Clay minerals and selected ecological aspects of soils on Veli Brijun Island, Croatia

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Franz OTTNER[1], Monika SIEGHARDT[2], Tomislav ERSTIĆ[3] and Marta MILEUSNIĆ[4]

1. INTRODUCTION

An academic cooperation agreement between the University of Natural Resources and Applied Life Sciences (BOKU) and the Faculty of Forestry of the University of Zagreb was established in September 2000. In the context of this agreement, the Institute of Forest Ecology of BOKU was asked to develop a sustainable concept for the continuation of the devastated arboretum at Brijuni.

The arboretum was established in 1987. The basic idea of the two initiators, Prof. Dr. Ž. Borzan and Prof. Dr. M. Vidaković, was to give a floristic general view on the Mediterranean flora as well as on trees and shrubs from completely different climatic zones of the world (BORZAN et al., 1993). Plants from various countries were chosen as examples to document the lively diplomatic activities of the former Yugoslavian President Tito. Costly facilities to maintain the arboretum, like paved pathways, water supply, a nursery and a house for employees and guests, were established. Due to warfare these investments were destroyed, the maintenance of the arboretum was neglected and furthermore completely abandoned. At present, the arboretum is in a poor condition. The fence is full of holes, so that deer can enter the arboretum regularly and feed on tree seedlings. Many of the non-autochthonous plants died as a consequence of the Mediterranean climate and lack of care.

The hypothesis of the ecological survey carried out by undergraduate student, Tomislav Erstić, was whether the general idea of the initiators of the arboretum could be sustainably continued, or whether an improved concept should be developed under the present ecological conditions with less maintenance efforts. Scientific soil research seemed to be a fundamental tool to prove these ecological hypotheses and was meant to support the elaborated concept. Data on mineralogical, physical, chemical and hydrological soil properties were collected and evaluated. Their ecological relevance was analyzed and served as fundament to the presented concept for the arboretum "Putevima Mira" (ERSTIĆ, 2005).

2. NATURE, HISTORY AND CULTURE ON VELI BRIJUN

The Brijuni archipelago (Fig. 1) was proclaimed a National Park in 1983. It covers an area of 7.42 km^2, comprising Veli Brijun (Big Brijun), Mali Brijun (Small Brijun) and Vanga (outside island), as well as several islets and the Kabula, Crnika and Stine reefs. The shores are mostly low and rocky with some pebble and sand beaches. The main characteristic of the archipelago is the extraordinary natural biological diversity enriched by man's traditional husbandry. Rich Mediterranean and Sub-Mediterranean vegetation is represented by holm oak, laurel, pine, olive, rosemary and underbrush. An extraordinary unity of natural elements and anthropogenesis has been achieved on Veli Brijun island, transforming farmlands and forests into landscape parks with vast meadows, tree-lined walks and gardens of sub-tropical vegetation. Some endangered plant species of Istria are quite widespread and develop freely. The ancient olive is about 1600 years old and it is one of the oldest trees in the Mediterranean (Fig. 2). Some of the smaller islands are excellent habitats of autochthonous birds as well as important seasonal habitats of northern bird species. The Saline bird reserve lies in the deep southern cove of Veli Brijun, with swampy plants and three small lakes. This bird reserve was developed on the remains of medieval salt pans which originate from ancient salt pans. Their traces are still visible today along the sea coast. The Brijuni National Park includes the surrounding sea with an exceptionally well preserved marine fauna with organisms typical of the northern Adriatic. Turtles and dolphins, the protected marine vertebrates, can occasionally be seen in the waters of Brijuni as well as other protected species, including different shells and some endemic species. The fish fauna makes the waters of Brijuni unique and different from other parts of the Adriatic. As a result of a millennium of anthropogenic influence on the archipelago of Brijuni, the animal kingdom on the islands, especially Veli Brijun, was enriched by many imported species (European hare, Aksis deer, Fallow deer, Mouflons) in addition to the autochthonous species, and these became acclimatised to

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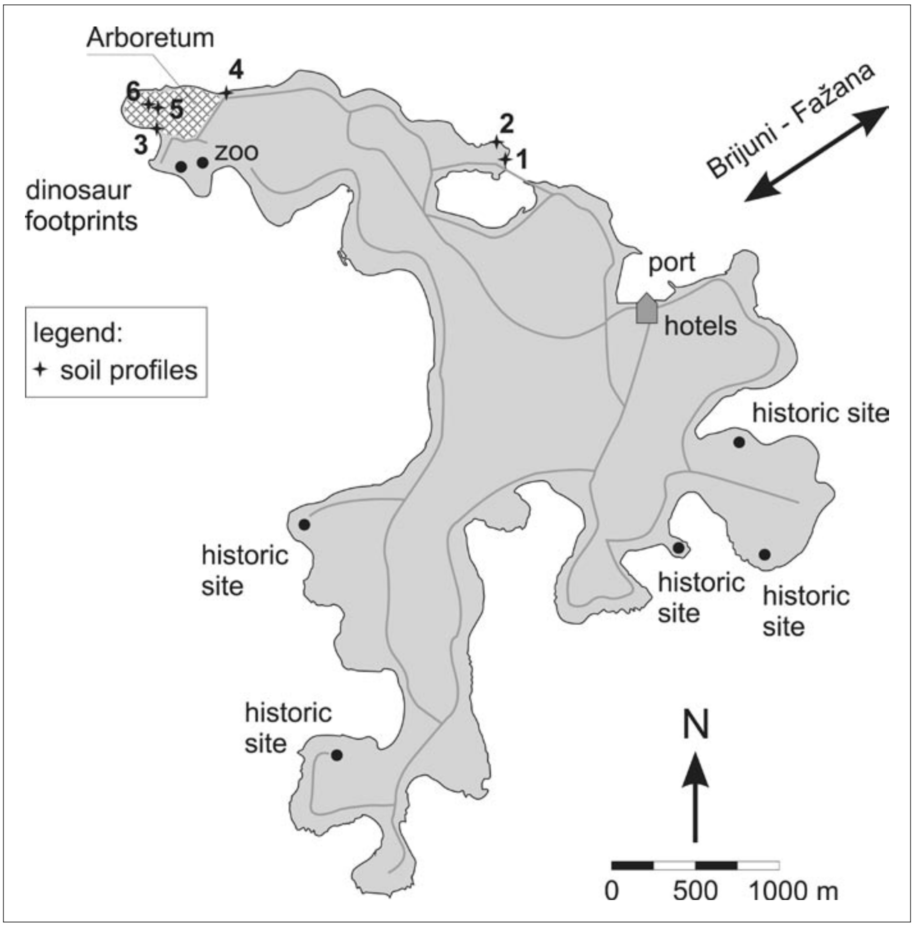

Fig. 1 Veli Brijun Island: location of soil profiles and tourist spots.

Fig. 2 Olive tree, about 1600 years old.

this habitat due to the almost ideal microclimatic conditions. The safari park lies on the northern edge of Veli Brijun, in an enclosed area. The park is the habitat of many exotic animals such as Indian elephants, llamas, zebras, nilgais and kob antelopes, Somalian sheep, Indian holy cows and autochthonous donkeys. The ethno park is an area within the Safari park representing a typical Istrian homestead with its autochthonous animal species: Istrian ox (Boškarin), Istrian sheep (Istrian "Pramenka"), donkeys and goats. It is intended both as a habitat and presentation of domestic animals of Istria. Dinosaur footprints (Fig. 3) are the earliest, most fascinating, traces of animal life in the Brijuni archipelago.

Fig. 3 Dinosaur footprints.

The Brijuni islands have been inhabited since prehistoric times. Among the many archaeological sites, the most significant is the pre-historic settlement on Gradina from the earlier neolithic period. There are also rich remnants of architectural heritage from Roman (Fig. 4) and Byzantine times. The most important ones are the ruins of a typical Roman summer palace, the Roman temples of Venus and Neptune, very valuable ruins dating from the late ancient–Byzantine period with decorative mosaics, the Byzantine basilica of St. Mary, dating from the sixth century, and Gothic and Renaissance churches. Roman builders appreciated the qualities of the Brijuni stones and they used them as building material not only on Brijuni but also for many towns in the Adriatic region.

Veli Brijun (Fig. 1) is the largest and most important island, where the most important new objects are situated, such as representational and memorial objects reminiscent of Tito's activities, museum, a zoo and other tourist facilities.

Fig. 4 Verige bay with the Roman ruins.

3. GEOGRAPHIC LOCATION AND GEOLOGICAL SETTING

The Brijuni archipelago is located southwest of Pula, parallel to the peninsula of Istria, at 44°55'32" latitude and 13°44'40" longitude. It comprises 14 islands: Veli Brijun, Mali Brijun, Sv. Marko, Gaz, Okrugljak, Supin, Supinić, Galija, Grunj, Vanga, Madona, Vrasar, Jerolim and Kozada with some underwater rocks, and these can be arranged into three groups, according to their alignment: five islands surround the island Veli Brijun, five are adjacent to the island of Mali Brijun and two islands are located in the Fažana Channel which separates the archipelago from the Istrian Peninsula. The average distance to the mainland is 3 km. The coastline of the islands is 46.8 km long; the total area is 743.3 hectares.

Due to their favourable geographical location the Brijuni Islands are known for their mild northern Mediterranean type of climate, characterized by mild winters with precipitation maxima and warm dry summers. During the summer season the subtropical high-pressure belt influences the area, during winter, cyclones are transported by the westerly winds. The Adriatic Sea functions as an air-conditioner for Brijuni: during summer the sea cools, in winter it warms the region. Figure 5 shows mean monthly precipitation and mean monthly temperature for Veli Brijun island. Snowfall is rare, about 5 days per year. The prevailing wind direction is from the north-east. The so-called *bura* from the NNE or ENE, a cold wind mainly in the autumn and winter season coming from the Učka mountain

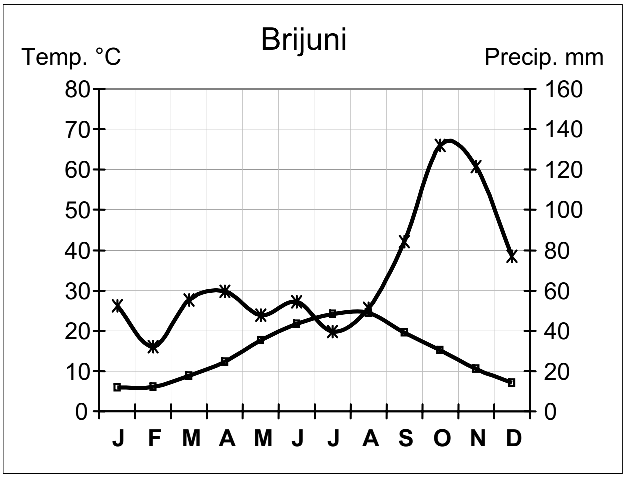

Fig. 5 Mean monthly temperature and precipitation for Veli Brijun (1991–2000). Annual mean temperature: 14.5°C, Annual precipitation: 806 mm.

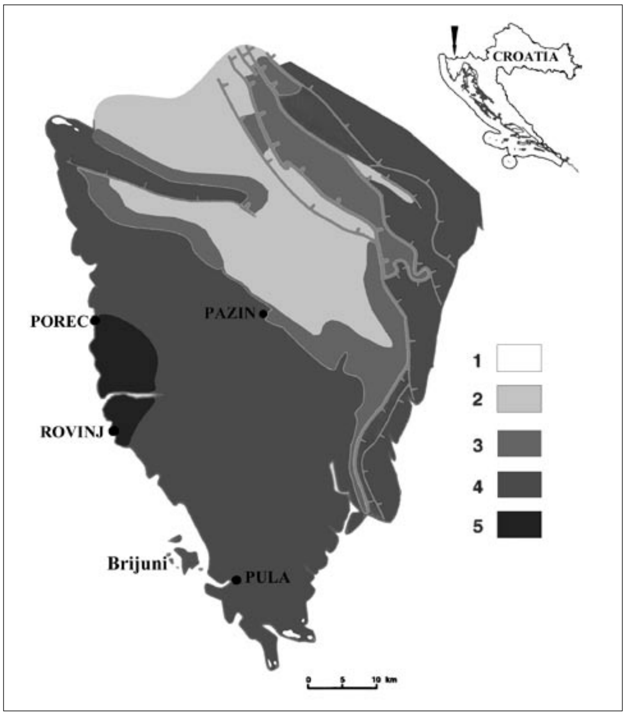

Fig. 6 Simplified geological map of Istria including Brijuni. Legend: 1 – Quaternary; 2 – Eocene; 3 – Paleocene; 4 – Cretaceous; 5 – Upper Jurassic.

is typical. It lowers the air temperature, increases soil erosion in the coastal region by increasing wave intensity and influences the tree morphology.

Geologically and geo-morphologically Brijuni are the extension of the South Istrian plateau (Cretaceous limestone) covered with a thick layer of red soil, the so-called "Red Istria". Since the depth of the channel of Fažana is just 12 m, Brijuni were until some 10,000 years ago an integral part of Istria. The present relief of the Brijuni Islands is the result of gradual sinking of this karstic area since the last ice age. The geological setting of Istria is presented in more detail as part of the guide to the Field Trip 1 in this book. Figure 6 gives a general overview of the geology of the area. Paleosols of Jurassic, Cretaceous and Palaeocene ages are commonly observed across the entire region. As a result of processes during Neogene and the Quaternary, surficial sediments, e.g. loess, were formed, as well as palaeosols and soils of different stages of development. Of these soils, the "Terra Rossa", the Mediterranean red soil, is most widely spread (DURN et al., 1999).

4. RESEARCH AREA

The research area is situated in the arboretum "Putevima Mira", which is located in the NW of the island Veli Brijun on the Barban peninsula. Veli Brijun (Fig. 1) is the largest and most important island. It has a total area of 561 hectares and its coastline is 25.9 km long. The arboretum has a total area of 7.87 hectares. It was established in 1987 (Fig. 1) after the islands were declared a National Park and memorial site. Following the establishment of the necessary maintenance facilities, 72 selected areas were improved with up to 50 cm of topsoil (probably derived from the island), to increase soil depth and support and improve plant growth. The areas were between 20 and 400 m^2 and amount to a total of 1.45 ha. Each area represents a country which was visited by President Tito. Characteristic species of the respective countries were planted. Furthermore, selected areas should represent the diversity of a genus or a species. The morphological characteristics of woody plants, their blossoms and fruits were supposed to become an attraction for visitors. Mediterranean plants as well as trees and shrubs from completely different climatic areas of the world were established. Outside of the defined areas in the arboretum the indigenous Mediterranean vegetation was kept.

At present the arboretum is in very poor condition. Apart from the network of paths, the entire infrastructure is destroyed or unusable. Both warfare and lack of maintenance by skilled personnel have led to the decay of the arboretum. The fence is holed and numerous deers enter the arboretum regularly and damage trees and seedlings. Non-autochthonous plants have died because of the Mediterranean climate and lack of care.

5. MATERIAL AND METHODS

5.1. Field methods

The map of Veli Brijun Island (Fig. 1) gives a general survey of the distribution of the investigated soil profiles on the island, as well the location of the arboretum. On the east coast, profiles 1 and 2 were dug at a distance of about 1.5 km apart from the arboretum. Profiles 3 and 4 are situated on the coastal part of the arboretum. Profile 3 is on the leeward side of the island, whereas profile 4 is situated on the windward side and is heavily influenced by the *bura*. In the arboretum, two soil profiles (5, 6) were dug with a soil depth of more than 50 cm. For comparison, one profile lies outside (Brijuni 5) and one in an area with additional soil deposit (Brijuni 6).

The profiles were prepared and the soil horizons were defined for soil classification according to the World ref-

Table 1 Chemical extraction and analytical methods.

Parameter	Extraction and analytic procedure	Reference
pH	suspension in deionised H_2O and 0.01 m $CaCl_2$ electrometric determination	ÖNORM L1083
C_{org}	Leco S/C 444	ÖNORM L1080
H_2O-soluble compounds	cold water extraction; determination of electrical conductivity (WTW 90); Cl, SO_4 with liquid chromatography (Dionex 5000)	ÖNORM L1092
adsorbed cations CEC	1 M ammonium acetate-extraction simultaneous ICP–OES (Optima 3000 XL, Perkin Elmer)	MEIWES et al. (1984)
pedogenous and active oxides	Extraction with dithionite-citrate and with oxal-acidic ammonium oxalate; determination of Fe-oxides with simultaneous ICP–OES (Optima 3000 XL, Perkin Elmer)	MEHRA & JACKSON (1960)

erence Base for Soil Resources (WRB; DECKERS et al., 1998). Soil colour was determined using MUNSELL COLOUR CHARTS (1994). Qualitative soil samples were taken from each genetic soil horizon for laboratory analyses.

To distinguish the potential rooting depth the actual soil depth throughout the arboretum was measured using a soil corer.

5.2. Laboratory methods

Vegetation roots were removed from the soil samples and the coarse and fine soil fractions were separated by dry sieving (2 mm). Mass and conversion factors for calculating oven-dry reference weights were determined.

5.2.1. Chemical methods

Chemical extraction and analytical methods are presented in Table 1.

5.2.2. Hydrological methods

To distinguish hydrological soil parameters water potential/water content curves were determined according to the Austrian standard procedure (ÖNORM L 1063), using undisturbed soil cores and a pressure-plate equipment (Soil Moisture Inc. Santa Barbara, USA).

Determination of density and bulk density was carried out according to the Austrian standard procedure (ÖNORM L1068 and B 3121), in addition to a helium pycnometer (Micromeritics, Instrument Corporation, Georgia, USA).

5.2.3. Mineralogical methods

XRD–Methods

The samples were studied by means of X-ray diffraction (XRD) using a Philips 1710 diffractometer with automatic divergent slit, 0.1° receiving slit, Cu LFF tube 45 kV, 40 mA, and a single-crystal graphite monochromator. The measuring time was 1 s in step-scan mode and step size of 0.02°. Bulk samples as well as the clay fractions (<2 µm) were analyzed.

The sample preparation generally followed the methods described by WHITTIG (1965) and TRIBUTH (1989). The dispersion of clay particles and destruction of organic matter were achieved by treatment with dilute (10%) hydrogen peroxide. The separation of the clay fraction was carried out using a Beckman labor centrifuge. The exchange complex of each sample (<2 µm) was saturated with Mg and K using chloride solutions and shaking. The preferential orientation of the clay minerals was obtained by suction through a porous ceramic plate similar to the methods of KINTER & DIAMOND (1956). To avoid disturbance of the orientation during drying, the samples were equilibrated for 7 days above a saturated NH_4NO_3 solution. Afterwards expansion tests were made, using ethylene glycol, glycerol and dimethylsulfoxide (DMSO) as well as contraction tests heating the samples up to 550°C. After each step the samples were X-rayed from 2–40°2θ.

The clay minerals were identified according to THOREZ (1975), BRINDLEY & BROWN (1980), MOORE & REYNOLDS (1997), and WILSON (1987). Semiquantitative estimations were carried out using the corrected intensities of characteristic X-ray peaks according to RIEDMÜLLER (1978).

The semiquantitative mineral composition of the bulk samples was estimated using the method described by SCHULTZ (1964).

Particle size distribution

The particle size analysis was carried out in combination with the clay mineral analysis. The coarse parts of the samples were fractionated using sieves with mesh-sizes ranging from 2000 to 40 µm. The fine particles were analyzed by means of sedimentation analysis with a sedigraph 5000ET (Micromeritics, Instrument Corporation, Georgia, USA).

6. RESULTS

6.1. Soil depth

Generally, the fine soil depth is very shallow over the entire arboretum, rock outcrops occur frequently. Sometimes the fine soil occurs only in fissures between boulders, where soil depths of more than 70 cm can be found. However, along the shore, the soil profile depth is higher due to the fact that the major part of the soil material was transported to the shore by solifluction.

In the western part of the arboretum, soil depths do not exceed 20 cm. Small slabs are scattered over the whole

Fig. 7 The depth of the dense clay layer in the arboretum.

area which come from the transport of material to the arboretum. Many Medieval small quarries could also be the reason for the countless cairns which can be found in the entire arboretum. Unwanted limestone slabs were piled up into small cairns.

Soil depths in the arboretum increase in an eastward direction, however, a narrow belt which crosses the arboretum from the southern to the northern coast shows the highest soil depths. The soil depths found with the soil auger are 60 cm or more, but at depths of 70 cm the soil density increases due to the high clay content. Therefore, in these depths it was impossible to penetrate to the C-horizon. The site for the Brijuni 5 profile was chosen in this area. The soil depth then decreases again in an eastward direction.

Many extensive rock formations can be observed, in the arboretum and boulders protrude from the surface for up to 60 cm. A very dense clay layer (hardly penetrated by roots) was found almost throughout the arboretum at various soil depths. Figure 7 shows the position and depth of this dense clay layer.

6.2. Description and properties of the soil profiles

From all the profiles, only numbers 4, 5 and 6 (Fig. 1) can be visited during the field trip.

6.2.1. Brijuni 4 Profile

The profile Brijuni 4 is located on the east coast of Veli Brijun, which is the windward side, near the entrance to the arboretum at about 2 m above sea level. Figure 8 shows the profile in autumn 2004. Erosion marks due to wind, water and mass movement can be seen nearby. The actual horizon descriptions are given in Table 2. The boundaries between horizons vary from gradual to diffuse and wavy.

Even if a definite E-horizon is not distinguishable, according to the World Reference Base for Soil Resources (WRB; DECKERS et al., 1998), it is classified as a chromic Luvisol on carbonate rocks with Mull and high bioturbation in the uppermost horizon (according to the Austrian Soil Classification System: Relictic Brown Soil; Mull-Reliktbraunerde).

Particle size distribution

To a depth of 110 cm a silt–clay-ratio of about 50 to 50 can be found. Below this, the soil becomes increasingly denser and the ratio shifts to 40 to 60. The sand content can be neglected. Figure 9 illustrates the particle size distribution with soil depth.

Bulk mineral analyses

Sheet silicates and quartz can be found with medium contents, whereas the amount of plagioclase decreases with the soil depth. Mica is present in traces and the amount of K-feldspar increases with soil depth. Haematite and goethite are present in the profile in small amounts.

Clay mineral analyses

Illitic material is the dominant clay mineral at 69–73 wt.%; no distinct changes in clay mineral distribution with the soil depth can be observed in this profile (Table 3). The vermiculite content is distributed irregularly within the soil profile. Kaolinite – mostly in its poorly-crystallized form

Fig. 8 The Brijuni 4 soil profile in autumn 2004.

as fire clay – constitutes between 18–24 wt.%. The mixed layer mineral in the soil profile shows a regular composition with vermiculite as one component and either illite or secondary chlorite as the other. The quantification must be regarded as a rough estimate due to the low amounts of this mixed-layer mineral.

Chemical analyses

Selected soil chemical results are presented in Table 4. The data support both the particle size distribution and the soil classification. The cation exchange capacity (CEC) increases with soil depth, as does the proportion between pedogenic Fe-oxides and active Fe-oxides.

Due to the dense forest cover, which mostly consists of Mediterranean sclerophyllic trees and shrubs, the pH-values of the uppermost horizon are about 1 pH-unit lower than those in the Brijuni 1 and 2 profiles, where grass and herbaceous plants with few Mediterranean shrubs dominate the vegetation cover. The high organic carbon content in the uppermost A-horizon is noticeable and due to the forest cover and high bioturbation. The C/N ratio in the A-horizon is low (11) and an indication of the high biological activity.

The profile is influenced by seawater due to its proximity to the shore: the electric conductivity increases from a depth of 110 cm downwards and is mostly caused by the elevated water soluble Cl^- and SO_4^- contents. At this depth the CEC and Na contents are also significantly increased.

6.2.2. Brijuni 5 Profile

The Brijuni 5 profile was sampled in the arboretum but outside a planting area, so no additional soil material was

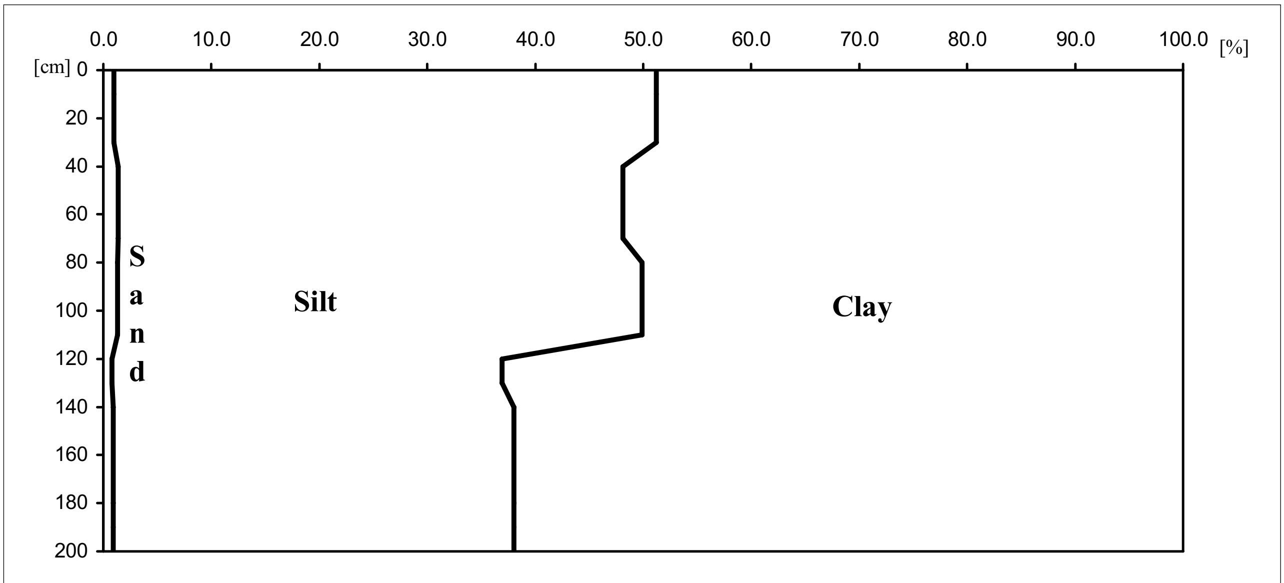

Fig. 9 Particle size distribution in the Brijuni 4 profile.

Table 2 Selected soil descriptive parameters for the Brijuni 4 profile.

A	0–30 cm; clay–silt; dark reddish brown (5YR 3/3); strong medium blocky subangular; many fine to medium roots
B1	30–75 cm; clay–silt; reddish brown (5YR 4/4); strong medium blocky; common medium to fine roots
B2	75–110 cm; clay–silt; reddish brown (5YR 4/4); strong medium angular blocky; few fine roots
Bt(g)	110–200 cm; clay–silt; reddish brown (5YR 4/4); up to 165 cm medium angular blocky, below fine angular blocky and weak prismatic with common limestone clasts (Ø 10–40 cm), few, faint, fine mottles; moderately salty

Table 3 Clay minerals (mass %) in the Brijuni 4 profile.

Lab. Nr.	Horizon	Vermiculite	Illitic material	Kaolinite	Mixed Layer
7094	0–30	3	70	22	5
7095	30–75	7	69	20	4
7096	75–110	4	73	18	5
7097	110–135	4	69	24	3
7098	135–200	5	72	19	4

Table 4 Selected chemical soil parameters for the Brijuni 4 profile.

soil depth (cm)	pH H_2O	pH $CaCl_2$	C_{org} mg/g	CECeff mmolc/kg	Fe_{ped} / Fe_{act}	electric conductivity µS/cm	H_2O soluble Cl mg/kg	H_2O soluble SO_4 mg/kg
0–30	7.0	6.2	32.00	70.4	5.5	60.9	121.3	78.8
30–75	7.4	6.4	8.44	58.2	6.6	91.6	236.2	221.5
75–110	7.1	6.1	7.75	53.4	5.5	114.7	325.1	384.0
110–135	6.4	5.9	7.32	80.4	7.6	407.0	1325.6	1711.8
135–200	7.0	6.4	7.78	85.0	7.0	293.0	1136.9	802.4

Table 5 Selected soil descriptive parameters for the Brijuni 5 profile.

A	0–12 cm; silty clay; dark reddish brown (5YR 3/3); strong coarse blocky subangular structure; many fine to medium roots
Bt1	12–35 cm; silty clay; reddish brown (5YR 4/4); strong medium angular blocky; common medium to fine roots
Bt2	35–50 cm; silty clay; reddish brown (5YR 4/4); very strong medium angular blocky to prismatic; very dense

present. The profile is situated on a flat terrain, about 10 m above sea level. Measurement of soil depth by auger showed that the fine soil depth exceeds 70 cm. The actual horizon description is given in Table 5. The boundaries between horizons are gradual to diffuse and wavy.

Again, according to the WRB, the soil is a chromic Luvisol with Mull and high bioturbation in the uppermost horizon (according to the Austrian Soil Classification System: Relictic Brown Soil, Mull-Reliktbraunerde).

Particle size distribution

The high clay content (up to 70 wt.%) throughout the entire soil profile are remarkable (Fig. 10). The fine clay fraction amounts to 46 wt.%. The sand fraction is negligible. The ratio of silt to clay is about 30 to 70.

Bulk mineral analyses

Layer silicates and quartz are present in this profile in high and medium amounts respectively. Plagioclase occurs in small amounts, mica only in traces. Traces of K-feldspar can only be found in the uppermost as well as in the lowermost horizons.

Clay mineral analyses

The distribution of illite in the profile shows enrichment in the uppermost horizon (Table 6). The content of 81 wt.% is the highest amount of illitic material in all the samples of the investigated profiles. Vermiculite shows the opposite trend. Whereas the vermiculite content is only 2% in the upper horizons, it increases to 5% in the lower parts of the soil profile. As in the Brijuni 4 profile, kaolinite occurs in its poorly crystallized form. The kaolinite content is only slightly lower than that in the previous profile discussed above. Haematite and goethite are also present in small amounts.

Figure 11 shows the diffractogram of the clay fraction of the A-horizon (0–15 cm) of the Brijuni 5 profile, while Fig. 12 shows one for the Bt-horizon (30–40 cm).

Table 6 Clay minerals (mass %) in the Brijuni 5 profile.

Lab. Nr.	Horizon	Vermiculite	Illitic material	Kaolinite	Mixed Layer
7099	0–15	2	81	13	4
7100	15–30	3	77	17	2
7101	30–40	5	71	21	3
7102	40–50	4	68	22	6

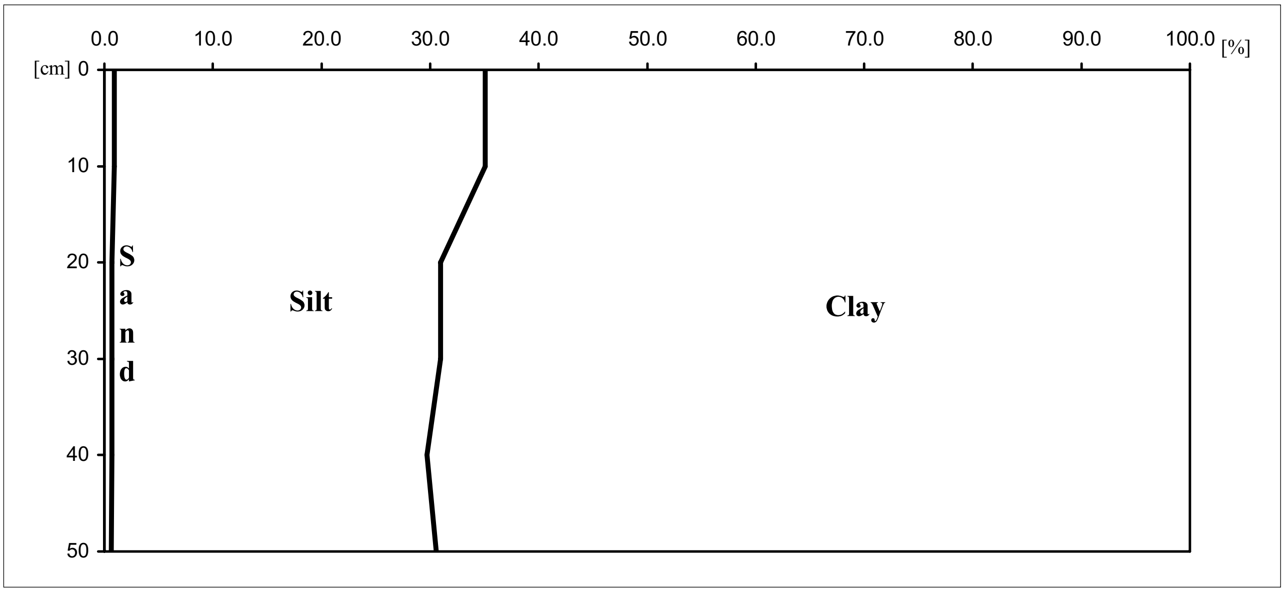

Fig. 10 Particle size distribution of the Brijuni 5 profile.

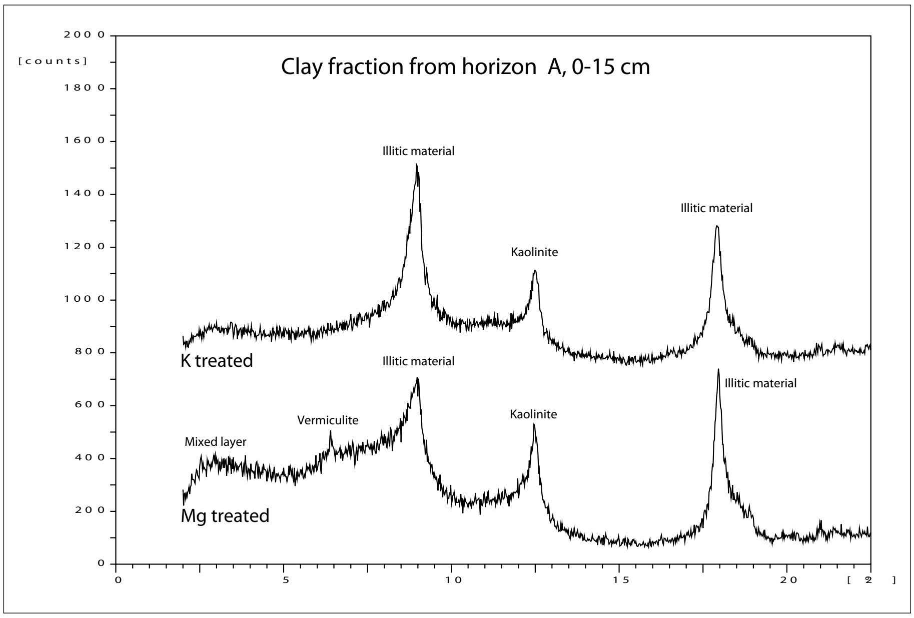

Fig. 11 Diffractogram of the clay fraction from the Brijuni 5 profile.

Chemical analyses

Selected soil chemical analytical results are presented in Table 7.

The data, together with the particle size distribution, support the soil classification. The cation exchange capacity (CEC) decreases with soil depth; the higher values in the A-horizon being the result of the high humus content as indicated by the high content of C_{org}. The ratio between pedogenic Fe-oxides and active Fe-oxides significantly increases with soil depth. The pH-values are clearly lower in all horizons than those of the profile Brijuni 4. This difference is related to the absence of sea water spray; the Cl^- and SO_4^- content are 10-times lower than in Brijuni 4. The C/N-ratio with 19 in 30–40 cm depth is quite high, because of the high content of organic carbon, which may be attributed to root debris of the sclerophyllic vegetation and wind-protection of the site, whereas Brijuni 4 is fully exposed to wind erosion of vegetation litter and has herbaceous undergrowth.

The pF-curves (not presented) for this profile show that the soil is even more dense than that of Brijuni 4. At a depth of 32 cm only 10% of the soil water is available at a water-potential of -1.0 bar. The data for bulk density, density and porosity given in Table 8 confirms these findings.

6.2.3. The Brijuni 6 Profile

The Brijuni 6 soil profile was excavated within an area of added topsoil (area 6, Japan) and is used here for comparison with Brijuni 5, where no material was added, and to analyse the material for soil depth melioration. The sampling point is at about 10 m a.s.l.; the profile is situated on level terrain. Only the first two horizons of the additional material were sampled, because at a depth of 30 cm a buried A-horizon was met (A2), which is the original genetic

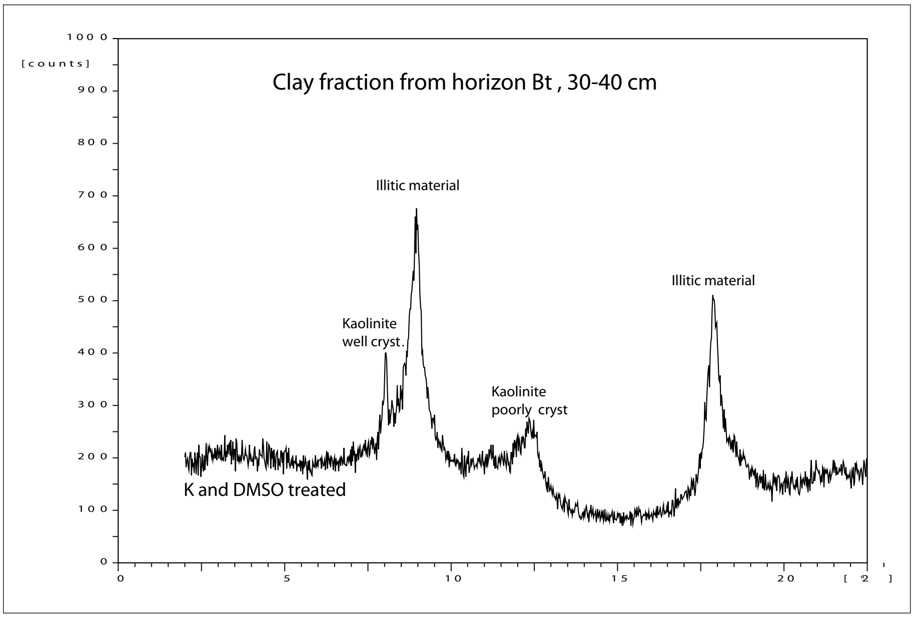

Fig. 12 Diffractogram of the clay fraction from the Brijuni 5 profile which shows the two types of kaolinite.

A-horizon. The rest of the profile below 30 cm is similar to the profile 5 which is only some metres beside. The horizon description for profile Brijuni 6 is given in Table 9. The boundary between horizon A1 and Bt1 is gradual to diffuse and wavy; between Bt1 and the buried A2 it is rather abrupt and smooth, while it is diffuse and irregular between A2 and A2/Bt2, the intermixed layer, as well as between A2/Bt2 and Bt2.

According to the WRB, the profile can be classified in two ways: firstly as an Anthrosol which might not really target the exact classification because it is used for soils with a long-lasting anthropopedogenic influence. Here, additional soil material was deposited in a single event twenty years previously and a new A-horizon developed, so this soils doesn't fit the requirements for such a classification. Secondly, the term anthric chromic Luvisol, reflects the genesis of the profile in a better way. The topsoil shows forest Mull. According to the Austrian Soil Classification System it is an Anthropogenic Relictic Brown Soil ("Schüttungsboden").

Particle size distribution

This profile shows a low sand content, <2 wt.%. In the added material the silt:clay ratio is about 45:55 whereas in the "old" soil profile the respective ratio is 30:70.

Bulk mineral analyses

This profile shows a very similar mineralogical assemblage to the other soils. Sheet silicates and quartz are present in medium amounts. The plagioclase content decreases with soil depth, mica and K-feldspar only occur in traces.

Table 7 Chemical soil parameters for the Brijuni 5 profile.

soil depth (cm)	pH H_2O	pH $CaCl_2$	C_{org} mg/g	CECeff mmolc/kg	Fe_{ped} / Fe_{act}	electric conductivity µS/cm	H_2O soluble Cl mg/kg	H_2O soluble SO_4 mg/kg
0–15	6.7	6.3	47.05	100.06	2.9	70.0	30.0	30.2
15–30	6.5	5.8	16.91	77.38	5.8	31.0	34.7	27.9
30–40	6.5	5.6	9.30	70.55	8.0	26.2	35.8	49.5
40–50	6.5	5.6	7.57	69.68	8.6	29.0	29.4	96.7

Table 8 Bulk density, density and porosity of the Brijuni 5 soil profile.

genetic soil horizon	soil depth cm	bulk density g/cm³	density g/cm³	porosity pore vol. %
A	1–5	1.58	2.47	36.0
A	5–9	1.75	2.58	32.0
Bt	16–20	1.82	2.61	30.2
Bt	20–24	1.83	2.64	30.7
Bt	33–37	1.97	2.70	27.0
Bt	45–49	1.98	2.70	26.7

Table 9 Selected soil descriptive parameters for the Brijuni 6 profile.

A1	0–10 cm; new developed, recent A; silty clay; dark reddish brown (5YR 3/3); strong coarse subangular blocky; many fine to medium roots
Bt1	10–30 cm; new deposited B; silty clay; reddish brown (5YR 4/4); strong medium angular blocky; common medium to fine roots
A2	30–40 cm; original A-horizon, buried, silty clay; dark reddish brown (5YR 3/3); moderate medium to fine angular blocky; common medium to fine roots
A2/Bt2	40–55cm; silty clay; reddish brown (5YR 3/4); moderate medium to fine angular blocky, few fine roots
Bt2	55+ cm; silty clay, reddish brown (5YR 4/4); very strong medium angular blocky to prismatic; no roots, very dense

Table10 Chemical soil parameters for the Brijuni 6 profile.

soil depth (cm)	pH H_2O	pH $CaCl_2$	C_{org} mg/g	CECeff mmolc/kg	Fe_{ped} / Fe_{act}	electric conductivity µS/cm	H_2O soluble Cl mg/kg	H_2O soluble SO_4 mg/kg
0–10	7.6	7.0	26.98	108.91	5.6	101.0	30.3	21.4
10–20	7.6	7.0	12.86	93.12	5.9	62.2	38.0	24.0

Clay mineral analyses

In this profile only 30 cm of the heaped-up material was analyzed. The slightly lower content of illite in the surficial horizon is noticeable. Vermiculite, haematite and goethite occur in small amounts.

Chemical analyses

The respective analytical results are presented in Table 10.

Both analyzed horizons are added material, and it can be concluded that this material came from the island and is the same as that used for the construction of the golf course as our analyses (not shown in this guide) indicate. The values for soil density (2.64 g/cm^3) confirm this hypothesis, which is the same for the uppermost horizons of the profiles Brijuni 1, 2 and 6. The pF-curve demonstrates that at a soil water potential level of -1 bar 80% of the water is retained in the soil. This result is very similar to that of Brijuni 1, which is located at the boundary of the golf course.

7. DISCUSSION

7.1. Soil systematic position of "chromic Luvisol"

KUBIENA (1953) uses the terms "Terra Rossa" or "Mediterranean Red Earth" for reddish, clay rich soils derived from limestones in the Mediterranean region. As these soil types are within the soil class of "Terra Calcis", their relationship to brown loam ("Terra Fusca"), red loam and red earth of the humid–temperate climate is evident. KUBIENA (1986) describes the matrix of the "Terra Rossa" as yellowish coloured with crystals of haematite, goethite and amorphous iron, with a very stable structure. According to DUCHAUFOUR (1968), the main soil forming processes for the "Terra Rossa" are rubification, clay development, clay transformation, and processes that can be summarized as lessivage: clay mobilization by dispersion, clay transport by descending percolating water (eluviation) and clay deposition (illuviation). DUCHAUFOUR (1998) defines these soils as brown soils where a second process (lessivage) was superimposed on brunification. Two soil horizons are typical: the first, A or E, impoverished in clay and iron, with a lighter colour, and the second, the Bt, enriched in clay and iron, showing "argillans" around structural units. According to DUDAL (1978), the "Terra Rossa" is a chromic Luvisol, because of its clay-rich horizon. SKOWRONEK (1978) summarizes that all ideas for the systematic classification of the "Mediterranean Red Earth" contain an extremely clay-rich horizon.

The actual WRB version (ZECH & HINTERMAIER-ERHARD, 2002) also includes soils that have a clay-rich horizon below a horizon with low clay content, due to biological or geogenic (solifluction) processes as Luvisols. However, differences in clay content throughout the soil profile and the existence of a clay rich horizon are prerequisites for the classification of a soil as a Luvisol.

The three soil profiles shown here have all the properties necessary for classifying them as Luvisols, even if a lighter coloured distinct E-horizon cannot be distinguished: the clay contents and the iron contents increase with soil depth and the soil structure changes from subangular blocky to angular blocky to prismatic. In addition, the soil colour with a hue of 5YR allows the classification of the soils as chromic Luvisols (FAO–ISRIC–ISSS, 1998).

The "Terra Rossa" or chromic Luvisol is widely distributed in Istria. The typical reddish colour forms a soil cover over limestone of various depths, from some cm to several metres. This reddish colour is derived from Fe-oxides (haematite) that are formed because of dehydration from iron hydroxides (goethite) during hot and dry climatic periods. Several authors (e.g. DUCHAFOUR, 1998; DURN et al., 1999) show that these soils were developed during the Tertiary, thus being relictic and often polycyclic, sometimes with heavily eroded topsoil horizons.

Fig. 13 Location of the FAO reference profile.

7.2. Comparison of the analytical results

7.2.1. Clay minerals

Profile 5 is composed of distinct horizons, whereas profile 4 shows a more or less disturbed sequence. In profile 6 the deposited material which was added 20 years ago was analyzed.

In all the profiles illite is the dominant clay mineral accounting for 61–81 wt.%. In the undisturbed profile 5 noticeable enrichment of illite can be seen in the uppermost layers of the profile. This illitization derives from the greater availability of K from decaying plants, which is taken up by vermiculite, and then results in the formation of illite. In the Brijuni 4 profile which is influenced by solifluction, this process is less dominant, because the surficial layers of the profile were repeatedly covered with transported material.

Vermiculite with a basal spacing of 14 Å has been observed in all the profiles and shows the opposite trend to illite in its distribution. This means that the vermiculite is transformed into illite by the uptake of K.

Kaolinite characteristically occurs in "Terra Rossa" soils in high amounts. In all the investigated profiles the values did not exceed 28 wt.%, the lowest values were found in profile 4 at 18 wt.%. The majority of the kaolinite occurs in the form of fire clay – a poorly crystallized form of kaolinite. Only a small portion (about 10–20%) occurs as the well-crystallized form. These quantities of kaolinite are relatively low compared to other "Terra Rossa" profiles (DURN et al., 1999).

In almost all the examined soil samples a mixed-layer mineral was discovered. Due to the low amounts it was impossible to carry out an exact quantification. However, it could be determined that vermiculite, illite and partially chlorite are constituents of this mixed-layer mineral. The dense clay layer (Fig. 7) does not reflect changes in the clay mineral composition but is purely the result of increased clay content up to 70 wt.%. The bulk density of this compacted clay layer reaches values of almost 2 g/cm^3, comparable to clay from industrially used brick clays.

In profile 3 (not shown in this guide) a remarkable clay component occurs: it is yellow and consists of illitic material which could be transformed smectites, derived from volcanic ash deposited 120 million years ago (OTTNER, 1999).

7.2.2. Chemical analysis

The lowest pH-values (6.5) can be found in the Brijuni 5 profile, which is located inside the arboretum and shows the impact of forest cover. The relatively high pH-values (7.6) in the uppermost horizon of profile Brijuni 6 confirm the assumption that the material was transported to the arboretum from outside the forest somewhere on the island and that it was mixed. The soil pH-data resemble those of the soils from the golf course. In all three profiles the A-horizons have a C/N-ratio between 11 and 13, which is typical for a mull. In all profiles the CEC-values clearly exceed 24 cmolc/kg clay and the pedogenic Fe-oxide contents increase with soil depth which is required by the WRB for classification as a Luvisol. Elevated water-soluble Cl^- and SO_4 contents and the high electrical conductivity of the Brijuni 4 profile are a consequence of its shore location and the subsequent influence of seawater. In addition, the PAK-content (not presented here) of the fine soil below 100 cm depth derived from the use of diesel on boats is worth mentioning.

Comparison of these profiles with the reference profile for the southern part of the Istrian peninsula north of Pula, (Fig. 13), from the soil map of Europe (FAO/UNESCO 1981), the analytical and descriptive data show similarities or even agreements with that agricultural soil. In these profiles the sand fraction is very low; the silt/clay-proportion is about 50/50, and the clay content increases to 75% with soil depth. When we consider the impact of agriculture (ploughing, removal of harvest, fertilization), the similarities refer to colour, pH, organic carbon, nitrogen and CEC. Only the carbonate content shows differences. Whereas the Brijuni-profiles have very low to no carbonate contents, the FAO-profile exceeds 35 mg/g.

8. FUTURE OF THE ARBORETUM

The results of this soil survey confirm the assumption that the visions and basic ideas of the initiators of the project "Arboretum Putevima Mira" can hardly be sustained without extraordinarily high expense and effort. It goes without saying that plants of completely different climatic zones cannot survive in the Mediterranean climate, even with daily care. The results of our extensive soil scientific investigations support this statement.

The soil depths are very shallow (20–30 cm) throughout the arboretum. Woody species can barely root in these shallow soils. However, the initiators of the project knew about this problem and therefore, soil material was heaped up to about 50 cm in restricted areas to enable the plants to develop a compact root system.

The soil results show that the additional soil material most likely comes from the island, thus being no improvement for the plants from a soil-science viewpoint. The analytical results of the profiles have shown that this material was the same as that used for the construction of the golf course. Instead of using well structured medium textured soil, material was used which has a clay content of more than 55%. The use of such a very dense soil is one of the reasons for the decay of the non-autochthonous plants in the arboretum. The pF-curves, together with the data on density and bulk density, are tools to estimate water availability. The reduced water storing capacity and water availability for tree roots are caused by the generally high clay content as well as by the shallow depth at which a dense, largely impenetrable clay horizon with a clay content of more than 70% occurs in the arboretum. In all the surveyed profiles the bulk density of the soil above the dense clay layer is about 1.8 g/cm^3, the maximum density is 2.7 g/cm^3, which is far too high for most deciduous or coniferous trees from temperate regions.

Table 11 Water potential of selected plant groups (after LARCHER, 2003).

Plant group	negative water-potential (bar)
tropical rain forest trees	15–40
beech	20
conifers	15–22
e.g. picea abies	20
sclerophyllic trees	35–45
mediterranean shrubs	40–80

Table 11 shows evidence that trees from temperate climates, e.g. conifers, can deal with soil–water-potentials of about -15 to -22 bar, sclerophyllic trees about double, Mediterranean shrubs four times as much. Due to their extensive root system and the numerous stomata sclerophyllic plants (sclerophyllous evergreen) transpire and photosynthesize intensively when the water supply is good, e.g. after rain, whereas during dry periods they are able to reduce or even cease their evapotranspiration. Representatives of this group include bay (*Lauris nobilis*), ilex (*Quercus ilex*), arbutus (*Arbutus L.*), carob (*Ceratonia siliqua*), olive (*Olea europaea*) and myrtle (*Myrtus communis*).

Figure 14 shows the water storing capacity of soils which is dependent on fine soil depth, structure, texture and pore volume. In general, sufficient amount of water

Fig. 14 Water storing capacity of soil in the arboretum.

can be stored in the soils for the adapted Mediterranean vegetation. However, the water potential values of the Brijuni soil samples show that the water is retained in the pores of the soil with such great tension that only a small amount of the water is available to the plants. This allows only woody species adapted to the climatic and pedological situation to survive without extensive care. The heaped-up soil material did not result in any improvement in terms of soil-hydrology. Therefore, it is necessary that only trees and shrubs that are adapted to the ecological conditions, the climate and the soil in this area are displayed in the arboretum. If we assume an annual precipitation of about 800 mm and an annual mean temperature of more than 14°C, the water requirements of non autochthonous plants cannot be met.

At present, the arboretum is in a very poor condition. With the exception of the network of paths, the whole infrastructure was destroyed or is unusable. However, it is clear that the idea to establish numerous areas that represent the species diversity all over Europe cannot be sustained. Four–five skilled persons would be needed for daily care and maintenance in the arboretum and it is doubtful that even then species indigenous to North Europe would grow. To stop further decay of the arboretum, the fence should be mended immediately so that deer can no longer enter and damage the existing trees and the regrowth of Mediterranean species.

An ecologically sustainable concept would be an arboretum with Mediterranean plants adapted to the actual climatic and pedological situation. The concept of the different areas for each European country should be abolished in favour of a concept with different areas which demonstrate the diversity of Mediterranean genera or species. Furthermore, it would be advisable to plant more shrubs and flowering plants to make the arboretum more attractive. At the moment there are almost only trees in the arboretum. The main building is in great need of renovation, as is the watering system for the plants. The arboretum must be an attraction for visitors giving a memorable experience for the whole family. Attractions such as a permanent soil profile or a "scented garden" could serve this purpose.

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