



Fire impact on soil-water repellency and functioning of semi-arid croplands and rangelands: Implications for prescribed burnings and wildfires

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ABSTRACT

An unintended fire outbreak during summer 2015 in the semi-arid Israeli Negev resulted in the burning of extensive croplands and rangelands. The rangelands have been managed over the long term for occasional grazing, while the croplands have been utilized for rainfed wheat cropping. Yet, during the studied year, the croplands were left fallow, allowing the growth of herbaceous vegetation, which was harvested and baled for hay before the fire outbreak. The study objectives were to investigate the impacts of fire, land-use, and soil depth on water-repellency and on the status and dynamics of some of the most important organic and mineral soil resources. Additionally, we aimed to assess the severity of this fire outbreak. The soil-water repellency was studied by measuring the soil's water drop penetration time (WDPT) and critical surface tension (CST). A significant effect of fire on soil hydrophobicity was recorded, with a slight increase in mean WDPT and a slight decrease in mean CST in the burnt sites than in the non-burnt sites. Yet, soil hydrophobicity in the burnt lands was rather moderate and remained within the water repellency's lowest class. A significant effect of land-use on the means of WDPT and CST was also recorded, being eleven-fold greater and 7% smaller, respectively, in the rangelands than in the croplands. This is consistent with the almost eightfold greater mean above-ground biomass recorded in the non-burnt rangelands than in the non-burnt post-harvest croplands, revealing the positive relations between available fuel load and soil-water repellency. The effect of soil depth was significant for CST but not for WDPT. Overall, the gathered data suggest that fire severity was low to moderate. Fire was also found to significantly affect the <250 µm particle size fraction of the unconsolidated material cover, its mass being twofold to threefold greater in the non-burnt than in the burnt sites. Yet, soil organic carbon and ammonium-N were also studied, and generally showed higher values for the burnt lands. Overall, this study shows that the low- to moderate-fire severity only slightly increased the soil water repellency, and at the same time, increased on-site availability of some important soil resources. Nevertheless, it is acknowledged that such fires could impose risks to off-site air and water source quality. This study has implications for the assessment of geo-ecosystem functioning, as well as for the status and dynamics of soil resources following prescribed burnings or wildfires.

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1. Introduction

Controlled burnings of farmland crop residue or rangeland above-ground biomass have been prevalent as a common management practice in extensive areas around the world (Brooks et al., 2006). The

objectives of prescribed burnings are varied, ranging between the control of weeds (Koski et al., 2011) and pests in croplands (DeFrancesco and Murray, 2011), the control of woody vegetation and other invasive plant species in grasslands and chaparral rangelands (Veatch et al., 2014), and as means to control wildfire in shrublands and tree plantations (Shakesby et al., 2015).

However, while possibly fulfilling these aims, similar to wildfires, burning management practices can have some detrimental impacts on soils. These include the uneven wetting patterns of the soil profile, the development of preferential flow, the decreased availability of water for vegetation, and the increased susceptibility to overland flow generation and soil erosion (Doerr et al., 2000; Bachmann et al., 2002).

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These effects have been widely attributed to fire-induced soil–water repellency (DeBano and Krammes, 1966), which stems from the decreased mutual attraction forces (adhesion) between the water and solid surfaces (Doerr et al., 2000). The soil–water repellency feature is derived from the fire's high temperatures that cause the vaporization of the soil organic compounds, which condense and coat soil particles that become hydrophobic (Letey, 2001).

Regardless, assuming similar fuel load availability, differences in fire impacts between different land-uses (e.g., croplands vs. rangelands) are attributed to vegetation species composition. For example, in Alicante in southeastern Spain, it was found that that *Rosmarinus officinalis* (L.) induced greater soil water repellency than that of *Pinus halepensis* (Miller), and that this soil feature under these two species was greater than that under *Brachypodium retusum* (Pers. Beauv.) (Arcenegui et al., 2007). At the same time, Ansley et al. (2006) highlighted the importance of the fire timing. For a temperate mixed-grass savanna in Texas, United States, Ansley and colleagues reported that late-summer and winter fires, occurring when (highly productive) C₃ grasses and forbs are active and (lesser productive) C₄ grasses are dormant, have a large impact on soil organic carbon and black carbon dynamics.

In addition, water repellency was reported to be generally related to the soil texture, and positively related to the soil organic carbon content (DeBano, 1981; Bisdom et al., 1993). This is particularly relevant in coarse textured soils, where macro-aggregation processes are relatively little, and the non-aggregate encapsulated organic carbon becomes available for vaporization and vertical redistribution. Additionally, the development of water repellency is negatively related to the soil moisture content, because dry soil is a poor conductor of heat (DeBano, 1981).

No less important than the absolute temperature is the temperature gradient which develops across the soil profile (DeBano, 1981). That way, water repellency tends to increase with soil depth, because the organic compounds' vapors move down throughout the decreasing temperature gradient across the soil profile – from the hottest surface layer to the cooler deeper layers – where they condense and coat mineral particles. Depending on the burning severity, the water repellent soil layer can be developed in a wide range of depths, ranging between few mm to several cm from the surface (DeBano, 1981; Letey, 2001).

In addition to the fire effects on the solid soil, burning also affects the dynamics of unconsolidated material cover on the ground surface. These materials include both organic matters such as plant litter and ash, as well as mineral substances, such as dust and non-aggregated substances (Parsons et al., 2010). Specifically, fire outbreaks can eliminate such materials through their burning (Miesel et al., 2007), or deposit the flying, partially-burnt materials (Rau et al., 2008), resulting in on-site depletion or insertion, respectively, of soil resources, and with the successive impact on the soil quality and fertility.

This study's major objective was to assess the impact of fire outbreak on the geo-ecosystem functioning of rangelands and croplands, as determined by soil–water repellency, as well as by the status and dynamics of some of the most important, organic and mineral soil resources. The secondary objectives were to examine the effects of land-use, i.e., croplands vs. rangelands, and soil depth, on these soil features. Additionally, we aimed at assessing the severity of this fire outbreak. The study's major hypothesis was that the fire induced water repellency in the fire-prone lands, and decreased the on-site availability of soil resources. The impact on soil water repellency is attributed to the burning of above-ground biomass, which results in the deposition of some ash on the ground surface, as well as the 'baking' of the ground surface, with the resultant vaporization of the vegetation- and soil-organic matter. These combined effects lead to the condensation of some of the organic matter, with the resultant coating of soil particles, which become hydrophobic. At the same time, the impact on on-site availability of soil resources, despite the deposition of some ash on the ground surface, is attributed to the elimination of the largest part of above-ground biomass by the burning. The second hypothesis was that the fire-induced

repellency increased with soil depth. This expected effect is attributed to the descending temperature gradient across the soil profile, which enables the condensation of the organic matter vapors at relatively deeper depths. The third hypothesis was that the fire-derived repellency impact was greater in the rangelands than in the croplands. This is due to the (easily observable) greater fuel load in the rangelands, with the expected higher fire severity and greater rates of vaporization and condensation of organic matter, than that in the (fallow but) harvested croplands.

2. Materials and methods

2.1. Regional settings

The study region extends across the north-western semi-arid Negev in southern Israel (31° 35' N, 34° 59' E, 93–101 m.a.s.l.). Mean daily temperatures in the coldest (January) and warmest (July) months are 12 °C and 26 °C, respectively (Bitan and Rubin, 1991), and long-term mean annual cumulative precipitation is 230 mm, occurring between November and March (Israel Meteorological Service). Lithology of the region is comprised of calcareous sandstone, and topography is comprised of extensive flat plains transected by wide and deep wadis (ephemeral rivers). Soil is classified as loessial Calcic Xerosol (FAO, 2015). The study site consisted of the southern edges of the Agricultural Research Organization's Migda Farm for croplands, and the nearby Patish Wadi's wide shoulders for rangelands (Fig. 1).

Similar to the extensive rainfed croplands across the region, the studied farmlands have been continuously cultivated and sown with wheat (*Triticum aestivum* L.) over the long term. However, during the cropping year of fall 2014 to spring 2015, the farm's croplands were left fallow, allowing the spontaneous growth of a range of native herbaceous vegetation species, including: *Sinapis alba* L., *Chrysanthemum coronarium* L., *Erucaria hispanica* L. Druce, *Malva sylvestris* L., *Erodium moschatum* L. L'Hér., *Raphanus raphanistrum* L., *Centaurea iberica* Trevir. & Spreng., and *Carthamus tenuis* Boiss. & Blanche Bornm. During March 2015, the herbaceous vegetation was harvested, baled for hay, and taken off the field. As practiced in extensive cropping systems elsewhere, the combine harvester table was set to 10-cm height, leaving vegetation stems of this height, which remained attached to the ground surface.

Rangelands across the study region have mainly encompassed marginal lands, such as wadi shoulders. The rangelands have been prone to occasional grazing by flocks of sheep and goats. Main herbaceous vegetation species in the rangelands have included grasses, forbs, and legumes, including: *S. alba*, *C. coronarium*, *E. hispanica*, *C. iberica*, *C. tenuis*, *Trigonella arabica* Delile, *Schismus arabicus* Nees, *Stipa capensis* Thunb., and *Cynodon dactylon* L.

An uncontrolled fire – breaking out following the expansion of an intentional burning of agricultural residues on a day with a heat wave, where temperatures exceeded 40 °C – took place on May 18th 2015, emerging from the farmlands south of Patish Wadi. The fire outbreak advanced northward, towards Patish Wadi, and further north, towards the southern parts of the Migda Farm. On its track northward, the fire burnt approximately 210 ha of open lands in Patish Wadi and an additional approximately 20 ha of the Migda's farmlands, as well as approximately 160 ha of the surrounding croplands. About two weeks after the fire outbreak, a survey (of the 0–1, 1–2, and 2–3 cm depths) of the study site's croplands and rangelands was undertaken in order to determine the soil texture. The survey revealed a sandy loam texture (63.8% ± 2.3 sand, 18.5% ± 1.4 silt, and 17.7% ± 1.5 clay), with no significant effect of any of the land-use or depth.

2.2. Remote sensing-based assessment of fire severity

Fire severity was calculated by spectral indices that track the reflectance changes in burnt areas, mainly related to vegetation

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