Persistence and intensity of soil water repellency from soils with andic properties from the Campania region (Southwest, Italy) under different forest types

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Introduction

Soil water repellency (SWR) is a property of many soils that is getting more and more interesting for the scientific community, because of its consequences on soil erosion risk, runoff or infiltration rates and even plant ecology. The presence of hydrophobic organic acids released by roots and plant tissues, fungal activity, organic matter mineralization rates, or wildfires are considered the main causes of SWR. Some of the consequences of SWR are reduced soil infiltration rates, enhanced runoff flow and soil erosion. Significance of these effects depends upon the severity and spatial variability of SWR. SWR is often associated to vegetation types, although it cannot be assumed that certain species always induce water repellency under natural conditions. Because of resins, waxes and aromatic oils in their tissues, evergreen trees as eucalyptus and coniferous are usually associated with soil hydrophobicity, although it has been found also in a variety of soils, climates and vegetation types. But the relationship between water repellent soils and plant species is not always one-to-one. Soil properties as texture, aggregation, acidity, microbiome and other are also implied in the development of hydrophobicity. Regarding organic matter, several authors have reported inconsistent results after studying the relationship between soil organic matter content and SWR. A possible explanation for this is that quality of organic matter is more important than content. Consequently, it is necessary to investigate the role that organic matter content and properties play in the development of hydrophobicity in different soil and vegetation types.

The objective of this research is the study the relationship between SWR and organic matter properties in andic soils from the Campania region (SW Italy) under different vegetation types.

Methods

EXPERIMENTAL DESIGN

Soil samples were collected in Andosols under different natural or anthropized forest types (*Pinus* sp., *Fagus* sp., *Castanea* sp. and *Acacia* sp.) in the Italian Campania region: Monte Vezzi (Ischia, Naples); Castello (Cervinara, Avellino); Lago Laceno (Bagnoli Irpino, Avellino); Monte Santa Croce (Roccamonfina, Caserta). Figure 1 shows the location of sampling areas. Persistence and intensity of SWR is studied and compared to other soil properties related with SWR occurrence: soil acidity and salinity, texture, organic C content, humic and fulvic acids and soil lipid content. SWR was also studied in soil samples after soil lipids were extracted.

Figure 1. Study area.

ANALYTICAL METHODS

Soil water repellency. Persistence and intensity of SWR was studied in sieved (2 mm) samples from soil horizons from selected profiles using the WDTP test and the percentage of ethanol (PE) test, respectively. The WDPT was carried out applying five drops of distilled water (0,5 μL) onto the surface of each soil sample, and time required for infiltration was recorded and classified (<5 s, wettable; 5-60 s, slightly water repellent; 60-600 s, strongly water repellent; 600 s – 1 h, severely water repellent; > 1 h, extremely water repellent). For the PE test, drops of standardized solutions of ethanol in water (0.0, 3.0, 5.0, 8.5, 13.0, 24.0, and 36.0 %) are applied to a soil surface and their instant or short-term (<5 s) infiltration was observed. Applying drops with increasing surface tensions (decreasing ethanol concentrations) until a drop resists infiltration, allows the classification of the soil sample into a surface tension category between two ethanol concentrations.

Soil acidity and salinity. Soil pH and electrical conductivity of soil extracts were assessed in 1:2.5 and 1:5 soil:KCl 1N and soil:water preparations, respectively.

Soil texture. Sand fraction (2-0.05 mm) was determined by wet sieving. Clay fraction was determined by the pipet method. Silt fraction was calculated as the difference between 100% and the sum of sand and clay fractions.

Organic C and humic acids. Soil samples were treated with an aqueous solution (100 mL) of $Na_4P_2O_7$ and NaOH. The resulting solution was heated at 65 ºC during 48 h. Total extractable C (TEC) was determined in an aliquot (10 mL) by oxidation with $Cr_2O_7K_2$ (10 minutes, 160 ºC) and titration with FeS. Humic (HA) and fulvic acids (FA) were determined in an aliquot (25 mL). The solution was acidified and the precipitate (HA) was separated by centrifugation from the supernatant (FA and other organic fractions). The supernatant was extracted and passed through a polyvinylpyrrolidone column in order to separate FA from the other material, FA being retained by the sorbent. HA from the precipitate were redissolved. FA and HA content was determine by titration after oxidation with $Cr_2O_7K_2$.

Lipids. Soil lipids were extracted in a dichloromethane–methanol solution. The extract was evaporated in a water bath using a rotary evaporator (Büchi V-811) to remove solvents. Lipid fractions were transferred into pre-weighed vials and oven-dried (30 ºC). Lipid contents were determined gravimetrically.

Results and discussion

Table 1 shows the characterization of studied soil profiles. Soil texture was mostly sandy, with sand content between 420 and 836 g/kg. All soils were acid, with pH ranging between 4.44 and 6.95. Highest TEC content was observed in soils under Castanea and Acacia (Ischia) and Fagus (Lago Laceno), with TEC ranging between 44.3 and 63.1 in the Ah horizon.

Persistence of SWR (expressed as logWDPT) is shown in Figure 2. Most soil horizons showed subcritical SWR, with droplets infiltrating in a short time (WDPT < 5 s), and two soil profiles showed strong to extreme SWR (Roccamonfina under *Pinus* and Lago Laceno under *Fagus*) in Ah horizons. Soil horizons under Castanea and Acacia were wettable or showed subcritical water repellency (WDPT > 2 or >4 s) and PE class 1. Soils under pine plantations in the Lago Laceno area showed subcritical WR just in the Ah horizon. In contrast, soils under Fagus (Lago Laceno area) and Pinus (Roccamonfina) showed strong WR in the upper horizons. In the first case, WR was strong in the Ah horizon (WDTP 380 s, EP class 6) and subcritical (WDTP 1-2 s) in E, Bh, Bw and C horizons. In the second case, WR was observed through the soil profile in the Ah (WDTP 473 s, EP class 5), E (108 s, 4), Bh (204 s, 3) and Bw (4 s, 1), with C horizon remaining wettable.
Although SWR is expected to increase with TEC content and decrease in depth, strong to extreme WDPTs were observed in surface or inmediately subsurface horizons with TEC content above 30 g/kg, humic acid content above 10 g/kg and lipid content above 1 g/kg.

Table 2 shows the R-Pearson ranked correlationships between WDPT, PE classes and different soil properties. WDPT and PE class were moderately correlated (r 0.685). WDPT was significantly correlated to pH (r -0593) and TEC (r 0.361), but no significant correlations were found between WDPT and humic or fulvic acids, lipids or other variables, as expected. In contrast, intensity of SWR (PE) was significantly correlated to TEC (r 0.514), humic acids (r 0.500), fulvic acids (r 0.515), lipids (r 0.425) and N-Kjeldahl (r 0.414). Both variables, WDPT and PE, measure different aspects of SWR. As a consequence, in the study area, soil acidity and organic carbon are responsible of delayed infiltration of water. On the other hand, the intensity of SWR is controlled by organic matter chemical properties and composition.

Table 1. Characterization of soil horizons. WDPT, persistence of SWR; PE, intensity of SWR; WDPT2, persistence of SWR in lipid-free soil samples; EC, electric conductivity; TEC, total extractable carbon; HA, humic acid content; FA, humic acid content.

PROFILE	H	DEPTH	VEGETATION	LOCATION	WDPT (s)	PE	WDPT2 (s)	Clay (g/kg)	Sand (g/kg)	Silt (g/kg)	pH (KCl)	EC (dS/cm)	TEC (g/kg)	HA (g/kg)	FA (g/kg)	Lipids (g/kg)	N-Kjeldahl (g/kg)
107014	A	0-10	Castanea, Acacia	Ischia	2	1	0	34	612	354	6.2	0.255	44.3	26.7	7.6	3.210	3.33
107014	Bw	10-30	Castanea, Acacia	Ischia	2	1	0	34	528	438	5.6	0.441	14.4	5.5	3.3	0.657	0.20
107014	2Bw	30-50	Castanea, Acacia	Ischia	2	1	0	13	772	215	5.3	0.139	10.2	3.8	3.5	0.552	0.55
107014	2BC	50-65/80	Castanea, Acacia	Ischia	2	1	0	27	749	224	5.5	0.131	4.6	1.6	1.8	0.317	0.85
107014	3C1	65/80-110	Castanea, Acacia	Ischia	4	1	1	76	457	467	5.3	0.119	1.9	0.9	0.8	0.249	0.00
107014	3C2	110-160	Castanea, Acacia	Ischia	4	2	1	96	420	485	5.3	0.111				0.409	0.00
109601	O	2-0	Castanea	Cervinara													
109601	A1	0-15	Castanea	Cervinara	1	1	0	11	812	177	5.74	0.208	20.8	9.0	8.0	1.337	4.67
109601	A2	15-28	Castanea	Cervinara	1	1	0	9	804	187	5.88	0.129	20.1	7.2	6.6	0.990	2.95
109601	B1	28-42	Castanea	Cervinara	1	1	0	14	722	264	5.87	0.128	12.7	5.3	5.8	0.706	1.56
109601	B2	42-60/75	Castanea	Cervinara	1	1	0	13	795	192	6.34	0.109	7.9	3.4	3.5	0.518	0.86
109601	C1	60/75-100/105	Castanea	Cervinara	1	1	0	13	741	246	5.55	0.153	4.7	1.7	1.8	0.434	0.79
109601	C2	100/105-140	Castanea	Cervinara	1	1	0	10	836	153	5.57	0.973	3.1	1.4	1.4	0.243	0.36
109613	O	2-0	Castanea	Cervinara													
109613	A1	0-30	Castanea	Cervinara	2	1	0	11	732	257	5.58	0.134	17.6	7.3	5.2	0.912	1.428
109613	A2	30-50	Castanea	Cervinara	2	1	0	17	667	316	5.55	0.125	13.4	3.2	3.9	0.656	1.064
109613	Bw1	50-80	Castanea	Cervinara	2	1	0	17	596	387	5.72	0.122	9.5	2.4	3.2	0.489	1.08
109613	Bw2	80-110	Castanea	Cervinara	2	1	0	7	753	240	5.39	0.122	7.1	1.8	2.7	0.322	0.80
109613	Bt1	110-130	Castanea	Cervinara	2	1	0	33	450	517	5.55	0.875	6.3	1.0	2.5	0.276	1.19
110101	O	5-0	Fagus	Lago Laceno	3600											272.503	
110101	Ah	0-9	Fagus	Lago Laceno	380	6	3600	7	720	273	4.93	0.760	63.1	36.0	15.0	3.230	12.35
110101	AE	09-16	Fagus	Lago Laceno	2	1	0	9	678	313	4.58	0.280	38.3	14.1	7.0	1.050	5.27
110101	Bhs	16-38	Fagus	Lago Laceno	2	1	0	1	751	248	4.44	0.300	42.2	15.3	9.4	0.960	4.32
110101	Bw	38-60	Fagus	Lago Laceno	2	1	0	0	696	304	4.61	0.300	32.7	8.0	10.3	1.100	3.39
110101	C	60-70	Fagus	Lago Laceno	2	1	0	25	625	350	5.27	0.210	22.8	5.8	6.2	0.870	2.28
110108	O	2-0	Pinus	Lago Laceno													
110108	Ah	0-20	Pinus	Lago Laceno	4	2	3	13	675	312	6.34	0.200	52.8	21.4	6.9	2.470	14.42
110108	A2	20-30	Pinus	Lago Laceno	1	1	0	6	571	423	6.91	0.122	25.7	7.3	5.0	1.039	11.45
110108	Bw	30-50	Pinus	Lago Laceno	1	1	0	5	529	466	6.88	0.141	26.7	7.0	4.9	1.137	4.18
110108	Bw2	50-80	Pinus	Lago Laceno	1	1	0	7	510	483	6.95	0.126	31.4	9.2	7.1	1.325	3.68
110113	Ah	0-5	Pinus	Roccamonfina	473	5	5	16	657	327	5.08	0.119	38.7	15.0	9.5	1.566	10.32
110113	AE	5-15	Pinus	Roccamonfina	108	4	1	5	736	259	4.96	0.101	33.1	8.4	9.2	1.277	5.56
110113	Bh	15-19	Pinus	Roccamonfina	204	3	4	14	560	426	4.84	0.093	36.7	12.4	8.2	1.379	4.38
110113	Bw	19-25	Pinus	Roccamonfina	4	1	1	9	704	287	5.11	0.080	16.7	2.6	6.7	0.757	3.98
110113	C	25-34	Pinus	Roccamonfina	1	1	0	2	782	216	5.25	0.058	5.9	0.5	1.9	0.511	2.40
110120	Ap1	0-5	Castanea	Roccamonfina	2	1	0	18	516	466	5.76	0.109	40.9	14.3	7.9	1.412	4.83
110120	Ap2	5-18	Castanea	Roccamonfina	2	1	0	10	537	453	5.37	0.075	24.0	7.5	5.0	0.794	3.53
110120	AE	18-34	Castanea	Roccamonfina	2	1	0	9	704	287	5.19	0.035	20.7	4.1	4.8	0.641	2.87
110120	Bh	34-40	Castanea	Roccamonfina	2	1	0	15	619	366	5.18	0.037	21.5	4.2	4.6	0.752	0.00
110120	Bw	40-60	Castanea	Roccamonfina	2	1	0	7	674	319	5.2	0.034	18.3	4.2	3.2	0.676	2.44
110120	CB	60-	Castanea	Roccamonfina	2	1	0	39	689	271	5.09	0.034	8.7	1.2	1.7	0.479	1.61

After lipids from soil samples were extracted, persistence of SWR (was assessed again (WDPT2). SWR decreased in soil samples with droplets infiltrating instantaneously (WDPT 0 s).

Surprisingly, some samples showed similar or increased SWR. In the Ah horizon from Lago Laceno under *Fagus*, for example, WDPT increased from 380 s (strong water repellency) to 3600 s (extreme water repellency). This was a non-expected response, although it may be attributed to conformational changes in organic substances coating soil mineral particles during the process of lipid extraction.

Another possible explanation is that the effect of humic/fulvic acids was masked by lipids in these soils, as WDPT2 from water-repellent soil samples (WDPT2 > 0 s) after lipid extraction showed significant and strong correlations with humic acid content.

However, further research is needed to confirm or reject these hypotheses.

Figure 2. Evolution of persistence of SWR (log WDPT) in depth for different soil profiles.

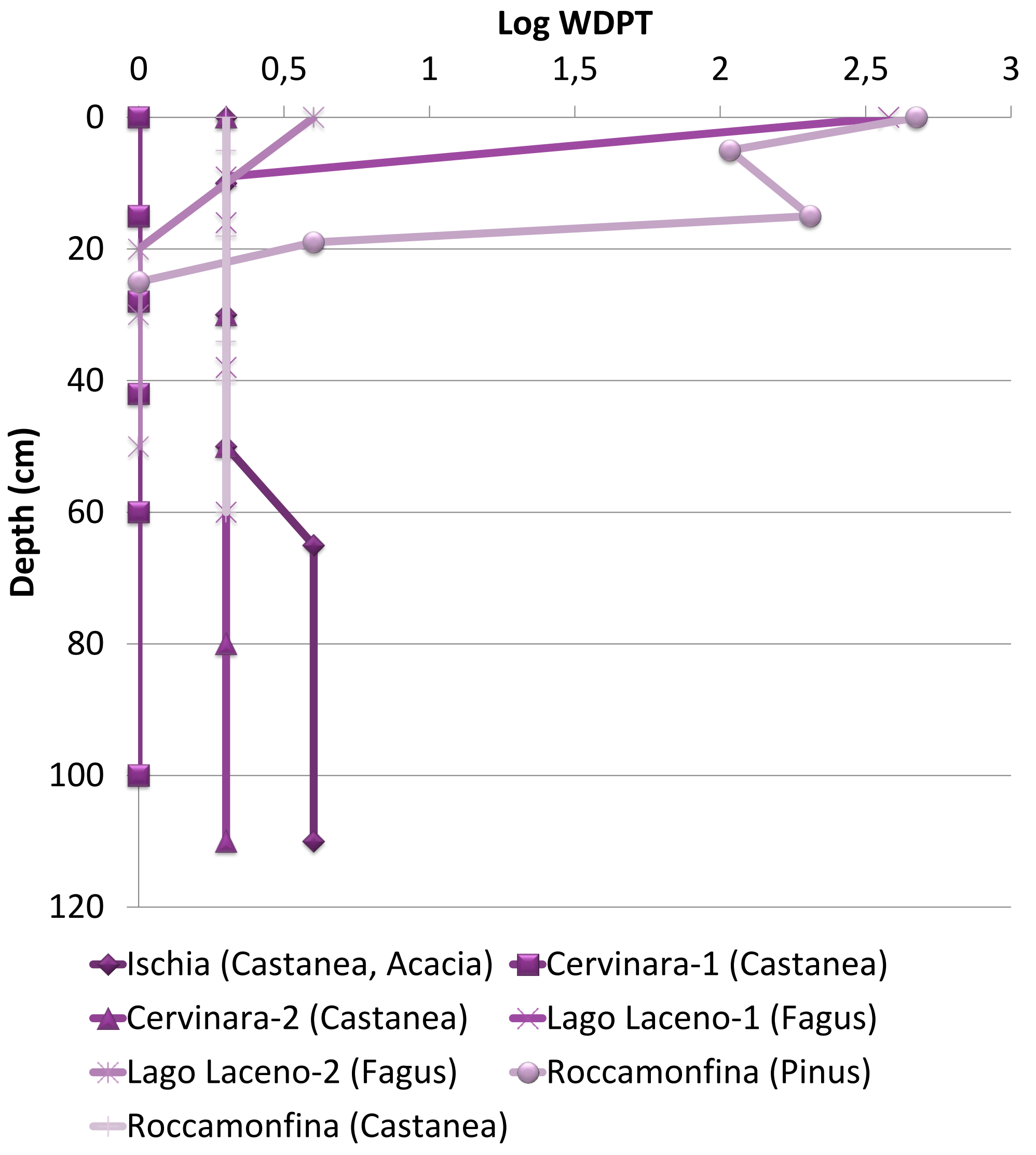

Table 2. R-Pearson rank correlations between persistence of SWR (WDPT), intensity of SWR (PE), and persistence of SWR in water-repellent soil samples after lipid extraction (WDPT2). No significant correlations (p>0.05) are not displayed.

	WDPT	PE	WDTP2
PE	0.685, p 0.0000		
pH (KCl)	-0.593, p 0.0004		
EC			0.987, p 0.000
Total extractable C	0.361, p 0.0328	0.514, p 0.0024	
Humic acids		0.500, p 0.0031	0.811, p 0.027
Fulvic acids		0.515, p 0.0023	
Lipids		0.425, p 0.0107	
N-Kjeldahl		0.414, p 0.0131	