

Assessment of Regional Site-Specific Sorghum Ergot Severity Potential Using Radar-Rainfall Measurement

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The United States produces approximately 25% (14) of the world grain sorghum on an estimated 3 to 3.6 million hectares annually. A large proportion of grain sorghum produced in the country is used for livestock feeding, and most of the production is concentrated in the Great Plains and south-central states. Kansas is the leading state in production, followed by Texas, and in 2004, these two states accounted for 72.2% (42.7 and 29.5%, respectively) of the total grain sorghum planted acreage in the country (1). In addition to grain sorghum production, about 95% of the United States' hybrid sorghum seed supply is produced in the Texas Panhandle (approximately 40,000 ha), primarily because of the absence of major pest problems (partly attributed to the desert-like climate), which provided ideal conditions for seed production. However, this changed in 1997 with the introduction of the fungus *Claviceps africana* Freder., Mantle, & De Milliano, the causal agent of sorghum ergot (8).

Since its first detection in 1997, sorghum ergot has been consistently present in the Texas Panhandle and periodically has caused widespread damage (Fig. 1). During the first year of its introduction, nearly 45% of the seed production fields in the region were affected. Ergot prevalence in the region declined during the subsequent 3 years, and the threat of the disease appeared to have diminished. However, cross-spectral analysis of historic temperature and rainfall data for the Panhandle predicted that occurrences of ergot-favorable conditions in the region are periodic rather than a regular year-to-year phenomenon (20). As predicted, in 2002, sorghum ergot affected 87% of the seed production fields in the region, some so severely that harvesting was difficult because of the sticky honeydew. There was

another widespread ergot epidemic in 2004 that affected over 90% of the fields in the Panhandle.

In collaboration with various seed companies in the region, we have been monitoring the prevalence of sorghum ergot in the Texas Panhandle every year since 1997. To determine the magnitude of the impact of rain on the epidemiology of sorghum ergot in the region, we collected rainfall data from three North Plain Evapotranspiration (NPET) network weather stations representing the southern (Earth), central (Bushland), and the northern (Etter) Panhandle. Total rainfall data for the months of August and September (most of the flowering occurs during these months) were collected for the past 8 years (1997 to 2004). The scatter diagram of the relationship between rainfall amount and the percentage of fields with ergot showed a moderately high correlation ($r = 0.72$, $P < 0.0001$) (Fig. 2; the scatter plot and the confidence ellipse were generated using SAS software, SAS Institute Inc., Cary, NC). Rainfall frequency also correlated significantly with prevalence of the disease, but to a lesser degree than rainfall amount ($r = 0.54$, $P = 0.0059$, data not shown).

C. africana generally requires cool weather and humid conditions for opti-

imum infection (5). Rainfall reportedly is not required for infection as long as relative humidity is high (2). However, the Texas Panhandle is characterized by a desert-like climate with hot, dry weather during the summer. Maximum temperatures ranging between 35 and 40°C, accompanied by low relative humidity, are not uncommon during sorghum flowering season. Prolonged occurrences of high humidity during the summer are usually associated with rain showers. In this region, rain also plays a significant role in suppression of maximum temperature such that it remains within ergot favorable range (20). A sudden drop of several degrees in temperature is not an uncommon event during an afternoon rain shower. Furthermore, rainy and damp weather that favors ergot development is suboptimal for pollination and can lead to a reduction in pollination efficiency, exposing the ovaries to infection. Rainfall also may be instrumental in washing spores of the pathogen from the air and may also play a major role in spore release from the honeydew matrix and subsequent dispersal in the form of wind-driven aerosol. Therefore, it stands to reason that rainfall has to be a major component of any regional ergot risk-assessment system in the Texas Panhandle.

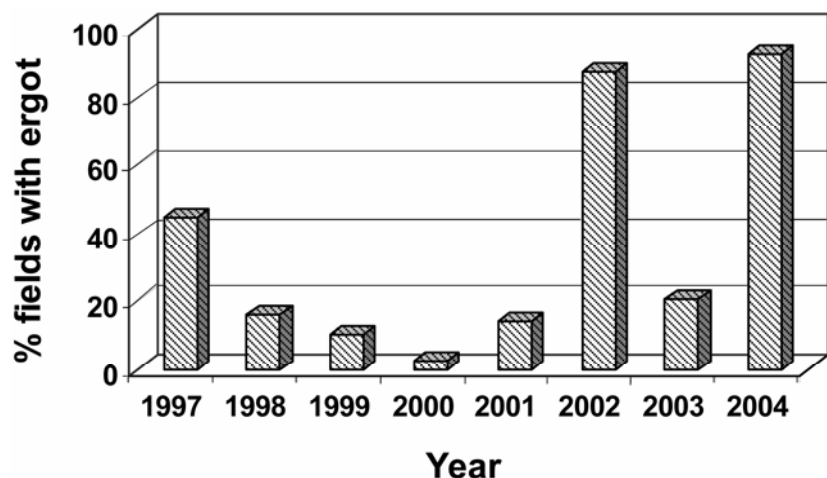


Fig. 1. Percent sorghum hybrid-seed production fields in the Texas Panhandle affected by sorghum ergot from 1997 to 2004 (an average of approximately 200 fields per year).

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Rainfall, as important as it may be in influencing the regional ecosystem, is one of the most spatially variable weather factors (3,7,12). Rainfall events are often sparse and irregular and can vary within a small area both in incidence and intensity. Rain gauges provide point measurements, and existing ground weather stations are too far apart to provide accurate representation of localized rainfall events. Data on relationships between rain gauge density and rainfall spatial variability are scanty, but the few studies that exist indicate that a rain gauge spacing of less than 5 km would be required to explain more than 90% of the variability (3,7). This is far below the current distances between existing weather stations, which often exceed 50 km (13), and too wide to account for local rainfall variability. The lack of adequate data on spatial variability of precipitation has been a major hindrance in site-specific implementation of decision support systems for rain-driven plant disease epidemics. Radar-estimated rainfall may provide a potential solution to the lack of site-specificity in rain gauge-based rainfall data.

Radar-based precipitation estimates have greater spatial resolution and coverage than gauge-based point-precipitation measurements (18). NEXRAD (Next Generation Weather Radar), commonly known as Doppler radar, which has been in operation in the United States since the early 1990s, generates a large number of diverse meteorological and hydrological products, including real-time hourly rainfall and wind velocity (4,11). NEXRAD provides a 4 × 4 km resolution for rainfall measurement out to a radius of 230 km from radar location (4,17). More detailed information on the radar operation system in the United States and its potential use for plant disease risk forecast has been described elsewhere (4,19). The primary objective of this investigation was to assess the feasibility of using radar-estimated rainfall in development of a regional site-specific sorghum ergot forecast system for the Texas Panhandle.

MATERIALS AND METHODS

Radar rainfall data processing and acquisition. Radar rainfall data are processed in several stages. In stage I, the raw radar reflectivity is converted into rainfall depth using a reflectivity-precipitation rate (Z-R) relationship (4). The stage I data are further corrected (bias adjusted) at the National Weather Service River Forecast Centers using ground truth rain gauge data (stage II). The stage III processing involves making a mosaic of the precipitation estimates from multiple radars to further reduce any errors by using better estimates from overlapping radars. The stage III product is generally used for estimation of hourly rainfall amount. The processed data are archived in XMRG file format on polar

stereographic projection called hydrologic rainfall analysis project (HRAP) with spatial resolution of 4 × 4 km (4,17). The HRAP grid is a coordinate system used for defining individual grid cells of the radar data. For this project, the stage III radar rainfall data for the Texas Panhandle were obtained from the Arkansas-Red Basin (Tulsa, OK) and the West Gulf (Fort Worth, TX) River Forecast Centers via *ftp* and decoded into an ASCII format in ArcInfo.

Ergot severity map development. After acquisition, the radar rainfall data in each grid were incorporated into weather-based sorghum ergot severity models (21) in an ArcInfo-GIS system using the arc macro language (AML). Two ergot severity models, based on cumulative departures of temperature and relative humidity from maximum and minimum thresholds, respectively, were used as inputs. The two models were similar except that the departures were accumulated after spore deposition over an 18-h period for one (18-h model), and over a 24-h period for the other (24-h model). Whenever there was at least 2.5 mm of rainfall in the HRAP grid, a relative humidity value of 90% was entered in the models. Otherwise, both temperature and relative humidity values for the models in each grid cell were interpolated using the spline interpolation method from the nearest station of the 15 NPET weather stations scattered throughout the Panhandle. An ergot severity map for the Panhandle for each model then was created from the 4 × 4 km grid points using the inverse distance weighting (IDW) interpolation technique for two dates, one representing widespread rainfall events (29 August 2002) and the other localized events (7 September 2003). Both the spline and IDW interpolation methods are components of the Spatial Analyst in the ArcGIS system.

RESULTS AND DISCUSSION

The 2002 sorghum ergot epidemic described above was first observed in the first week of September, 7 days after a rain storm that passed through the region during the 24-h period ending at 6:00 A.M. on 29 August (Fig. 3). The duration between the storm event and the onset of disease matched the time between infection and honeydew development, leaving little doubt that the disease was associated with the storm. The NEXRAD precipitation data, in conjunction with the sorghum ergot severity model, was able to partition the region into multiple areas varying in ergot severity. For the 2002 epidemic, the 18-h model, using NEXRAD rainfall estimates, predicted ergot severity in the Panhandle to range between 8.5 and 31.1% sorghum floret infection per panicle (Fig. 4A). The 24-h model predicted greater ergot severity in many locations (maximum of 40%) than the 18-h model (Fig. 4B). The greater ergot severity prediction for the 24-h model suggests that some of the florets that would not develop disease within 18 h after infection would develop disease after an additional 6 h.

In 2003, sorghum ergot was observed in about 20% of the fields and was localized and sporadic. There were isolated rain showers over several days in early-to-mid-September similar to the storm during the 24-h period ending at 6:00 A.M. on 7 September, for which the image is shown (Fig. 5A). Thus, it was difficult to pinpoint a particular rainfall event responsible for the occurrence of the disease in 2003. For 7 September, the 24-h model predicted 0 to 7% of the florets (per panicle) to be infected depending on the location (Fig. 5B). The 18-h model predicted slightly less ergot severity than the 24-h model (not shown). However, both models predicted zero ergot severity for areas of the Panhandle where there was no rainfall on that day.

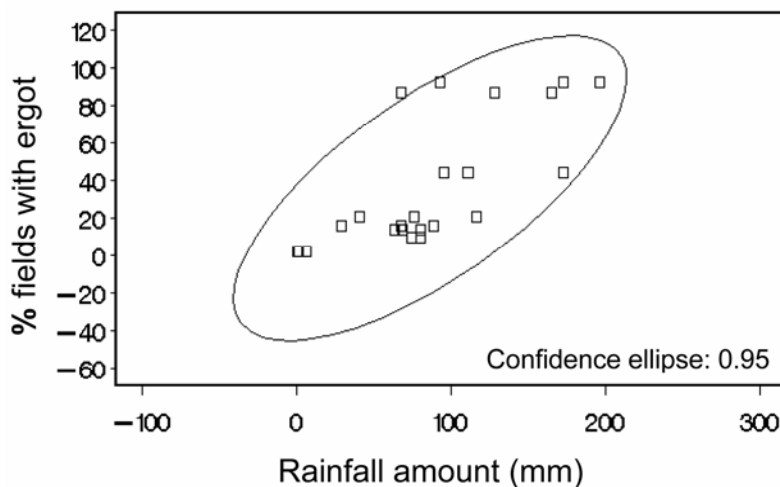


Fig. 2. Relationships between sorghum ergot prevalence (% fields with ergot) and yearly total rainfall amount for the months of August and September ($r = 0.72$, $P < 0.0001$) in the Texas Panhandle from 1997 to 2004. Rainfall data were pooled from three weather stations representing the southern (Earth), the central (Bushland), and the northern (Etter) Panhandle.

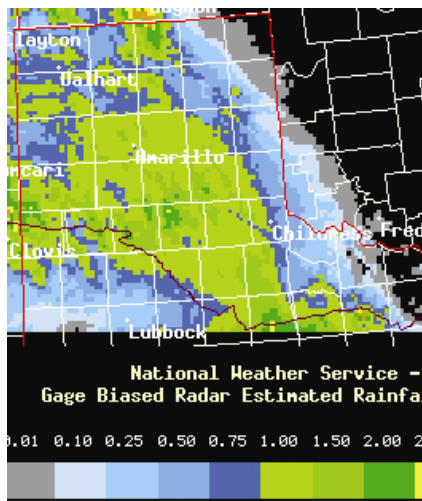


Fig. 3. NEXRAD image of a rainstorm that affected most of the Texas Panhandle during a 24-h period ending at 6:00 A.M. 29 August 2002.

Radar rainfall has been previously used to predict diseases of peanuts (6,10). The radar-based peanut disease advisory program provided results comparable to the onsite gauge-based rainfall measurements. Radar-based rainfall estimates are more applicable for interpolation and regional risk assessment than gauge-based, point-measured rainfall estimates. Comparisons of radar-based and gauge-based rainfall estimates and factors associated with each method of measurement were described previously (9,19). In this study, the two sorghum ergot severity models, based on radar estimated rainfall, were able to partition the Texas Panhandle into grids of 4 km² exhibiting various levels of ergot severity.

The ergot pathogen can infect within 24 h after spore deposition and may take up to 36 h to reach the ovaries (2). Control of ergot was reported with some chemicals up to 36 h after inoculation with a spore suspension of the pathogen (16). Hence, the 18- and 24-h models may provide timely disease warnings for appropriate management actions. Even if infected florets fail to produce seeds after management action (e.g., chemical spray), suppression of honeydew development (16) is still very important because of the adverse effects of the sticky honeydew as a seed contaminant (reduction in seed quality) and its impediment of mechanical harvesting (15).

The ergot severity maps were based on HRAP 4 km² grids, and each grid in the maps can be identified with its latitude/longitude coordinates. Because of this unique identity of each grid cell, the severity maps can potentially be developed into a web-based, site-specific ergot forecast system in which growers may use the GPS locations of their fields to assess ergot severity risk and determine whether management actions are necessary.

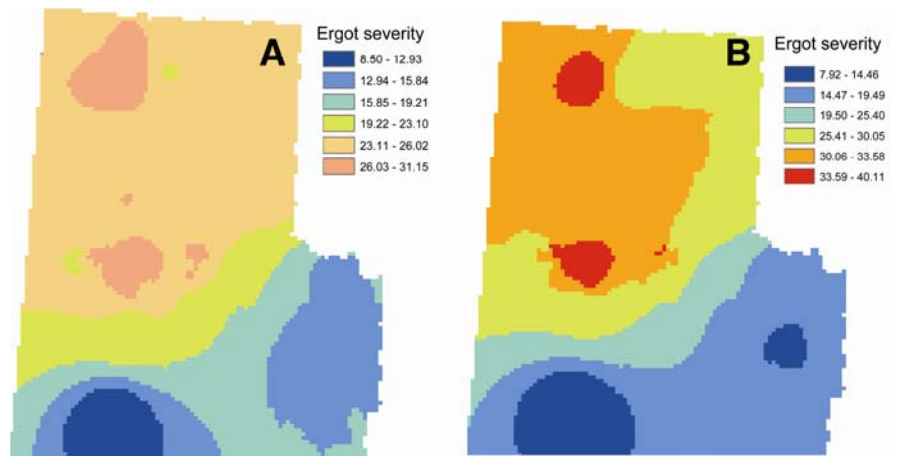


Fig. 4. Varying levels of ergot severity (% florets affected) potential associated with the 29 August storm (Fig. 3) as predicted by the A, 18-h model and B, 24-h model.

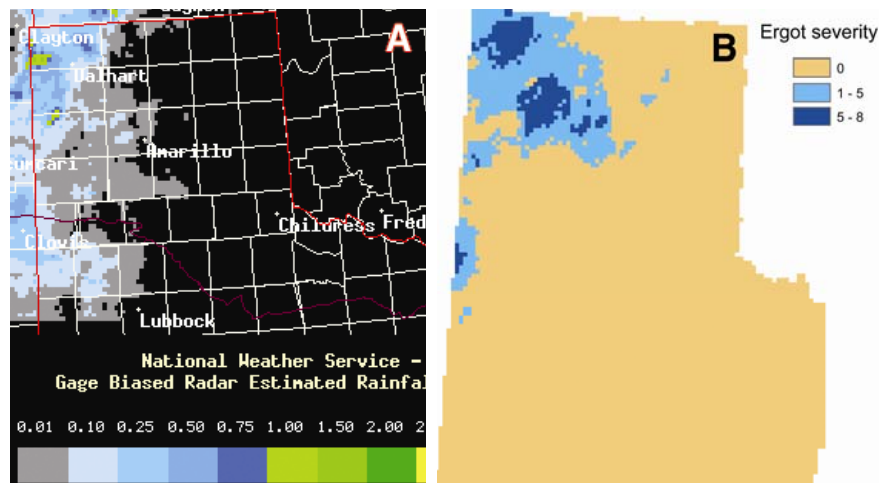


Fig. 5. A, NEXRAD image of a rain shower event in the northwestern Texas Panhandle during the 24-h period ending at 6:00 A.M. on 7 September 2003, and B, varying levels of sorghum ergot severity (% florets affected) potential associated with this storm as predicted by the 24-h model.

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