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Quantifying economic losses associated with levels of wheat streak mosaic incidence and severity in the Texas High Plains

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ABSTRACT

Wheat streak mosaic (WSM), caused by the *Wheat streak mosaic virus* (WSMV), which is transmitted by the wheat curl mite (*Aceria tosichella*), is the most prevalent virus disease of wheat in the Texas High Plains. Infected plants initially exhibit mosaic symptoms, which lead to severe stunting, complete chlorosis and, in the most severe cases, eventually plant death. Wheat plants infected with WSMV have lower forage and grain yields and exhibit reduced water-use efficiency compared to non-infected plants. The disease impact on water-use efficiency raises an important issue of whether diseased fields should be irrigated as frequently as non-diseased fields. The issue becomes more relevant when energy costs and the dwindling water resources from the Ogallala Aquifer are taken into consideration. This study examined the potential economic losses due to WSM, using data collected from two fields in 2007 and 2009. A hand-held hyperspectral radiometer was used to quantify severity of WSM in multiple 1 m^2 plots along two transects, each stretching from the edges of the fields to their centers. Grain yield declined exponentially ($R^2 = 0.79$, $P < 0.0001$) with increasing disease severity, as measured by reflectance at 555 nm. For economic analysis, grain yield from each plot was used for determining cost adjustments and linked revenues in relation to WSM severity levels, which allowed calculations of potential profit reduction. The method enables one to compare losses associated with different levels of WSM severity to a baseline with little or no WSMV infection. Results show that losses from the disease are primarily an outcome of reduced revenue due to a decrease in grain yield, and, as expected, losses incurred per unit land area rapidly increase with increasing disease incidence and severity. Furthermore, producers incur additional marginal losses when irrigating fields with WSM because there is little or no return for irrigation inputs, as water-use efficiency of severely diseased wheat is drastically reduced. Results from this study are useful in estimating losses at differing levels of disease incidence and severity and represent the first step in development of an economic threshold for wheat streak mosaic.

1. Introduction

Wheat streak mosaic (WSM), caused by *Wheat streak mosaic virus* (WSMV), is the most widely prevalent virus disease of wheat in the Texas High Plains (Burrows et al., 2009). The virus is transmitted by wheat curl mites (*Aceria tosichella* Keifer), which are typically blown into wheat fields from nearby grass vegetation or fields with mite-infested volunteer wheat (Christian and Wallis, 1993; Wiese, 1987; Price, 2015). Infected plants exhibit leaf symptoms ranging from mosaic and streaking to complete chlorosis and stunting, resulting in substantial yield loss (Atkinson and Grant, 1967; Byamukama et al. 2014; Workneh et al., 2009). Disease severity gradients are often observed in affected fields, with the most severe symptoms occurring near the edges (Workneh et al., 2009, 2010) but, in some cases, entire fields can be severely affected. In the Texas High Plains region, planting season generally runs from late August through early December and fields are mostly planted to hard red winter wheat as a dual purpose crop (intended both for grain production and winter forage for cattle grazing). Fields planned for grazing are planted early to maximize forage biomass. However, WSM is usually more severe in early planted fields than in fields planted later in the season, which is mainly attributed to an overlap with green grass vegetation ("green bridge") harboring viruliferous mites (Bowden et al., 1991; Somsen

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and Seal, 1970; Price, 2015).

Wheat plants infected with WSMV have significantly less root weight, plant biomass, and water-use efficiency than non-infected plants (Price et al., 2010; Workneh et al., 2010). Its impact on water-use efficiency raises an important management issue of whether diseased fields should be irrigated as frequently as non-diseased fields. The issue becomes more relevant when energy costs and dwindling water resources in the region are taken into consideration (Postel, 1998). Approximately 1/3 of the wheat production in the region (amounting to one million ha) is irrigated with water from the Ogallala Aquifer (Anonymous, 2006). However, there is a growing concern over the decline of the water level in the Aquifer as withdrawals continue to exceed recharges, resulting in increased energy costs for pumping irrigation water (Mcguire, 2006; New, 2006). Growers often question whether it will be cost effective to apply midseason management inputs, such as fertilizer, insect control and irrigation, to fields with WSM, due to the lack of information on economic thresholds for differing levels of disease incidence and severity. A recent study on the effect of WSM showed that irrigated wheat producers incurred greater losses to the disease than dry-land producers and that a blanket application of irrigation water to an infected crop would not alleviate the disease problem but rather contribute to the economic loss (Velandia-Parra et al., 2010). Knowledge of the economic impact of different levels of WSM incidence and severity is essential for identification of disease thresholds, above which additional inputs become unprofitable. For this reason, the primary objective of this study was to estimate economic losses at different levels of WSM incidence and severity.

2. Materials and methods

2.1. Field data collection and analysis

Wheat streak mosaic severity assessments were conducted in irrigated wheat fields planted to WSM-susceptible cultivars in 2007 and 2009 in Lamb and Hale counties, respectively, in the Texas Panhandle. In each field, two transects were established, stretching from the outside edge to the center of each field. The 2007 field contained 60 sampling locations per transect at 2.5 m intervals, while the 2009 field had 48 in one and 56 in the other, with 6 m intervals. The length of transects and number of sampling intervals were dependent on the length of the disease severity gradient from the edges of the fields.

At each location, when wheat development was between Feekes scale 8–10.1 (Large, 1954), the severity of wheat streak in a 1 m^2 area (5 rows) was quantified by taking reflectance measurements at 555 nm, using a hand-held hyperspectral radiometer (Fig. 1) (SD, 2000; Ocean Optics, Dunedin, FL). Others have used different wavelengths to detect and differentiate healthy from diseased plants (Stilwell et al., 2013), but we found that reflectance measurements taken at 555 nm were strongly correlated with visual WSM severity assessments (Workneh et al., 2009). Normally, green healthy leaf tissue produces lower reflectance values while chlorotic diseased leaves produce higher reflectance values (Workneh et al., 2009, 2010; Stilwell et al., 2013, Fig. 1). In late June of each year, wheat at each location along the transects was harvested from 0.8 m^2 area and the relationship between WSM severity levels and grain yield was determined using regression analysis.

2.2. Economic analysis

The economic impact of WSM was analyzed using an enterprise budgeting approach, previously described by Kay and William (1999). This approach determines cost adjustments as well as

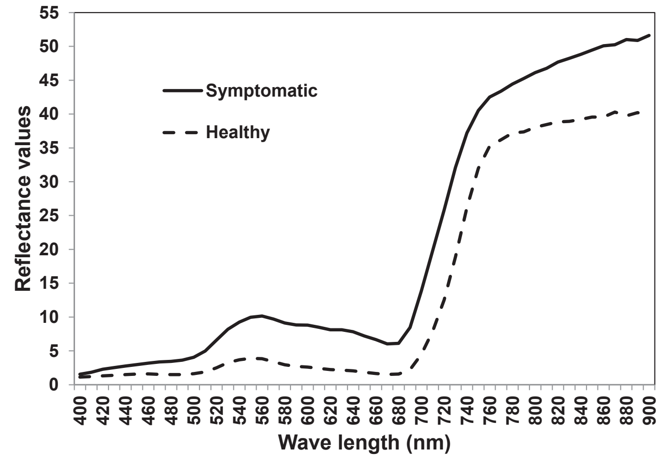

Fig. 1. Reflectance values of healthy and symptomatic wheat at various wavelengths for one of the fields used in this article.

linked revenues in relation to WSM occurrence, which allows for the calculation of potential profit reduction (per ha). Net revenue is determined by deducting the total variable costs incurred from the gross revenue, and is expressed as:

$$\prod_w = p_w * Q_w - TVC\,(Q_w),$$

where $\prod_w$ = wheat profit, p_w = wheat price, Q_w = wheat quantity (grain yield), and $TVC(Q_w)$ = total variable cost of wheat production, including seed, fertilizer, irrigation, operator and hand labor, gas, repair, and maintenance. In this analysis, total cost is exclusive of fixed costs such as land rental, major equipment etc. Because of its negative impact on grain yield and quality, WSM affects gross revenue, which is calculated as a product of price and yield. Gross revenue is also affected by the effect of WSM on water-use efficiency, as there is little or no return for irrigation and associated expenses when the disease is severe and widespread. In this study, reductions in revenues due to WSM were estimated using data from the fields described above to calculate its economic impact.

3. Results and discussion

For both years, the relationship between grain yield and reflectance values showed similar trends, which could easily be explained by an exponential model. Thus, data from both years were combined and fitted to an exponential model $Y = a^*(e^{-bX})$ where Y is predicted yield, a and b are parameters, and X is reflectance value ($R^2 = 0.792$, $P < 0.0001$, Fig. 2). Linear models are generally easier to interpret and would have been better for use in the economic analysis. However, as easily seen in Fig. 2, fitting a linear model would exclude reflectance values above 8 (X-axis), which are a very important part of the data. These values represent severely infected areas corresponding to zero or near zero kg/ha in yield. Overall the exponential model provided a good prediction of the yield based on the disease severity levels. However, as seen from the regression and the residual plot graphs (Figs. 2 and 3, respectively), the model under-predicted the yield at lower disease severity levels (reflectance values between 4 and 6), which represent overlapping regions of healthy and diseased areas. The distribution of the residual plots appeared to be random without a clear trend until yield levels of about 3000 kg/ha (which corresponded to healthy or near healthy areas), suggesting that overall the data were well described by the model except near disease-free areas of the fields, where the impact of the disease on yield was