Geoderma 157 (2010) 109–117

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Antecedent soil moisture affecting surface cracking of a Vertisol in field conditions

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ARTICLE INFO

Article history:
Received 22 June 2009
Received in revised form 15 March 2010
Accepted 30 March 2010
Available online 13 May 2010

Keywords:
Vertisol
Shrinkage crack
Soil water
Hysteresis
Recharge

ABSTRACT

Cracking of shrink–swell soils influences landscape hydrology. Watershed models that address soil cracking phenomena generally use a relationship between shrinkage and current soil water content to estimate the extent of cracking. Although antecedent soil moisture prior to soil shrinkage is found to affect the shrinking of expansive soils in laboratory measurements, field observations are limited. In a previous study, a series of in situ surface crack measurements over 10 years indicated the effect of soil moisture just prior to the start of cracking (antecedent soil moisture) on cracking extent, but this relationship was not specifically analyzed. The objectives of this study were (i) to estimate the antecedent soil water content prior to cracking, (ii) to analyze the effect of antecedent moisture on crack area density in microhighs and microlows, and (iii) to assess the temporal distribution of antecedent soil moisture in relation to an estimated water availability index. Soil cracking was measured on a 10-m × 10-m plot of Laewest clay (fine, smectitic, hyperthermic Typic Hapludert) covered with native tallgrass vegetation on 42 dates during 1989–1998. Gravimetric soil water content was measured on 50 dates; 18 dates corresponded to crack measurements. Gilgai microtopograhy was mapped, and surface crack area density was calculated. For days when soil water content was not measured, it was estimated from precipitation and evapotranspiration. Antecedent soil water content prior to cracking was estimated for depth at 10 cm using daily estimates of soil water content and field notes on cracking. Results indicated that the temporal variation in surface crack area density of the study area during 10 years was related to dynamics of current and antecedent soil water content on microhighs and microlows ($R^2 = 0.68$ and 0.59, respectively). Prediction accuracies improved with classifying drying–wetting conditions during cracking. Dynamic temporal changes in the surface crack area density exhibited dependence on a long-term (multi-year) cycle of antecedent soil water content superimposed by short-term (within a year) cycles of current soil water content.

1. Introduction

Soil cracking, driven by drying of shrink–swell soils, alters infiltration, runoff, evapotranspiration and redistribution of water and chemicals. This phenomenon contributes to complex spatial and temporal variability of water redistribution in the landscape, and creates challenges to modeling of surface hydrology. Present models that simulate water flow in shrink–swell soils use shrinkage characteristics based on current soil water content (e.g. Hendrickx and Flury, 2001; Greco, 2002; Deliberty and Legates, 2003; Arnold et al., 2005; Cao et al., 2006; Bradley et al., 2007; Bedient et al., 2008; Lepore et al., 2009). Laboratory characterization of soils reinforces the idea that soil shrinkage, and therefore crack formation, is a function of current soil water content. Commonly used laboratory measurements are the coefficient of linear extensibility (COLE), which relates soil shrinkage potential to soil water loss (Grossman et al., 1968; Reeve et al., 1980; Yule and Ritchie, 1980a; Bronswijk, 1990b), and the soil shrinkage characteristic curve (e.g. Haines, 1923; McGarry and Daniells, 1987; Bronswijk, 1988, 1991; Mitchell, 1992; Coulombe et al., 1996; Olsen and Haugen, 1998; Braudeau et al., 1999; Boivin et al., 2006; Cornelis et al., 2006).

In most shrink–swell studies, soil water loss is calculated between the current soil water content and a constant, such as the soil water content at field capacity (associated with a matric water potential of −33 kPa or −10 kPa) or at saturation. However, a variable initial soil water content caused by soil water content history may affect the magnitude of shrinking and swelling of soils containing smectitic clay minerals (Yule and Ritchie, 1980a; Parker et al., 1982; Wilding and Tessier, 1988; Tessier, 1990, Santamarina et al., 2001; Wells et al., 2003, 2007; Saiyouri et al., 2004). In this paper, we use the terms antecedent and current soil water content to identify soil moisture prior to surface desiccation cracking, when the soil surface is still closed, and at the time of crack measurement, respectively. The term initial soil water content specifies any soil moisture condition at the beginning of a measurement, with or without the presence of desiccation cracks.

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doi:10.1016/j.geoderma.2010.03.020

The complex processes of shrinking and swelling, and associated crack opening and closing in Vertisols and vertic intergrades depend on the microstructure and intra- and interparticle porosity of soils (Wilding and Tessier, 1988; Tessier, 1990; Quirk, 1994; Coulombe et al., 1996). Available water is one of the external factors driving the balance of attractive and repulsive interparticle forces. These attractive (capillary suction, London–van den Waals and ion–ion correlation) and repulsive (structural water and osmotic) forces depend internally on mineralogy, cations, electrolyte concentration, and organic matter, but also externally on varying climate, parent material, topography, land use, vegetation, and stress history (Quirk, 1994). The effect of stress history on soil cracking is most noticeable from extreme wetting and drying or compaction (Santamarina et al., 2001; Saiyouri et al., 2004). Considering the effect of the history of drying–wetting on soil shrink–swell, it was observed in electron microscopic and X-ray scattering studies that initial soil water content played a significant role in shrink–swell processes of smectitic clay samples (Tessier, 1984 reviewed by Wilding and Tessier, 1988; Tessier, 1990). On core samples taken from Vertisols, initial moisture prior to desiccation has been also shown to affect the final magnitude of shrinkage (Yule and Ritchie, 1980a).

In addition to high initial moisture, repeated dry–wet cycles have enhanced swelling in small soil samples (Parker et al., 1982; Peng et al., 2007). Additionally, in a large repacked sample of a smectitic Vertisol (76.5-cm × 80-cm × 30-cm), a sequence of simulated wetting and drying increased swelling and vertical crack depth during subsequent wetting and drying cycles (Wells et al., 2003, 2007; Römkens and Prasad, 2006). It was postulated that the spatial and temporal variability of antecedent soil moisture caused the increase in swelling and cracking during the repeated wetting–drying cycles (Wells, personal communication, 2008).

In a previous study conducted by Kishné et al. (2009) based on a 10-yr crack monitoring of Vertisols, findings indicated the effect of antecedent soil moisture on cracking to cause variation in shrinkage and retained soil water content due to hysteresis. Soil cracks were mapped in field conditions (Fig. 1) on a 100-m^2 site of smectitic Laewest clay with gilgai in native grassland in the Texas Gulf Coast Prairie on 42 dates during 1989–1998 (Miller et al., 2010). The greatest extent of cracking was measured in 1997 and 1998 (Fig. 2) preceded by months of above normal precipitation. These dates in 1997 and 1998 had about 10-fold greater crack area density than dates with similar soil water content but below normal precipitation in the prior months, i.e. 1995 and 1996. Temporal trends in the extent of cracking, expressed as crack area density, were similar on microlow and microhigh gilgai categories (Fig. 2). However, surface cracking occurred with a much smaller extent in microlows despite of greater shrinkage potential measured as COLE to 1 m depth (Kishné et al., 2009). Current gravimetric soil water content proved to have an overall weak, negative relationship with surface crack area density. The weak relationship between measured gravimetric soil water content and crack area density was somewhat improved by separating microhighs and microlows and by grouping data according to drying, uniform and wet soil moisture conditions within 10–25 cm. A probable influence of antecedent soil moisture was hypothesized, but not tested because antecedent soil water content prior to cracking was not the objective of that study.

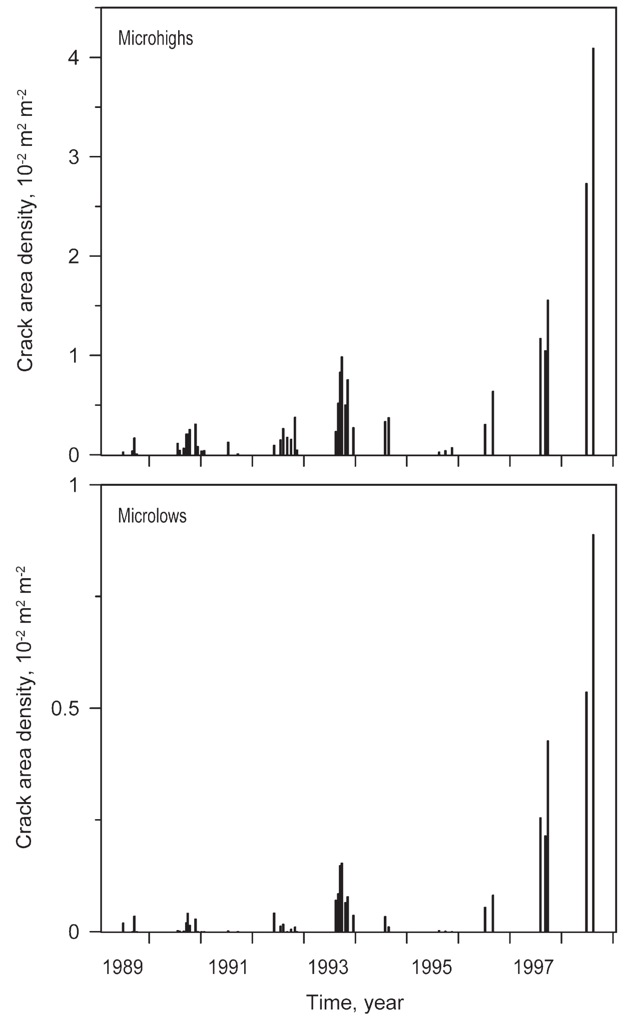

Fig. 2. Crack area density measured on the surface of microhigh and microlow microtopography of Laewest clay on 42 dates over the 10-yr study period. Note different scales on each *y*-axis.

In the current investigation, we study the temporal dynamics in surface cracking at the previously investigated Vertisol site (i.e. Kishné et al., 2009; Miller et al., 2010). Particularly, we focus analysis on the relationship of antecedent soil moisture prior to cracking and long-term weather variations with cracking densities measured over 10 years, in this 10-m by 10-m area of a Vertisol. The specific

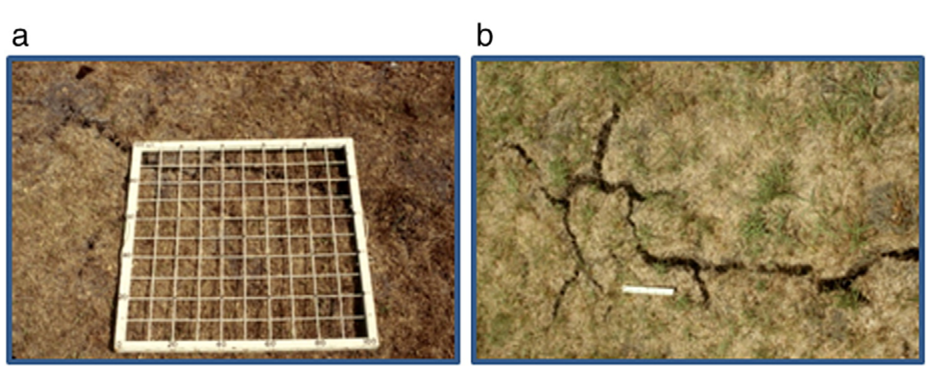

Fig. 1. Field photos demonstrating a) the measurement grid with 10-cm × 10-cm cells used to map cracks and b) surface cracking with a 30-cm long ruler on September 3, 1993.