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Afforestation affects vertical distribution of basic soil characteristics and taxonomic status of sodic soils

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Abstract: Afforestation, settled before 60–90 years and adjacent solonetzic grasslands, representing the natural vegetation cover were compared in this study based on their basic soil characteristics (pH, $CaCO_3$ content, soil organic carbon (SOC), and exchangeable sodium percentage (ESP)) up to 2 m depth. The assumption was that the plantings of arbour vegetation can change soil characteristics of sodic soils not only in superficial layers but even in larger depths. Grasslands and forest soils were compared by standardised depths. Afforested soils showed lower pH in the depth at 0–100 cm, and slightly higher SOC content in subsoil (20–100 cm). $CaCO_3$ content was significantly different (higher) only at the depth of 50–100 cm in afforested soils. Remarkable differences in ESP values were measured. Afforestation had in almost every layer (0–20, 20–50, 50–100 and 150–200 cm) a significant lower ESP value than grassland soil samples from the same depths. As the value of the ESP is relevant from soil classification purposes as well, the leaching of sodium also can change the taxonomic status of the soils from soils with *natric* horizon, to soils with Sodic or Bathysodic qualifiers.

Keywords: salt-affected soils; land cover change; desodification; sodicity; soil carbon sequestration

The salt-affected soils cover 5 340 km^2 (5.8%) of Hungary (Pásztor et al. 2018). These unfavourable soil conditions mean strong limitations for the arbour vegetation (Tóth 1972). Especially high alkalinity coupled with sodicity (e.g. in natric horizons) appearing in shallow depth (10–50 cm), and high salinity of the topsoil, is not tolerable for most tree species. Additionally, the clay-rich texture of soils, the occurrence of vertical properties, carbonate accumulation and gleyic conditions in deeper soil layers, also do not facilitate the development and management of forests.

Obviously, the share of forest cover – especially natural ones – is extremely low on these soils, only 11 000 ha (2.0%), additionally, most of them are afforestation planted during the last century for many different reasons (Tóth 1972). Their evaluation form foresters, nature conservationists and ecologists are controversial, but even if the extent is low, they have relevance in the dominantly non-arbour landscape, providing microhabitats, structuring the landscape, increase landscape diversity.

Native forests, if present, are a relevant factor in soil formation processes on salt-affected soils (Tóth 1972). In the few natural forests on sodic and alkaline soils (Ohat, Újszentmargita) there is no sodium accumulation in the topsoil and the highest exchangeable sodium percentage (ESP) is in the deeper soil horizons, (below 60–90 cm), and ESP values are lower (< 25%) under forests as in grasslands (Szabolcs et al. 1978).

Tree plantation on sodic soils under tropic conditions proved to be effective in reducing topsoil pH and ESP, improving soil hydraulic conductivity and

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water capacity (Mishra et al. 2003), therefore afforestation was applied successfully for soil reclamation aims too (Bhojvaid and Timmer 1998, Mahdy 2011).

Generally, the conversion of land cover from grassland to forest change relevant components of soil development. An increase in biomass, altered decomposition of organic matter, changes in microclimatic conditions and soil water regime are responsible for quick superficial changes in soil conditions. Also, the root system of trees reaches deeper soil layers (1–1.5 m) and develops a denser network compared to grasses, taking a larger amount of water up, and from deeper layers of the soil (Nippert and Holdo 2015, Mujica and Bea 2020). It results, in turn, in the soil layer at the depth of the root system into drier (Balog et al. 2014), and as many studies showed, the decrease in groundwater table (Jobbágy and Jackson 2007, Nosetto et al. 2007, Gribovszki et al. 2017). Studies in afforestation on non-sodic, sandy soils reported increased electric conductivity (EC), i.e. salinity of groundwater and deeper soil layers (Tóth et al. 2014). Parallelly, under tree plantings in the topsoil, the moisture (and sodium) fluxes into the upper soil layers (evaporation) are reduced, which might facilitate the leaching of sodium and decrease of pH and EC (Balog et al. 2014, Tóth et al. 2014) in topsoil layers.

In this study, the comparative evaluation of the vertical distribution of soil properties, supposedly affected by afforestation, is aimed below plantations and native grasslands with clay-rich soil texture and sodium affected soils. The basic assumption is that trees planted on sodic soils changed the soil pH, concentrations of organic carbon, carbonates, and exchangeable sodium in the soils. The main research tasks of this study are to quantify these changes and describe the vertical pattern of them, comparing the grasslands and afforested soils, which have, before setting the plantations similar patterns and variability of soil properties. To identify possible changes in the soil taxonomic status was also aimed, since the changes in soil properties may affect diagnostic features of soils, expectedly reflecting also in the classification of them.

MATERIAL AND METHODS

Study sites. The Püspökladány "Salinization Experimental Yard" (Figure 1) was founded in 1924 on a flat alluvial plain. It could be characterised by flat topography at an average elevation of 86–87 m a.s.l., warm humid continental climatic conditions with an annual main temperature of 10.1 °C and annual average precipitation of 520 mm, with shallow (1–5 m) groundwater table (Novák and Tóth 2016).

Afforestation offers there a possibility to study the soil conditions of plantations on more than 400 ha. The experimental afforestation was planted in an alkaline-sodic environment, covered by a mosaic of the large variety of native grassland associations

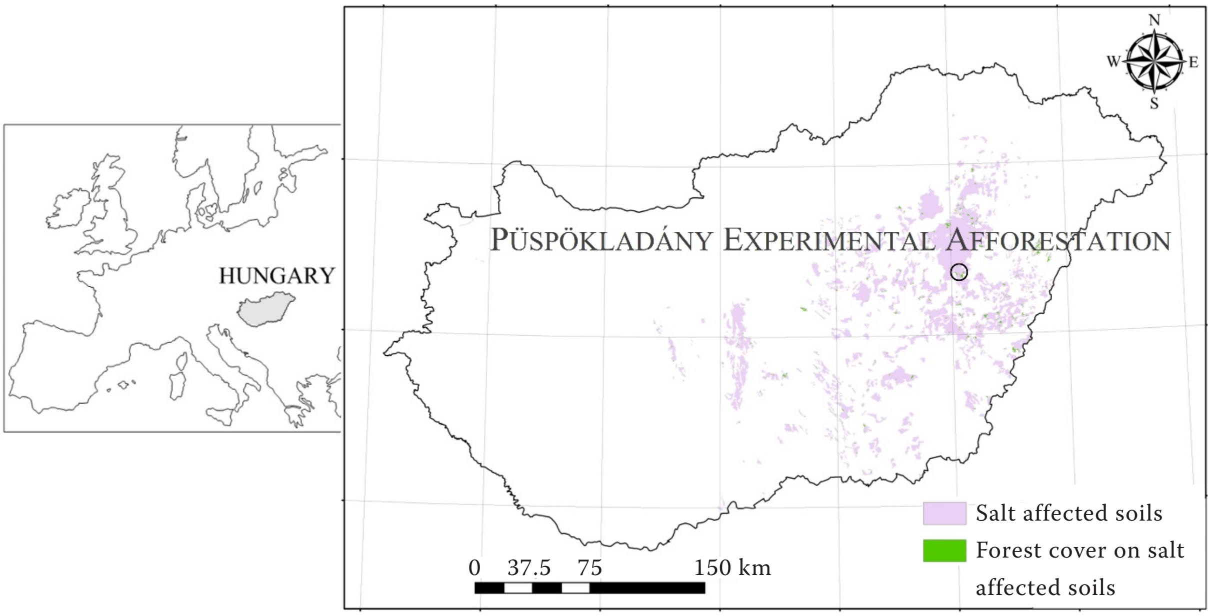

Figure 1. The extent of the salt-affected soils and afforestation on salt-affected soils in Hungary, with the location of the study area

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(Tóth 1972) dominated by *Festuca pseudovina* Hack., *Alopecurus pratensis* L., and *Agrostis stolonifera* L. Soils of the area show up sodic characteristic in shallow or deeper horizons with different grade of expression (Novák et al. 2017), which is indicated in application of Natric horizon or Sodic, Protosodic, Bathysodic qualifiers in classification (IUSS WG WRB 2015). Additionally, salinity and vertic features occur as the influence of saline groundwater, and the high smectite content of the parent material (Szőőr et al. 2008, Novák et al. 2017). At the level of WRB reference groups of the soils within the study area are very variable (Gleysol, Solonetz, Chernozem, Phaeozem, Kastanozem and Vertisol) (Novák et al. 2017).

The plantation of trees was usually carried out after pretreatment of soils (Tóth 1972) with native (*Quercus robur* L., *Fraxinus angustifolia* Vahl), and non-native (occasionally even invasive) tree species (*Fraxinus pennsylvanica* Marsch., *Robinia pseudo-acacia* L., *Ulmus pumila* L.). A high variety of chemical, physical and biological soil reclamation technologies were applied, to change the unfavourable soil conditions, making them more suitable for tree plantation. Frequently deep plough and mixing of soil layers until 30–50 cm depth was coupled with the application of lime or/and gypsum as pretreatment to facilitate cation exchange from Na^+ to Ca^{2+} in sodic soil horizons. In other cases, salt-tolerant plants, with a strong root system, effective in penetrating the dense natric horizons (*Eleagnus angustifolia* L., *Tamarix* spp.) were applied previously before the afforestation. Even if the most detailed documentation of vegetation and soil surveys, carried out before the plantation were partially lost during the World War II, publications and archived materials show, that the diversity of soil conditions in sites selected for plantations ranged from extremely alkaline and sodic, to the more favourable, showing up alkalinity and sodicity only in deeper soil horizons.

Field soil sampling. Following the boundary line of tree plantation, sampling locations at regular distances (100 m) were selected pairwise, and drilled samples were collected on both sides of that boundary: in native grassland and forest, located 50 m from each other. Totally, 19 drilled soil profiles located in afforestation and 17 in native grasslands were settled, representing the soil diversity in- and around the studied afforested area. In two places, the opposite side of the forest sampling places were cancelled from sampling because of its anthropogenic disturbed surfaces, which is why the number of forest and grassland sampling sites is not equal. Samples from drilled profiles were taken in regular depth intervals and organised into horizons according to the visual changes of soil texture, colour, and consistency along with the profiles, until the unaltered parent material. For the evaluation of laboratory measurements samples were assigned to standardised depths, which allowed the comparison of soils with different horizonation.

Further, two representative soil profiles were opened in afforested sites, and two soil profiles on native grasslands. The soil profiles were excavated until the depth of the unaltered parent material, to 150–110 cm depth. Soil profiles were described and sampled according to WRB guidelines (Jahn et al. 2006) and classified using the WRB classification key (IUSS WG WRB 2015). Altogether data of 21 soil profiles from afforestation and 19 profiles from native grassland habitats were sampled, analysed, and compared with each other.

Soil analytics. Bulk soil samples were dried at 105 °C for 24 h after homogenisation and removal of organic remnants and plant roots. The total organic carbon of bulk samples was determined by the wet oxidation method (Ponomareva and Plotnikova 1980). The pH_{H_2O} was measured in 1:2.5 suspensions with a standard glass electrode. Inorganic carbon was measured by the volumetric calcimeter (Scheibler) method (Chaney et al. 1982). For the exact determination of soil texture class grain size distribution was analysed by combined wet sieving (2–0.2 mm fractions) and pipette method (< 0.2 mm fractions).

The cation exchange complex was analysed by the modified Mehlich method (Buzás 1988), applying barium chloride-triethanolamine solution (pH 8.1) to the eluation process of the adsorbed cations. The cation content of the eluate was determined by atomic absorption spectrophotometry (Perkin-Elmer), at the following wavelengths: Na^+ λ = 589.0 nm; K^+ λ = 769.9 nm; Ca^{2+} λ = 422.7 nm; Mg^{2+} λ = 285.2 nm. Exchangeable sodium percentage was calculated as follows (Bleam 2017) and expressed in %:

$$\text{ESP \%} = \frac{\text{Na}^{+}_{\text{exch}}\left(\frac{\text{cmol}}{\text{kg}}\right)}{\text{Ca}^{2+}_{\text{exch}}\left(\frac{\text{cmol}}{\text{kg}}\right) + \text{Mg}^{2+}_{\text{exch}}\left(\frac{\text{cmol}}{\text{kg}}\right) + \text{K}^{+}_{\text{exch}}\left(\frac{\text{cmol}}{\text{kg}}\right) + \text{Na}^{+}_{\text{exch}}\left(\frac{\text{cmol}}{\text{kg}}\right)} \times 100$$

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Data evaluation. Samples from unequally dissected horizons of the drilled and excavated profiles were ordered into five standardised depth classes (0–20, 20–50, 50–100, 100–150 and 150–200 cm) and evaluated separately. Measured values of the soil variables from the two different vegetation types of the same depth classes were presented in boxplots and statistically compared with independent samples Mann-Whitney *U*-test. Statistical analyses were carried out by SPSS 20.0 (Armonk, USA, IBM Corp.).

RESULTS AND DISCUSSIONS

The studied soils have an averaged texture of silty clay loam, with 30.4 ± 9.0% clay, 60.9 ± 7.0% silt, and 8.7 ± 3.6% sand content. The texture and its vertical variability were not different in grassland and forested profiles. The pH, soil organic carbon (SOC) content, carbonates and ESP showed high variability according to land cover and soil depth, as described in the following sections. The excavated two soil profiles were classified as Solonetzs in grasslands, and as Kastanozem and Phaeozem in afforestation according to the WRB. Two examples of soil profiles are shown in Figure 2.

Comparison of soil properties in grassland and afforested soils. Since a pairwise comparison of the soil profiles was not possible, considering the sampling plot pairs may have different vertical horizonation and occasionally different taxonomic statuses, the comparison was done in two groups (forests, and grasslands), comparing soil properties of the two groups at the standardised soil depths.

Like in other studies (Holubík et al. 2014), the pH in soil layers of 0–20 cm proved to be significantly lower below afforestation (6.0 ± 1.2), as in the same layers of grassland vegetation (6.8 ± 1.3) (Figure 3A). Similarly, in the layers of 20–50 cm depth of 7.4 ± 1.0 in forests and 8.6 ± 1.0 in grasslands, and of 50–100 cm with 8.1 ± 0.7 in forests and 9.1 ± 0.6 in grasslands (Figure 3A). Below that depth differences are not remarkable, and not significant in soil pH (Table 1).

Comparing the $CaCO_3$ content of soil layers in afforested and grasslands soils differences showed up not as clear (Figure 3B). The vertical distribution of carbonates shows maximum at the depth of 100–150 cm in grasslands and 50–100 cm below forests. Anyway, the difference in carbonates content between forests and grasslands at 100–150 cm is not significant, only at the 50–100 cm depth (Table 1),

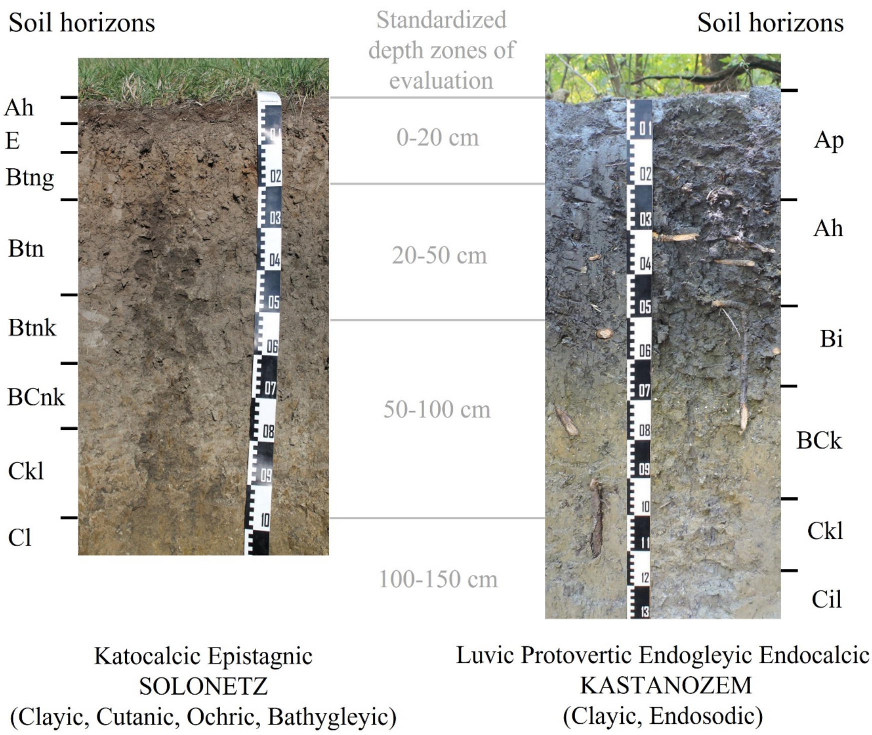

Figure 2. Soil horizons and World Reference Base (WRB) classification of a grassland (left) and an afforested (right) soil profile of the sampling area

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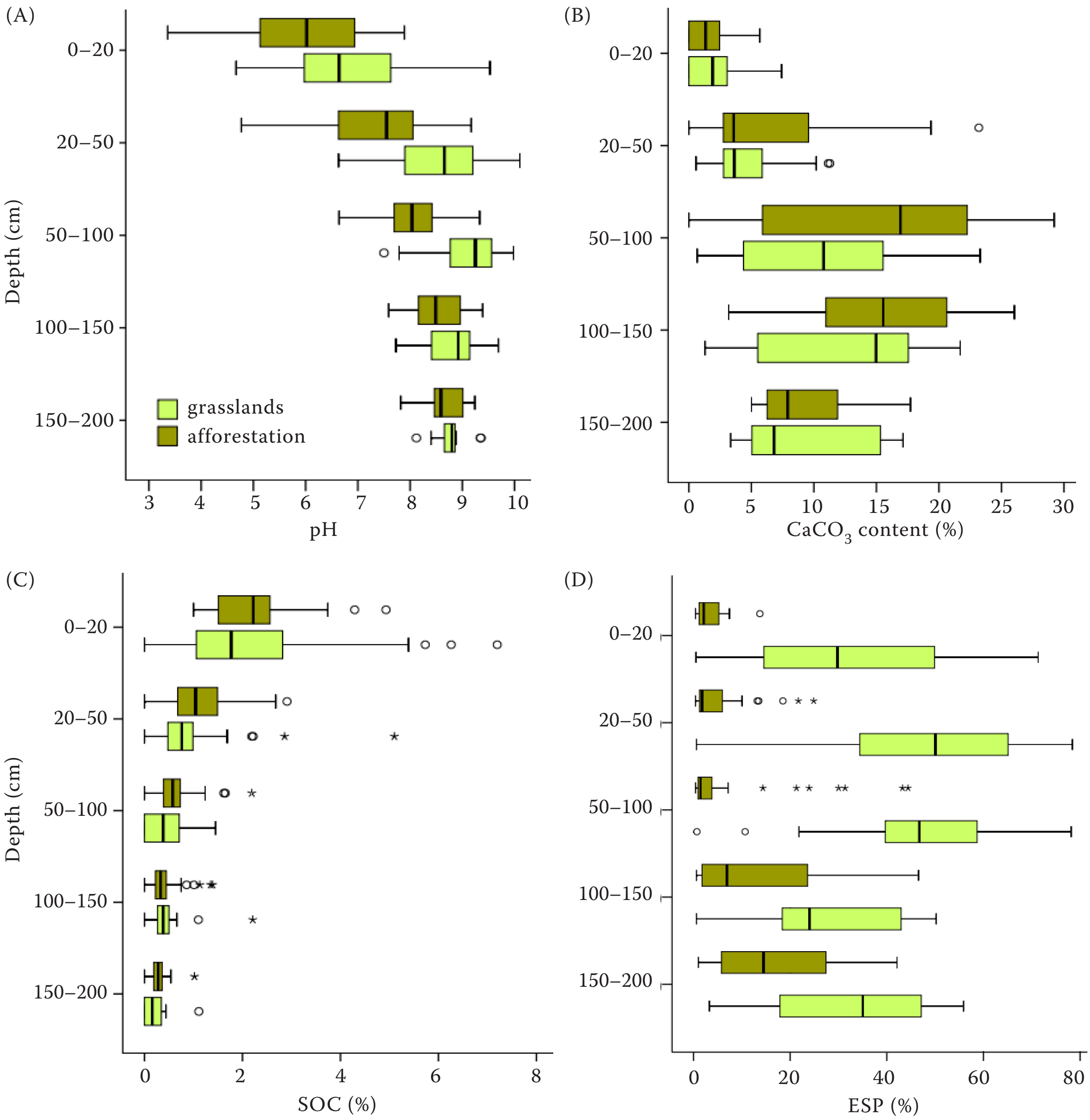

Figure 3. Vertical distribution of (A) soil pH_{H_2O}; (B) soil $CaCO_3$ content; (C) soil organic carbon (SOC) content and (D) exchangeable sodium percentage (ESP) in grassland and afforestation soil profiles (Boxplots indicate min., max., lower and upper quartiles and median values)

where the carbonate content of afforestation proved to be higher (15.1 ± 8.6%) than that in the grassland soils at the same depth (10.2 ± 6.4%). The overlying soil layers show up relatively low carbonate content, as a typical feature of meadow solonetz soils of this region. It is a result of the long and intense soil profile development and differentiation process since the parent material of soils contains 8–10% of carbonates. Afforestation affects calcium-carbonate dynamics, as far as the mobilisation in topsoil continues, meanwhile the Ca^{2+}-content of rising capillary water at the root depth may concentrate since roots take out cations in a restricted amount from the soil solution, but the increased amount of water. Apparently, this can lead to increased accumulation of carbonates at the depth of 50–100 cm below forests.

The vertical distribution of SOC in afforestation compared to grassland soils shows a rather sur-

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Table 1. The significant differences in soil properties between grassland and afforested sites (nonparametric Mann-Whitney *U*-test)

Variable		Depth (cm)				
		0–20	20–50	50–100	100–150	150–200
pH	Independent samples Mann-Whitney *U*-test significance	0.013*	0.000***	0.000***	0.153	0.393
$CaCO_3$ content		0.190	0.394	0.002**	0.147	0.722
SOC content		0.184	0.012*	0.007**	0.568	0.153
ESP		0.000***	0.000***	0.000***	0.100	0.040*

*P < 0.05; **P < 0.01; ***P < 0.001; SOC – soil organic carbon, ESP – exchangeable sodium percentage

prising pattern (Figure 3C). Holubík et al. (2014) and Vopravil et al. (2021) referred about increased SOC concentration in topsoil after afforestation on agricultural land, as a result of increased primary production. Despite that, no significant increase in SOC content compared to the grasslands could be detected in the topsoil (0–20 cm) layer of tree plantings in our study, with 2.1 ± 1.7% and 2.2 ± 1.0%, respectively. Slightly, but significantly increased SOC content in forest samples compared to grasslands was measured in the layers at 20–50 cm (1.2 ± 0.6% and 0.9 ± 0.9%) and at 50–100 cm (0.6 ± 0.4% and 0.4 ± 0.4%) (Table 1).

The expected increase of SOC concentration was moderate, and not present only in subsoil layers, supposable caused by increased subsurface biomass below the forest. An increase of surficial SOC stocks as studies by Singh et al. (2012) and Mishra and Sharma (2010) reported after afforestation of sodic arable lands in tropic, or non-sodic arable lands under temperate climatic conditions (Holubík et al. 2014, Vopravil et al. 2021), can not be expected after afforestation of native sodic grasslands. Therefore, the forcing of afforestation, replacing native grassland vegetation with only carbon sequestration purposes remains questionable in these soil conditions.

The most apparent difference between forested sites and grasslands soil characteristics showed in the vertical distribution of ESP values (Figure 3D). In grassland sites, high values of ESP are typical in topsoil, and subsoil layers over 100 cm, showing a definite decrease before that depth. In forested sites, higher ESP values do not occur in soil layers over 100 cm depth, but also in deeper layers, values remain below the typical values of grasslands. The differences are distinct and significant in layers over 100 cm in depth (Table 1). In order at depths at 0–20, 20–50 and 50–100 cm, 31.5 ± 21.0% and 3.4 ± 3.1%; 47.0 ± 23.8% and 5.3 ± 7.0%; 46.0 ± 17.1% and 6.8 ± 12.0% in grasslands and in afforestation. Differences are not significant at the depth of 100–150 cm. In the depth at 150–200 cm again significantly higher ESP was measured in grassland soils at 32.4 ± 19.0% as in the afforestation (16.7 ± 13.9%).

Comparing the grasslands and afforestation ESP vertical profiles, the vertical position of maximal ESP of each profile seems to be obvious that sodium accumulation in exchangeable form shows up higher maximum values (up to 80%) in shallow soil horizons (at 50–100 cm depth) below grasslands and lower values (up to 40–50%) in deeper vertical position (at 50–150 cm) below afforestation. Statistically, these differences in depth and maximal ESP values proved not significant with Mann-Whitney *U*-test.

The most relevant difference of afforested sodic soils is the lower ESP until 1.5 m depth, compared to the ESP values of the grassland soils. Based on the findings of former studies, this change is due to the more intense water consumption of forest vegetation (Craine et al. 2002, Gribovszki et al. 2017), taking out moisture from deeper soil layers (Fiedler et al. 2002), therefore slowing down the capillary rise of water and sodium over the rooting depth of trees (Balog et al. 2014), the recent study showed, that the already reported decrease of electrical conductivity (EC) in topsoil (Tóth et al. 2014) might affect deeper soil layers and reflect also in decreased exchangeable sodium adsorption conditions. This and all further significant effects of afforestation are summarised in Figure 4.

Studies by Gribovszki et al. (2017) and Tóth et al. (2014) reported decreased soil EC under tree plantings in the top 1 m soil layer and increased EC values below 1 m depth. The decreased conductivity of soils affects the cation exchange complex and reduces the ESP values in these soil layers too. The ESP in this recent study showed significantly lower values compared to grasslands until 1.5 m depth under tree plantings. Anyway, soil texture is heavier and the initial

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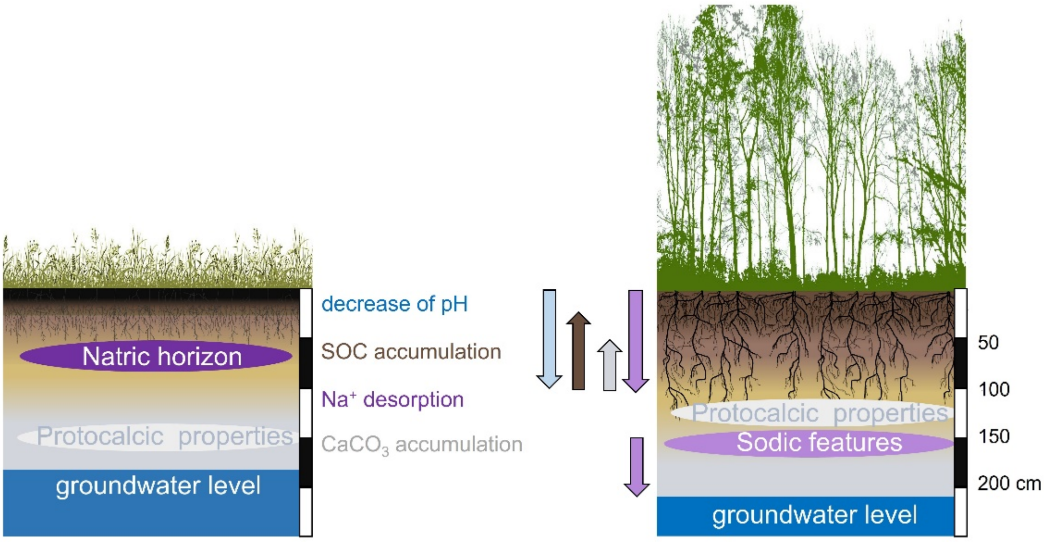

Figure 4. Consequences of afforestation on sodic soils to diagnostic soil features

sodium saturation grade is higher in this recent study compared to the sampling sites of Tóth et al. (2014).

Influences of the changes on the taxonomic position of soils. The vertical position and the maximal value of the ESP have relevancy in the classification purposes of the soil profiles. Namely, the diagnostic criteria of *natric* horizon require ESP value > 15% in some of the soil layers (> 15 cm thick) starting between the soil surface and 100 cm depth (IUSS WG WRB 2015). Solonetz soils, having *natric* horizons may change their taxonomic status if sodium adsorption decreases in the soil below this value, or if it is shifting to the deeper part of the soil (Figure 4). Also, the application of the Sodic qualifier, which is common in soils of other reference groups of the study area (Kastanozems, Chernozems, Vertisols), requires > 6% ESP (IUSS WG WRB2015). This taxonomic consequence of the desodification of afforested soils is not mentioned by other studies reporting decreased ESP after forest plantation (Mishra and Sharma 2010, Singh et al. 2012) because the very high ESP values of initial soils remain still after the strong decrease in the range of *natric* horizons.

With intensified leaching, both values and depth of sodium adsorption may shift lower and vertically deeper, excluding the application of *natric* or/and *sodic* diagnostics. High (> 6%) ESP values deeper than 100 cm will be classified as Bathysodic, which qualifier (Figure 5), because of the application of Bathy- (deep, in the depth – greek) specifier will be posted at the end of the list of supplementary qualifiers, and it is just optional to indicate it in the soil name.

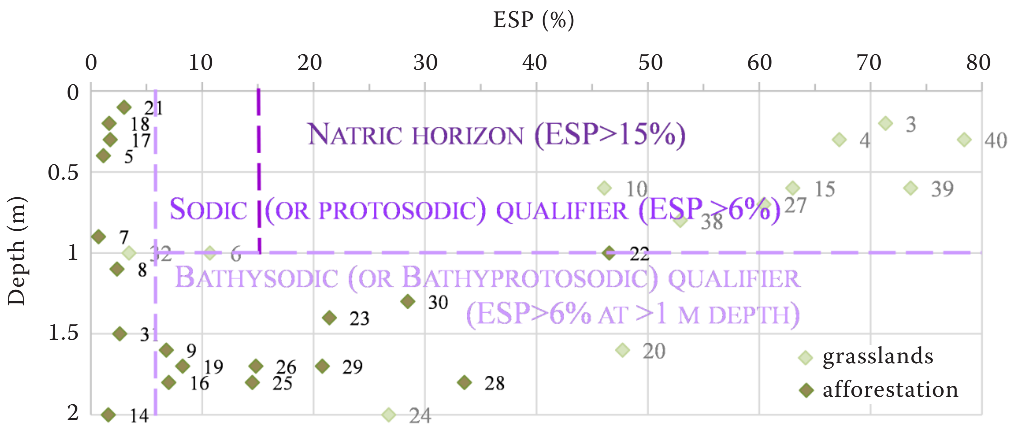

Figure 5. Positioning of studied soil profiles according to their maximum exchangeable sodium percentage (ESP) values and its vertical position, and the relationship to applicability of diagnostic natric horizon, Sodic and Bathysodic qualifiers

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REFERENCES

Balog K., Gribovszki Z., Szabó A., Jobbágy E., Nosetto M., Kuti L., Pásztor L., Tóth T. (2014): Effect of forest plantations on subsurface salt accumulation in lowlands with shallow groundwater. Agrokémia és Talajtan, 63: 249–268.

Bhojvaid P.P., Timmer V.R. (1998): Soil dynamics in an age sequence of *Prosopis juliflora* planted for sodic soil restoration in India. Forest Ecology and Management, 106: 181–193.

Bleam W. (2017): Acid-base chemistry. In: Blaem W. (ed.): Soil and Environmental Chemistry. 2nd Edition. Cambridge, Academic Press, 253–331. ISBN: 9780128041956

Buzás I. (ed.) (1988): Methods Textbook to Agrochemistry and Soil Science 2. Budapest, Mezőgazdasági Kiadó, 243. (In Hungarian)

Chaney R.C., Slonim S.M., Slonim S.S. (1982): Determination of calcium carbonate content in soils. In: Chaney R.C., Demars K.R. (eds.): Geotechnical Properties, Behavior, and Performance of Calcareous Soils. Baltimore, American Society for Testing and Materials, 3–16.

Craine J.M., Wedin D.A., Chapin F.S., Reich P.B. (2002): Relationship between the structure of root systems and resource use for 11 North American grassland plants. Plant Ecology, 165: 85–100.

Fiedler F.R.P.E., Frasier G.W., Ramirez J.A., Ahuja L.R. (2002): Hydrologic response of grasslands: effects of grazing, interactive infiltration, and scale. Journal of Hydrologic Engineering, 7: 293–301.

Gribovszki Z., Kalicz P., Balog K., Szabó A., Tóth T., Csáfordi P., Metwaly M., Szalai S. (2017): Groundwater uptake of different surface cover and its consequences in great Hungarian plain. Ecological Processes, 6: 39.

Holubík O., Podrázský V., Vopravil J., Khel T., Remeš J. (2014): Effect of agricultural lands afforestation and tree species composition on the soil reaction, total organic carbon and nitrogen content in the uppermost mineral soil profile. Soil and Water Research, 9: 192–200.

IUSS Working Group WRB (2015): World Reference Base for Soil Resources 2014 (update 2015). International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. World Soil Resources Report No. 106. Rome, Food and Agriculture Organisation of the United Nations.

Jahn R., Blume H.P., Asio V.B., Spaargaren O., Schad P. (2006): Guidelines for Soil Description. Rome, Food and Agriculture Organisation of the United Nations, 97.

Jobbágy E., Jackson R.B. (2007): Groundwater and soil chemical changes under phreatophytic tree plantations. Journal of Geophyisical Research, 112: 1–15.

Mahdy A.M. (2011): Comparative effects of different soil amendments on amelioration of saline-sodic soils. Soil and Water Research, 6: 205–216.

Mishra A., Sharma S.D., Khan G.H. (2003): Improvement in physical and chemical properties of sodic soil by 3, 6 and 9 years old plantation of *Eucalyptus tereticornis*: biorejuvenation of sodic soil. Forest Ecology and Management, 184: 115–124.

Mishra A., Sharma S.D. (2010): Influence of forest tree species on reclamation of semiarid sodic soils. Soil Use and Management, 26: 445–454.

Mujica C.R., Bea S.A. (2020): Estimations of rooting depths and sources of plant-available water (PAW) in flatland petrocalcic soils under different land uses. Geoderma, 361: 114019.

Nippert J.B., Holdo R.M. (2015): Challenging the maximum rooting depth paradigm in grasslands and savannas. Functional Ecology, 29: 739–745.

Nosetto M.D., Jobbágy E.G., Tóth T., Di Bella C.M. (2007): The effects of tree establishment on water and salt dynamics in naturally salt-affected grasslands. Oecologia, 152: 695–705.

Novák T.J., Tóth Cs.A. (2016): Development of erosional microforms and soils on semi-natural and anthropogenic influenced solonetzic grasslands. Geomorphology, 254: 121–129.

Novák T., Balla D., Rásó J., Botos Á., Mester T. (2017): Taxonomic position of the soils of the NAIK ERTI Experimental Station of Püspökladány according the WRB 2015. Budapest, Hungarian Soil Science Society, 189–197. (In Hungarian)

Pásztor L., Laborczi A., Bakacsi Z., Szabó J., Illés G. (2018): Compilation of a national soil-type map for Hungary by sequential classification methods. Geoderma, 311: 93–108.

Ponomareva V.V., Plotnikova T.A. (1980): Humus and Pedogenesis. Leningrad, Nauka, 65–74. (In Russian)

Singh K., Pandey V.C., Singh B., Singh R.R. (2012): Ecological restoration of degraded sodic lands through afforestation and cropping. Ecological Engineering, 43: 70–80.

Szabolcs I., Várallyay Gy., Mélyvölgyi J. (1978): The soils and landscape ecology of Újszentmargita. Agrokémia és Talajtan, 27: 1–30. (In Hungarian)

Szöőr Gy., Balázs É., Novák T., Kovács-Pálffy P., Kónya P. (2008): Mineralogical composition of genetic horizons of crusty meadow solonetz soil profile from Püspökladány based on X-ray diffraction and thermal analysis. Acta Geographica ac Geologica et Meteorologica Debrecina: Geology Geomorphology Physical Geography Series, 3: 9–14.

Tóth B. (ed.) (1972): Afforestation on Salt Affected Soils. Budapest, Akadémiai Kiadó, 266. (In Hungarian)

Tóth T., Balog K., Szabó A., Pásztor L., Jobbágy E.G., Nosetto M.D., Gribovszki Z. (2014): Influence of lowland forests on subsurface salt accumulation in shallow groundwater areas. AoB Plants, 6: plu054.

Vopravil J., Formánek P., Janků J., Holubík O., Khel T. (2021): Early changes in soil organic carbon following afforestation of former agricultural land. Soil and Water Research, 16: 228–236.

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