Testing the divergence of selected taxa of genus *Cotoneaster, Juniperus, Picea* and *Viburnum* – the influence of climate changes on intensive roof gardens

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ABSTRACT: The research has been conducted in several phases for 10 years on existing intensive roof gardens in the Trenčín district. The first phase was carried out within the GP 1/4419/47 *Adaptability of Cultural Vegetation in Consequence of Global Draining and Warming.* Roof gardens are a good place for simulating natural phytocenose sites that are able to accumulate rainfall without taking it to drainage. The second phase of research was conducted within a continuation of GP 1/1316/04, verifying xeric plants for conditions of changing climate in a urbanized environment on different construction systems. For a statistical evaluation it was necessary to select taxa in at least three roof gardens. The basic hypothesis was that all plants are conditionally suitable for roof gardens. Another assumption was that the maintenance of all roof gardens is uniform. Results have shown that some plants are more adaptable and drought-tolerant even if the maintenance of roof garden is not appropriate.

Keywords: test divergence; humidity; aridity; intensive roof gardens; growths; *Cotoneaster*; *Juniperus*; *Picea*; *Viburnum*

The lack of green areas in towns leads to the construction of new gardens on the roofs of buildings such as shopping centres, garages, undergrounds or residential buildings. Better construction systems of buildings as well as of roof gardens allow their better utilization in urbanized areas.

Natural materials such as gravel, sand, ground brick, or pumice stone were used in the first roof gardens. Today, these materials are supplanted by technically produced moulded plastics for water accumulation, often made of recycled raw materials or mineral substrates. Their use is ideal not only for their water absorption attributes, but also for their ability of water releasing, which is beneficial for the controlled ecological environment. As the technical problems were solved, especially by using waterproof and root-proof plastic foils, the attention focused on problems related to selection of the best fitting biological assortments for each climatic region.

It is not possible to choose only one suitable phytocenose because of aesthetical and compositional reasons. Another important problem is varying weather conditions with rapid changes of extreme temperatures during a day/year that are not repeated permanently. These climate periods are not predictable and as a result the plants can survive several years and then suddenly die. Their adaptation abilities are not so quick so they may not survive one extremely humid or dry period. It is not possible to take a working group of plants from one climatic region to another one with similar conditions. It is necessary to verify the long-term coexistence of plants in each specific climate environment by scientifically controlled experiments.

We can divide roof gardens into extensive and intensive. Extensive roof gardens are defined as simple systems with low layers and with low weight (up to 300 kN/m^2). They can also be defined as non-irrigated gardens, which has an influence on plant assortments depending only on local rainfall.

Intensive roof gardens are defined as systems with selected plants, trees and shrubs cultivated in a similar manner as in the ground spaces. Layers of intensive gardens are thick (more than 300 kN/m^2, occasionally even 2,000 kN/m^2). Roofs with such a capacity can be founded as ordinary gardens. Intensive roof gardens need intensive maintenance (except for areas with regular rainfall) and regular irrigation.

With respect to roof gardens designing Slovakia can be divided into five climatic regions:

1. Warm southern lowland areas with maize production, average temperature 9.5°C and average rainfall 450–550 mm.
2. Low hilly areas with cereal production, average temperature 8–9°C and average rainfall 550–650 mm.
3. Hilly areas with beet production, average temperature 7–8°C and average rainfall 650–750 mm.
4. Submontane areas with potato production, average temperature 6–7°C and average rainfall 750–850 mm.
5. Mountain areas without agricultural production, with average temperature lower than 6°C and average rainfall over 850 mm.

Drainage layers in the latter areas should be at least 0.2 m thick, consisting of coarse-grained materials (fraction 32–64 mm) for a sufficient effectiveness in case of intensive rainfalls. Plastic drainage layers should have rough leaks with rapid water outflow.

It is thus more effective to build roof gardens in lowland, low hilly or hilly areas; a thin drainage or hydro-accumulating layer able to cover the water demand of plants is sufficient there. The use of mineral substrates is ideal because of their water absorbing abilities and weed-control effect.

Plants for extensive roof gardens are selected from ecosystems of the surrounding area or areas with similar average temperature and rainfall. These roof gardens become balanced communities with minimal needs for maintenance. It can be a moss-stonecrop community (in humid areas with the rainfall of 800 mm per year), grass community with an admixture of low perennials, community of south oreophyte (in warm areas with average annual temperature above 8°C). In areas with a higher amount of rainfall, cover plants and mesophyte perennials can also be used; however the substrate thickness has to be at least 250 mm. The area of the garden can fulfil microclimatic functions, such as increasing humidity, catching dust and emission, as well as aesthetic and urbanization functions.

Plants for intensive roof gardens are selected according to altitude steps dependent on moistness and frost-resistance. It is especially necessary to select plants with the following attributes: root resistance to substrate overheating, plants with patulous roots, tolerance to windiness and radiation. The plants that are aggressive or invasive are not suitable. Roof gardens plans are made according to usual architectonic principles respecting the author and trends.

MATERIALS AND METHODS

Our research was aimed at roof gardens in Trenčín, Nemšová and Detva. The basic technology of all established roof gardens was identical, with similar plants. For testing it was possible to choose the same taxa from all roofs. Irrigation was realized on all roofs, as well; it was under the control of irrigation apparatus and it ran automatically. The basic hypothesis of the research was that all growth conditions on all researched roofs were the same. For a statistic evaluation it was important to grow at least three same taxa on each roof.

We chose seven roof gardens situated on three buildings as the research objects. An extensive analysis of all roof gardens preceded our research. This analysis was supported by a verification scale. All landscape elements were tested according to this scale (group-planting, ground-cover plants). The basic hypothesis was that all plants planted on the roofs are suitable for this type of planting. Our research revealed some differences between selected woody plants. The reaction of woody plants to climate changes was more or less positive. Plants that do not change their aesthetic or compositional aspect are important for this type of decorative use. A rapid accumulation of biomass is unsuitable because plants degrade soil, and need to be replaced fast. The replacement of a plant in a roof garden has to be done together with soil. This increases the upkeep costs.

For a narrow research we selected taxa, which were planted at least on three roofs. The first phase consisted of: *Juniperus chinensis* L. Old Gold, *Juniperus virginiana* L. Skyrocket, *Picea glauca* (MOENCH). VOSS. Conica, *Viburnum rhytidophyllum* HEMSL., *Cotoneaster dammeri* SCHNED. and *Cotoneaster salicifolius* FRANCH. Gnom, *Pinus mugo* TURRA. Some of these woody plants grew separately (*Juniperus virginiana* L. Skyrocket, *Picea glauca* (MOENCH). VOSS. Conica), some grew like ground-covers (*Juniperus chinensis* L. Old Gold, *Cotoneaster dammeri* SCHNED. and *Cotoneaster salicifolius* FRANCH. Gnom, *Pinus mugo* TURRA). For both these groups we chose specific research methods.

Annual shoots which grew as first behind the terminal shoot were measured on plants. We measured these shoots at the end of the vegetation period. Methods were different for separately-grown plants and for ground-cover plants. For separately-grown plants we selected two average plants in every roof garden. On every plant we measured five shoots from different parts of the plant (one from the top, but not the terminal shoot; one from the eastern part, one from the western part, one from the northern part and one from the southern part). Shoots taken from separately-grown plants were averaged; for the statistical evaluation we thus used only one, average value.

For ground-covering plants the method of measuring was different. We laid down a square (1 × 1 m) on the spread (a so-called Latin square). In this frame we selected a shoot. The selected shoot was the first one behind the terminal shoot. Measuring on spread was repeated until we had five entries. In case of deciduous plants *Viburnum rhytidophyllum, Cotoneaster dammeri* and *Cotoneaster salicifolius* not only the length of shoots was measured, but also the length and the width of the leaves (in the case of *Viburnum* we could do measuring *in situ*, in the case of other plants we had to cut the shoots and measure them in the laboratory). The length of the shoots was measured with precision to 1 mm, in case of *Cotoneaster* taxa with precision to 0.5 mm. The first phase of the research was conducted in 1999–2000, the second phase in 2004–2005. During the first phase it was possible to choose seven taxa of woody plants. During the second phase we did not find *Pinus mugo* in three roof gardens; therefore we continued the research only with six taxa.

Expected null hypothesis that all the roofs were irrigated equally was not statistically confirmed. Different lengths of shoots on the same plants and on different roofs showed to be the result. A diffusion analysis was used for basic resolution. It indicated significant differences between measured shoots. Differences between selected pairs of roofs were indicated by the Sheffe's test.

The analysis confirmed that some plants on roofs without adequate irrigation (this condition was due to a defect on irrigation system) had shorter shoots without change of appearance, while some other plants had shorter shoots, but their leaves turned yellow, leaves and shoots got dry, which resulted in a considerable change in their appearance; this change we observed distinctly on *Cotoneaster* taxon.

Two climatically different years could influenced the differences between plants. The first year (1999) was humid, whereas the year 2000 was arid. There was a marked difference in rainfall in summer months; winter months were balanced. The difference in the amount of rainfall in Piešťany, during the period IV–X, was 204 mm, in Vígľaš-Pstruša it was 268 mm.

As for climatic characteristics there were differences not only in the amount of rainfall but also in the average temperature during the vegetation period. In 1999 the average temperature during the vegetation period in Prievidza was lower by 0.1°C, in Vígľaš-Pstruša it was lower by 0.2°C.

Diffusion analysis of two-stage classification in case of interaction existence was used to exclude other interaction factors between the two tested years. Taxon *Picea glauca* Conica was used for testing, because it was suitable for this method. However, the interaction did not have the expected effect. Only different amounts of rainfall during the tested years were the result. The influence of humid and arid year was so strong that no other interaction was significant.

Deciduous plants reacted differently than conifers, and thus some additional methods were used for further research. Apart from shoots, also leaves, their amount, and the width and length of every leaf were measured on plants. The width and length was measured with the precision to 0.1 mm. The non-parametric test of average value hypothesis was used to compare the increase of leaf surface. *Cotoneaster dammeri, Cotoneaster salicifolius* and *Viburnum rhytidophyllum* were tested. These plants were tested in humid and arid years. In the case of *Cotoneaster dammeri* and *Cotoneaster salicifolius* significant differences were observed, whereas *Viburnum rhytidophyllum* seemed to be a stabile plant that is able to assimilate to changes. The difference was not significant even at a 95% expectation (level $\alpha = 0.01$).

RESULTS AND DISCUSSION

The taxa of woody plants that grew at least in three roof gardens were tested. The first phase consisted of: *Cotoneaster dammeri, Cotoneaster salicifolius* Gnom, *Juniperus chinensis* Old Gold, *Juniperus virginiana* Skyrocket, *Picea glauca* Conica, *Viburnum rhytidophyllum* and *Pinus mugo***.**

Pinus mugo was excluded from the second phase of the research, since it was no more found on three roofs. However it seemed to be a perspective woody plant for roof gardens as it is able to assimilate to changes without aesthetic deformation.

The measured shoots of each plant were statistically evaluated. The differences were found for each plant on different roofs. Some of these differences were significant, up to 99% of significance. The intention of selection of woody plants for intensive roof gardens was not the fast increase of biomass, but the appearance of a plant that can retain its form also in the case of potential climate extremes. The most stabile of all the studied plants seems to be *Juniperus chinensis* Old Gold. Its reaction to bioclimatic changes is a retardation of annual shoots. It has no habit changes, no changes of leaf color, or shoots deformations. This taxon can stand longer drought without deformation (damages). *Picea glauca* Conica has a similar reaction, but it requires higher humidity.

Table 1. Statistical evaluation of the length of shoots – diffusion analysis

No.	Taxon	1999	2000	Fischer's tabs	
				α = 0.05	α = 0.01
1	*Cotoneaster dammeri*	6.51**	3.41	2.87	4.43
2	*Juniperus chinensis* Old Gold	9.55**	1.28**	3.24	5.19
3	*Juniperus virginiana* Skyrocket	3.27*	4.85*	2.45	3.53
4	*Picea glauca* Conica	11.88**	3.98	3.24	5.24
5	*Pinus mugo*	34.15**	3.34	3.88	6.93
6	*Viburnum rhytidophyllum*	15.63**	0.93*	3.24	5.29

*Significant difference, **very significant difference

Table 2. Statistical evaluation of the length of shoots – diffusion analysis

No.	Taxon	2004	2005	Fischer's tabs	
				α = 0.05	α = 0.01
1	*Cotoneaster dammeri*	5.59**	3.65*	2.87	4.43
2	*Juniperus chinensis* Old Gold	8.32	3.20	3.24	5.19
3	*Juniperus virginiana* Skyrocket	3.51*	5.63*	2.45	3.53
4	*Picea glauca* Conica	7.25**	12.80**	3.24	5.24
5	*Viburnum rhytidophyllum*	12.84*	10.82**	3.24	5.29

*Significant difference, **very significant difference

Taxon *Viburnum rhytidophyllum* seems to be relatively stabile, but on several roofs it had a wrong location (in the sun). *Juniperus virginiana* Skyrocket is quite a fast-growing plant, and it degrades rapidly; in roof gardens this taxon needs a deeper substrate layer. The least suitable seemed to be the genus Cotoneaster. Tested taxa, *Cotoneaster dammeri* and *Cotoneaster salicifolius,* are fast growing woody plants and in case of adequate humidity they create huge amount of biomass. However they have rather a bad reaction under arid conditions; their leaves fall and terminal shoots get dry.

When selecting woody plants for intensive roof gardens it is possible to take as a basis the analysis of areas of origin. Taxa of *Juniperus* genus seem to be generally suitable as long as we ensure a substrate layer adequate to their size. Especially the *Juniperus* taxa from the ground-cover group are suitable; these plants come from extreme climatic and geographic conditions and so they are used to weather extremes.

Taxa *Juniperus horizontalis*, *Juniperus sabina* or *Juniperus communis* grow at higher altitudes, on rocky pan with higher humidity. *Juniperus chinensis* comes from the environment with low humidity and it is used to aridity.

Picea glauca Conica likes higher humidity. In arid summers this taxon shortens shoots, but does not changes its habit. This taxon seems to be one of the most suitable for intensive roof gardens. It grows slowly and it is long-lasting.

Viburnum rhytidophyllum has a wax film on the surface of the leaf and from the bottom side the leaf is fluffy. This protects *Viburnum* from high evaporation. In an adequate light shade *Viburnum rhytidophyllum* is a nice evergreen plant. We can plant it also separately.

Tested *Cotoneaster dammeri* and *Cotoneaster horizontalis* come from wet hard-leaf forests, with a relatively constant stream of moisture. Their reaction on soil-moisture fluctuation decreases their aesthetical value.

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Testovanie rozdielnosti vybraných taxónov rodu *Cotoneaster, Juniperus, Picea* a *Viburnum* vplyvom klimatických zmien na intenzívnych strešných záhradách

ABSTRAKT: Výskum bol realizovaný počas obdobia 10 rokov po etapách na existujúcich strešných záhradách intenzívneho typu v podmienkach okresu Trenčín. Prvá etapa bola riešená v rámci GP 1/4419/47 *Adaptabilita kultúrnej vegetácie v dôsledku globálnej aridizácie a otepľovania*. Súčasťou projektu boli aj záhrady na strechách ako jeden z fenoménov, kde je možné nasimulovať prirodzené fytocenózy schopné akumulovať zrážkovú vodu, ktorá sa zadrží v prostredí a nemusí sa odvádzať do kanalizácie. Druhá etapa výskumu je riešená v rámci GP 1/1316/04 *Overovanie suchovzdorných rastlín pre meniace sa podmienky klímatu pre urbanizované prostredie na rôznych typoch konštrukčných systémov.* Projekt 1/1316/04 je priamym pokračovaním výskumu predchádzajúceho projektu. Aby bolo možné realizovať štatistické vyhodnotenia, bolo nutné, aby vybrané taxóny drevín boli prítomné aspoň na troch testovaných strechách. Základnou hypotézou bol predpoklad, že všetky vysadené dreviny sú vhodné na strešné záhrady a že boli vybraté správne. Ďalšia hypotéza predpokladala, že údržba všetkých striech je rovnaká. Vo výsledkoch sa dokázalo, že niektoré z vysadených drevín sú oveľa prispôsobivejšie prostrediu a odolávajú suchu aj pri nedokonalej údržbe strešnej záhrady.

Kľúčové slová: testovanie; vlhkosť; sucho; intenzívne strešné záhrady; prírastky; *Cotoneaster*; *Juniperus*; *Picea*; *Viburnum*

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