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Soil enzyme activities during the 2011 Texas record drought/heat wave and implications to biogeochemical cycling and organic matter dynamics☆

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ABSTRACT

Extreme droughts and heat waves due to climate change may have permanent consequences on soil quality and functioning in agroecosystems. During November 2010 to August 2011, the Southern High Plains (SHP) region of Texas, U.S., a large cotton producing area, received only 39.6 mm of precipitation (vs. the historical avg. of 373 mm) and experienced the hottest summer since record keeping began in 1911. Several enzyme activities (EAs) important in biogeochemical cycling were evaluated in two soils (a loam and a sandy loam at 0–10 cm) with a management history of monoculture (continuous cotton) or rotation (cotton and sorghum or millet). Samplings occurred under the most extreme drought and heat conditions (July 2011), after precipitation resulted in a reduction in a drought severity index (March 2012), and 12 months after the initial sampling (July 2012; loam only). Eight out of ten EAs, were significantly higher in July 2011 compared to March 2012 for some combinations of soil type and management history. Among these eight EAs, enzymes key to C (β-glucosidase, β-glucosaminidase) and P cycling (phosphodiesterase, acid and alkaline phosphatases) were significantly higher (19–79%) in July 2011 than in March 2012 for both management histories regardless of the soil type ($P > 0.05$). When comparing all sampling times, the activities of alkaline phosphatase, aspartase and urease (rotation only) showed this trend: July 2011 > March 2012 > July 2012. Activities of phosphodiesterase, acid phosphatase, α-galactosidase, β-glucosidase and β-glucosaminidase were higher in July 2011 than July 2012 in at least one of the two management histories. Total C was reduced significantly from July 2011 to March 2012 in the rotation for both soils. Only the activities of arylsulfatase (avg. 36%) and asparaginase showed an increase from July 2011 to March 2012 for both soil types, which may indicate they have a different origin/location than the other enzymes. EAs continued to be a fingerprint of the soil management history (i.e., higher EAs in the rotation than in monoculture) during the drought/heat wave. This study provided some of the first evidence of the adverse effects of a natural, extreme drought and heat wave on soil quality in agroecosystems as indicated by EAs involved in biogeochemical cycling.

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1. Introduction

Drought and heat waves are expected to become more frequent and extreme due to global climate change for many regions (IPCC, 2007). The Southwestern U.S. is especially vulnerable, with drought frequency expected to increase significantly during the next century (Overpeck and Udall, 2010; Strzepek et al., 2010). Although periods of high temperatures and low precipitation are common in Texas, the period from October 2010 through September 2011 was the warmest and driest 12-month period on record (Hoerling et al., 2012). The average temperature in Texas for June through August 2011 was 30.4 °C, which was 2.9 °C above the long-term average and warmer than any previous single month. This record-breaking heat was accompanied by extreme drought conditions, with a drought index (i.e., Palmer drought severity index, PDSI) reaching a record minimum in September 2011 (Hoerling et al., 2012). In the Southern High Plains (SHP) of Northwest Texas, a leading region for U.S. cotton production, drought was so severe that almost all dryland crops were abandoned and irrigated crop

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yields were severely reduced with overtaxed wells not providing sufficient water to meet exceptionally high demand. While crop losses and record decline in groundwater supplies (HPWD, 2012) are clear impacts of the 2011 Texas drought and record heat, little is known about other less obvious consequences on ecosystem services related to biogeochemical cycling and soil organic matter (SOM) dynamics.

Enzyme activities (EAs) are critical to ecosystem functioning affecting nutrient transformation, carbon (C) sequestration and biogeochemical cycling of C, nitrogen (N), phosphorous (P) and sulfur (S). The activities of enzymes have been used as sensitive indicators of soil quality changes as affected by management and land uses in soils from humid and semiarid regions (Bandick and Dick, 1999; Ndiaye et al., 2000; Acosta-Martínez et al., 2003, 2004a,b). In the SHP region, increases up to 37% has been found in EAs after only 2–3 rotations of sorghum with cotton (Acosta-Martínez et al., 2011) and within two years following conversion from monoculture cotton to high input forage sorghum cropping systems without a change in soil organic C (Cotton et al., 2013). However, little is known about how these ecosensors respond to drought and whether soil type (e.g., differing textures) or management history affects the response under natural conditions in the field as most studies on the effects of drought and warming on soil EAs are conducted under simulated conditions (i.e., Sardans and Peñuelas, 2005; Bell et al., 2009). Under simulated drought conditions, soil EAs have shown a decrease as soil moisture is gradually reduced in native ecosystems in which other dynamics are involved (i.e., changes in plant physiology and biomass) (Sardans and Peñuelas, 2005; Sardans et al., 2008a,b). Warming alone has not shown consistent effects in EAs on different simulated studies, with no change to slight increases depending on other factors, i.e., season and climate (Bell et al., 2010; Steinweg et al., 2013). The majority of climate change research has concentrated on natural ecosystems (i.e., forests or grasslands) while studies on extreme weather conditions are lacking in agroecosystem-soil environments. Understanding how cycles of drought and extreme heat affect soil EAs under agroecosystems will provide valuable information regarding SOM dynamics and biogeochemical cycling that affect productivity.

Recognizing the record-setting drought and heat conditions occurring since the end of 2010, a soil sampling effort was initiated to better understand the effect of this extreme climatic event on EAs involved in C, N, P, and S cycling, along with SOM analysis, in agroecosystems. Our first objective was to determine the temporal response of EAs, beginning during peak drought conditions (July 2011) and continuing up to one year afterward. Our second objective was to evaluate if management history (i.e., rotation vs. monoculture cotton) could be differentiated via measurement of EAs during and after the drought on two different soil types (loam and sandy loam). Soil samples were collected from fields that had been under dryland monoculture cotton or cotton-forage rotation for at least five years. All fields were sampled during the peak of the drought/heat wave (July 2011) and when drought conditions improved slightly (March 2012), with only the loam fields sampled after one year (July 2012).

2. Materials and methods

2.1. Site descriptions

The SHP region has a dry steppe climate with mild winters and a mean annual precipitation of 465 mm (with most of the precipitation occurring from April through October). Two dryland production systems (monoculture cotton and a cotton-based rotation) on two soil types (loam and sandy loam) were selected and described in detail in Acosta-Martínez et al. (2011) and Davinic et al. (2013), respectively. The loam soil belongs to the Pullman series (Fine, mixed, thermic Torrertic Paleustolls) with an average pH of 7.4, 18.5% clay, 53.0% sand and 28.5% silt. These fields are located at the Texas Tech University field laboratory in New Deal, TX (33°45′N, 101°47′W; 993 m elevation). The sandy loam belongs to the Olton series (fine, mixed, superactive, thermic Aridic Paleustolls) with an average pH of 7.5, 12.0% clay, 69.5% sand and 18.5% silt. The fields are located at the USDA-ARS farm near New Deal, TX, USA (33°42′N, 101°49′W; 990 m elevation).

The monoculture system was tilled continuous cotton (*Gossypium hirsutum*) for both the loam and the sandy loam for at least five years prior to sampling. The rotation evaluated in both soils was tilled cotton rotated with a forage crop. The tilled cotton was rotated with forage sorghum (*Sorghum bicolor* L.) in the sandy loam for the last 5 years prior to this sampling. Similarly, tilled cotton was rotated with forage sorghum in 2004 and 2008 or foxtail millet (*Setaria italica* (L.) P. Beauv.) during other years in the loam (Zilverberg, 2012). Foxtail millet and forage sorghum are highly comparable C_4 forage crops with similar rooting structures and canopy features that require similar management practices involving tillage. Both are drought resistant, making them primary options to rotate with cotton in this semi-arid region.

2.2. Climatic conditions for each sampling time

Climate data was collected from the Lubbock National Weather Service weather station (NCDC, 2013), located within 10.5 km of all sample sites. Palmer drought severity indexes (PDSI) presented were calculated by the National Oceanic and Atmospheric Administration for the Texas Climate Division 1-High Plains and Panhandle region (NCDC, 2013), which encompasses most of Northwest Texas including the fields sampled. The PDSI is a soil moisture algorithm calibrated for relatively homogeneous regions, and a value below −4.0 is considered extreme drought conditions (Palmer, 1965). Soil temperature data was collected by the Texas Tech University West Texas Mesonet (WTM, 2013). The soil samples were taken from 0 to 10 cm during the peak drought/heat wave conditions (July 2011), after a reduction in the drought index was observed (March 2012), and after one year (July 2012) as summarized in Fig. 1. During July 2012 only the fields under loam soil were sampled as the fields under the sandy loam soil were converted to different cropping systems. Detailed discussion of climatic conditions for each sample time is below.

July 2011: Samples were taken on 25 July, and the average PDSI during this month was −6.1. Prior to this sampling, weather conditions were among the hottest and driest ever recorded for the SHP. During June and July 2011, average daily air temperature was 30.0 °C with an average daily maximum of 37.7 °C. These were the two warmest months on record in Lubbock, 5.7 °C and 3.6 °C above the monthly mean, respectively. Less than 2 mm of total precipitation occurred during these two months. In fact, the last precipitation event greater than 2 mm occurred in mid-May 2011, over 70 days prior to soil sampling. Overall mean soil temperature (5 cm) during June and July was 35.7 °C, the average daily maximum soil temperature was 45.0 °C, and the highest measured soil temperature was 48.0 °C. Gravimetric water content of soil samples was less than 2% for all soils at the time of sampling. Given the extreme weather conditions, it was not possible to establish crops, so all plots were fallow with bare soil during sampling.

March 2012: Despite precipitation during late 2011 and early 2012, less intense drought persisted with an average monthly PDSI of −3.3. Total precipitation was 18 mm during March, mean air temperature was 15.5 °C, and mean monthly soil temperature was 10.7 °C. A typical soil warming pattern occurred during the month,