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Soil affects throughfall and stemflow under Turkey oak (*Quercus cerris* L.)

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ABSTRACT

To investigate how soil properties affect throughfall and stemflow, we conducted a study in a forest of central Italy over a full hydrologic year to compare the chemical composition and the water fluxes of the throughfall and stemflow generated by Turkey oaks (*Quercus cerris* L.). The study was achieved on two adjacent areas that showed the same topography, supported Turkey oaks of the same height (about 20 m) and age (about 60 years), and received uniform precipitation (835 mm year^{-1}). However, the two areas differed for soil reaction, one being acidic (area A, mean profile-weighted pH_{H2O} = 5.84) and the other sub-alkaline (area B, mean profile-weighted pH_{H2O} = 7.55). The branching angle and canopy volume of the oaks differed statistically (Wilcoxon signed-rank test at $\alpha = 0.05$) between areas, with the slender trees of area A having more upward thrust branches. As a consequence, the oaks of area A produced more stemflow per unit canopy surface than those of area B, as indicated by the amount of stemflow per unit soil surface (15-cm radius) around the trunk base and by the stemflow funneling ratio per basal area ($F_{P,B}$). The annual fluxes determined for 17 solutes were higher in throughfall than in rainfall, except for F and HCO_3, reflecting the enrichment and acidification of the precipitation water as it flows through the canopy. For the full hydrological year, the enrichment ratios ($E_{P,B}$ and $E_{P,T}$) indicated that the stemflow of area A was more enriched than that of area B for the following solutes: total N, TOC, total acidity, carboxylic acidity, phenolic acidity, and NH_4. Several significant differences in throughfall (electrical conductivity, Ca, Mg, K, NO_3, total N, total organic C, organic anions) and in stemflow (pH, electrical conductivity, Ca, Mg, Na, Cl, NO_3, HCO_3) chemistry were observed between areas over the course of three time-series of rainfall events (throughfall series T1, from September to November 2004; throughfall series T2, from December 2004 to February 2005; stemflow series S1, from March to September 2004). The study further demonstrated the existence of strong links between the significant differences in soil properties (pH, exchangeable Ca and K, effective cation exchange capacity, total and organic C content, mineralogy) and the significant differences in throughfall and stemflow chemistry (pH, HCO_3, Ca, K, electrical conductivity) recorded between the two areas. The main processes involved in the short-scale spatial differentiation of throughfall and stemflow at the site appeared to be either soil-dominated like pedogenesis, mineral weathering and organic matter transformation, or tree-mediated such as elemental biocycling.

1. Introduction

Before reaching the soil surface, the chemical composition of incident atmospheric precipitation can be strongly modified by the vegetation. In the case of individual trees or of a full vegetation canopy, two major downward water fluxes were defined: the water percolating and dripping through the canopy, termed throughfall, and the rainfall that flows downward along branches and trunks, termed stemflow. Both throughfall and stemflow fluxes can release substances by solubilizing and washing off a wide range of compounds derived from atmospheric deposition or released by plant tissues such as organic compounds, gases, and dissolved ions (Cronan and Reiners, 1983; Levia Jr. and Frost, 2003; Levia and Herwitz, 2005; Zimmermann et al., 2007; Levia et al., 2011). In contrast, some of the dissolved substances included in the throughfall and stemflow solutions can be absorbed by plant and, under some conditions, adsorbed onto plant surfaces (Alcock and Morton, 1985; Chuyong et al., 2004; Song et al., 2016). Furthermore, the reaction of rainfall with gases such as CO_2, NO_x, and SO_x present in the atmosphere and/or trapped within the canopy produces acids (H_2CO_3, HNO_3, H_2SO_4), which increase the total acidity of the

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Table 1
Morphological description of the soil profiles from area A and area B at the Gallignano Forest, Ancona province (central Italy).

Landform: steep slope (10–15%); creeping phenomena have formed diffuse soil cracks (maximum depth is around 60 cm) and few small humps along the slope – exposure: NNW – altitude: 180 m – mean annual air temperature: 13.6 °C – warmest month: July (23.1 °C) – coldest month: January (4.9 °C) – mean annual precipitation: 780 mm – drainage class: moderately well drained – parent material: Plio-pleistocene fine-textured marine sediments.

	Depth[a] cm	Mean thickness cm	Colour[b]	Texture[c]	Structure[d]	Consistency[e]	Plasticity[f]	Roots[g]	Mycelia[h]	Boundary[i]	Other observations
Soil of area A											
Vegetation: Upper stratum: *Quercus cerris* L. – Lower stratum: *Fraxinus ornus* L., *Sorbus torminalis* (L.) Crantz, *Ostrya carpinifolia* Scop., *Acer campestre* L. – Understory: *Erica arborea* L., *Juniperus communis* L., *Lonicera xylosteum* L., *Lonicera caprifolium* L., *Ruscus aculeatus* L., *Smilax aspera* L., *Rubia peregrina* L., *Cyclamen repandum* S.S., *Festuca heterophylla* Lam., seedlings. Forest management: abandoned coppice. Soil: fine, mixed, acidic, mesic, Typic Dystrudept (Soil Survey Staff, 2014).											
Oi	3/2–0	2.3	–	–	–	–	–	0	0	cb	Undecomposed leaves of *Q. cerris*, *E. arborea*, *F. ornus*, and *O. carpinifolia*
Oe	2/1–0	1.3	10YR 3/2	–	–	–	–	$v_1$mi,vf,f	+	cb	
A	0–5/9	6.6	10YR 3/2	sil	3 m cr	mfr, wss	wps	2mi,vf,f,m	0	cb	
E	0–3/5	4.0	10YR 4/2 10YR 5/2	sil	2f,m cr 2f,m abk	cr = mfi, wss abk = mfr., wss	wps	2mi,vf,f,m; 3co 2mi,vf,f,m,co	0	cw	Roots abound into the cracks
EB	3/5–8/9	4.3	10YR 6/4 2.5Y 5/6	sil	2 m,c abk-sbk 3 m abk-sbk	mfi-fr, wss	wps	2mi,vf,f,m; 3co 2mi,vf,f,m,co	0 +	cw	Cracks fulfilled of A and E material colonized by few mycelia
Bw	8/9–23/29	17.6	10YR 4/4 10YR 5/6	sil	2 m,c abk-sbk 3 m,co abk	mfi-fr, wss mfi, wss	wps	2mi,vf,f,m,co 2mi,vf,f; 1 m,co	0 +	cw	Cracks fulfilled of A and E material colonized by abundant mycelia and roots. Few Mn nodules.
2Bw1	23/29–42/43	16.3	10YR 5/4 2.5Y 5/6	sic	2f,m abk 3 m abk	mfi, wss	wps ws	2mi,vf,f,m,co 2mi,vf,f; 1 m,co	+ + + + +	cs	Few Mn nodules
2Bw2	42/43–61/62	19.0	10YR 5/2 10YR 5/6	sic	2 m,c abk 3 m abk	mfi, wss mfi, ws	wps ws	2mi,vf,f,m,co 2mi,vf,f; 1 m,co	+ + + + +	cw	Few Mn nodules
2Bw3	61/62–70/73	10.3	10YR 4/4 10YR 5/4	sic	2 m,c abk 2 m abk	mfi, wss	wps	2mi,vf,f,m,co 2mi,vf,f; 1 m; $v_1$co	+	cs	Few Mn nodules
3Bw	70/73–79/83	9.0	2.5Y 5/2 2.5Y 5/4	sicl	2f,m sbk 2 m abk	mfi, wss	wps	1mi,vf,f; 2 m,co 1mi,vf,f,m; $v_1$co	0	as	Few concretions of $CaCO_3$
4BCk	79/83–94/98	15.0	2.5Y 7/2 2.5Y 7/4	sil	3 m sbk → 1th pl	mfr, wss	wps	2mi,vf; 3f,m,co 1mi,vf,f,m,co	0	–	Plentiful concretions of $CaCO_3$
Soil of area B											
Vegetation: Upper stratum: *Quercus cerris* L. – Intermediate stratum: *Quercus pubescens* Willd. – Lower stratum: *Fraxinus ornus* L., *Sorbus torminalis* (L.) Crantz, *Ostrya carpinifolia* Scop., *Carpinus betulus* L., *Acer campestre* L., *Fraxinus oxycarpa* Bieb. – Understory: *Juniperus communis* L., *Ruscus aculeatus* L., *Lonicera xylosteum* L., *Lonicera caprifolium* L., *Rubia peregrina* L., *Cyclamen repandum* S.S., *Smilax aspera* L., *Festuca heterophylla* Lam., seedlings. Forest management: abandoned coppice. Soil: fine, mixed, calcareous, mesic, Typic Eutrudept (Soil Survey Staff, 2014).											
Oi	6/4–2/1	3.3	–	–	–	–	–	0	0	cw	Undecomposed leaves of *Q. cerris*, *F. ornus*, *S. aspera*, and *O. carpinifolia*
Oe	2/1–0	1.7	5YR 2/1	–	–	–	–	0	+ + +	cw	
A	0–7/10	8.3	10YR 3/1 10YR 5/2	sl	3 m,sbk 3 m, cr	mfi, wss mfr., wss	wps	3mi,vf; 2f,m; 1co 3mi,vf,f,m; 1co	+ + +	cw	Cracks fulfilled of A material colonized by abundant mycelia
AB	7/10–16/22	10.3	10YR 4/3 10YR 4/4	sicl	3 m, sbk 3f,m, cr	mfi, wss mfr., wss	wps	2mi,vf; 3f,m; 1co 3mi,vf,f,m; 1 co	0 +	cw	Cracks fulfilled of A material colonized by few mycelia
Bw1	16/22–27/34	13.3	10YR 5/2 10YR 5/4	sicl	3 m sbk 3 m, cr	mfi, wss mfr., wss	wps	2mi,vf; 3f,m; 1co	0 +	cw	Cracks fulfilled of A material colonized by few mycelia
Bw2	27/34–47/55	19.7	10YR 4/4 10YR 4/2	sicl	3f,m sbk 2 m sbk	mfi, wss	wps	3mi,vf,f,m; 1co 3mi,vf,f; 2 m; 1co	+ + +	cw	Cracks fulfilled of A material colonized by abundant mycelia
Bw3	47/55–60/71	16.0	10YR 5/6 10YR 6/4	sicl	3f sbk 2 m sbk	mfi, wss mfi, ws	wps wp	1mi,vf; 2f; 3 m,co 2mi,vf,f,m,co	0	as	
2BCk	60/71–70/81	10.3	2.5YR 6/2 2.5YR 6/4	scl	2f,m,c abk-sbk 2 m sbk	mfi, wss	wps wp	2mi,vf 2mi,vf,f; 1 m,co	0	as	Common concretions of $CaCO_3$
3BC	70/81–81/93	11.0	2.5Y 6/4 2.5Y 7/4	scl	3f,m abk-sbk 2 m sbk	mfr, wss mfi, ws	wps wp	1mi,vf; 3f,m,co 2mi,vf,f,m; 1co	0	as	Between 2BCk and 3BC, fine, medium and coarse roots show horizontal trend

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