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Effects of a wood pine polypropylene compound on the soil thermal conductivity as a function of water content

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Abstract

Polymers changed soil physical properties and in particular soil thermal properties. In our laboratory experiment we used loam soil and a mixture of loam soil plus polymer compound to determine the effect of polymer on soil thermal conductivity. We measured thermal conductivity with KD2 Pro device and the received values ranged from 0.26 to 1.27 W m^{-1} K^{-1} for loam soil to water contents from 0.02 to 0.42 g g^{-1} and from 0.20 to 0.89 W m^{-1} K^{-1} for loam soil plus polymer to water contents from 0.02 to 0.50 g g^{-1}. Our results showed that when the polymer was added to the loam soil its thermal conductivity decreased.

Keywords: soil physics, thermal properties, polymers, thermal resistivity

1. Introduction

Urban and suburban areas present the impact of human and natural wastes on soils. This type of alter can vary between slightly effect and to become highly detrimental. Some typical wastes are polymers from the industrial and human areas. Even though, polymers tend to be used to control soil degradation and desertification, and also to improve arid and semiarid soils (Maghchiche et al., 2010).

As regards of this topic several researchers have investigated the effects of the polymers on soils, such as Aslam et al., 1989; Rizvi et al., 1989; Aslam, 1990. Basically, their experimental research was focused on polymers such as cellulose xanthate, polyacrylamides, hydrolyzed polyacrylonitrile or polyvinyl alcohols. The features of these polymers were focused on its chemical stability and its high molecular weight for applying on paper industry, mining, mineral and sugar industries and sewage treatment plants. Other applications have been as a soil conditioning material and soil aggregates, although applicable to a narrower range of soils (Aslam, 1990).

Wallace et al. (1986) presented their research about new-generation soil conditioners to sodic soils using polymers. In flocculation tests, followed by wet-sieving, particle sizes were approximately four to five times larger with new soil conditioners than natural soils. Water penetration was greatly improved on a sodic soil when conditioned with the new soil conditioner. Application of polyacrylamide in solution to all the soils increased stem emergence and dry weights of tomato seedlings.

Other effects of the polyacrylamide could be observed on soil physical properties. Dilkova (1972) investigated the influence of polymer Separan (hydrolysed polyacrylamide) on soil physical properties and also on soil thermal diffusivity (Dilkova and Ilieva, 1974). According to Dilkova (1972) there was an increase in size and water stability of soil structural aggregates and soil porosity, respectively. Bulk density decreseased after the treatment with Separan. Dilkova and Ilieva (1974) concluded that the polymer slightly decreased thermal diffusivity of the investigated soils.

Terry and Nelson (1986) applied two irrigation methods, such as sprinkle irrigation and flood irrigation, adding Polyacrylamide (PAM) only on flood irrigated plots to study the effects on soil physical properties. For this purpose bulk density, penetrometer resistance, aggregate stability, and infiltration rate were measured. The surface bulk densities of sprinkle irrigated soil and PAM treated, flood-irrigated soils were significantly lower than the flood irrigated control. The aggregate stability was improved, and infiltration rates were approximately twice as large as those of the flood-irrigated control. Also, the polyacrylamide cemented the aggregates together and increased their resistance to the erosion (Levy et al., 1992).

Hence, several authors have studied the effects of the polymers on soil physical properties, although not all physical properties. Interesting and important physical properties are the soil thermal properties as well. Yet, only few authors have focused their research on soil thermal properties. Such as DeBano et al. (1999, 2005) studying the irreversible damage when the fire is not too intense and soil heating brief, which occurs during deeply penetrating heat pulses and long-term exposures. Massman et al. (2008) studied the severity of the soil heating during a prescribe burn and wildland fire where the impacts can be significant and serious. Others investigations related with the soil heat transfer include the formation of a hydrophobic layer on the surface or within the soil, destruction of most of the organic material in the upper few centimeters of soil and the concomitant loss of soil aggregate stability (changes in soil pH and soil chemistry, long-term differences in soil moisture content, increases in soil bulk density with accompanying decreases in soil porosity. Therefore changes on soil structure (Huffman et al., 2001; Neary and Overby, 2006). Thus, when biomass on or above a soil surface burns, a heat pulse penetrates the soil. The resulting high soil temperatures can alter soil properties and kill roots and soil microbes (Campbell et al., 1994).

On the other hand, change in the soil thermal conductivity (λ, a measure of a soil's ability to conduct heat) is less obvious, but is not less significant because of its relationship to other changes in the soil properties owing to the fire. Changes in the soil structure occur whenever soil organic matter is burned. These changes influence soil thermal conductivity as it is strongly determined by soil structure (Farouki, 1986) and soil composition (e.g. de Vries, 1963; Campbell and Norman, 1998). Consequently, the purpose of this research is to explore at laboratory scale the variability on the soil thermal conductivity -λ- of a Fluvisol (loam texture) mixed with polymer pellets as a carrier and scott pine shavings as a filler.

To achieve the main goal, it was divided into two operative objectives: (i) to observe the relationship between soil thermal conductivity and water content, (ii) to evaluate the influence of polymer pellets on the soil thermal conductivity.

2. Materials and Methods

The soil samples were taken between 10 and 20 cm depth of alluvial-meadow soil (Fluvisol, according to FAO2006) in the experimental field of Tsalapitsa (42^{o}10.8'N, 24^{o}32.6'E, 192 m a.s.l), South of Bulgaria (Figure 1). The plot represented pristine conditions under grass association.

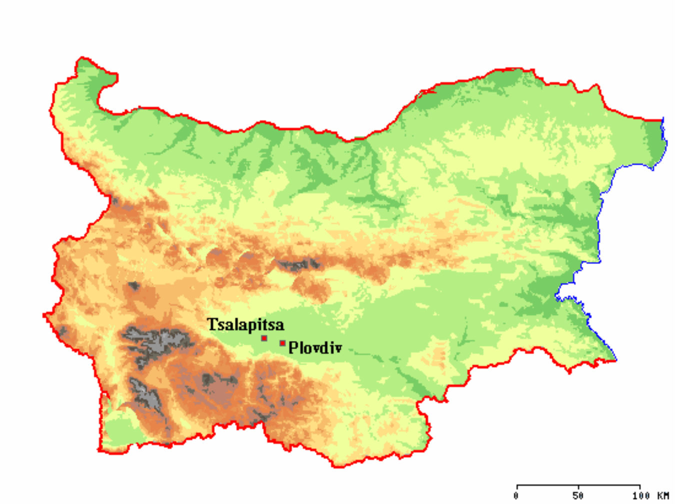

Figure 1. Location of soil sampling area in Tsalapitsa, Bulgaria.

Soil fractions were determined after chemical dispersion with sodium pyrophosphate ($Na_4P_2O_7$) without removal the organic matter and carbonates from the soil sample. Four sand fractions (2-1, 1-0.5, 0.5-0.25, 0.25-0.10 mm) were determined by sieving. The particle fractions less than 0.05, 0.02, 0.01, and 0.002 mm were determined by pipette method according to Kohn – modification V (after De Boodt, 1967). The sand fraction 0.10-0.05 mm was calculated after subtracting all measured fractions from 100%. Particle-size distribution and textural class were determined according to USDA (Soil Survey Division Staff, 1993). Total soil organic carbon (SOC) content was determined by modified Tjurin's method such as was indicated by Kononova (1966) and Filcheva and Tsadilas (2002). Soil water content (W, g g^{-1}), and bulk density (ρ_b, g cm^{-3}) of undisturbed soil samples were determined with cylinders of 100 cm^3 by gravimetric method after oven drying at 105°C until constant dry weight (Revut and Rode, 1969). Particle density (ρ_s, g cm^{-3}) was measured in 100 cm^3 picnometers. Consequently, total porosity (P, %) was calculated by;

$$P = \frac{\rho_s - \rho_b}{\rho_s} \times 100 \qquad [1]$$

where ρ_s is particle density and ρ_b is bulk density.

Direct measurements of thermal conductivity (λ), and thermal resistivity (ρ) (the ability to resist heat flow) were determined using KD2-Pro reader-logger device. SH-1 thermal sensor was used to determine the thermal conductivity and resistivity of the samples. Both are based on ASTM D5334. A Moplen polypropylene homopolymers with filler of scott pine shavings was added (30% in weight of sample) to the loam soil to investigate its effect on soil thermal conductivity. The main characteristics of the compounding used were to mix the polypropylene with 20% of wood pine shavings related to weight of total sample of polypropylene and filler. Thermal conductivity of this mixture was around 0.201 W m^{-1} K^{-1}, and its bulk density was around 0.97 g·cm^{-3}.

According to Rubio (2013, 2014), air dry soil and also different levels of soil moisture were achieved by adding certain amount of water to the samples and obtain a homogenous mixture. Several rings were used to compact the compound soil samples. Loam soil and loam soil plus polymer were wetted up and compacted to a target bulk density. This protocol avoided discrepancies due to the variable bulk density.

One thermal sensor per core was placed in the center of the ring and middle height. It maintained the same quantity of sample under and above the sensor to assist the accuracy of the measurements. Five moisture scenarios were determined between air dry and close to saturation. Water content of soil samples was measured by two different methods, (i) oven drying the sample at 105°C during 24h (Revut and Rode, 1969), and (ii) microwave oven (Miller et al., 1974; Routledge and Sabey, 1976; Rubio, 2014).

The several thermal properties tests were performed at room temperature, around 22 ºC.

3. Results and Discussion

The main soil characteristics of the studied alluvial-meadow soil (Kercheva, 2014) are summarized in Table 1. The soil was classified as Loam according to USDA (Soil Survey Division Staff, 1993), which was used in the current study to address the soil. Analyzed loam soil had very low organic carbon content (0.51%) according to classification of Filcheva (Raichev and Filcheva, 2011) (Table 1).

Table 1. Physical and chemical properties of the investigated A horizon (5-20 cm depth) of Fluvisol. Particle size distribution and texture class according to USDA; SOC = soil organic carbon content; BD = bulk density, W = water content at soil sampling, FC = field capacity (at -33 kPa suction); PWP = permanent wilting point (at -1500 kPa).

Sand (%)	Silt (%)	Clay (%)	Texture class	SOC (%)	BD $(g.cm^{-3})$	W $(g_{water}.g_{dry\ soil}^{-1})$	PD $(g.cm^{-3})$	FC $(g_{water}.g_{dry\ soil}^{-1})$	WP $(g_{water}.g_{dry\ soil}^{-1})$
44.0	35.8	20.2	Loam	0.51	1.53	0.12	2.64	0.20	0.09

During our laboratory experiment water content was measured by gravimetric method after drying in oven at 105°C for 24 hours and in microwave oven. It was established very good relevance between these two methods of drying (Fig. 2). Data measured fitted very acceptably, with a correlation coefficient of 0.997.

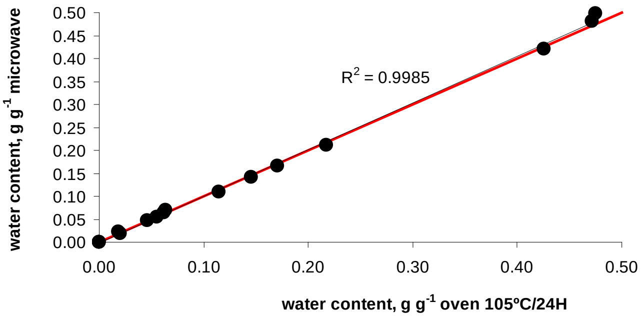

Figure 2. Comparison of soil water content determined by oven and microwave drying

Results from laboratory measurements of thermal conductivity using KD2-Pro device at several water content scenarios, and laboratory bulk densities of the investigated soil cores are presented in Table 2. The results showed that after adding a polymer to loam soil the values of bulk density decreased from 1.21 to 0.77 g cm^{-3} at air dry condition (W=0.02 g g^{-1}) and from 1.08 to 0.84 g cm^{-3} for water content close to saturation.

Measured values of thermal conductivity ranged from 0.26 to 1.27 W m^{-1} K^{-1} for loam soil at water contents from 0.02 to 0.42 g g^{-1}, and from 0.20 to 0.89 W m^{-1} K^{-1} for loam soil plus polymer at water contents from 0.02 to 0.50 g g^{-1}.

Total porosity (P, %) was calculated according to eq.1 and the values for soil plus polymer were higher than those for natural soil. A reasonable explanation of this phenomena could be related with the lower particle density of the mixture between loam soil and polymer compound. Since the bulk density of the polymer compound was around 0.97 g cm^{-3}. Therefore, the value of porosity for loam soil plus polymer decreased because its particle density was lower than the natural soil.

Table 2. Moisture scenarios (dry soil and saturation) and thermal conductivity (λ) of the soil samples. W = water content, ρ_b = target bulk density, and P = total porosity.

Soil texture	W, g g^{-1}	ρ_b, g cm^{-3}	λ*, W m^{-1}K^{-1}	P, %
Loam	0.02	1.21	0.26±0.002	54.3
	0.42	1.08	1.27±0.052	59.2
Loam plus Polymer	0.02	0.77	0.20±0.001	71.0
	0.50	0.84	0.89±0.01	68.3

* Average ± standard deviations n= 4

Thermal conductivity and resistivity values as a function of water content are shown in Figure 3. Soil water content had primary and highest influence on soil thermal conductivity. Thermal conductivity values of investigated natural loam soil increased rapidly in the range from air dry soil to a moisture level between wilting point and field capacity. The increase in water content caused smaller increase in thermal conductivity values. After adding the polymer the response of thermal conductivity was very close to a straight line in comparison with non linear relationship for natural loam soil. The results showed that when the polymer was added to the natural soil its thermal conductivity decreased on 23% at air dry soil, and around 45% for water contents between wilting point and field capacity, and 30% when soil sample was close to saturation.

As regards soil thermal resistivity, it decreased when soil pores were filled with water considering that the values of water and air resistivity are 1.7 and 40 m C W^{-1}, respectively. In the current study thermal resistivity had a similar curve type as for natural soil as the soil plus polymer. There was a fast decreasing in thermal resistivity from air dry soil to water content between wilting point and field capacity (Fig.3), especially when soil was close to saturation, showing certain thermal equilibrium. Values of thermal resistivity for loam soil plus polymer were higher than those for natural soil. These values could be related with the lower thermal conductivity of polypropylene plus wood pine shavings.

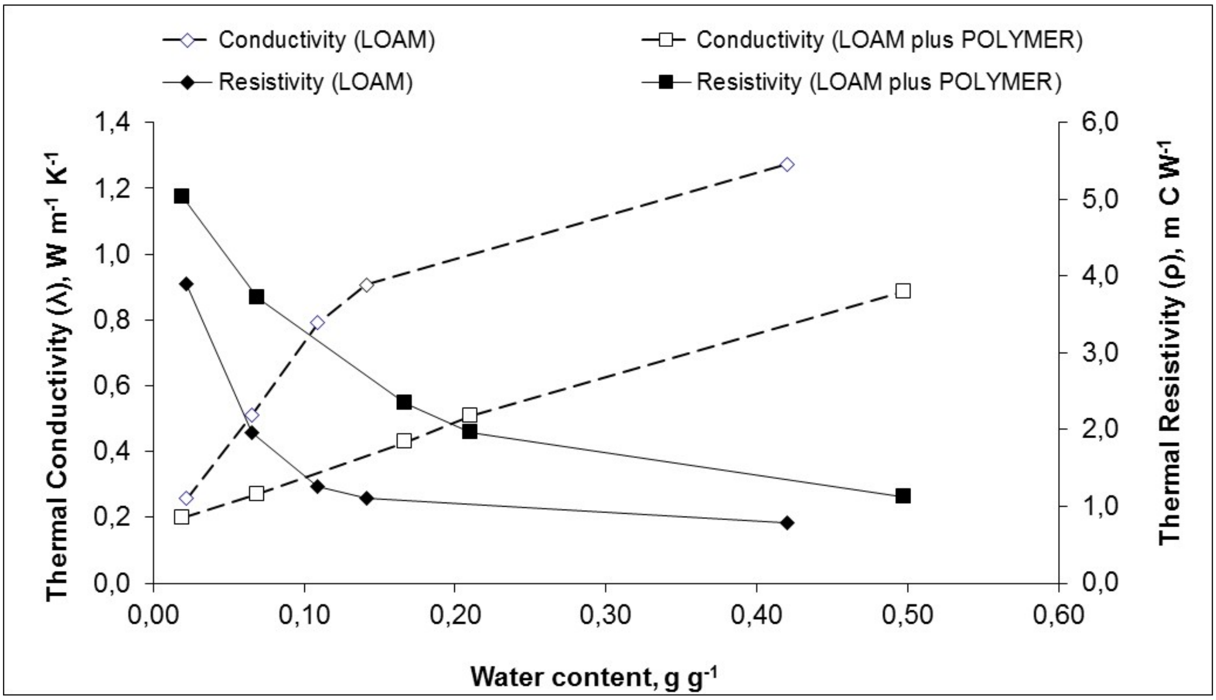

Figure 3. Thermal conductivity (λ) and thermal resistivity (ρ) as a function of water content for natural soil, and soil with compound.

4. Conclusions

As summary, the thermal behavior of natural loam soil presented the same values found by other author. However, when the Moplen polypropylene homopolymers with filler of scott pine shavings was added to the same soil sample the thermal conductivity decreased. The critical point was not shown on thermal conductivity relationship, however it existed when data was plotted in terms of thermal resistivity. The lower quantity of water absorbed by scott pine shavings provided a smoothly curve in terms of thermal conductivity variable. On the other hand, the variable temperature did not affect the test because was controlled on the whole of the process.

Eventually, the effects of the compound polymer on the soil did not improve the transfer of the heat flux inside the soil matrix, increasing the thermal conductivity value when water content increased in the soil.

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