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Research Letter

Effects of Drought on Crop Production and Cropping Areas in Texas

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Core Ideas

- Drought causes significant yield reductions both for rainfed and irrigated crops.
- Drought can have impact on cropping areas and crop yield.
- Changing crop types can be used to cope with drought challenges during drought periods.

Abstract: Increased crop yield is required to meet the needs of future population growth, but drought causes significant yield reductions for rainfed and irrigated crops. This study evaluates the impact of drought on crop yield and cropping area over 10 climate zones in Texas from 2008 to 2016. It also depicts the spatiotemporal distribution of crop yield and cropping area changes at each climate zone across the state. We analyzed the impact of drought on crop yields and cropping areas before and after the 2011 severe drought using annual crop yields of four major crops. Results show that drought had a greater impact on winter wheat (*Triticum aestivum* L.) and corn (*Zea mays* L.) and lesser impact on cotton (*Gossypium* spp.) and sorghum [*Sorghum bicolor* (L.) Moench] production across Texas. Cotton and corn hectarages were reduced during the drought period and increased after that, whereas winter wheat hectarage was reduced in the northern climate zones and increased in the southern climate zones before the drought. Results also indicate that drought impact on crop production may be reduced by replacing water-demanding crops such as corn with drought-tolerant crops such as sorghum and expanding irrigation hectarage during drought periods. It may be beneficial for Texas agricultural production to increase the hectarage of sorghum and other grains especially during drought periods. This study provides valuable information that can be used to adopt appropriate measures to cope with future drought challenges in drought-prone regions.

Agricultural production is directly affected by climate variables such as temperature and precipitation. These variables control crop growth and health, annual crop yield, and yield of the cropping system over time (Howden et al., 2007; Kang et al., 2009; Lehmann, 2013; Paudel et al., 2014; Liang et al., 2017). Climate extremes are expected to increase with climate change, which may negatively affect crop production (Troy et al., 2015). Although researchers have documented the effects of climate changes on agriculture at different geographical scales (Parry et al., 2004; Kang et al., 2009; Olesen et al., 2011; Lehmann, 2013; Troy et al., 2015), past studies did not focus on adaptive changes to improve cropping practices to manage the impact of drought on crop yields (Troy et al., 2015). There is still a need to study the effects of climate extremes on crop production and on developing adaptation measures for rainfed and irrigated crops because groundwater, a valuable resource for irrigation during the drought, is continuously declining.

Projected climate changes comprise more frequent weather extremes, including drought, which will affect many aspects of life, including water resources, health and prosperity of the inhabitants, and agriculture (Karl et al., 2009). The southern United States, including Texas, experienced a severe drought in 2011 to 2013 (Geruo et al., 2017). However, the 2011 Texas drought was the worst 1-yr drought in Texas history and caused $7.62 billion in losses in the agricultural sector alone (Guerrero, 2012). By October 2011, more than 90% of the state was under exceptional drought conditions (Ziolkowska, 2016).

Water deficit resulting from drought reduces crop yield because of its negative impacts on plant growth (Karl et al., 2009). Texas is a water-deficient state and highly vulnerable to droughts. Its vulnerability is compounded by a rapidly growing population (Singh and Mishra, 2011). Changes in the magnitude and

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Abbreviations: CDL, Cropland Data Layer; HP, High Plains; LRP, Low Rolling Plains; LV, Lower Valley; NC, North Central; SC, South Central; UC, Upper Coast.

frequency of droughts due to climate change will have severe impacts on agriculture, especially crop production, cropping systems, and livestock (Karl et al., 2009; Olesen et al., 2011). Cotton (*Gossypium* spp.), corn (*Zea mays* L.), grain sorghum [*Sorghum bicolor* (L.) Moench], wheat (*Triticum aestivum* L.), and soybean [*Glycine max* (L.) Merr.] are the major crops grown in Texas, in addition to livestock production (Johnson et al., 2013). Agricultural crops have different water needs, as some crops use water more efficiently than others (Gurian-Sherman, 2012). Sorghum and cotton, for example, require less water than corn to grow (Almas et al., 2007; Colaizzi et al., 2009).

A major drought can reduce crop yields and crop hectarage because less water and soil moisture are available for crop growth. During a drought, farmers may consider reducing their cropping hectarage and only plant drought-tolerant crops. However, it is important to understand the spatiotemporal variability of drought impact on crop yield and cropping areas to plan and mitigate its potential negative impact on agriculture (Zipper et al., 2016). This study focuses on drought effects, specifically precipitation deficit, on crop yield and cropping area of four major crops (cotton, corn, winter wheat, and sorghum) in Texas during 2008 to 2016, as crop yield is more sensitive to precipitation than to temperature (Kang et al., 2009). We address the following key research questions: (i) What is the impact of droughts on crop yield? and(ii) How does drought affect cropping areas across Texas?

Materials and Methods

Study Region

The study area is the state of Texas, where climate, geography, land cover, and precipitation vary significantly (Fig. 1). The distribution of annual average temperature and precipitation in the state suggests a drier southwest and a wetter northeast. The average annual precipitation increases almost uniformly from 25 cm in the west to 140 cm in the southeast, resulting in a statewide mean of 71 cm (Wong et al., 2015). Texas has 10 distinct climatic zones (Fig. 1) (TWDB, 2012). The western part of the state is sparsely populated, while its central and southeast regions are densely populated.

Extreme hydrologic conditions such as severe droughts and frequent flooding are quite common in Texas (Wurbs, 2015). There are three major land use groups across Texas: grassland (31%), shrub land (28%), and agricultural crops (22%) (Ray et al., 2017). The four major crops studied here—cotton, corn, winter wheat, and sorghum—are mainly cropped in the High Plains (HP), Low Rolling Plains (LRP), North Central (NC), South Central (SC), Upper Coast (UC), and Lower Valley (LV) climate zones. Each climate zone is dominated by one of the four crops. For example, cotton is typically grown in the HP climate zone, winter wheat in the HP and LRP climate zones, and sorghum mainly in the LV and UC climate zones.

The Texas landscape has mostly lower elevations in the south and east and higher elevations in the north and west. The state's lowest elevation, 0 m asl, is on the coast, with the highest elevation, 2655 m asl, in the north. The Texas landscape is dominated by sandy loam (24.5%), loam (20.1%), clay (17.4%), and clay loam (16.3%) soil types, whereas 21.7% of the state landscape has sand, loamy sand, silty clay loam, and other soil types (Ray et al., 2017). Texas relies significantly on irrigation for its 2.50 million ha of irrigated lands, 86% of which is irrigated using groundwater (Wagner, 2012).

Data and Methods

The main datasets used in this research are Cropland Data Layer (CDL; resolution = 30 m), annual crop yield, and annual average rainfall across the state. The geospatial CDL and crop yield data were obtained from the USDA National Agricultural Statistics Service for the period 2008 to 2016. The USDA developed Cropland Data Layers using geo-referenced crop-specific land cover (using Landsat 8), Disaster Monitoring Constellation satellite imagery, USGS elevation data and canopy cover fraction and imperviousness (%), and National Land Cover Dataset data (Boryan et al., 2014, 2017). The annual crop yield data of Texas for irrigated and

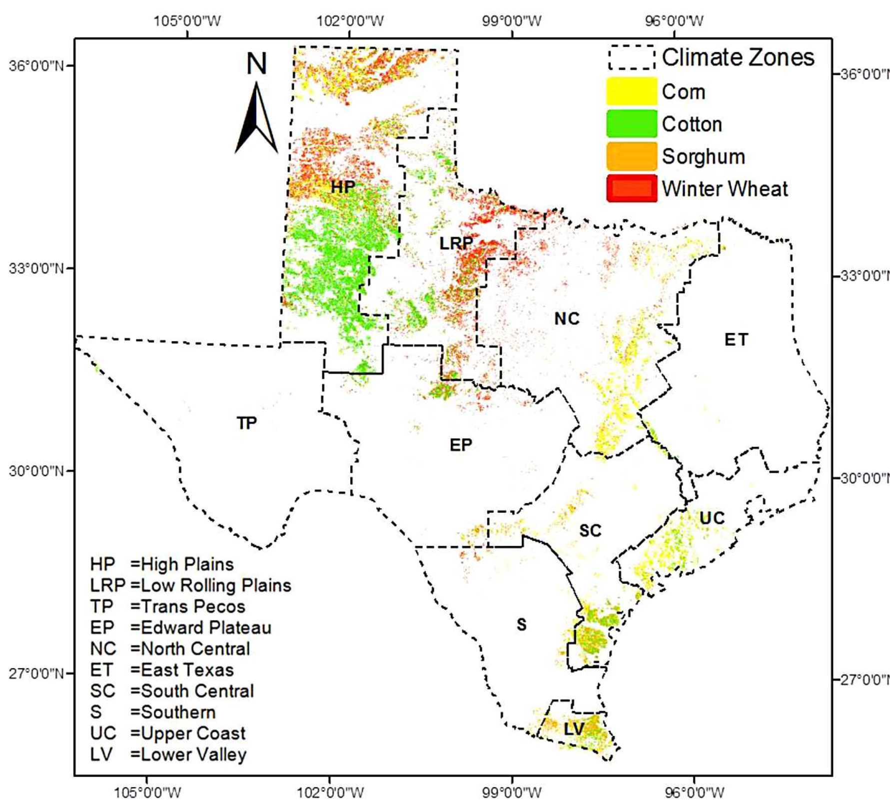

Fig. 1. Ten climate zones and the study domain (Texas). Cropland distributions for four major crops in the study domain.

nonirrigated (rainfed) crops were obtained from the USDA National Agricultural Statistics Service. The average annual rainfall data for each climate zone was obtained from the National Climatic Data Center (Menne et al., 2012).

We used ArcGIS 10.5.1 (ESRI, 2017) GIS tool to analyze the CDL and yield data in the study area. First, we obtained the annual spatial cropping area of all four major crops in the state. We then used climate zone's feature data to extract the corresponding cropping area within each climate zone. ArcGIS Spatial Analyst Tool "Extraction" was used to extract cropping area for each climate zone. We analyzed the impact of drought on crop yields and cropping areas before, during, and after the severe drought of 2011 to 2013 in three different periods: 2008 to 2011, 2011 to 2013, and 2013 to 2016. The annual crop yields of all four major crops during the period 2008 to 2016 were compared based on the deviations from baseline data. The relative changes in crop yield and cropping area across Texas were analyzed to reveal the impact of drought on them. Finally, to assess if irrigation mitigated drought effects, we compared the irrigated and rainfed crop yield data.

Results and Discussion

Drought Impact on Hectarage of the Four Major Crops across Texas

Table 1 summarizes the change in crop planting areas (irrigated and nonirrigated) within three selected periods: (i) before the drought (2008–2011), (ii) during the drought (2011–2013), and (iii) after the drought (2013–2016) for four major crops in 10 different climate zones in Texas. Corn and sorghum are mainly grown in 6 out of the 10 climate zones. Cotton is mainly grown in the HP climate zone, and winter wheat is grown in the HP and LRP climate zones (Fig. 1). Forty-one percent (6000 km^2) more cotton and 26% (620 km^2) more corn were planted in the HP climate zone during 2011 than in 2008 (Table 1). Between 2008 and 2011, winter wheat hectarage was reduced by 51% (1537 km^2) in the HP and 6% (409 km^2) in the LRP climate zones; winter wheat hectarage increased by 34% (1807) and 43% (121 km^2) in the NC and SC climate zones, respectively, during the same period (2008–2011). Sorghum hectarage increased in each climate zone, except at the NC and Trans Pecos climate zones.

During the drought period (2011–2013), cotton and corn hectarages were reduced by 21% (4400 km^2) and 18% (536 km^2), respectively, in the HP climate zone. In contrast, corn hectarage was increased by 30% (559 km^2) in the NC climate zone (2011–2013). Cotton hectarage was reduced in all climate zones. After the drought period (2013–2016), cotton and corn areas in 2016 were 4% (1785 km^2) and 71% (701 km^2), respectively, more than the area in 2013.

Results of this study show that drought had the greatest impact on cotton hectarage and the least impact on sorghum hectarage in the state. However, crop hectarage changes may not be attributed only to the effect of drought; some cropland losses might have been to a nonagricultural land use categories such as housing.

Drought Impact on Crop Yield

Irrigated and rainfed crop yields were the lowest in 2011 (Fig. 2a–2g). Corn and sorghum yields had similar positive responses to annual rainfall, increasing by 1.9 and 1.3 ton acre^{-1} (49 and 108%), respectively, under irrigated and rainfed conditions during 2011 to 2013, when annual rainfall was 250 mm higher than during the 2011 severe drought (Fig. 2a–2d). On the other hand, irrigated corn and sorghum yields slightly decreased during 2015 and 2016 in response to the floods that occurred during those two years.

Winter wheat production was not consistent during the 2011 to 2013 drought period; winter wheat yield was

Table 1. Changes in cropping areas of the four major crops (corn, cotton, sorghum, and wheat) at each of the climate zones in Texas during the three selected periods; before (2008–2011), during (2011–2013), and after the drought (2013–2016).†

Crop	Climate zone‡									
	HP	LRP	EP	ET	LV	NC	S	SC	TP	UC
	km^2									
	2008–2011									
Corn	619.9	4.0	−27.9	−50.7	9.2	−760.3	98.7	101.8	−1.2	−126.7
Cotton	6064.2	1879.7	886.6	102.7	421.3	589.9	239.4	948.1	32.5	666.7
Sorghum	−185.6	−587.4	−162.4	31.5	−654.3	494.7	−267.4	−368.0	8.4	−163.4
Wheat	−1537.0	−408.6	110.7	100.3	−14.4	1806.9	2.2	120.8	−5.1	−19.4
	2011–2013									
Corn	−536.3	−0.3	15.4	68.8	14.5	559.2	199.8	17.3	−0.4	381.7
Cotton	−4401.5	−1031.3	−561.6	−115.5	−596.6	−624.2	−195.9	−949.6	−31.2	−585.1
Sorghum	961.1	72.2	150.8	33.9	1152.4	−127.5	50.6	692.4	−7.2	594.1
Wheat	2394.2	1285.2	282.8	0.4	−2.4	−133.8	42.0	41.9	−0.3	−5.7
	2013–2016									
Corn	1785.3	21.4	−7.1	21.2	96.5	990.8	−225.5	227.4	2.2	−33.7
Cotton	700.7	−174.8	135.5	58.3	222.7	160.9	−20.7	25.2	31.8	142.6
Sorghum	−168.0	255.9	70.4	−35.3	−139.7	−371.4	308.3	−129.3	−4.2	−298.7
Wheat	−572.8	−222.9	−3.9	−125.3	0.2	−1744.5	55.5	−94.3	10.3	−46.9

† Negative values represent a decrease in hectarage in a current year from the previous year.

‡ EP, Edward Plateau; ET, East Texas; HP, High Plains; LRP, Low Rolling Plains; LV, Lower Valley; NC, North Central; S, Southern; SC, South Central; TP, Trans Pecos; UC, Upper Coast.

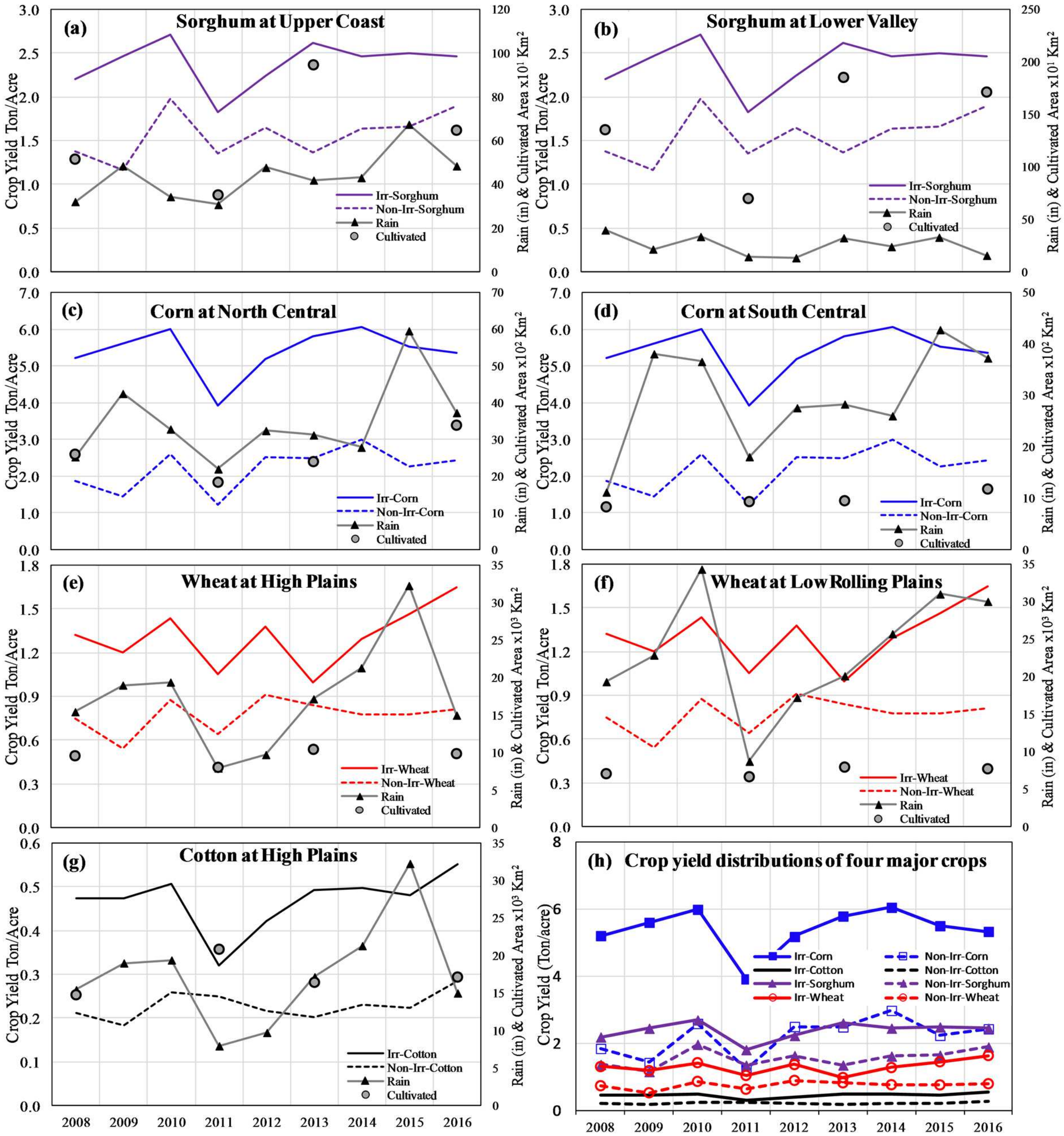

Fig. 2. Crop cultivated land, cropping area and yield under rainfed and irrigated conditions at the selected climate zones where four major crops (cotton, corn, wheat, and sorghum) are grown in Texas. (Crop yield data were used at state level.)

reduced in 2011 and 2014, but it increased in 2010 and 2012. However, irrigated winter wheat yield has been continuously increasing since 2014, and it was not significantly impacted by floods because winter wheat was harvested before the flood events hit Texas.

The irrigated cotton yield reached its lowest level in 2011 but increased during 2012 to 2013, a period of a moderate drought that had a little impact on cotton yield. Irrigated crops had higher yields than the same crop under rainfed conditions (Fig. 2h). The highest and lowest differences between the irrigated and rainfed crop yield were registered with corn and winter wheat, respectively. Corn is known for its sensitivity to water stress.

Overall, results show that the drought had a greater impact on the yield of rainfed crops than that of their corresponding irrigated crops. It may be beneficial for agricultural crop producers in Texas to consider increasing the hectarage of sorghum and other grains during drought periods, given their drought-tolerance capabilities.

Summary and Conclusion

We evaluated here the impact of drought on the yield and cropping areas of four major crops (cotton, corn, winter wheat, and sorghum) across Texas's 10 climate zones during 2008 to 2016. Results indicate that if drought periods increased in the future, crop yields would tend to decrease. These findings concur with those of Karl et al. (2009). If irrigated hectarage increased in the future using groundwater resources, the total crop yield would also increase. However, it depends on how the irrigated areas could be expanded during the droughts when limited water sources would be available for irrigation.

This study also investigated the spatiotemporal distributions of yields and cropping areas of four major crops before and after the drought across Texas. Our findings show the impact of climate variables (e.g., precipitation), and irrigation during the crop growing season on crop yield. The results clearly show that the drought impact on crop production could be reduced by changing crop type because the drought had a significant impact on cotton and least impact on sorghum in the state. Therefore, a proper strategy such as shifts in crop hectarage among climate zones, crop types, and expansion of irrigation hectarage could reduce the potential impact of drought on crop production. These results may help Texas crop producers develop robust strategies for coping with future drought challenges.

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