Vulnerability of Hay Production to Drought in Two Counties of Northern Oklahoma

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Abstract. Vulnerability of hay production to drought has potential to impact farmers in Oklahoma. For Payne and Mayes Counties, yearly total hay production and yearly average soil volumetric water content (0-40 cm) data were compared to determine which counties hay production is more vulnerable to drought based on vulnerability index (VI). Possible causes of any observed patterns in vulnerability are discussed. Results indicate vulnerability of hay production to drought is higher in Payne County, with VI of 1.21 compared to Mayes County with VI of 0.97. We propose that counties throughout Oklahoma that experience decreased or more variable precipitation will likely have higher vulnerability towards hay production.

Introduction

To "map vulnerability" is an attempt to identify where crop production is vulnerable to climate change (Simelton et al. 2012). Soil moisture and hay production depend on many factors such as soil type, climate change, farming practices, irrigation methods and other variables. Fraser (2007) and Fraser et al. (2011) proposed that vulnerability of an agricultural system to adverse weather can be observed when relatively small weather anomalies have disproportionately large impacts on crop production.

The purpose of this study is to compare two counties' hay production vulnerability to drought in Oklahoma: Payne County of north-central and Mayes County of northeast. More specifically, our objectives are to determine how drought frequency, drought severity, and vulnerability of hay production to drought vary between counties. Secondly, to propose possible causes for any observed patterns in vulnerability between the two counties.

Materials and Methods

Soil moisture at 5 and 25 cm and hay production data from each county was used. From the Oklahoma Mesonet (Oklahoma Agweather, 2013) soil moisture data was obtained from 1997-2013 for Payne County and 2000-2013 for Mayes County. From the National Agricultural Statistics Service (U.S. Department of Agriculture, 2013) we obtained total hay production data from both counties. Available data for both counties spanned from 1960 to 2008. Available years of hay production data to soil moisture data were used.

Soil volumetric water content (θ) was calculated for each depth and station. θ was a generated estimate from an average daily temperature differential (ΔT ref) by thermal dissipation probes. Matric potential (Ψ_m) (kPa) was then calculated based on Illston et al. (2008) (See Excel supplement). The Ψ_m values were converted to θ by inserting them into van Genuchten's equation:

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{[1 + (-\alpha\Psi_m)^n]^m}$$

as described in Scott et al. (2013). Where θ_r is the residual volumetric water content ($cm^3\ cm^{-3}$), θ_s is the saturated volumetric water content ($cm^3\ cm^{-3}$), α, n, and m are fitting parameters. m = 1-1/n (Schaap et al. 2001).

Drought frequency, severity, and vulnerability of hay production were determined by vulnerability index (VI), generated from crop failure index (CFI) and drought index (DI). Indices were calculated as defined in Simelton et al. (2012). CFI for each county was calculated by smoothing crop harvest (metric tons) data using a polynomial regression model to de-trend data eliminating any possible technical increases in yield. Smoothed harvest was divided by actual harvest. DI for each county was calculated from θ estimated as the county mean for October – October. DI was de-trended using a linear regression model and dividing smoothed θ by the actual θ. From θ at 5 and 25 cm depths from each station, average θ at 0-40 cm was determined.

VI was then calculated as:

$$VI_i = \frac{CFI_i}{DI_i} = \frac{\left(\frac{\widehat{H_i}}{H_i}\right)}{\left(\frac{\widehat{\theta_i}}{\theta_i}\right)}$$

where $\widehat{H}_i$ is smoothed harvest, H_i is actual harvest, $\widehat{\theta}_i$ is smoothed volumetric water content, and θ_i is actual volumetric water content. Standard deviations (σ) of DI were calculated in Microsoft Excel (2010) for both counties. Drought severity was determined based on categories generated from the amount of deviations from expected dryness. Category 1 = 1 deviation from expected, category 2 = 2 deviations from expected, and category 3 = 3 deviations from expected.

ANOVA for regression was used for statistical analysis of annual VI to annual precipitation (r^2=0.45), and for average θ at 0-40 cm by year (r^2=0.47) for Payne County (See Excel supplement).

Results and Discussion

Overall, results indicate hay production in Payne County is more vulnerable to drought than Mayes County with a VI of 1.21 and 0.97, respectively. Based on drought severity, category 1 was most frequent for both counties, with a higher frequency of drought severity greater than category 1 occurring in Payne County (Table 1). Average VI increased with severity in Payne County, but remained highest in category 1 for Mayes County (Table 1).

Table 1. Drought frequency (DF) and Average vulnerability index (VI_{AVG}) per drought severity category for Payne and Mayes Counties, Oklahoma.

County		Drought severity Category 1	Category 2	Category 3
Payne	DF (%)	0.1667	0.0830	0.0830
	VI_{AVG}	1.2200	1.4050	1.8822
Mayes	DF (%)	0.2222	0.0000	0.1111
	VI_{AVG}	1.1070	NA	0.6899

Average VI increased with drought severity in Payne County. However, this is not the case for Mayes County. Several factors influenced differences observed between counties for overall vulnerability and average VI. One factor is precipitation. 2006 had the lowest annual precipitation for both counties, thus both were in category 3 droughts. Precipitation in Mayes County was variable throughout the year with most occurring in May, June, and July. CFI seems most dependent on variability of precipitation. Even with low annual rainfall, the majority could occur in the growing season of that crop. Therefore, CFI may not be as low as expected. This is likely the reason for low average VI for Mayes County.

Annual VI is highly correlated to annual precipitation in Payne County. As precipitation fluctuated from year to year (Fig. 1A), VI fluctuated simultaneously (Fig. 1B) (p=0.01). This shows that for Payne County, precipitation determines the vulnerability of hay production.

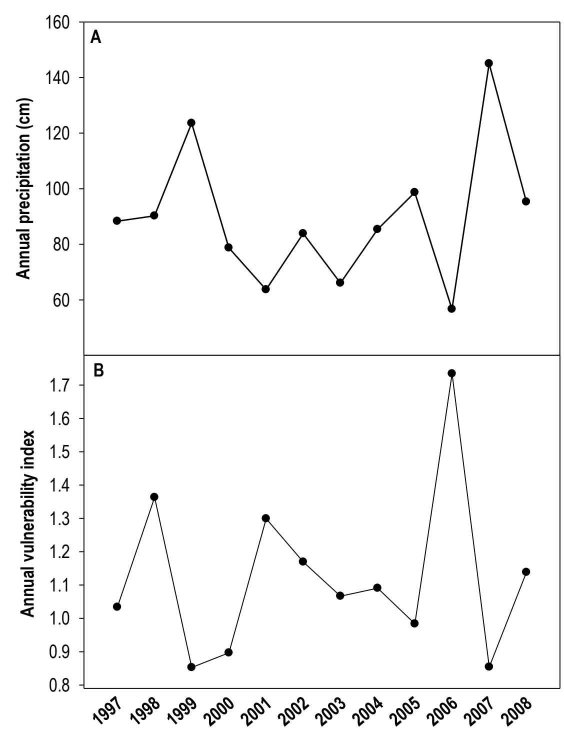

Figure 1. (A) Annual precipitation (cm) for Payne County, Oklahoma. (B) Annual vulnerability index for Payne County, Oklahoma.

Another factor is θ. It is notable that θ in Payne County significantly decreased on an annual bases (p=0.01) compared to a more stable θ in Mayes County. This significant decrease in θ for Payne County is likely one reason for a higher VI. If this trend continues, it is likely that Payne County will continue to have higher vulnerability of hay production to drought and could possibly lead to diminishing hay production in the future.

Payne County is subjected to highly variable rainfall patterns and soil moisture. Since it is located in the western region of the High Plains, local climate is influenced by soil moisture. This climatic factor is highly variable when compared to the consistency of moisture rising from the Gulf of Mexico. Mayes County is located in northeastern Oklahoma. Therefore, much of the precipitation it receives is steadily supplied by moisture rising up from the Gulf of Mexico (Johnson 2008).

Differing geologic material beneath both counties influenced soil development. Mayes County exhibits shallow residual soils that have paralithic contact close to the surface preventing cultivation and soil loss. However, Payne County encompasses an area of much deeper soil which ultimately led to a reduction in potential productivity as soil has eroded through long term conventional farming practices (McDonald 1938).

Conclusion

This study indicates that vulnerability of hay production to drought is greater in Payne County and is highly dependent on precipitation. While extreme changes in annual precipitation are likely to affect vulnerability of hay production, variability and timing of precipitation throughout the year are likely major factors in VI for Mayes County. With θ decreasing each year and the high dependence on precipitation for hay production, it's probable Payne County will continue to see higher VI and possibly diminishing future hay production. More data availability from past years would have benefitted this study. Continuation of this study should be assessed moving forward.

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