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THE EFFECT OF SOIL PHYSICAL PROPERTIES OF AN ENTISOL ON THE GROWTH OF YOUNG POPLAR TREES (*POPULUS* SP.)

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Abstract

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The effect of soil physical properties of an Entisol on the growth of young poplar trees in a forest nursery was studied. In parts of the nursery where the growth of poplar trees was limited, the results showed lower permeability and higher field capacity, thus resulting in insufficient soil aeration. These conditions are attributed to the higher values of SAR and ESP found there, which caused clay dispersion and blocking of soil pores. In other parts of the nursery, the growth of poplar was normal. These unfavorable soil physical conditions along with the high pH values are considered responsible for the poplar growth retardation.

Key words: clay dispersion, field capacity, air capacity, SAR, ESP, poplar

Introduction

Poplar is the common name given to all species of the genus Populus. Conventional hybridization among poplar species has resulted in trees that combine desirable characteristics of different species. Hybrid poplars are grown as short-rotation woody perennials. Poplars occur naturally in most temperate and cold regions in the Northern Hemisphere. Since they generally have a high soil moisture requirement, most species grow along the moist, free draining floodplains of rivers and streams (National Poplar and Willow Users Group, 2007).

The soil factors, which determine the growth of poplar trees according to their importance, are as follows (Broadfoot, 1969): a) soil physical properties, b) available water during growth period and c) soil fertility level, which contributes by 20% to the total growth of poplar trees (Broadfoot and Baker, 1979).

Soil physical conditions are determined by certain properties such as bulk density, porosity, pore size distribution, pore orientation and continuity, and related properties such as shear strength and soil resistance to root penetration, hydraulic conductivity and infiltration, water-holding capacity and soil air renewal (Alifragis, 2008). If soil resistance to root penetration is high and the soil properties mentioned above are such that do not favor an optimum water holding capacity or a satisfactory soil air renewal rate, the growth of the poplar plant root system will be decreased. Consequently, the roots exploit a smaller soil volume and they have a lower quantity of available water, nutrients and O_2 at their disposal. As a result, the growth of the above ground part of the plant is limited as well. Such a negatively affected growth of young poplar trees was observed in a part of the state forest nursery in Nea Chalkidona, Thessaloniki, North Greece (Macedonia), due to the unfavorable soil physical conditions prevailing in the rhizosphere.

The purpose of this work is to study in detail the role of the soil physical properties in the physiological growth of the young poplar plants.

Materials and Methods

In this study, two Entisols were used, sampled from two sites (profiles 1 and 2) selected in a poplar field located in the state forest nursery of Nea Chalkidona, Thessaloniki (Photo 1). This forest nursery is located close to the Axios River and the climate of the region is of Mediterranean type.

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The soil of profile 1 (Site 1) is representative of the part of the forest nursery where the plant growth was optimum. On the other hand, the soil of profile 2 (Site 2) represents that part of the field which was characterized by severely limited plant growth (Photo 2). Soil samples, undisturbed and disturbed, were taken from the two profiles and from 0-40 cm, 40-80 cm, 80-95 cm and >95 cm depths.

The undisturbed soil samples were sampled by means of stainless metallic cylinders. These samples were used for the construction of the soil water retention characteristic curves used for the calculation of field capacity (FC), air capacity, and the determination of the resistance to penetration (PR), bulk density (D_b) as well as for the laboratory measurement of the saturated soil hydraulic conductivity (K_s).

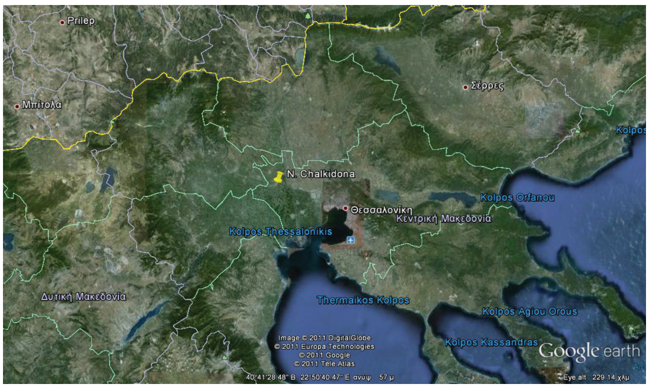

Photo 1. Location of the N. Chalkidona state forest nursery (Region of Central Macedonia – North Greece)

Photo 2. Photograph taken from the forest nursery of Nea Chalkidona. In the background (left), the young poplar trees with optimum growth are easily distinguished (Site 1). In the front part of the photo, the limited growth of young poplar trees is obvious (Site 2)

The PR was determined in undisturbed soil samples which had previously been equilibrated at 1, 10, 100, 1000 and 10^5 kPa suction pressure, respectively (Panayiotopoulos et al., 1994). The conical edge of the penetrometer used, had an angle of 60°, a base diameter equal to 3 mm and a penetration velocity of 1.52 mm·min^{-1}. The PR was calculated as the strength faced by a conical edge for penetrating into a depth of 10 mm from the surface of the sample via the cross-section of the base of the conical edge (Bengough and Mullins, 1990). The PR measurements were repeated three times for each soil water suction value and, in each sample, two measurements were conducted.

The K_s was determined in soil samples with dimensions of 7.5 cm (in diameter) x 10.0 cm (in height), in five replications, using a constant head permeameter, while a solution of 0.005 M $CaSO_4$ was used as a "discharge liquid" (Klute and Dirksen, 1986). K_s were calculated by means of Darcy's Law, i.e.

$$K_s = \frac{Q \cdot L}{A \cdot \Delta t \cdot \Delta\psi} , \qquad (1)$$

where Q = volume of solution passing through the soil sample in Δt time when the potential difference applied to the sample was equal to Δψ, L = height and A = cross section of the soil samples.

The bulk density (D_b) was determined as the mass of dry soil per unit bulk volume, the soil being dried at 105°C (Blake and Hartge, 1986).

Total porosity (n) was calculated by means of the relation:

$$n = 1 - \left(\frac{D_b}{D_s} \right) , \qquad (2)$$

where D_s = soil particle density (~ 2.65 Mg·m^{-3}).

Field capacity (FC) was calculated as the soil moisture expressed by volume, under suction of the soil water at 10 kPa (Marshall and Holmes, 1988) and air capacity as the difference of the moisture, expressed by volume of the soil samples, between saturation and FC (Hillel, 1982).

The disturbed soil samples after being air-dried were ground and sieved through a 2 mm sieve. In the soil fraction of < 2 mm particle size, the following properties were determined (in two replications): a) particle size analysis by pipet method (Gee and Bauder, 1986), b) organic matter by the wet oxidation method (Nelson and Sommers, 1982), c) pH (saturation paste) (McLean, 1982), d) electric conductivity in saturation extract (Rhoades, 1996) and e) free $CaCO_3$ by use of Bernard calcimeter.

Five poplar plants were selected from near and around each of the two profiles and measurements included root system and the above ground part of the plant. The soil surrounding the root system of each of the sampled plants as well as the soil attached to the roots was removed by the use of flowing water under pressure. In each plant the number and length of main roots, the number and length of secondary roots, the dry matter mass of the root system, the height of each tree and the dry matter mass of shoots and leaves, were measured. The poplar trees studied were of clone I-214. As the study was conducted in a nursery, the trees were very densely planted, approximately 1.0 m x 1.5 m. This applies to both sampling sites.

To evaluate the effects of the studied soil properties on poplar growth, the experimental data were statistically analyzed by running ANOVA, the Least Significance Differences (LSD) method and Student's *t*-test, using the JMP-7 statistical software (Sall et al., 2007).

Results and Discussion

It was found that the soils studied, showed a tendency of increasing clay content by depth. The soil texture is loamy (L, SiL and SCL) and the soil is classified as Entisol (Table 1) according to Soil Taxonomy (1999).

The pH value was quite high (>7.7), especially in the lower layers of profile 2, and it was generally higher than the optimum pH required for the growth of poplar (pH 7) (FAO, 1958).

The organic matter content was higher than the average content for cultivated soils of North Greece (~1.15%) (Koukoulakis et al., 2000), while the $CaCO_3$ content is relatively high in profile 2. For example, in 80-95 cm depth, $CaCO_3$ content is 3.5 times higher in profile 2 than in profile 1. As far as the EC values, they are lower in profile 2 than in Profile 2, with the difference being significant at $p<0.05$ level of probability (Table 1).

Another significant difference between the two profiles was found among the SAR and ESP values (Table 1). More specifically, in the lowest depths of the two profiles (>80 cm), the SAR and ESP values were higher than in the upper layers. In these depths, the SAR and ESP values of profile 2 were higher than the corresponding values of profile 1, the difference being statistically significant at $p<0.05$ level.

Under conditions of decreased EC and high SAR, as in the case of deeper layers of profile 2, an increase in clay dispersion is expected (Papatolios et al., 2000). The presence of high percentage of dispersed clay has unfavorable consequences and causes the degradation of the soil structure and of the related soil physical properties such as hydraulic conductivity, water retaining capacity and soil air renewal capacity (Brady and Weil, 2007).

The most important physical properties for the two profiles are given in Table 2. There are significant differences ($p<0.05$) along the depth of each profile, between the D_b values for each layer, while the two profiles differ with respect to the D_b and n values statistically significantly ($p<0.05$) only at the 80 – 95 cm depth. In profile 1, the saturated hydraulic conductivity (K_s) shows a continuous increase with the depth; however, significant differences ($p<0.05$) were found only between the 0-40 cm and 80-95 cm depths, as well as between the >95 cm depth and all the upper soil layers. In profile 2, the K_s increased up to the 80-95 cm depth, followed by a decrease in the lower layers. Significant differences for K_s, were found between the deeper soil layers and the ones above them. The comparison between the two profiles showed that profile 2 has lower K_s values in relation to profile 1, and the

Table 1
Particle size analysis and some chemical properties of the soils

Depth, cm	Sand, %	Silt, %	Clay, %	Textural class	pH	Org. matter, %	$CaCO_3$, %	EC, dS/m	SAR, meq/$L^{1/2}$	ESP, %
Profile 1										
0-40 cm	34.75	44.40	20.85	L	7.7	2.52	2.39	2.85	3.21	4.89
40-80 cm	23.56	54.45	21.99	SiL	8.1	1.02	3.26	1.41	4.62	6.48
80-95 cm	22.07	53.06	24.87	SiL	7.8	0.29	2.38	2.30	6.53	8.92
>95 cm	23.85	49.51	26.64	L	8.1	0.22	1.40	2.19	12.69	16.0
Average profile	26.06	50.36	23.59		7.9	1.01	2.36	2.19	6.76	9.07
Profile 2										
0-40 cm	36.03	43.75	20.22	L	7.8	1.88	3.33	1.19	1.73	2.56
40-80 cm	18.98	56.32	24.70	SiL	8.1	1.74	1.81	1.04	3.61	5.13
80-95 cm	23.47	52.97	23.56	SiL	8.7	1.17	8.51	1.47	13.74	16.8
>95 cm	17.08	54.31	28.61	SCL	8.7	1.09	3.08	1.67	22.55	25.10
Average profile	23.89	51.84	24.27		8.3	1.47	4.18	1.34	10.41	12.40

differences for the >95 cm depth were statistically significant ($p<0.05$).

In situ observations indicated that in the part of the nursery where plant growth was limited, the soil surface remained covered with water (flooded) during winter as well as the first spring months. The field capacity (FC) did not show changes with the depth in none of the profiles studied. Yet, the comparison between the two profiles showed that profile 2 has a higher FC than profile 1, the difference being statistically significant at $p<0.05$ level for the 40 – 80 and 80 – 95 cm depths, respectively. The increased FC of profile 2 should correspond to a rather low air capacity. However, statistically significant differences with respect to air capacity were not found between the two profiles or between the corresponding depths. Air capacity expresses the ability of a soil to store air, but it does not give any information about the ability of the soil to renew the soil's atmosphere. The absence of statistically significant differences with respect to air capacity between the two profiles does not necessarily mean that the soil aeration in the two profiles studied, is similar.

Figure 1 presents the changes of soil resistance to root penetration (PR) under soil water suction in both the profiles studied, showing an expected increase in PR with suction of the soil water, due to the increase of cohesion and friction. According to Bengough and Mullins (1990), a PR value of 3MPa constitutes a critical level for the root growth. Although the selection of the profiles was made based on the poplar tree growth, it must be mentioned that a safe conclusion for the aforementioned differentiation cannot be reached based only on the PR values. Even though PR values for suction forces >1000 kPa, differ between the two profiles, such high suction values are not met under real conditions during the irrigation of crops, such as the ones in this forest nursery.

Table 2
The most important physical properties of the profiles

Depth, cm	Bulk density, $Mg{\cdot}m^{-3}$	Porosity, $m^3{\cdot}m^{-3}$	Field capacity, $m^3{\cdot}m^{-3}$	Air capacity, $m^3{\cdot}m^{-3}$	Saturated hydraulic conductivity, $cm{\cdot}h^{-1}$
Profile 1					
0-40 cm	1.33	0.520	0.430	0.090	2.34
40-80 cm	1.20	0.588	0.427	0.161	5.26
80-95 cm	1.50	0.488	0.413	0.075	9.83
>95 cm	1.44	0.514	0.440	0.074	15.73
Average profile	1.37	0.528	0.428	0.100	8.29
Profile 2					
0-40 cm	1.33	0.540	0.447	0.093	0.77
40-80 cm	1.24	0.578	0.471	0.107	1.40
80-95 cm	1.29	0.538	0.457	0.081	7.88
>95 cm	1.44	0.505	0.436	0.069	6.50
Average profile	1.33	0.540	0.453	0.088	4.14

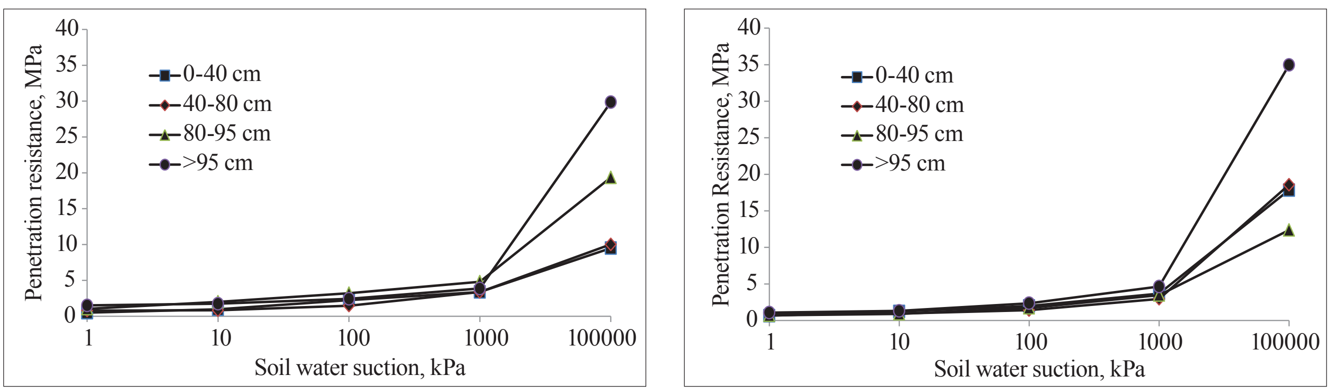

Fig. 1. Changes of resistance to penetration in relation to soil water suction in profiles 1 and 2, respectively

Table 3 presents agronomic information in relation to the growth of the young poplar trees such as number and length of primary (main) roots, number and length of secondary roots, root system dry matter mass, height of trees, shoot and leaf dry matter mass. As it can be easily discerned, the poplar tree growth near and around profile 2 is significantly lower than the corresponding growth of the trees around profile 1. So, it was found that tree height in Site 2 was 60% lower compared to that of the optimum growth in Site 1, while dry matter of root system was only 11% of that of the optimum growth. Finally, total root length reached 46.6% the root length of optimum growth. Comparison of all the means showed that the differences between trees corresponding to profiles 1 and 2, are statistically significant ($p<0.05$) in all cases.

The documented reduced growth of the poplar trees in profile 2, cannot be justified simply on the basis of one soil property. The reason for the reduced plant growth must be attributed to a number of soil properties, which interact and, in the case of profile 2, have undesirable values.

More specifically, the high SAR and ESP values found in the deeper soil layers of profile 2, are expected to cause clay dispersion followed by clay movement. This has probably contributed to the decrease of pore cross section (size), as well as clogging. These changes resulted in the decrease of K_s and an increase of FC, a fact that was supported by the results of this study and by the presence of water on the soil surface for a long period. The natural consequence of these changes is the reduction of the soil air renewal rate. Therefore, these unfavorable conditions combined with the high pH values, constitute a suspending factor for the unrestricted growth of the poplar trees, both root system and the above ground part.

Conclusions

The reduced growth of the young poplar trees is attributed to the combined effects of unfavorable soil physical conditions and the high soil pH, which are dominant in the lower layers of profile 2. These unfavorable conditions are due to clay dispersion caused by the high SAR and ESP values and to clay movement causing clogging of the pores and subsequent increase of the water holding capacity. At the same time, there is a decrease of the hydraulic conductivity and the soil air renewal rate.

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Table 3
Agronomic information in relation to the growth of the young poplar trees

Number of tree	Main roots			Secondary roots			Dry matter mass of root system, g	Tree height, m	Shoot dry matter mass, g	Leaf dry matter mass, g
	Number of roots	Mean length of roots, cm	Total root length, cm	Number of main roots	Mean root length, cm	Total root length, cm				
Profile 1										
1	5	98.2	491	14	35.0	490	205	4.30	770	130
2	7	88.7	621	7	53.1	372	140	3.30	390	30
3	8	71.3	570	9	72.7	654	190	4.05	740	140
4	7	70.1	491	21	48.9	1027	290	3.70	790	120
5	9	75.4	679	14	65.1	911	180	3.90	550	85
Mean	7.2a	80.7a	570.4a	13a	54.96a	690.8a	201.0a	3.85a	648a	101.0a
Profile 2										
6	6	60.8	365	4	36.0	144	29	1.75	83	21
7	4	51.0	204	0	0	0	9	1.25	34	10
8	5	35.0	175	6	36.0	216	21	1.64	83	10
9	7	43.7	306	4	29.0	116	20	1.50	54	12.5
10	6	49.5	279	4	20.0	80	29	1.73	104	16
Mean	5.6a	48.0b	265.8b	3.6b	24.2b	111.2b	21.6b	1.57b	71.6b	13.9b

Means not followed by the same letter in each column, are statistically significant at $p<0.05$

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