PhD THESIS

Research into the characteristics of green roofs and the effect of culture substrate on vegetation development

(ABSTRACT)

PhD Student **Mihaela Simona Varvară (Rebrean)**

Scientific Coordinator **Prof.univ. dr. Marcel Dîrja**

ABSTRACT

This doctoral thesis examines some of the characteristics of green roofs as well as the effect of the culture substrate on vegetation development. Given the complexity of these structures and their reliance on a number of interdependent factors (building strength, waterproofing, climate, substrate, vegetation, irrigation systems), this paper's research addresses several variants. One aspect concerns the substrate composition, while another concerns the quantity and quality of water leaks. The primary goal of the study was to collect additional data in order to make green roofs as adaptable and accessible to our climate as possible, as well as to provide a comprehensive picture of their construction and implementation in Romania.

The paper is presented in 147 pages, plus abstract, divided into 7 chapters, with 17 graphs, 70 figures, and 48 tables. It was necessary to consult a number of 144 bibliographical sources, both domestic and international, in order to develop the doctoral thesis.

Chapter 1, "The State of International and National Research on Green Roofs," presents a bibliographic study that is primarily focused on international literature but also includes data from national scientific literature. The current international and national status of green roofs, the definition and types of green roofs, the components of green roofs, the comparison and maintenance of green roofs, the benefits and legislation on green roofs are all addressed in this study.

Green technology, as represented by green roofs and vertical walls, is gaining traction and popularity due to its numerous environmental and social benefits, including improved air quality, reduced gas and pollution emissions, improved aesthetic qualities, and energy savings due to better insulation and rainwater management. (CHENG et al., 2010; WOLVERTON & WOLVERTON, 1993; LIU & BASKARAN, 2003; OBERNDORFER et al., 2007; SANTAMOURIS et al., 2007; CURRIE & BASS, 2008). Noi cercetări se fac pentru a identifica plantele sustenabile pentru acoperişurile verzi umbrite. Se fac cercetări şi asupra plantelor care oferă şi alte beneficii decât cele decorative cum ar fi: eliminarea nutrienţilor poluanţi din precipitaţii New research is being conducted to identify long-lasting plants for shady green roofs. Plants that provide other benefits than decoration are also being studied, such as the removal of polluting nutrients from precipitation (BUCUR et al., 2007) and the provision of habitat for insects and other animals. Green roofs continue to grow in number, with or without a standard. This increase can be attributed to improved education, information, and recommendations. (WARK & WARK, 2003).

The first chapter's subchapters are intended to provide current and focused information on green roofs, how they work, their components, benefits, and current legislation.

The importance of green roof research is justified in **Chapter 2 "Pursued Objectives."** One goal of this doctoral thesis was to create efficient models and general regulations for the implementation of green roofs in Romania, as well as to highlight their benefits. Therefore, our studies concentrated on the benefits of green roofs and the development of culture substrates suitable for these systems, both technically and visually. Several components of the extensive green roofs were monitored to provide a more complete picture, in order to observe and determine the development of different plant species depending on the composition of the substrate. Another aspect of the research was to determine the quantitative and qualitative water flow through the proposed areas, the source of water being rainwater, but also additional sources of water as a method of sustaining vegetation during the warmer months (of drought), in order to provide comprehensive data on the substrate's ability to retain and release micro and macroelements into the external environment as possible.

To achieve these objectives, the following four objectives were established:

O_1: air quality in terms of heat and humidity, with two graduations: traditional and green roof;

O_2: the roof's design from the standpoint of the substrate component, with three graduations: substrate 1 - 30% peat + 30% expanded clay + 30% perlite + 10% broken tile; substrate 2 - 50% peat + 10 expanded clay + 30% perlite + 10% broken tile; substrate 3 - 50% peat + 30% expanded clay + 10% perlite + 10% broken tile;

O_3: the development of vegetation on green roofs, with *Festuca*, *Poa* and *Lolium* grasses-turf;

O_4: the quantity and quality of water drained from green roofs as a potential source of pollution in the urban environment due to heavy metal leaks released in rainwater technical-municipal installations.

Chapter 3, "Particularities of the natural / artificial environment in which the experiment took place," describes the locations where the experiments were carried out, their natural characteristics and location, as well as the climatic conditions. The doctoral thesis was completed in two countries: Romania and Germany. The first part of this paper was carried out at the University of Agricultural Sciences and Veterinary Medicine in Cluj-Napoca, where a corresponding bibliographic study was carried out, with a focus on international literature but also including data from national scientific literature. The second part of the doctoral thesis was completed in Germany, in Neubrandenburg, at the Hochschule University of Applied Sciences, and in Romania, in Cluj-Napoca, at the University of Agricultural Sciences and Veterinary Medicine, and in Alba Iulia, at a private house.

To achieve the doctoral thesis objectives, the experiments were conducted in both stationary experimental conditions (on the roof of the Hochschule University of Applied Sciences in Neubrandenburg and in private gardens in Alba Iulia and Cluj-Napoca) and laboratory conditions. The green roof models in Cluj-Napoca and Alba

Iulia were designed to track the impact of meteorological conditions on the substrates as well as plant growth and development.

A comparative analysis was performed between these three locations in order to correlate the results obtained from the experiences that took place in the cities of Cluj-Napoca and Alba Iulia with the climatic data of the city of Neubrandenburg, Germany. This analysis was performed to observe the differences and climatic similarities with the purpose of determining whether the results obtained from the experiences made in Germany can also be applied in Romania.

Chapter 4 "Material and method". The use of recycled materials is a basic principle in the construction of green roofs (MELISSA CURIE & BIREN, 2004).

Three types of planting substrates were created to simulate a green roof system, which differ in composition, particle size, texture, porosity, and degree of compaction. The three types of planting substrates were created by combining various proportions of peat, expanded clay, perlite, and broken tile to produce substrates with varying water and nutrient retention capacities.

Two types of turf seed mixtures were used in the experiments: Finess and Thermal Force as well as two species of succulent plants: *Sedum* sp. And *Sempervivum* sp. The two groups of plants were chosen because they are the most common plants for green roofs and have the best aesthetic characteristics and environmental requirements. The two species of succulent plants are *Sedum sp*. with the variety *Sedum sarmentosum* and *Sempervivum sp*. with the varieties *Sempervivum tectorum* and *Sempervivum arachnoideum*.

A wide range of equipment was used to carry out the necessary experiments for this doctoral thesis, with the help of which data could be recorded and monitored. Only reagents of recognized analytical quality and distilled water or water of equivalent purity and without oxidants were used for the analysis of micro and macroelements, as well as heavy metals from runoff.

A subchapter refers to the setup of the experiments and the results obtained, and it includes a more detailed description of how each step was carried out and what materials, apparatus, and reagents were used.

Chapter 5 entitled **"Results and discussion**" includes the results obtained from the experiments carried out - an important point in terms of future research on the conditions of implementation of green roofs in Romania, with an exact application in Cluj-Napoca and Alba Iulia, but also with the possibility of expansion in other cities .

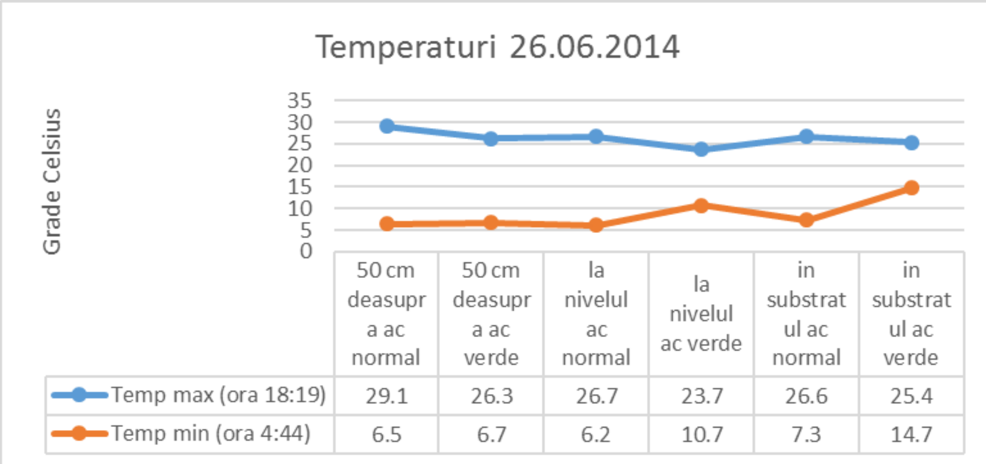


Chart. 5.1. Extreme temperatures on 26.06.2014 in Neubrandenburg
Sursa/ source: VARVARĂ şi colab.,2015a

According to the chart above, a maximum temperature of 29.1 ° C was recorded from the reference point on 06/26/2014 at 6:19 p.m., and the temperature difference between the traditional and green roofs is approximately 3 ° C, the same difference that was recorded on LOG 32 placed on the growth substrate and the one on gravel. The temperature difference between a traditional and green roof substrate is approximately 1 ° C. The minimum temperature difference between a traditional and a green roof is between 0.2 and 7.4 ° C, which means that the temperature on a traditional roof's gravel is lower at night than the temperature on a green roof's growing substrate.

The type of substrate also influences the quality and quantity of runoff (MORAN et al., 2005; TEEMUSK & MANDER, 2007; ALSUP et al., 2010). Following the experiments, it can be seen that the smallest amount of sand particles is found in substrate 1 (30% - peat, 30% - expanded clay, 30% - perlite, and 10% - broken tile) of 35.72 %, and the highest amount is found in substrate 2 (50% - peat, 10% - expanded clay, 30% - perlite, and 10% - broken tile) of 41.96%. The smallest amount of gravel was found in substrate 2 (50% peat, 10% expanded clay, 30% perlite, and 10% broken tile) of 34.75%, and the highest amount was found in substrate 3 (50 % peat, 30% expanded clay, 10% perlite, and 10% broken tile) of 48.13%. The main difference between them is due to the main composition of these varying substrates.

As shown in the graph below, after two months of experimentation, substrates 2 and 3 have a rising and covering rate of more than 65 percent, while substrate 1 has only 40 percent, indicating that the composition of the substrates is also very important for plant growth rate.

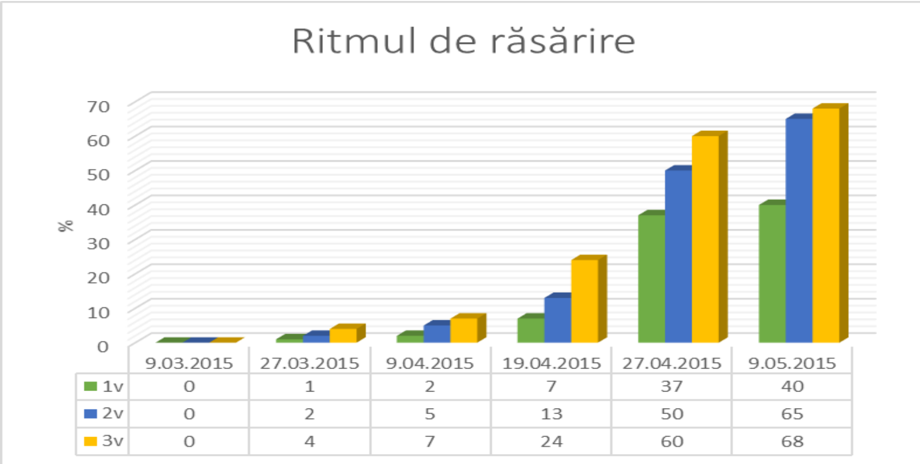


Chart 5.2. The rising rhythm of the lawn

Table 5.1. Green biomass compared to dry biomass

Substrat/ Substrate	Varianţa/ Alternative	%	Diferenţa/ Difference	Semnificaţia/ Meaning
B1A1	16.47	100.0	0.00	Mt.
B2A1	11.60	70.4	-4.88	0
B1A2	19.29	100.0	0.00	Mt.
B2A2	12.14	63.0	-7.14	00
B1A3	18.64	100.0	0.00	Mt.
B2A3	11.07	59.4	-7.57	000

DL (p 5%)=4.51 DL (p 1%)=6.83 DL (p 0.1%)=10.96

Note: B1A1 – substrat 1 x biomasa umedă; B2A1 – substrat 1 x biomasa uscată; B1A2 – substrat 2 x biomasa umedă; B2A2 – substrat 2 x biomasa uscată; B1A3 – substrat 3 x biomasa umedă; B2A3 – substrat 3 x biomasa uscată.

In substrates 2 and 3 the differences are distinctly significant compared to substrate 1 in terms of plant growth and development (biomass), respectively in substrate 1 between wet and dry biomass there is a difference of 4.88 g compared to the other two substrates where the difference is about 7 g.

The graph below shows that there is a statistically significant difference (a) between substrate 1 without vegetation but also with vegetation and substrates 2 and 3, without and with vegetation, which cannot be seen between substrates 2 and 3, without and with vegetation, where there is no statistical difference (b). There is no statistically significant difference (A) between substrate 1 with vegetation and substrate 1 without vegetation; the same is true for substrates 2 and 3, without and with vegetation.

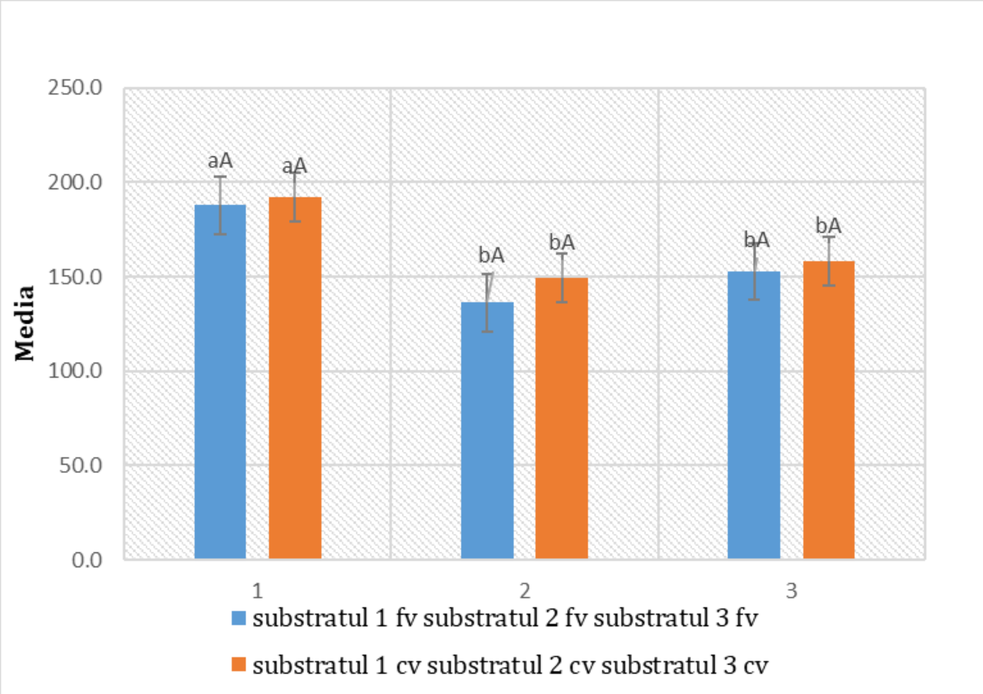
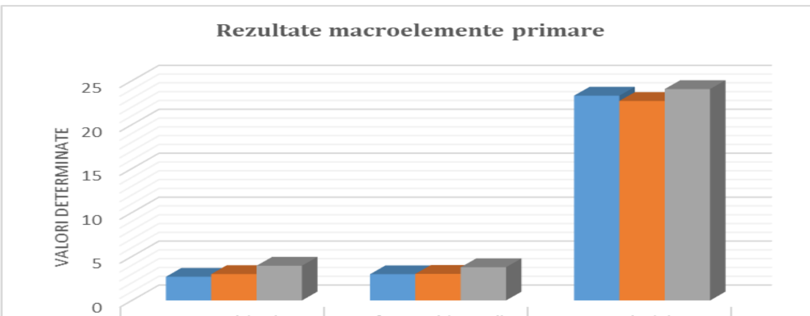


Chart 5.3. Leakage differences between substrates without vegetation and with vegetation



	Azot total (NT)	Fosfor total (Ptotal)	Potasiu (K)
1	2.7	2.985	23.3
2	3	3.025	22.7
3	3.95	3.78	24.05

Chart 5.4. Primary macroelement results

The results show that nitrogen and phosphorus have similar values in all three substrates, ranging between 2.7 and 3.95 mg/l, while potassium has very high values ranging between 22.7 and 24.05 mg/l.

According to graph 5.4, substrat 1 loses less azot and fosfor, respectively 2,7 mg/l and 2,985 mg/l, than substrat 3, which loses more, 3,95 mg/l azot and 3,78 mg/l fosfor. In terms of potasium, substrate 2 has a smaller loss of 22,7 mg/l than substrate 3, which has a larger loss of 24,05 mg/l.

Table 5.2. Influence of sampling period on substrate type and calcium and magnesium

Simbol/ Symbol	Concentrație/ Concentration [μg /l]	Procent (%)	Diferența/ Difference	Semnificația/ Meaning
B1A1C1	1.65	100.0	0.00	Mt./Control
B2A1C1	0.69	41.8	-0.96	-
B1A1C2	0.72	100.0	0.00	Mt./Control
B2A1C2	2.52	352.4	1.81	*
B1A2C1	1.24	100.0	0.00	Mt./Control
B2A2C1	1.82	146.8	0.58	-
B1A2C2	0.81	100.0	0.00	Mt./Control
B2A2C2	2.52	311.1	1.71	*
B1A3C1	1.45	100.0	0.00	Mt./Control
B2A3C1	1.04	71.7	-0.41	-
B1A3C2	0.69	100.0	0.00	Mt./Control
B2A3C2	2.24	326.3	1.55	*

DL (p5%)=1.39 DL (p1%)=2.41 DL (p0.1%)=4.93

Nota: A1 – substratul 1, A2 – substratul 2, A3 – substratul 3, B1- prima prelevare, B2 – a doua prelevare, C1 – Magneziu, C2 – Calciu

For all three substrates, magnesium loss exhibits statistically uncertain changes from one determination to the next (small losses), whereas the amount of calcium lost from one determination to the next does not (the amount of calcium increased significantly during the second determination for the same substrate).

Table 5.3. The influence of lost microelements

Nr. Crt	Varianta/ Alternative	Diferența/ Difference	Clasificarea/ Classification
1	C1	0.02	A
2	C2	1.63	A
3	C4	2.91	A
4	C3	36.59	B

Note: C1 – Cupru, C2 – Zinc, C3 – Fier, C4 – Mangan

When compared to the other three microelements (copper, zinc, and manganese) determined in water loss / leakage, iron is clearly significant (Table 5.33.)

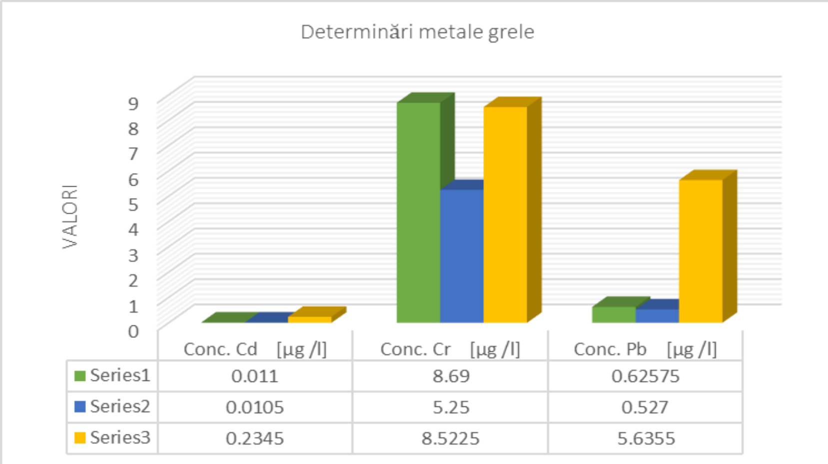


Chart 5.5. Result ofheavy metal determinations

According to the graph above (Graph 5.5.) The highest losses of cadmium (8.69 g / l), chromium (5.25 g / l), and lead (8.52 g / l) can be seen in substrate 2. Another observation is that the amount of lead lost in substrate 3 (5.63 g / l) is greater than the other two heavy metals, whereas substrate 1 is the only substrate that retains the greatest amount of heavy metals, with losses as follows: cadmium 0.011 g / l, chromium 0.0105 g / l, and lead 0.2345 g / l.

The results of the pH measurement show the following:

- nine samples have a low acidity;
- only two samples have a neutral pH;
- sample 7 has a high alkaline pH.

Chapter 6 "Conclusion and Recommendation". During the doctoral studies, the conclusions can be outlined based on the experiments carried out and the interpretation of the resulting data, after which some recommendations can be made to clarify and confirm the knowledge regarding green roof systems, the temperature and humidity differences between a traditional roof and a green roof, the culture substrates, the suitability of the vegetation, and the quality and quantity of water drained from a green roof.

The findings in this paper support previously published scientific studies on the temperature and humidity differences between a green roof and a traditional roof. Even though these experiments were conducted in Germany, in the city of Neubrandenburg, the results can be emphasized onwards and used to develop guidelines for the implementation of green roofs in Romania.

After analyzing the obtained results, the following conclusions can be drawn:

- A positive influence on the temperature and humidity inside a building with a green roof,
- the substrate composed of: 50% peat, 10% expanded clay, 30% perlite and 10% broken tile has the highest percentage of sand, so the passage of water through the substrate is much slower, while the substrate composed of: 30% peat, 30 % expanded clay, 30% perlite and 10% broken tile, has the lowest percentage of sand and the infiltration rate is higher, we can say that peat is the factor that influences the passage of water through the substrate
- the speed of water infiltration in the culture substrate is influenced by the composition of the substrate, respectively the sand and gravel particles, because the higher the sand content, the higher the soil permeability,
- The development of the studied plants: grasses with *Festuca*, *Poa* and *Lolium* species and succulent plants with *Sedum* and *Sempervivum* species, behave very well, which indicates a very good suitability of these species in the arrangement of green roofs
- in the substrate with a composition of 30% peat, the water losses are higher regardless of whether the substrate is covered or not with vegetation, compared to the substrates with 50% peat where the water losses from artificial rains are lower.
- Potassium is lost through rainwater much faster and in much larger quantities than nitrogen and phosphorus.
- the value of the losses of microelements in the water drained by precipitation through the substrate of a green roof system are higher in iron than in the other microelements studied, so that iron is the microelement that is lost the fastest, regardless of the substrate composition and timing of determinations, this may be due to the fact that iron is an element with variable states depending on physical, chemical and trophic factors.
- substrate 1 is the one that stores the best heavy metals and the losses are the smallest, while substrate 2 is the one that retains the least cadmium, chromium and lead letting them drain into the rainwater.

The research findings have resulted in the following recommendations:

- To achieve a perfect substrate for a green roof, granulometry computation must be performed, and in order to counteract the existing deficiencies, additional analyses will be performed, and these shortcomings will be eliminated.
- It is obvious that a green roof's natural growing environment will not completely solve the problem of water leaks from rainfall and must be combined with other measures to reduce these leaks, but the longer these plants delay water flow, the less the sewer system will suffer and reach overflow.

- It is advised to monitor the availability of nutrients for vegetation and to apply fertilizers based on the type of plants chosen for the green roof.

Chapter 7 entitled **"Originality and Innovative Contributions"** contains personal aspects brought to the specialized literature:

- Creation of a substrate suitable for an extensive green roof system;
- Study of the green roof design from the standpoint of substrate composition: granulometry, infiltration speed, maximum water retention;
- Analysis of vegetation development on a green roof, with a vegetal carpet consisting of grass-turf and succulents;
- Determination of the quality of the drained water on the green roof system with succulent plants by analyzing the primary macroelements: nitrogen (N), phosphorus (P), and potassium (K), as well as the secondary: calcium (Ca) and magnesium (Mg), of the microelements: iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn), but also heavy metals: Cadmium (Cd), Chromium (Cr) (Pb)

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