Afforestation on Salt Affected Soils in Hungary

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The East Hungarian experimental station of the Forestry Research Institute at Püspökladány was set up in 1924. The main reason for its establishment was the fact that Hungary had limited timber resources and was obliged to import roughly half of its wood requirement. New timber production base had to be established to lighten this import load, particularly by means of afforestation on the almost completely treeless lowland areas of Eastern Hungary.

In this part of the country a considerable proportion of the soils (25—33% of the cultivated area in some regions) is salt affected. These conditions cause particularly serious problems in the case of afforestation, since the root systems of the trees penetrate so deep that they give a sensitive response to the effects of salts found in the deeper horizons of soil types which are not typically salt affected (e. g. chernozem, meadow and peaty soils). This necessitated investigating the effect of salinity and alkalinity on trees and determining the possibilities of afforestation in salt affected areas. It was for this purpose that the Hungarian state set up the Püspökladány experimental forestry station.

When the research began, no data were available, neither in Hungary nor in the international literature, on the conditions required for successful afforestation on salt affected soils. Consequently, the research carried out in Hungary and the scientific and practical results achieved in this field are pioneering and of fundamental importance.

The task confronted was the following: it had to be determined on what types of salt affected soil — or on other soils influenced by alkalinity — under what ecological conditions, with what tree species and with what techniques can afforestation be successfully carried out.

In certain parts of Hungary the salinization and/or alkalization of soils have been caused by fluctuating saline groundwaters which exert their harmful influence on the upper soil layers. Consequently, when planning afforestation on salt affected soils, consideration must be given to both the solonchak and solonetz types of soils, and also to the water soluble salts, particularly the sodium salts, which accumulate in different layers of the soil profile, and to the Na^+ fixed in adsorption complexes.

Salts dissolved in water disturb the life functions of the vegetation and are toxic in higher concentrations. This is particularly true of sodium salts which undergo alkaline hydrolysis, primarily Na_2CO_3. The anions of the dissolved salts also make a difference: sulphates cause less damage, while chlorides and especially the carbonates of Na are more strongly toxic.

The toxic effect of the salts is strongly felt by the majority of woody plants, with different threshold values of tolerance depending on the species. A salt content of 0.10 % or a phenolphthalein alkalinity of 0.05 % does not usually affect trees. Poplars are sensitive to a salt content of over 0.15 % and cannot be grown above 0.20 %. There are, however, differences between poplar varieties. *Aigeiros* poplar hybrids are more sensitive, while *Populus alba* is less so. Poplars give a strong negative response to sodium carbonate alkalinity of over 0.05 %. For *Quercus robur* the corresponding salt tolerance threshold values are 0.20% – 0.25%, while the phenolphthalein alkalinity tolerance is 0.10 – 0.15 %. Higher salt contents are tolerated by *Elaeagnus angustifolia* and *Tamarix* species *(T. odessana, T. tetrandra)* to a threshold value of 0.5 %. Recently successful trials have also been made with *Ulmus pinnato-ramosa* on saline soils with salt contents up to 0.50 %. On soils with a salt content of over 0.50 % or a phenophthalein alkalinity over 0.20 % no tree or shrub species can survive under Hungarian ecological conditions. Under dry conditions the greatest accumulation of salts and the strongest soil alkalinity can be tolerated by the *Tamarix* species (particularly *T. tetrandra);* nevertheless, it is now considered wiser to avoid this species because, due to its high salt toleranting ability, the roots are able to penetrate into the deeper layers and take up large quantities of dissolved salts from the soil. In the course of transpiration these salts then reach the leaves and shoots and are precipitated out onto their surfaces. Rainfall then washes the salts off the leaves and shoots onto the surface and into the upper layers of the soil, thus increasing the originally lower or completely lacking salt content. It is worth noting that, by contrast, *Elaeagnus angustifolia*, which has a shallow root system, exerts a significant ameliorative effect, since the free nitrogen of the air is fixed in the soil by the microorganisms which live in symbiosis with the roots. Consequently, rich undergrowth with a high N requirement develops, leading to an enrichment of the soil with organic matter.

On the other group of salt affected soils, the alkali soils, it is primarily the increase of Na^+ in the adsorption complex which causes problems for afforestation. These mainly structural alkali soils, including the solonetz soils which are particularly widespread in Hungary, have bad physical characteristics and, as a result, extremely unfavourable water regime properties. Due to the compacted nature of the soil structure, the considerable air requirements of tree roots cannot be fully satisfied. In plant breeding contex this form of alkalinity is also known as physical alkalization.

If the exchangeable Na^+ content is less than 10 % of the S value, it does not prevent the successful cultivation of the majority of tree species, provided the other conditions of the site are favourable. For example, poplars and oaks *(Quercus robur)* may grow well on this type of weakly solonetzic soil. If the exchangeable Na^+ content is 10 – 20 % of the S value, the growth of these tree species is retarded, and above 15 % only oak trees *(Quercus robur)* or, if the water supply is good enough, white poplars *(Populus alba)* can be planted with any degree of success. At higher exchangeable Na^+ contents even the oak produces poor growth, while at over 30 % of the S value only *Ulmus pinnato-ramosa*, *Elaeagnus angustifolia* or, in extreme cases, *Tamarix* species can be planted.

Naturally, the effect of the salts and the Na^+ ions fundamentally depends on the depth at which they are found Their harmful effects are exerted primarily if — in the case of relatively favourable water regime — the salts accumulate within 0—60—70 cm, or — under drier conditions — within 90—100 cm below the surface. If the salt accumulation occurs at a greater depth, its detrimental effect is manifested in shortening the normal lifespan of the trees. The shorter lifespan of the trees is, in fact, a general phenomenon on salt affected soils. The extent to which salinity and/or alkalinity make their effects felt is also influenced by other soil characteristics and ecological factors. A high $CaCO_3$ content in the soil is sufficient in itself to produce a bad water regime, since a higher calcium carbonate content, particularly when finely distributed, increases the physiological dryness of the soil for the trees. On calcareous alkaline soils there is always a danger of an increase in the Na_2CO_3 content, or at least of strong alkalinity. A calcium content of 6—10% may be beneficial if it is not accompanied by sodium carbonate alkalinity. Under moist conditions a $CaCO_3$ content of over 15% within the upper 70—80 cm layer, or over 10% on dry growing sites, will in itself cause a depression in the growth of the trees.

If there is a large proportion of fine particles in the texture of the soil, the unfavourable effects of the Na^+ ion content of the adsorption complex (poor water conductivity and unfavourable water regime, poor aeration etc.) increase. This further reduces the possibility of tree cultivation, since layers with such properties can only be penetrated by the tree roots with difficulty, if at all.

On heavy textured salt affected soils and on others influenced by salinity and/or alkalinity the nature of the surface water supply is a vitally important ecological factor. As the result of differences in the microrelief, often in the order of only tens of cm, precipitation falling on the soil flows from the higher to the lower areas, since the infiltration of water into the soil is slow on heavier soils, particularly when they are salt affected. The water regime on the higher lying areas is poor, since less of the precipitation is utilized, due to runoff on the surface (the average annual precipitation on areas of salt affected soils in Hungary is 520—550 mm). The surface water supply is good on lower lying areas, since more water is available for infiltration into the soil than actually falls on the area, due to runoff from higher areas. On areas with a better surface water supply the water regime is considerably improved and the soil is able to store sufficient water to cope with droughts (which regularly occur during the second half of the summer). The larger quantity of water may create more favourable leaching conditions, and it certainly promotes a reduction in the concentration of the salt solution in the soil. On saline areas with a good surface water supply the characteristic soil types are meadow solonetzes and meadow (or possibly peaty) soils with salt accumulations in the deeper layers. These are the best sites for afforestation on salt affected areas: moist oak forests *(Quercus robur)* with a high timber yield can be planted, while less heavy textured soils are suitable for poplar forests. Saline areas with a poor surface water supply usually consist of various types of meadow solonetzes. If the top layer of the soil which can be used by the roots is at least 40 cm thick, *Elaeagnus angustifolia* can be planted; if the top layer is 60—100 cm thick, oak trees with a poor timber yield, often more in the nature of bushes, can be grown, while a thicker top layer means that oak forests with a medium timber yield can be established. These oak forests are always of a dry character.

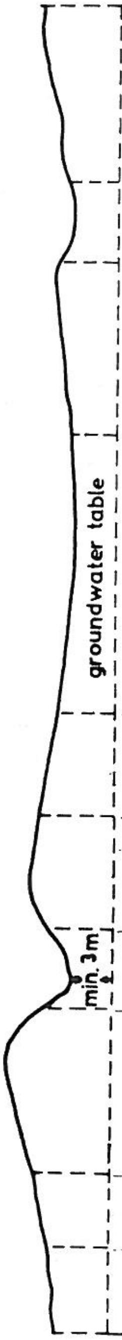
The correlations between the relief forms, soil types and afforestation possibilities on salt affected soils are depicted in Fig. 1.

The importance of the natural features, of changes in the microrelief and of the surface water supply are well illustrated by the timber characteristics of two near-by oak woods which make up part of the experimental forest of the East Hungarian Experimental Forestry Station. One is located in a deeper lying section of the forest, under the influence of the fluctuating water table. The surface water supply is good. The soils may be classified as slightly — moderately solonetzic meadow soils. The thickness of their top layers is medium to deep, its moisture status varies periodically. The characteristic data of the 40 year-old oak tree stand are: average tree height 15.4 m, average diameter at breast height 17.5 cm, total timber yield 294 m^3/ha, average annual growth rate 7.2 m^3/ha. The other oak wood was planted on a strongly solonetzic soil at a near-by, higher lying site having a poor surface water supply. The top layer of the soil is medium thick. The moisture status of the soil is dry; the characteristic data for the 32-year-old oak trees on this site are: average tree height 11.5 m, average diameter at breast height 13.0 cm, total timber yield 137 m^3/ha, average annual growth rate 4.0 m^3/ha.

Growing sites in Hungary, including saline and alkali sites, are classified within the framework of the forestry site typological system on the basis of the afforestation possibilities and their value for timber production. The individual growing site categories are determined on the basis of the associations indicative of the climate (this is always forest-steppe in salt affected regions), the hydrological characteristics and the genetic soil type (sub-type), while the growing site sub-categories are also determined by the physical soil type and the thickness of the top layer which can be utilised by the trees. The hydrological characteristics of the growing site are defined by waters other than precipitation which falls directly onto the area, and independent of the water capacity of the soil. Consequently the following hydrological categories are distinguished on salt affected areas: sites unaffected by surplus water (e.g. areas with a poor surface water supply and a low water table), sites with a varying water supply (e. g. areas with a good surface water supply, where there is a periodic abundance of water, but a deficiency of water in the second half of the summer), sites influenced periodically by the groundwater, and sites under its permanent influence.

In the forest-steppe climate which includes salt affected areas, the various categories of surface soil thickness (i. e. the layer which can be penetrated by tree roots and thus utilized by the trees) are as follows: very shallow: 0—40 cm, shallow: 40—60 cm, medium: 60—90 cm, deep: 90—140 cm, very deep: $>$ 140 cm. On salt affected soils with a very shallow surface soil layer afforestation is impossible without amelioration; where the surface soil layer is shallow, *Ulmus pinnato-ramosa*, *Elaeagnus angustifolia*, *Pyrus pyraster* and *Tamarix* species may be planted; on salt affected sites with a medium surface soil layer slowly growing, dry oak woods may be planted if the area is unaffected by surplus water, and oak or white poplar *(Populus alba)* forests may be planted if the soil is under the influence of a fluctuating water table; on salt affected soils with a deep surface soil layer oak or poplar forests with a good timber yield may be established.

On salt affected areas the growing site conditions may change in a mosaic manner even within a small area. Thus, it is very important to identify these differences in site conditions within the salt affected territory and to treat them



medium high	meadow solonetz turning into steppe formation; dry	**dry oak** (Quercus robur, Qu. cerris)
medium	crusty and medium meadow solonetz; extremely dry or very dry	without amelioration Elaeagnus angustifolia or bushy oak (Qu. robur) at best
riverbed type of structure	meadow solonetz, or meadow soil with salt accumulation in deeper layers; dry or semi-dry	moist oak (Qu. robur) or poplar (Populus "Marilandica", P. "Robusta")
medium — medium high	medium meadow solonetz turning into steppe formation; very dry	bushy or dry oak (Qu. robur)
	shallow and medium meadow solonetz; extremely dry or very dry	without amelioration Elaeagnus angustifolia or oak (Qu. robur) at best
medium deep	(weakly-medium-strongly) solonetzic meadow soils, often with considerable accumulation of $CaCO_3$; moist, semi-dry or very dry	moist or dry oak (Qu. robur, Qu. cerris) or poplar (Populus "Marilandica", P. "Robusta", P. "I-214")
medium	shallow and medium meadow solonetz; extremely dry or very dry	without amelioration Elaeagnus angustifolia or bushy oak (Qu. robur) at best
medium high — high	meadow chernozem with salt accumulation in deeper layers, meadow solonetz turning into steppe formation	dry oak (Qu. robur, Qu. cerris)
riverbed type of structure	meadow soil, or meadow soil slightly saline in deeper layers	moist oak (Qu. robur) or poplar (Populus "Marilandica", P. "Robusta", P. „I-214")
high	meadow chernozem (meadow chernozem saline in deeper layers); dry or semi-dry	dry oak (Qu. robur) or poplar (Populus "Robusta")
medium high	meadow solonetz turning into steppe formation; dry	dry oak (Qu. robur, Qu. cerris)
medium	shallow and medium meadow solonetz; extremely dry or very dry	without amelioration Elaeagnus angustifolia or bushy oak (Qu. robur) at best

Fig. 1.
The possibilities of afforestation on salt affected soils

separately. Practical assistance is given by differences in the microrelief and, on natural, undisturbed grasslands, by the plant associations covering the soil (phytocoenological categories). A narrow river-bed type of depression in a high-lying salt affected plateau which makes up a section of the experimental forest attached to the Experimental Forestry Station may be taken as an example. The growing site on the plateau is unaffected by surplus water and has a shallow meadow solonetz soil with a very shallow (a mere 7—10 cm) surface soil layer which is extremely dry. Sunk into this is a 40 m wide, about 1000 m long and 1—1,5 m deep riverbed-like depression, where the growing site — covered by slightly solonetzic meadow soils and meadow soils saline in deeper layers — is under the periodical influence of the groundwater, with a good surface water supply and a periodically semi-moist or semi-dry, medium-deep top layer. The salt affected plateau is unsuitable for afforestation but there is a well growing poplar forest *(Populus × euramericana* cv. *'Robusta')* in the depression. The characteristic timber data for 17-year-old trees are: average tree height 19.4 m, average diameter at breast height 23.2 cm, total timber yield 237 m^3/ha, average annual growth rate 13.9 m/ha.

The most important tree species for afforestation on salt affected soils are the oak *(Quercus robur*, or *Quercus cerris* on drier calcareous soils), the poplar and, under sufficiently moist conditions, the white willow *(Salix alba)*. Under the more favourable conditions defined above, these are capable of producing good timber growth of high commercial value even on salt affected growing sites. On salt affected soils giving lower timber yields *Ulmus pinnato-ramosa* and *Elaeagnus angustifolia* may be succesfully planted, always as a protective forest belt (soil conservation, protection from wind erosion). In addition to these main tree species, *Ulmus effusa*, *Fraxinus angustifolia* ssp. *pannonica*, *Fraxinus pennsylvanica*, *Pyrus pyraster* and *Amorpha fruticosa* may be planted on more favorable salt affected growing sites as part of a mixture of tree species.

On saline and alkali soils, apart from the salt conditions, the type of water regime is the decisive factor from the viewpoint of successful afforestation. Consequently, all the agrotechnical measures must be aimed at improving the water balance of the soil, at promoting the infiltration into the soil of water reaching the surface, and at retaining as much as possible of the infiltrating water. To this end, afforestation on salt affected lands must be preceded by high quality soil preparation. Care must be taken when ploughing to ensure that the salt accumulation layer is not mixed with the less saline upper soil layers. In certain cases it may be better to loosen the soil to some depth without turning it. Again in the interest of an improvement in the water balance, young forest areas should be regularly cultivated until the young growth completely covers the soil surface. The aim of soil cultivation is to systematically prevent weeds from competing for the water, while loosening the soil promotes better aeration and prevents the evaporation of soil moisture.

In some cases it may be necessary to establish protective forest belts on salt affected soils with an extremely shallow surface soil layer (e. g. around agricultural centres or animal husbandry units) where afforestation cannot be successfully carried out. In order to solve this problem, a complex amelioration technique has been developed at the Experimental Forestry Station, combining physical, chemical and biological elements of amelioration.

Physical amelioration consists basically of constructing two 10 m wide ridges with a maximum height of 100 cm, where the 20 m wide forest belt is to be planted. In rainy periods water is collected and stored in the ditches formed at the edges of the ridges and between them, and the soil of the ridges is regularly moistened by this water in a lateral direction.

Chemical amelioration consists of the application of a combination of lime + gypsum. The proportion of lime to gypsum is a function of the mean pH value in the original upper 20 cm soil layer. The quantities of amendments and the proportions in which they should be applied are given in Table 1.

Table 1

Quantities of amendments as a function of pH values, needed for complex amelioration preceding afforestation

Mean pH value in the upper 20 cm soil layer	Quantity to be applied, t/ha	
	lime sludge (from sugar factory)	gypsum sludge (from sulphuric acid works)
< 7.5	52	—
7.5—7.7	43	9
7.8—7.9	35	17
8.0—8.2	26	26
8.3	17	35
> 8.3	5	52

Note: The quantities given refer to 50% active agent content. If the active agent amounts are taken into consideration, other materials containing $CaCO_3$ or $CaSO_4$ may also be applied

In order to improve the soil biologically, on the chemically ameliorated ridges green manure plants must be grown, which are then ploughed under. The most suitable species for this purpose is *Lathyrus sativus*, or possibly sunflower. This aim can also be achieved with organic manure if it is available.

This method of ameliorative afforestation can only be employed successfully on solonetz-type soils where the top 20 cm of soil contains no lime and has a phenolphthalein alkalinity of less than 0.15%, with a pH value of 8.7 at most.

The technological process for complex ameliorative afforestation on salt affected areas is as follows: the chosen strip of land to be afforested is ploughed to a depth of 20 cm (it is advantageous to complement this with subsoil loosening without turning); if organic manure is available, it should be spread at the rate of 35 t/ha; 50% of the calculated amendment requirement is then distributed and mixed shallowly into the ploughed soil; a 2×10 m wide ridge system with a maximum height of 100 cm is constructed by special ploughing; the second half of the calculated amendment requirement is distributed and mixed lightly into the surface of the ridges; a green manure crop is sown and ploughed under at a suitable stage of development (this operation can be omitted if organic manure was applied); the ridges are finally planted with mixed stands of the following tree species: *Ulmus pinnato-ramosa. Elaeagnus angustifolia* and *Pyrus pyraster*, with *Quercus* on better quality sections and rows of *Fraxinus pennsylvanica* and *Ulmus effusa* running along the lower, moister edges of the ridges.

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