. pp. 455-460.
Book
Szőke, A. (2015): Magyarországi zöldtetők elterjedésének feltételei és lehetőségei. Sedum Kft, ISBN 978-963-12-3994-2 pp. 1-117.