STATISTICAL AND HYDROLOGICAL MODELING OF SOIL AND SUBSOIL SALT-ACCUMULATION CAUSED BY TREE PLANTATIONS ESTABLISHED ABOVE SHALLOW SALINE GROUNDWATER

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Abstract

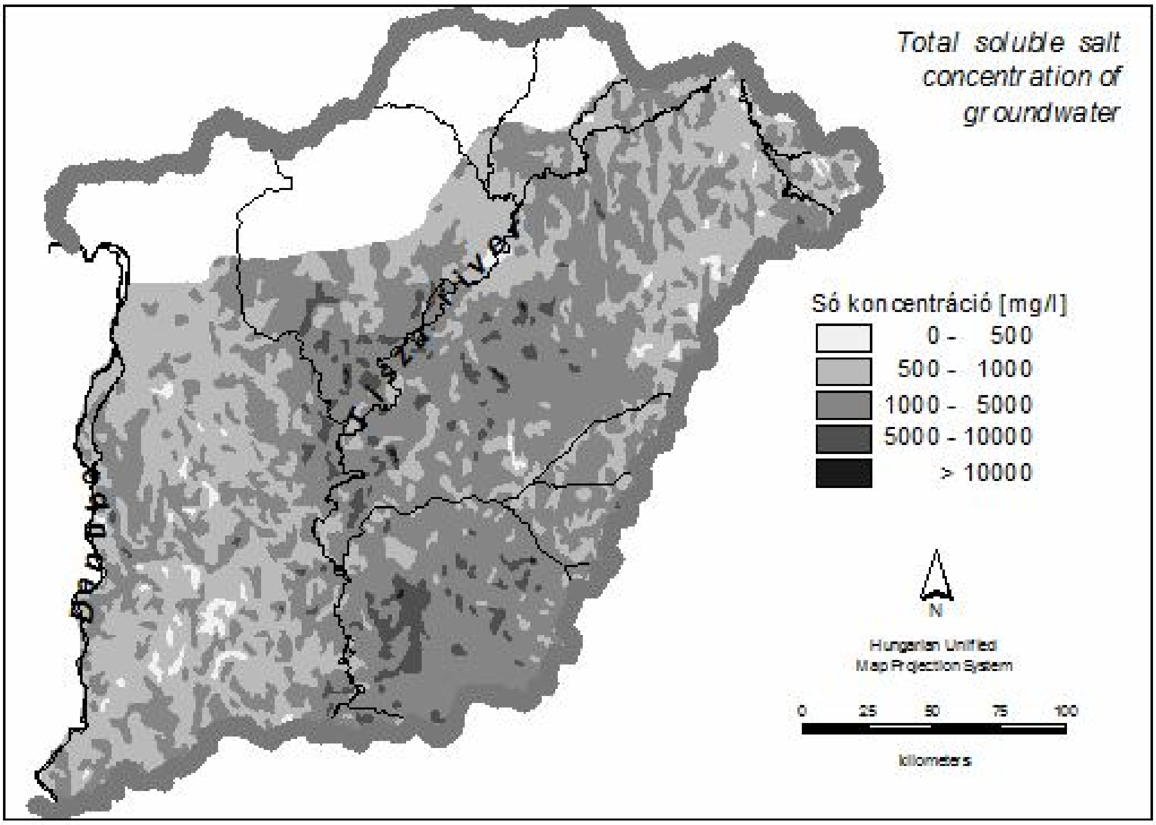
In Hungary there has been a great increase in forested area during the last hundred years, from 1.1 to 2.0 million ha. At present an average of 15.000 hectares are forested each year. The hydrological effect of trees differs from that of crops or grasses in that, due to their deep roots, they extract water from much deeper layers. It has been demonstrated that trees cause subsurface salt accumulation above shallow saline groundwater in areas with a negative water balance. Nevertheless when a decision is made on the afforestation of a plot, salinity and depth of groundwater are often not considered.

We will carry out a detailed investigation of the Hungarian situation through the systematic study of all affecting factors, like climatic water balance, groundwater depth and salinity, tree species, subsoil layering and stand age. Subsequently we will provide guidelines for the optimization of further afforestation. At the regional scale we will sample 108 plots for groundwater depth and salinity, soil and subsoil salinity, and vegetation characteristics in both recently forested and non-forested sites in the Great Hungarian Plain. These data will be entered in a statistical model for predicting the effect of afforestation on soil, subsoil, and groundwater salt accumulation. At the stand-scale 16 representative forested and non-forested sites (chosen from the 108 plots studied) will be monitored for groundwater depth to quantify groundwater uptake by trees under differing conditions. The novelty of the research lies in the comparative and comprehensive consideration of all main factors of salt accumulation across different continents, the Argentine Pampa versus the Hungarian Plain.

Introduction

In Hungary there was a great increase in the acreage of afforested areas during the last hundred years, from 1.1 to 1.8 million ha. For the coming 30 years some 700 000 ha more afforestation is planned (Andrasevits et al., 2005). The hydrological effect of trees differs from that of crops or grasses in that, due to their deep roots, they extract water from much deeper layers. It has been demonstrated that trees cause subsurface salt accumulation above shallow saline groundwater in areas with a negative water balance. (Bazykina 2000, Nosetto et al., 2007, 2008).

The area suggested for afforestation by the National Forest Strategy, 2009 covers areas where other agricultural activity is not profitable, and this area is overlapping with the area of saline shallow groundwaters as shown by Map 1,2 and there is a considerable risk that undesired, deleterious salt accumulation will occur in newly afforested areas.



Map 1. Total soluble salt concentration of groundwater in the Great Hungarian Plain

With our project our intention is to quantify the risk and provide guidelines for the optimal selection of plots and trees in order to reduce the risk of subsurface salt accumulation in Argentine and Hungary with the same methodology and evaluation techniques. The novelty of the research lies in the comparative and comprehensive consideration of all main factors of salt accumulation across different continents, the Argentine Pampa versus the Hungarian Plain (Table 1).

Table 1. The most important climatic and geographical parameters of the study sites in Argentine Pampa and Hungarian Plain

	Pampa Deprimida	***Püspökladány (Alföld)***
Localisation	34°36' – 38°00' S 56°43' – 63°26' O	46°00' – 48°25' N 19°00' – 22°55' E
Area (km²)	90.000	47.000
Annual average temperature (°C)	13.8 – 15.9	10 – 12
Annual average precipitation (mm)	850 – 900	525 – 585
Relief	Plain 0 – 30 m asl	Plain 75 – 125 m asl
Natural vegetation	pastures (*Sporobolus, Stipa, Panicum, Paspalum, Agrostis*)	pastures (*Agrostis, Alopecurus, Artemisia, Festuca*)
Soils	Natraquoll, Natraqualf, Natralboll – Argiudoll, Hapludoll at higher sites	Endoaquoll, Calciaquert, Natrustoll +Calciustoll at higher sites
Groundwater table (m)	1- 3	1 – 3 (previously) 4 – 5.5 (at present)

Process of salt accumulation caused by different vegetation types

To determine the effects of vegetation on water dynamics and salt accumulation there are many field studies (for example Bazykina 2000, Heuperman 1999 etc). Roberts (1950) showed that pH and EC values were significantly different under the bare ground and half-shrubs, due to the effects of roots on salinization. Most of the studies about the effects of vegetation change on salt and water dynamics derives from deforestation (Nosetto 2007), the experience on the effects of afforestation is less. The hydrological effect of trees is much different from the crops or grasses, being characteristic for the earlier land-use. Due to their deep roots, trees extract water from much deeper layers and there is an increased water absorption and transpiration. As Fig 1 from Jobbágy et Jackson, 2004 shows there is a tendency of salt accumulation under the established tree stand. Groundwater is recharged under native grasslands, in contrast to the discharge of groundwater under tree plantations, because there is more evaporation than precipitation. In the discharge zone under tree plantations salt concentration increases with increasing depth and distance from recharge zone. This increase can be explained according to Salama et al 1993: asthe transpiration and water extraction of roots, weathering processes, evaporation, leakage between aquifers. Where the conditions are favorable a horizontal groundwater flux will accelerate the rate of salt accumulation.

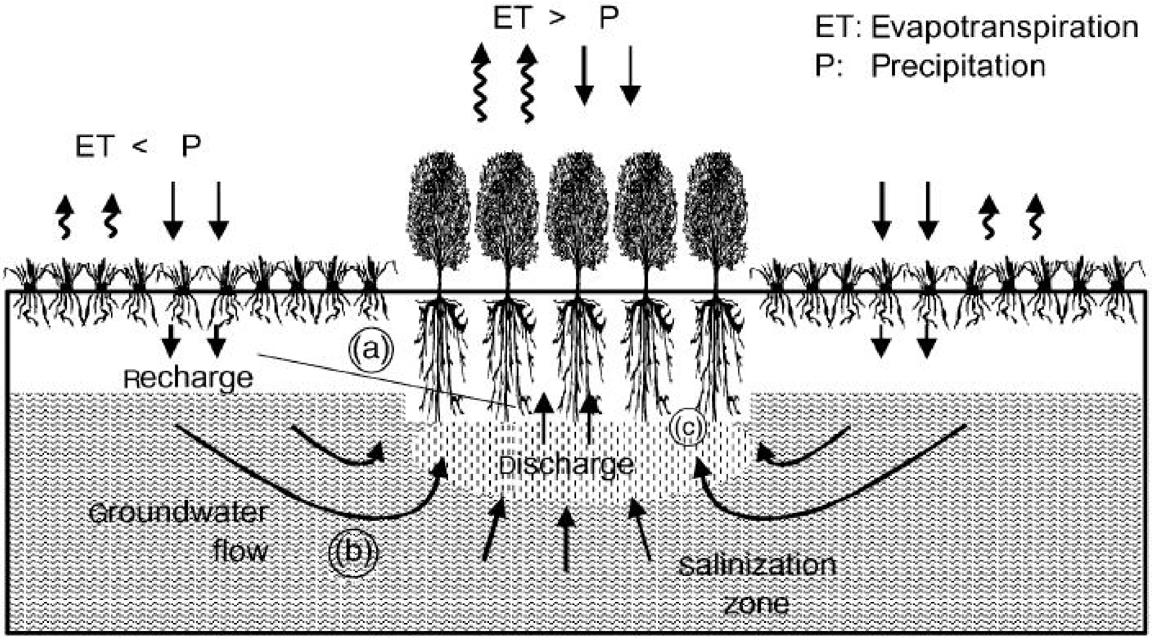


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Fig 1. The scheme of salt accumulation above a shallow groundwater as described by Jobbágy and Jackson, 2004

The model of our study

We will carry out a detailed investigation of the Hungarian situation through the systematic study of all affecting factors, like climatic water balance, groundwater depth and salinity, tree species, subsoil layering and stand age. Subsequently we will provide guidelines for the optimization of further afforestation. The novelty of the research lies in the comparative and comprehensive consideration of all main factors of salt accumulation (climatic, hidrological, biological factors, see Fig 2 of Nosetto et al 2008) across different continents, the Argentine Pampa versus the Hungarian Plain. Only limited number of factors were studied so far by Nosetto 2007, 2008, Bazykina, 2000 and others, and the spatial variability of soil texture is disregarded. In Hungary it is a very strong limiting factor and deserves consideration as suggested by Várallyay, 2002.

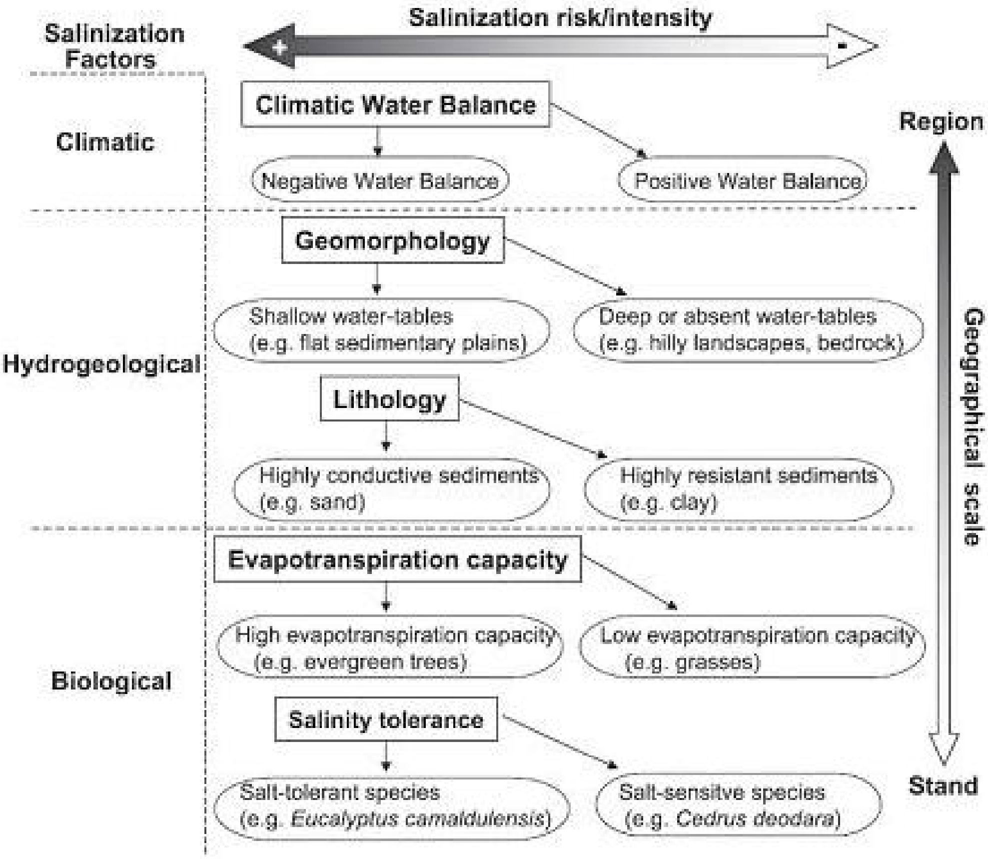


Figure 2 Hierarchical framework for predicting salinization following vegetation changes. Climatic water balance defines the possibility of salinization at the regional scale. Where rainfall does not meet vegetation water needs and groundwater has the potential to offset this deficit, salinization can proceed. Hydrogeological factors (geomorphology and lithology) affect salinization from landscape to regional scales, restricting salinization to areas where groundwater can be accessed and used at significant rates by plants. Biological factors dictate the intensity of salinization across the landscape through the regulation of evapotranspiration rates and salinity tolerance thresholds.

Factors of salt accumulation

Climatic water balance

All the modifying factors listed in Fig 2 will be studied in the project. In our previous paper the effect of climatic water balance was described in detail for the Argentine Pampas. Throughout the Great Hungarian Plain there is a great range found in the annual climatic water deficit (difference between potential evaporation and precipitation), ranging from 100 to more than 250 mm (Pécsi et al, 1985) as shown by Fig 3, but the effect of these differences on soil or subsoil salt accumulation have not been evaluated yet.

Hydrogeological conditions

When the saline groundwater is shallow, the probability of salt accumulation increases (Fullerton and Pawluk 1987) due to increased salt fluxes towards the soil surface (Tóth et al 2001). The range of groundwater depths (watertable) in the Great Hungarian Plain (GHP) was tabulated by Tóth et al., 2001 and ca 77% of the area was found to lie above groundwater depths between 1 and 4 meter (Map 2, Table 2), the most frequent category was the 2 to 4 m.

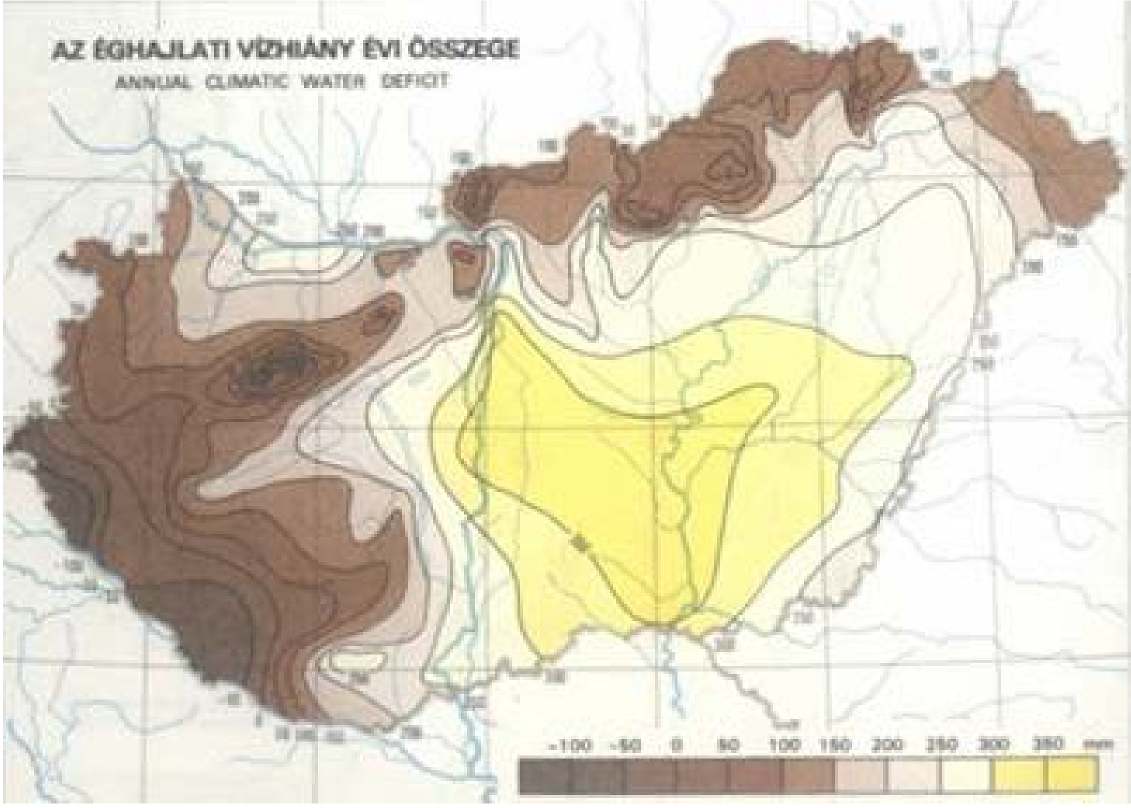


Fig 3. The annual climatic water deficit in Hungary

Table 2. The occuring categories of hydrogeological variables and their percent area on the hydrogeological maps. a. Depth of groundwater. b. Textural classes of near-surface geological formations (sequences and original map codes). In sequences of textural classes G, S, I and C means 2 m thick gravely, sandy, silty, clayey layers, respectively. The five letter sequences of textural classes of 2 m thick layers starts from surface 0-2 m layer and ends at 8-10 m layers. c. Total soluble salt concentration of groundwater. The required categories are gray colored.

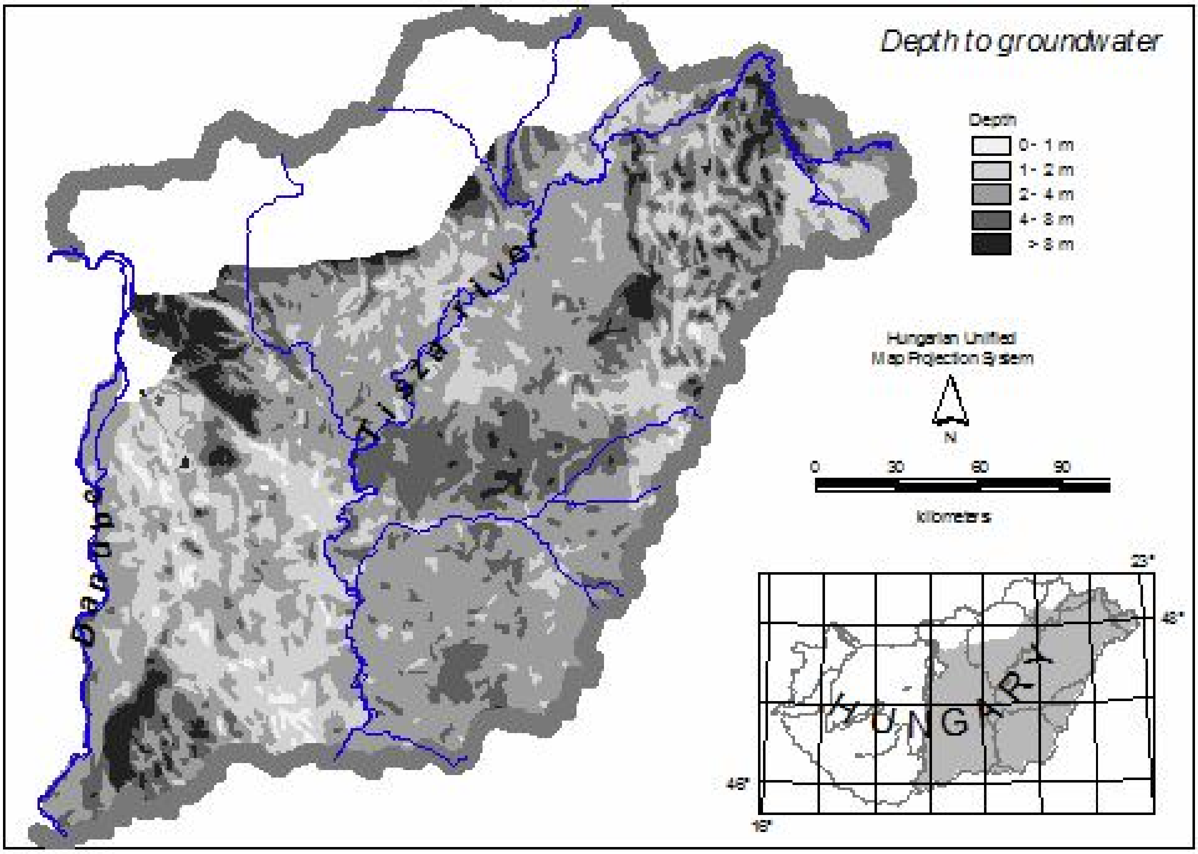
a. Depth to groundwater (m)				
< 1	1-2	2-4	4-8	> 8
1.2	15.8	61.1	17.8	4.2

b. Textural classes of near-surface geological formations (sequences and original map codes)																	
SSSSS	SSCCC	SCCCC	SISSI	SSGGG	SCSCC	SCGGG	III II	IISSS	ISSSS	ISIIS	ICCCI	CCCCC	CCSSS	CSSS	CICII	CCGGG	CSCSS
12	5.8	0.8	5.3	1.2	0.3	0.3	1.7	3.7	2.1	2.4	0.2	45.2	4.9	6.4	2.8	2.2	2.6

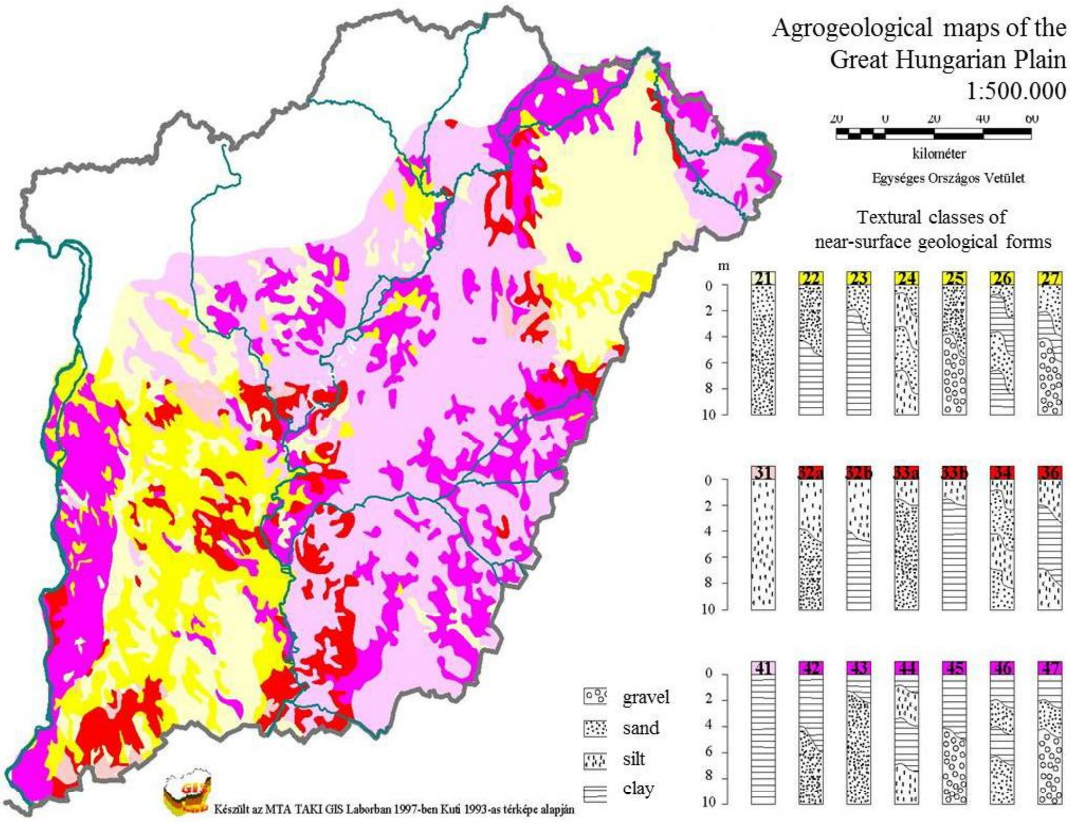
c. Total soluble salt concentration of groundwater (g/l)				
< 0,5	0,5 - 1	1 - 5	5 - 10	> 10
1.8	39.6	54.8	3.8	0.1

The same publication showed that in ca 59% of the GHP areas have shallow groundwaters more saline than 1 g/l (Map 1, Table 2.), but more than 5 g/l salt concentration is just in ca 4% of the GHP. Between the salinity of groundwater and soil there is often close proportional relationship, since a greater salt concentration in groundwater increases the salt flux towards the soil surface (Endrédy 1941, Darab 1967, ’Sigmond 1927).

Also Tóth et al. (2001) listed the typical subsoil textural sequences in GHP and found that 45% of the area can be characterized as clay, 12% as sand down to the depth of 10 m. Some 30% of the area are characterized by variable layers of silt, sand and clay (Map 3, Table 2). Categories with downward fining are small and not extended (12,2%), there is no leaching process (’Sigmond 1927), but the downward fining of the texture promotes capillary rise from the groundwater, if the soil layers are categorized in intermediate textural classes (Gardner 1960).



Map 2. Depth to groundwater



Map 3. Textural classes of near surface geological formations, showing the different classes in the rows: 21-27 sandy, 31-37 silty, 41-47 clayey classes.

Biological factors

At present the most common tree species used for afforestation in the GHP are English oak, (*Quercus robur L.*), black locust, (*Robinia pseudoacacia L.)* and various poplars, most often (*Populus alba L., P. ×canadensis Moench*). These trees are characterized by different growth rate, rooting system and rooting depth according to Crow, 2005. The order of salt tolerance between the species is hypothesised to be *Q robur* > *P species* > *R pseudoacacia* but all three species have some tolerance according to UMES, 2004.

A further factor affecting the salt accumulation is the stand age. This factor determines rooting depth, growth rate and related water uptake and results in increasing salt accumulation underground by time (Bazykina, 2000). The three species have very different cutting ages.

Materials and methods

Study sites

The studies will be done at two scales as hinted by Fig 2. At the regional scale throughout the Great Hungarian Plain altogether 108 afforested stands will be visited to collect data on groundwater, soil and vegetation characteristics. These data will be used in a statistical modeling for the prediction of the effect of afforestation on soil, subsoil, groundwater characteristics. At the stand-scale studies carried out at 16 selected plots the effect of age group of trees, groundwater level, groundwater salinity and soil texture on the transpiration of trees will be assessed by detailed temporal monitoring. These will be monitored to quantify groundwater uptake by trees under differing conditions.

At each stand/plot two boreholes will be prepared (one inside, one outside of the plot in order to provide replicates) in a transect delineated based on the heterogeneous growth of vegetation.

Analysis methods

The studied 108 stands (Table 3) will represent the most important combinations of the factors which affect the subsoil salt accumulation as shown in Fig 2.

Table 3. Availability of occuring forest stands for testing the theoretical sampling design based on orthophotos and detalied topographic maps (1:10,000). The theoretically suitable combinations are gray colored. Empty cells indicate non existing combination of the factors

	Tree species	*Quercus robur L.*			*Robinia pseudoacacia L.*			*Populus sp.*			Unidentified tree sp.		
	Texture sequence	sand	clay	silt	sand	clay	silt	sand	clay	silt	sand	clay	silt
Groundwater salt concentration	*Groundwater-table depth*												
0.5-1 g/l	1-2 m	5	6	2	9	9	5	10	8	11			5
	2-4 m			3		1	10		2	9			1
	4-8 m	9	12	3	15	13	16	9	6	13		1	
1-5 g/l	1-2 m	6	8	0	15	6	3	14	3	3	1	1	1
	2-4 m												
	4-8 m	8	9	3	14	9	5	11	9	7		1	2
5-10 g/l	1-2 m	1	2	0	2	3	0	2	3	1	1	4	3
	2-4 m	1	5	2	3	5	1	3	5	1		4	1
	4-8 m	1	5	3	1	4	0	0	4	1	2	8	2

The number of study sites is received as 3^3x2^2 based on the theoretical sampling design: three mentioned species [*Q robur, R pseudoacacia, Populus species*] X common texture sequences [clay, sand, variable silt] X common water-table [1-2, 4-8 m] X salt concentration of the groundwater [1-2, 5-10 g/l] X stand age [young, medium, mature].

There will be two versions of the equations: one numerical based on the measured data and one using categories of widely available information sources, such as AGROTOPO database (Várallyay and Molnár, 1989), existing groundwater depth and salinity maps by Tóth et al. 2001. The effect of existing soil and subsoil salinity on the tree growth characteristics will be analysed in those studied plots, which are covered by a series of available ASTER satellite images with spring and autumn recordings.

Experiences with the sampling design

We chose from among the numerical categories the extreme ones (gray colored in Table 3), because based on our expectations they will provide suitable range of the salt accumulation process. With the help of orthophotos and detalied topographic maps (1:10,000) we chose tree plantations with suitable size (1 ha). The available maps don't provide information on stand age, so we have to use another special forest database.

To some of the theoretical categories, especially those with high groundwater salt content, we could assign few (0-3) occuring stands and in these cases we might face problems during statistical evaluation. The uneven distribution of the classes is well documented by Table 2, see for example the less (0.5-1 g/l) and more saline (5-10 g/l) groundwater classes with 39.6 and 3.8 % territorrial distribution, a 10 times difference. This situation is well reflected by the last three lines of Table 3. At least 3 stands would be needed in each cell to provide three age classes of the species, but in several cases (13 of the full table) these are not available. The possible solution is the selection of a neighbouring class in this table. Also the stands with so far unidentified species (last three columns of Table 3) provide a reserve for our studies.

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