Evaporation from soils of different texture covered by layers of water repellent and wettable soils

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Abstract

Water repellent soils are able to channel water deep into the soil profile by fingered flow, minimising water storage in the water repellent top layer where water is most susceptible to evaporation. To date, the effect of water repellent or wettable surface layer on evaporation from wet sublayer has only been reported for coarse materials, and an increase in water repellency led to a greater delay in water evaporation. The objective of this study was to assess the effect of water repellent vs. wettable top layers with different thickness on water evaporation from coarse and fine texture subsoils that were pre-moistened. Clay loam soil samples were taken from *Pinus pinaster* woodland of Ciavolo, Italy, and sandy soil samples from *Pinus sylvestris* woodland of Sekule, Slovakia. Evaporation from soil samples was determined from the loss of weight in laboratory conditions. Water in the clay loam soil from Ciavolo was held for a longer period due to slower evaporative loss than in the sandy soil from Sekule, and the impact of the water repellent layer on the loss rate over time is related to its thickness. Over 550 hours, about 90% of the initial stored water was evaporated from the uncovered clay-loam soil sample from Ciavolo. In the same time, the 0.3, 1, and 2 cm-thick duff layers, respectively, saved about 23, 34, and 58 % of water from evaporation, and evaporation of 90% of water took over 780, 1100, and 1450 hours. It means that the clay loam soil cover with the 0.3, 1, and 2 cm-thick duff layers resulted in prolonging the evaporation by 10, 23, and 37.5 days, respectively. As to the sandy soil from Sekule, 98% of water was evaporated from the uncovered soil sample over 240 hours. In the same time, the 0.3, 1, and 2 cm-thick water repellent soil layers, respectively, saved about 7, 45, and 59 % of water from evaporation, and evaporation of 98% of water took over 330, 606, and 774 hours. It means that the sandy soil cover with the 0.3, 1, and 2 cm-thick water repellent soil layers resulted in prolonging the evaporation by about 4, 15, and 22 days, respectively. It can be concluded that water repellent surface layers, created by pine trees, are able to delay evaporation significantly for both coarse and fine textured soils, which may be particularly beneficial for plants during hot and dry periods in summer.

Keywords: duff; evaporation; pine; soil; water repellency

Introduction

The climate of Europe has become more extreme in the last century. Exceptional summer heat waves, associated with increased potential evapotranspiration and lack of precipitation, are increasing in frequency and duration (Abeli et al. 2014). In Slovakia, the average annual air temperature increased of about 1 °C in the period 1991–2014, and the highest increase was observed in the months of January, June, July and August (Labudová et al. 2015). The climate in summer tends to consist of long hot and dry spells interspersed with intense rainfalls (Faško et al. 2008). In the period 1981–2014, Italy experienced a 1.18 ± 0.22 °C increase in average annual air temperature (ISPRA 2015). The highest increase is observed in summer and spring seasons with an expected average increasing trend of 0.42–0.46 °C/10 years. Also occurrence and duration of hot spells showed a statistically increasing trend starting from 1980s, and in 2014 the total duration of hot spells exceeded by 17 days the long-time average (ISPRA 2015).

The predicted higher frequencies of extended droughts due to climate change will promote the occurrence of soil water repellency (SWR) with corresponding implications for site and catchment hydrology (Bachmann et al. 2016). SWR is caused by organic compounds derived from living or decomposing plants or micro-organisms, wildfire ash and treated wastewater application (Doerr et al. 2000; Schacht et al. 2014; Tinebra et al. 2019). It is influenced by soil temperature (Novák et al. 2009), moisture (Oostindie et al. 2017; Leelamanie and Nishiwaki 2019), texture (Benito et al. 2019), pH (Diehl et al. 2010), soil organic carbon (SOC) and clay (mainly kaolinite) content (Lichner et al. 2002). SWR generally increases during dry summer conditions, while it is reduced or completely eliminated after prolonged and/or heavy precipitation (Taeumer et al. 2006; Orfánus et al. 2016). This change in water repellency is thought to be accompanied with a change in orientation of organic materials with amphiphilic structure (Hallett 2008). Re-establishment of water repellency may be associated with the energy input during heating or a new input of hydrophobic substances (Doerr and Thomas 2000). SWR can decrease infiltration, increase runoff and soil erosion, and worsen germination and growth of vegetation (Ward et al. 2015; Fér et al. 2016). The release of hydrophobic substances in soil is, in a similar fashion to allelopathy, used by plants to suppress the germination of competing vegetation and to improve water conservation by channelling water deep into the soil profile following preferential flow pathways, while at the same time reducing evaporation due to the hydrophobic capillary barrier formed as consequence of modified liquid/gas interface geometry in partially saturated regions (Doerr et al. 2000; Bachmann et al. 2001; Hallett

2008). There is some evidence to suggest that rates of vapour flow and diffusion may also be suppressed in very strongly water repellent soils (Bachmann et al. 2001; Davis et al. 2014).

To date, the effect of water repellent or wettable surface layer on evaporation from wet sublayer has only been reported for coarse materials, and the water repellent material was in most cases prepared artificially (Bachmann et al. 2001; Shahidzadeh-Bonn et al. 2007; Shokri et al. 2008; Kim et al. 2015; Rye and Smettem 2017). All the five mentioned studies showed considerable suppression of evaporative water losses from hydrophobic porous media relative to hydrophilic media under similar evaporative demand. Evaporation suppression in hydrophobic media was attributed to interruption of capillary liquid flow and to reduction in capillary driving force (Shokri et al. 2008). HYDRUS-1D code was used to simulate cumulative actual water evaporation at the top of soil samples (Fér et al. 2018).

The objective of this study was to assess the effects of 0.3-, 1-, and 2-cm thick water repellent duff (= decomposed forest floor) layers vs. 0.3-, 1-, and 2-cm thick wettable clay loam soil layers on evaporation from wet clay loam soil taken from *Pinus pinaster* woodland of Ciavolo in the island of Sicily, Italy, and compare them with similar effects on sandy soil taken from *Pinus sylvestris* woodland of Sekule in the Borska nizina lowland, southwest Slovakia.

Material and methods

Study sites

Soil was sampled in two artificial pine woodlands representative of the reforestations applied in the past decades to tackle land degradation. The first woodland is located in Ciavolo in the island of Sicily, Italy (37°45'40.6" N, 12°34'09.0" E). According to the Köppen-Geiger climate classification, the region is classified as Mediterranean – hot summer (Csa) (Kottek et al. 2006). A summer warm and dry period alternate with heavy rainfalls mostly occurring in autumn and winter. The average annual temperature in Sicily is 17.7 °C. The average annual rainfall is 632 mm with highly variable distribution both in space and time (Drago 2005). The number of consecutive dry days frequently exceeds 100 (ISPRA 2015). Elevation is 105 m a.s.l. and the surface slope is low (4.4%). The soil is a Rhodoxeralf (Soil Survey Staff 2014) with a depth of 0.40–0.60 m and the parent material is calcareous sandstone. According to USDA classification, the soil texture is clay loam (Gee and Bauder 1986).

Two sampling sites (approximately 5 x 5 m each) were arranged in the Ciavolo woodland. The first sampling site was located under the 30 years old *Pinus pinaster* trees, and soil were sampled from the duff layer. The second sampling site was located in a glade vegetated with spontaneous annual grasses (*Avena fatua* L., *Galactites elegans* (All.) Soldano, *Hypochaeris achyrophorus* L., *Oxalis pes-caprae* L. and *Vulpia ciliata* Dumort). Soil was sampled at 0–5 cm depth. Physical and chemical properties of soil samples are reported in Table 1.

The second woodland is located in Sekule in the Borska nizina lowland, southwest Slovakia (48°37'10" N, 16°59'50" E). According to the Köppen-Geiger climate classification, the region has temperate climate without dry season, warm summer (Cfb) (Kottek et al. 2006). Mean annual precipitation is 550 mm, which is mainly summer-dominant. The mean annual temperature is 9 °C. Elevation is 158 m a.s.l. and surface slope is negligible. The soil is formed by aeolian sand, and it is classified as Psamment (Soil Survey Staff 2014). According to USDA classification, soil texture is sandy (Gee and Bauder 1986).

Two sampling sites were arranged in the Sekule woodland. The first sampling site was located under the 30 years old Scots pine (*Pinus sylvestris*) trees, and “woodland soil” samples were taken from the topsoil layer. The second sampling site was located in a glade covered with biological soil crust in an initial stage of succession and “pure sand” soil was sampled at 50 cm depth, where a limited impact of vegetation or organic matter can be found

(C_{org} = 0.03%). Physical and chemical properties of soil samples are reported in Table 1. Soil microscopic mosses, lichens, fungi, cyanobacteria, and algae, recorded at this site, are listed in Lichner et al. (2012).

Table 1 Physical and chemical properties of samples taken from the studied sites in Ciavolo, Italy, and Sekule, Slovakia.

Study site	Sample	Sand (%)	Silt (%)	Clay (%)	Total carbonates (%)	Organic carbon (%)	pH (H_2O)	pH (KCl)
Ciavolo	Duff	24.3	37.5	38.1	0	22.7	6.79	6.64
	Mineral soil	36.9	34.5	28.5	3.80	2.73	7.77	6.97
Sekule	Woodland soil	95.1	2.3	2.6	< 0.05	0.83	5.65	4.39
	Pure sand	94.9	1.7	3.4	< 0.05	0.03	5.54	4.20

Estimation of SWR characteristics

The persistence and extent of soil water repellency were used to quantify this soil property (Lichner et al. 2017). The persistence of soil water repellency was measured by means of the water drop penetration time (WDPT) test, which measures how long the hydrophobicity persists on a porous surface. In this study, 58 ± 5 μL drops of distilled water from a medicinal dropper were placed onto the soil surface and the time required for infiltration was recorded. A standard droplet release height of approximately 10 mm above the soil surface was used to minimise the cratering effect on the soil surface (Doerr 1998). The following classes of the persistence of SWR were distinguished: wettable or non-water-repellent soil (WDPT < 5 s), slightly (WDPT = 5–60 s), strongly (WDPT = 60–600 s), severely (WDPT = 600–3600 s), and extremely (WDPT > 3600 s) water repellent soil (Bisdom et al. 1993).

The repellency index RI, as a characteristic of the extent of soil water repellency, was calculated from the water sorptivity, S_w(–2 cm), and ethanol sorptivity, S_e(–2 cm), estimated from the early-time cumulative infiltration, *I*, *vs.* time, *t*, relationships measured *in situ* using a minidisk infiltrometer Decagon (Decagon Devices Inc., 2012) under a pressure head value of $h = -2$ cm (Alagna et al. 2017, 2019). The sorptivity was calculated from equation (Clothier et al. 2000):

$$S(h_0) = I / t^{1/2} \tag{1}$$

Prior to the measurements in woodland soil, the organic layer was removed gently to prevent disturbance of the mineral soil. Duration of early-time infiltration is 60–180 s for a wettable (WDPT = 0–5 s) and slightly repellent (WDPT = 5–60 s) soil (Hallett, 2008), or it is equal to the time of passing the first five bubbles (with the total volume of about 1 mL) through MDI (Time to First Five Bubbles, TFFB, in Beatty and Smith, 2014) for strongly (WDPT = 60–600 s), severely (WDPT = 600–3600 s), and extremely (WDPT > 3600 s) water repellent soils. During this time the process is dominated by the capillarity and the other terms of the Philip infiltration equation can be neglected.

The repellency index RI was calculated using the equation (Hallett and Young 1999):

$$\mathrm{RI} = 1.95\, S_e(-2\ \mathrm{cm}) / S_w(-2\ \mathrm{cm}) \tag{2}$$

The following classes of the extent of SWR were distinguished: wettable or non-water-repellent soil (RI < 1.95), slightly (RI = 1.95–10), strongly (RI = 10–50), severely (RI = 50–110), and extremely (RI > 110) water repellent soil (Iovino et al. 2018).

Evaporation measurements methods

To investigate the impact of water repellent and wettable layers on evaporation from the soil samples taken at Ciavolo, four cylinders (51 mm inner diameter x 65 mm height) were filled with 142.3 g of wettable mineral soil collected from the glade, previously air-dried (sample

IDs 1–4). The soil was sieved at 2 mm and the cylinders were filled in three steps placing the same amount of sieved soil. At each step the soil was levelled applying a slight pressure by means a syringe plunger. Next the soil samples were wetted from the bottom for 24 hours and left to drain for 24 hours covered with a plastic film on the top of column to avoid evaporation. The bottom of each sample was then sealed with plastic film and the 0-, 0.3-, 1-, and 2-cm thick layers of water repellent duff sieved at 2 mm were placed on the surface of each cylinder. A ring of different height made of plastic was used to contain the duff layer. Finally, water evaporation from soil samples was determined from the loss of weight in a temperature controlled laboratory (22 ± 1°C temperature and 50% relative air humidity). Under these environmental conditions, the potential evaporation rate was about 1.95 mm d^{-1}. About 10 days after, a second experimental scheme was started, considering 4 soil samples prepared in the same way, where the 0-, 0.3-, 1-, and 2-cm layers of air-dried sieved (2 mm) wettable mineral soil taken from glade area were placed on the surface of each cylinder (sample IDs 5–8). Data of Ciavolo samples used in two experimental schemes are reported in Table 2.

Table 2 Data on the Ciavolo samples used in two experimental schemes

Sample ID	1	2	3	4
Mass of soil (g)	142.3	142.3	142.3	142.3
Mass of water (g)	66.7	69.9	69.3	66.3
Thickness of duff layer (cm)	0	0.3	1	2
Sample ID	5	6	7	8
Mass of soil (g)	142.3	142.3	142.3	142.3
Mass of water (g)	71.5	68.7	72.3	68.3
Thickness of mineral soil layer (cm)	0	0.3	1	2

Nearly the same experimental schemes were run with the woodland soil and pure sand samples from Sekule. Four cylinders (51 mm inner diameter x 65 mm height) were filled with pure sand, previously air-dried (sample IDs 1–4). Then the soil samples were wetted from the bottom for 24 hours and left to drain for 24 hours covered with a plastic film on the top of column to avoid evaporation. The bottom of each sample was then sealed with plastic film and the 0-, 0.3-, 1-, and 2-cm thick layers of water repellent woodland soil were placed on the surface of each cylinder. Finally, water evaporation from soil samples was determined from the loss of weight in the laboratory (30 °C summer 2016 temperature and 15% relative air humidity). Under these environmental conditions, the potential evaporation rate was about 4.42 mm d^{-1}. About 10 days after, a second experimental scheme was started, considering 4 soil samples prepared in the same way, where the 0-, 0.3-, 1-, and 2-cm layers of air-dried pure sand were placed on the surface of each cylinder (sample IDs 5–8). Data on the Sekule samples used in these schemes are presented in Table 3.

Relative evaporation E_r from soil sample can be expressed by the equation:

$$E_r = E_{cum} / W_i \qquad (3)$$

where E_{cum} is cumulative evaporation (mm), and W_i is an initial soil water content of the soil sample (mm). Relative evaporations estimated after 257 hours (Ciavolo) and 239 hours (Sekule) were used to quantify the influence of different top soil layers on the evaporation kinetics. However the experiment was continued until the almost complete water evaporation.

Table 3 Data on the Sekule samples used in two experimental schemes

Sample ID	1	2	3	4
Mass of soil (g)	169.5	176.7	172.1	178.3
Mass of water (g)	35.5	37.0	35.9	37.8
Thickness of forest soil layer (cm)	0	0.3	1	2
Sample ID	**5**	**6**	**7**	**8**
Mass of soil (g)	183.8	194.9	189.9	196.1
Mass of water (g)	32.9	36.9	33.2	37.0
Thickness of pure sand soil layer (cm)	0	0.3	1	2

The impact of temperature on potential evaporation rate E (kg m^{-2} s^{-1}) was estimated using the calibrated Dalton equation (Biswas, 1972)

$$E = C(e_w - e_0) \tag{4}$$

where C (s m^{-1}) is a coefficient estimated by calibration, e_w (kg m^{-1} s^{-2}) is saturated vapour pressure (a function of temperature), and e_0 (kg m^{-1} s^{-2}) is actual vapour pressure.

Results and discussion

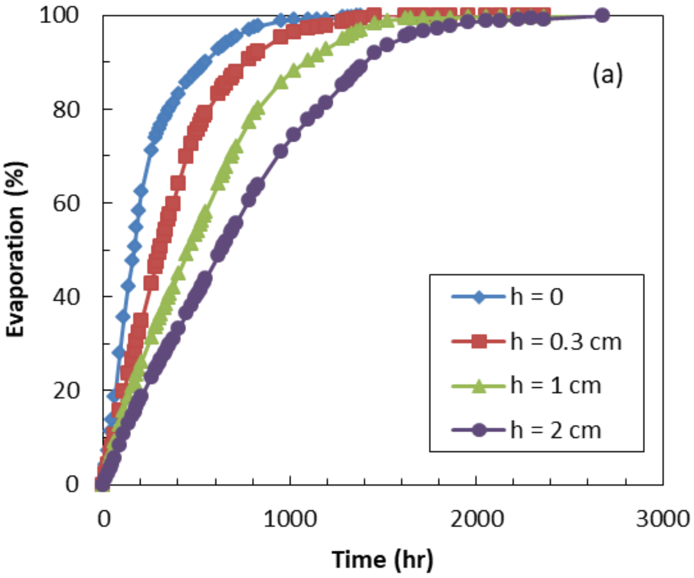
Mean values (MV) and standard errors (SE) of the water drop penetration time (WDPT) and repellency index RI estimated on samples from Ciavolo and Sekule are presented in Table 4. According to the WDPT test, the duff layer of Ciavolo was classified as strongly water repellent (Bisdom et al. 1993) as well as considering the RI classification proposed by Iovino et al. (2018). The woodland soil of Sekule was classified as severely water repellent according to both the WDPT and RI tests (Bisdom et al. 1993; Iovino et al. 2018).

Table 4 Mean values (MV) and standard errors (SE) of the water drop penetration time (WDPT) and repellency index (RI) estimated on samples from Ciavolo and Sekule

Study site	Sample	WDPT (s)		RI (–)	
		MV	SE	MV	SE
Ciavolo	Duff	483 ^{a}	30.6	40.6 ^{a}	10.2
	Mineral soil	2 ^{b}	0.3	2.8 ^{b}	0.2
Sekule	Woodland soil	1601 ^{a}	547	100.5 ^{a}	36.9
	Pure sand	1 ^{b}	0	0.8 ^{b}	0.2

Different superscript letters indicate significant difference in the study site soil property at $P < 0.05$ according to Two Tailed t-test

The impact of different (water repellent duff or wettable clay loam soil) surface layers on evaporation of wettable clay loam soil sampled in Ciavolo is shown in Figure 1. Compared to the control (i.e., wettable clay loam soil not covered with a surface layer, $h = 0$), the water repellent surface layer caused a reduction in the total amount of water evaporated after 257 hr by a factor 1.67–3.13 (Figure 1a), whereas the wettable surface layer, during the same time, caused a reduction in the total amount of water by a factor 1.58–2.23 (Figure 1b), depending on the thickness of surface layer considered.



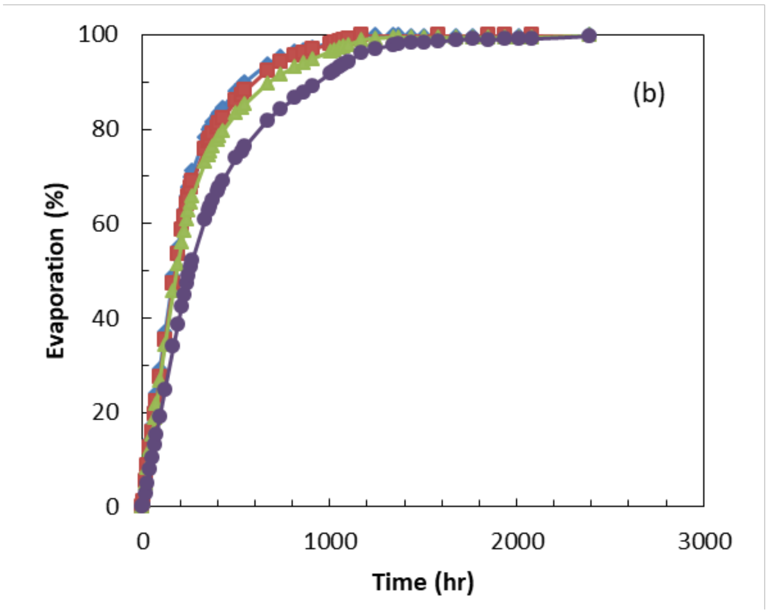


Fig. 1 Time evolution of evaporation, expressed as percentage of total evaporation, from wettable clay loam soil of Ciavolo, Italy, covered with (a) the water repellent duff layers and (b) the wettable clay loam soil layers. The term *h* refers to the thickness of water repellent duff layer (a) and wettable clay loam soil layer (b).

Over 550 hours about 90% of water was evaporated from the uncovered clay-loam soil sample from Ciavolo. The 0.3-cm-thick duff layer saved about 23% of water and the 0.3-cm-thick air-dried clay-loam-soil layer saved about 13% of water in the same time, consequently water repellent layer allowed to reduce about 10% water evaporative loss. The 1-cm-thick duff layer saved about 34% of water and the 1-cm-thick air-dried clay-loam-soil layer saved about 16% of water in the same time, i.e., about 18% of water was saved from evaporation due to water repellency of surface layer. The 2-cm-thick duff layer saved about 58% of water and the 2-cm-thick air-dried clay-loam-soil layer saved about 25% of water in the same time. This means that about 33% of saved water can be associated to the presence of the hydrophobic layer covering the wettable sublayer. These findings are in agreement with the findings of Ward et al. (2013), who found that residue retention saved about 70% more water from evaporation than residue removal.

Evaporation of 90% of water from clay-loam soil samples from Ciavolo covered with 0.3, 1, and 2 cm-thick duff layers, took over 780, 1100, and 1450 hours, respectively. It means that the clay loam soil cover with the 0.3, 1, and 2 cm-thick duff layers resulted in prolonging the evaporation by 10, 23, and 38 days, respectively.

The impact of different (water repellent or wettable sandy soil) surface layers on evaporation from wettable sandy soil sampled in Sekule is shown in Figure 2. Compared to the control (i.e., wettable sandy soil not covered with a surface layer, h = 0), the water repellent surface layer caused a reduction in the total amount of water evaporated after 239 hr by a factor 1.00–2.22, and the wettable surface layer caused a reduction in the total amount of water evaporated after 224 hr by a factor 0.89–1.19, depending on the thickness of surface layer. These findings are in agreement with the findings of Rye and Smettem (2017), who found that tanks with water repellent surface layers lost less water to evaporation following rain events in autumn and winter than tanks filled with wettable sand only, retaining at least 1.5 times more moisture than wettable controls after 5 days of drying in winter, and over 2 times more moisture than wettable controls after 11 days of drying in autumn. The water repellent sand surface layers prepared artificially lost from 2 times (Shokri et al., 2008) to 5 times (Kim et al., 2015) less water by evaporation than wettable controls after 5 days of drying at 25°C.

Over 240 hours, about 98% of water evaporated from the uncovered pure sand sample from Sekule. The 0.3-cm-thick water repellent (pine forest) sand layer saved about 12% of water and the 0.3-cm-thick air-dried pure sand layer saved about 3% of water over the same time, i.e., about 9% of water was saved from evaporation due to water repellency of surface layer. The 1-cm-thick water repellent (pine forest) sand layer saved about 52% of water and the 1-cm-thick air-dried pure sand layer saved about 8% of water over the same time, i.e., about 44% of water was saved from evaporation due to water repellency of surface layer. The 2-cm-thick water repellent (pine forest) sand layer saved about 64% of water and the 2-cm-thick air-dried pure sand layer saved about 34% of water over the same time, i.e., about 30% of water was saved from evaporation due to water repellency of surface layer. These findings are in agreement with the findings of Bachmann et al. (2001), who found that under isothermal conditions water repellency decreased evaporation rates in sandy soils by as much as 25%.

Evaporation of 98% of water from the sandy soil sample from Sekule covered with 0.3, 1, and 2 cm-thick water repellent soil layers, took over 330, 606, and 774 hours, respectively. It means that the sandy soil cover with the 0.3, 1, and 2 cm-thick water repellent soil layers resulted in prolonging the evaporation by about 4, 15, and 22 days, respectively.

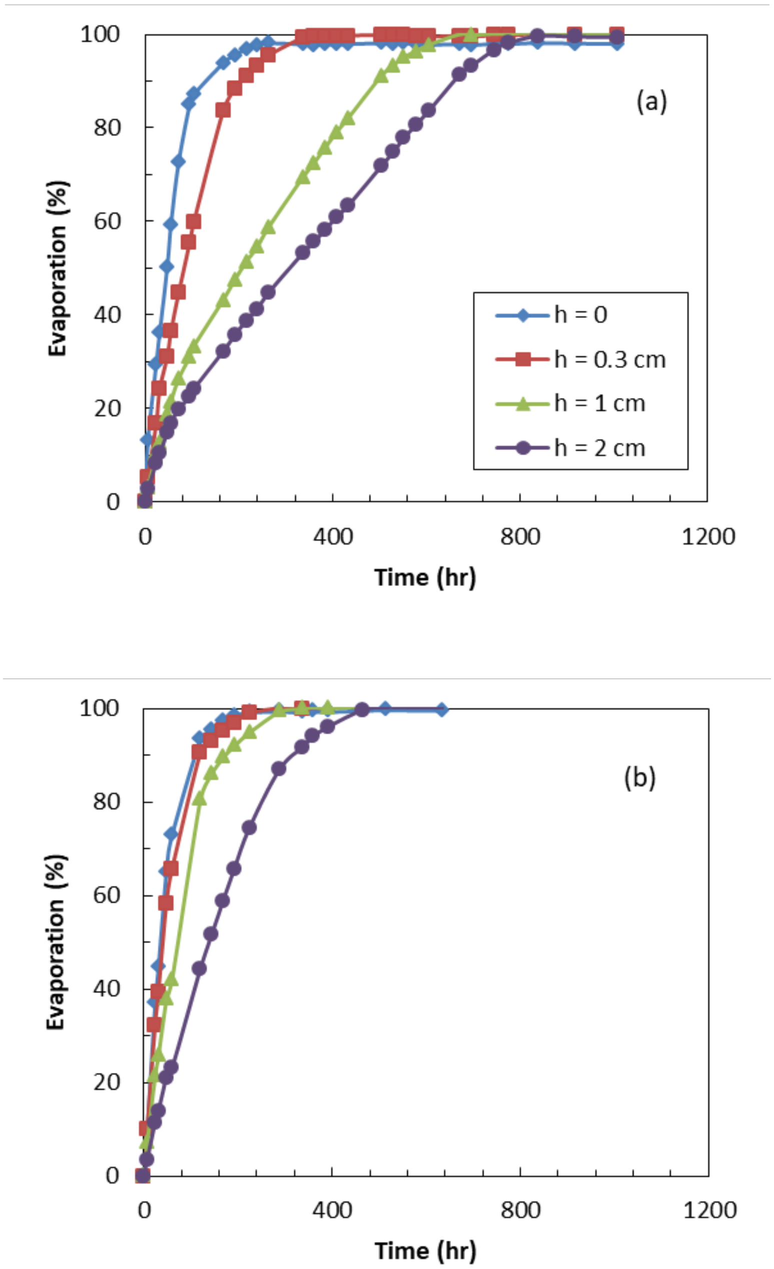


Fig. 2 Time evolution of evaporation, expressed as percentage of total evaporation, from wettable sandy soil of Sekule, Slovakia, for (a) the water repellent sandy soil layers and (b) the wettable sandy soil layers. The term *h* refers to the thickness of water repellent (a) and wettable (b) sandy soil layers.

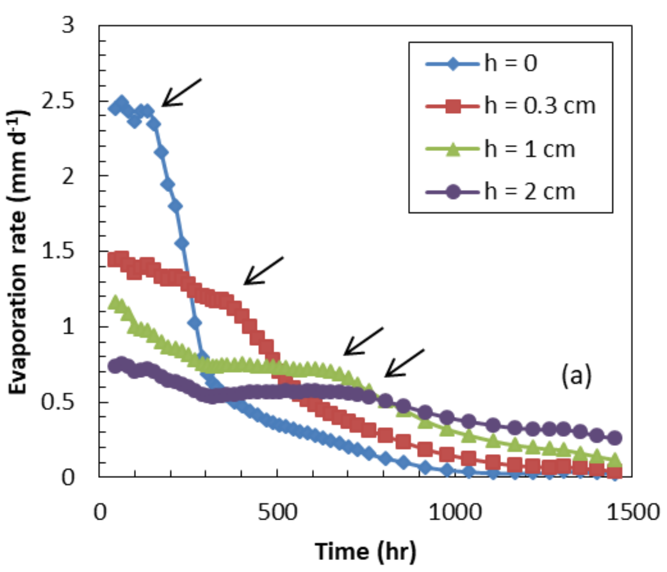
Relative evaporation E_r from soil samples, taken from Ciavolo (Italy) and Sekule (Slovakia) sites and covered by hydrophilic or water repellent soil layer of thickness 0, 0.3, 1, and 2 cm, estimated after 257 hours (Ciavolo) and 239 hours (Sekule) of evaporation are presented in Table 5.

Table 5 Relative evaporation E_r from soil samples, taken from Ciavolo (Italy) and Sekule (Slovakia) sites covered by hydrophilic or water repellent soil layer of thickness 0, 0.3, 1.0, and 2.0 cm, estimated after 257 hours (Ciavolo) and 239 hours (Sekule) of evaporation.

Study site	Duration of evaporation	Top layer material and thickness	Relative evaporation E_r (–)			
			0 cm	0.3 cm	1.0 cm	2.0 cm
Ciavolo	257 hr	Duff	0.70	0.43	0.31	0.23
		Mineral soil	0.71	0.68	0.64	0.51
Sekule	239 hr	Woodland soil	0.98	0.93	0.55	0.41
		Pure sand	1.0	0.99	0.95	0.74

It was found that the wettable soil layers of various thickness on the soil samples surface also decreased the evaporation, but significantly less than water repellent layers. The reasons are mainly by the retention capacity of the top soil layers. At the very beginning of evaporation from samples, it was necessary to increase the soil water content of the top soil layers, to increase their hydraulic conductivities and then, the evaporation rates were increased. The retention capacity of top soil layer is proportional to its thickness, and therefore, wettable soil layers are decreasing the evaporation rate too, but not significantly.

Evaporation rate evolution for the wettable clay loam soil sampled in Ciavolo covered with water repellent and wettable soil layers of different thickness is shown in Figure 3. The first (with nearly constant evaporation rate) and second (transient) stage of evaporation process (Kutilek and Nielsen 1994) are generally well identified. Furthermore, the duration and intensity of first stage is clearly influenced by repellent layer depth whereas only depth seems to play a role in the case of wettable layer. Compared to the control (i.e., *h* = 0), the duration of the nearly constant evaporation rate stage increased when the thickness of the surface duff layer increased. Also initial evaporation rate decreased at increasing the thickness of the water repellent top layer. The wettable clay loam soil layer was less effective in reducing evaporation rate from the wet clay loam soil samples. Also the transition from the initial constant stage of evaporation to the transient one, controlled by soil conditions, was more difficult to detect.



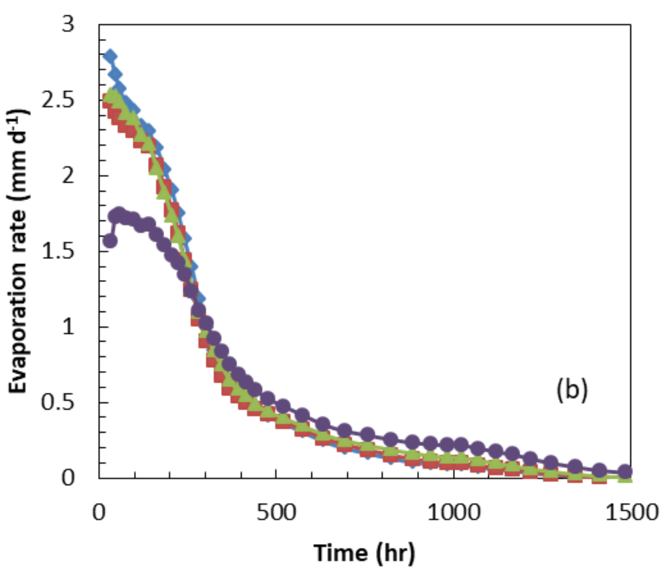
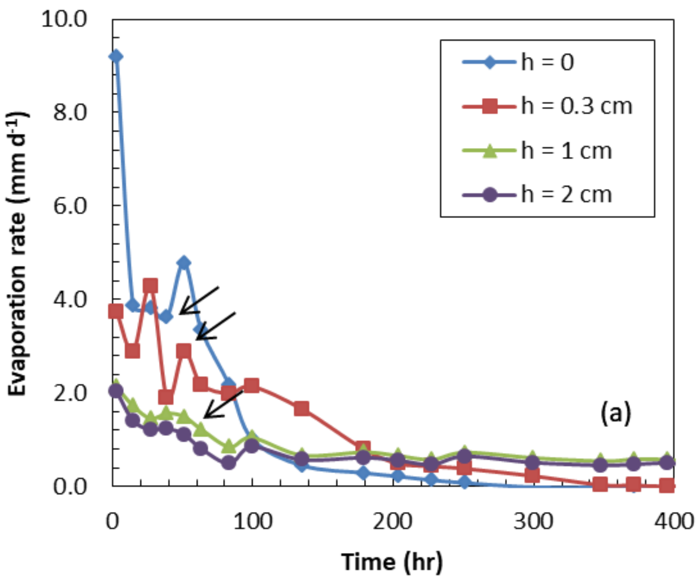


Fig. 3 Time evolution of evaporation rate from wettable clay loam soil of Ciavolo, Italy, covered with (a) the water repellent duff layers and (b) the wettable clay loam soil layers. The term *h* refers to the thickness of water repellent duff layer (a) and wettable clay loam soil layer (b). Arrows indicate transition from first to second stage of evaporation process.

The impact of different (water repellent or wettable sandy soil) surface layers on evaporation rate from wettable sandy soil sampled in Sekule is shown in Figure 4. In both cases, the thickness of the surface layer was the main factor influencing the reduction of the initial evaporation rate whereas the hydrophobic or wettable conditions of the surface layer similarly affected the initial stage of the evaporation process.



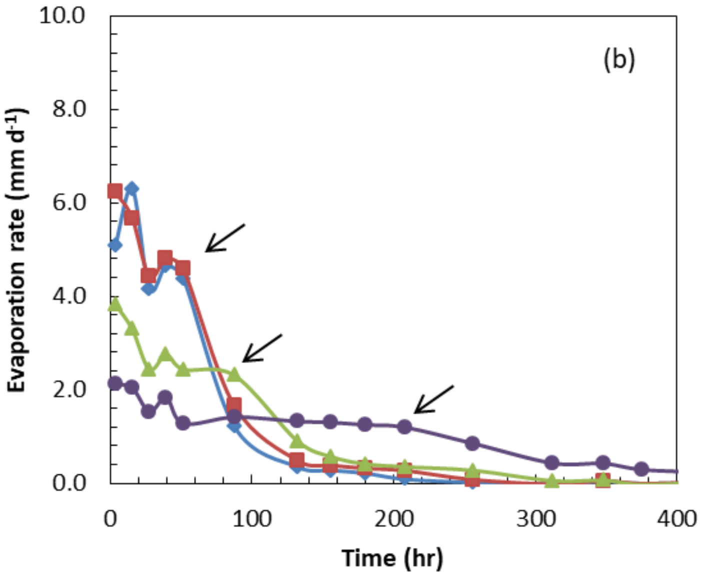


Fig. 4 Time evolution of evaporation rate, from wettable sandy soil of Sekule, Slovakia, for (a) the water repellent sandy soil layers and (b) the wettable sandy soil layers. The term *h* refers to the thickness of water repellent (a) and wettable (b) sandy soil layers. Arrows indicate transition from first to second stage of evaporation process.

The temperature dependence of potential evaporation rate, estimated from Eq. (4), is presented in Table 6. It can be seen that an increase in mean temperature from 25 °C to 30 °C (as a result of climate change) will result in an increase in potential evaporation rate from 3.16 to 4.42 mm d^{-1}, i.e. in 39.9%. This increase is of the same magnitude as the decrease in evaporation losses associated with a 1–2 cm thick cover of water repellent soil.

Table 6 The temperature dependence of potential evaporation rate.

Air temperature (°C)	20	25	30	35
Potential evaporation rate (mm d^{-1})	2.34	3.16	4.42	5.59

Conclusions

The water repellent surface layer can save water from evaporation for both sandy and clay loam soils, and the effect increased with the thickness of surface layer. Placing the 2-cm-thick surface layer of water repellent duff on clay loam soil resulted in prolonging the evaporation by 38 days. Similarly, placing the 2-cm-thick surface layer of water repellent soil on sandy soil resulted in prolonging the evaporation by 22 days, which may be particularly beneficial for plants during hot and dry periods in summer. In conclusion, strongly water repellent duff layers preserve the underlying soil moisture more effectively than severely repellent woodland sandy layers.

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Conflict of interest

The authors declare that they have no conflict of interest.

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