Estimating lodging speed of corn stalks and wind field of Bondurant, IA tornado using corn-fall pattern

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SUMMARY:
Tornadoes often inflict a large amount of damage on crops due to the geographic distribution of croplands in many parts of the world (e.g., USA, Canada, United Kingdom). However, despite numerous and extensive crop damage, the wind speed estimation of tornadoes occurring in these agricultural fields where structural density is much lower is underestimated because the current practice of tornado wind speed estimation utilizes structural damages. Furthermore, the bending strength and risk of crop lodging due to wind load are not yet well understood. In this study, the bending strength of corn stalks is measured using a 3-point bending moment test, and the critical lodging speed of corn at different growth stages was evaluated using the measured bending strength and crop lodging models, in which the critical lodging speed of corn at different growth stage can be a valuable crop "damage indicator" tool providing a range of lower bound wind speed estimate of different windstorms occurring throughout different seasons. The near-surface wind speed of the Bondurant, IA tornado that occurred in a cornfield was estimated in the EF1 range using the critical lodging speed and tree-fall analysis method.

Keywords: Corn lodging, tornado, crop-fall pattern, near-surface wind field

1. INTRODUCTION

For the past decades, there has been significant crop damage loss due to thunderstorms and tornadoes in the United States and the UK (Berry et al., 2013; NOAA, 2018). Due to the wind lodging of crops from the wind hazards, the crop yield reduces considerably (Berry et al., 2012). Furthermore, the majority of tornadoes in the United States damage agricultural areas, in which a large portion of the cropland is used to grow corn, but the wind speed estimation of these tornadoes poses a challenge due to the lack of structures in these regions (Guyer and Moritz, 2003). Fujita (1993) discusses the importance and reliability of utilizing crop damage patterns for estimating tornadoes' wind speed in agricultural areas. The near-surface wind field estimation of a tornado can be facilitated by analyzing the crop-fall pattern with an idealized vortex (Baker et al., 2020; Rhee and Lombardo, 2018).

Crops are susceptible to wind damage by lodging, which lodging is defined as the permanent deformation of the stem due to flexure leading to buckling. Only a handful of experimental works have been conducted to measure the bending strength of corns (Berry et al., 2020; Robertson et al., 2014). In this study, the authors seek to explore and present the experimental result of the behavior of the corn under bending at different growth stages and accurately estimate the critical lodging wind speed of corn by applying the crop lodging model (Baker et al.,

2014) to understand the vulnerability of corns against wind. Joseph et al. (2020) performed comprehensive experimental tests to obtain the dynamic and aerodynamic properties of corns, which provides essential parameters for estimating the lodging speed. The estimated critical lodging speed of corn is then used in the tree-fall analysis to estimate the near-surface wind speed of the 2018 Bondurant, IA tornado that left wide damage on the cornfield.

2. BENDING STRENGTH AND CRITICAL LODGING WIND SPEED OF CORN

A series of 3-point bending moment tests on corns at different stages was carried out to measure the bending moment strength of corn stalks at the base. Stalk bending strength is generally considered the most appropriate strength measurement in stalk lodging (Robertson et al., 2017). Following the guidelines of the past study on measuring the stalk bending strength of corns (Robertson et al., 2014), the stalk bending strength of corns was measured with a 3-point bending moment test. Fig. 1 shows the experimental setup of the 3-point bending moment test (left).
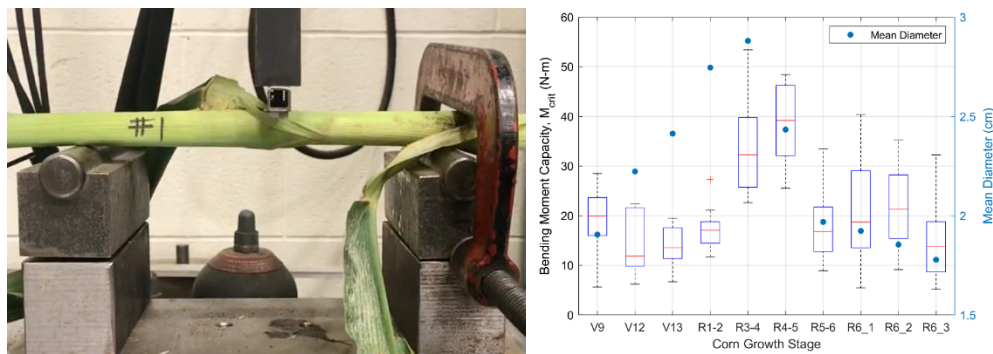

Figure 1. Experimental setup of 3-point bending moment test on corn stalks (left) and the box plot of corn bending moment capacity with a mean diameter at each grown stage (right)

The generalized crop lodging model (Baker et al., 2014) and the gust factor (Berry et al., 2003) were adopted to calculate the critical lodging wind speed of corn using the experimental bending strength values. Fig. 2 shows the critical gust wind speed of corn, where an evident decrease in critical gust wind speed is shown as the corn grows taller and bigger. Note that the critical lodging wind speed for the growth stage V9 through V12 exhibits exceptionally high wind speed due to small height and cross-sectional area despite the relatively low bending moment capacity.
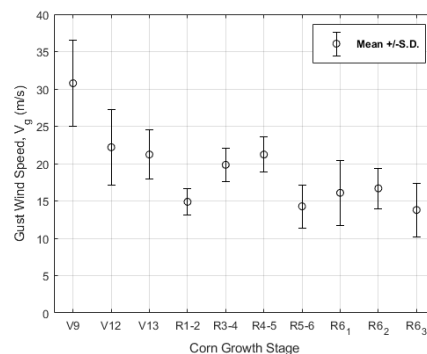

Figure 2. Critical gust wind speed range of corn at different growth stages

3. WIND SPEED ESTIMATION OF THE 2018 BONDURANT, IA TORNADO

A tornado outbreak occurred on July 19, 2018, in central Iowa, in which one of the tornadoes (EF2) touched down near Bondurant, IA, damaging large fields of corn. In the study area, the damage width was approximately 80 m and had a converging pattern which is typically found in tornadoes, but the area was rated an EF0 due to no presence of structural damage. The ground-based damage survey of the Bondurant, IA cornfield showed a growth stage of R4. Per Fig. 2, it could imply a lower bound wind speed of around 20 m/s. This value was also used in the tree-fall analysis to estimate the near-surface wind speed (Rhee and Lombardo, 2018) and yielded a maximum wind speed of 43 m/s (EF1), greater than the EF0 NWS rating.

4. CONCLUSIONS

Crop damage due to various windstorms has been a serious issue in the United States and other countries, resulting in a significant loss in yield. A series of 3-point bending moment tests on corn at different growth stages was conducted to examine the critical lodging wind speed of corn. The result of this study will be compared to the result of Berry et al. (2021) where a similar study was conducted in the UK. The critical lodging speed of corn at different growth stages can be used as a corn "damage indicator" of different windstorms throughout different seasons and also used as one of the input parameters for the tree-fall analysis to estimate the near-surface wind field of the tornado.

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