TECHNICAL OVERVIEW OF THE CROP LODGING MODEL

Definition of lodging

Lodging is defined as the permanent displacement of crop stems from their vertical position as a result of stem buckling and/or root displacement. It is most likely to occur 2-3 months before harvest and is associated with a reduction in yield and grain quality, as well as increased susceptibility of grain to mycotoxin-producing fungi.

Figure 1: Maize Lodging

Lodging risk factors and control techniques

Lodging risk is strongly correlated to various morphological characteristics of a plant and by extension, the husbandry techniques which determine these plant characters. For instance, the height to the centre of gravity, natural frequency, stem strength and anchorage strength have been identified as important determinants of lodging risk. Consequently, farmers have used strategies such as the selection of more lodging resistant cultivars and the application of plant growth regulators (PGRs) to control lodging. These strategies incur additional costs to growers and do not completely eradicate the lodging problem. Therefore, a need arises for a predictive tool which allows farmers to assess lodging risk and tactically apply husbandry techniques which have been proven to mitigate this risk.

Description of the physics of the conceptual model

Over the past two decades, crop lodging studies spearheaded by Professors Chris Baker and Mark Sterling, have led to the development of a conceptual lodging model for wheat and cereal crops which represents a plant as a simple mechanical system under the influence of wind and rain (Figure 2). The conceptual model proposes that wind gusts penetrating the crop canopy deflect the plant and cause it to oscillate at its natural frequency. The resultant simple harmonic motion of the plant is subsequently damped through energy dissipation in the stem and root system, aerodynamic resistance (drag forces) and interaction with neighbouring plants. By relating mean and fluctuating wind velocities to their corresponding mean and fluctuating displacements, stem base forces and bending moments, a system of equations has been derived which allows computation of stem and root failure moments and ultimately relates the base bending moment to the wind spectra and the natural frequency of the crop. Lodging is predicted when the wind-induced bending moment at the base of the stem exceeds either the stem failure moment for an individual shoot (stem lodging) or the anchorage failure moment for the entire plant (root lodging). Therefore, in addition to considering the plant characters which determine lodging risk, the conceptual model also accounts for dynamic wind loads acting on the plant and the effects of rainfall on anchorage strength.

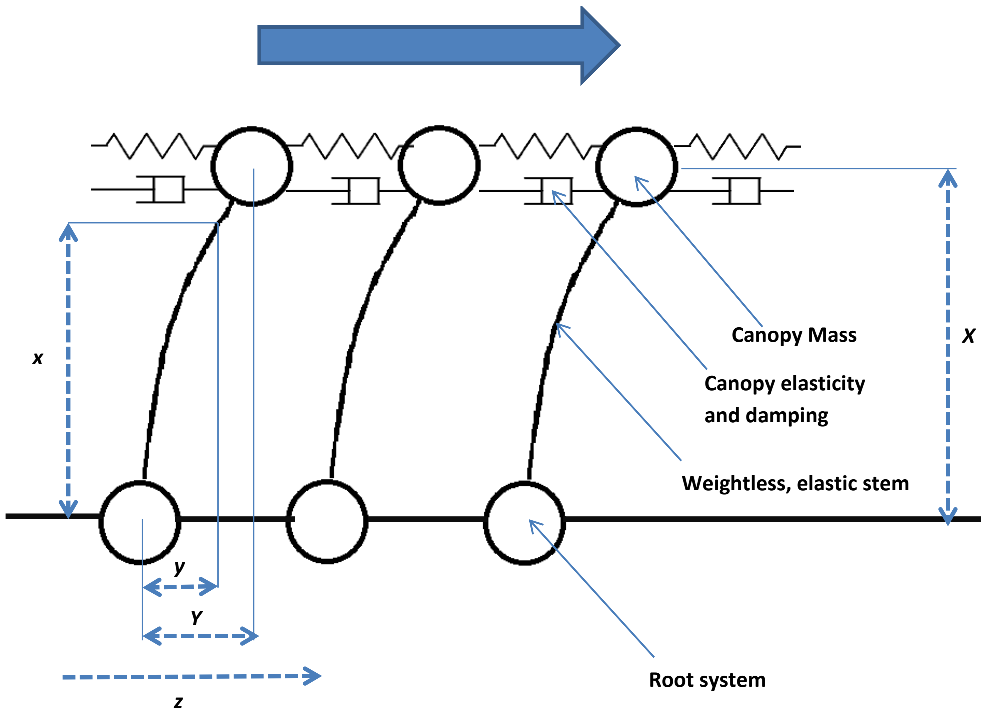

Figure 2: Schematic of the mechanical model of a plant

The conceptual model has been incorporated into a methodology which presents a simple graphical approach for assessing crop lodging risk in cereals. Through the application of suitable strength criteria for stem and root lodging, mean velocities for lodging can be defined as functions of plant and weather parameters. The occurrence of lodging is subsequently determined by the parabolic relationship between two driving variables - daily rainfall intensity and mean wind velocity at crop height, as illustrated in Figure 3. Lines corresponding to the stem lodging velocity at the first node, $\overline{U}_{LS1}$, and at stem base, $\overline{U}_{LSB}$, are superimposed on the parabolic curve in Figure 3. The line corresponding to the saturation velocity, $\overline{U}_S$, is also included in the figure. $\overline{U}_S$ is defined as the mean wind velocity at saturation rainfall intensity for which root lodging occurs. The output of the generalised lodging model may be interpreted as follows:

- Lodging does not occur for mean wind velocity and daily rainfall intensity data pairs lying in the white region, i.e. beneath the parabolic lodging curve and to the left of the line corresponding to the minimum stem lodging velocity at any point along the stem, in this case, $\overline{U}_{LS1}$. (Neither stem nor anchorage strength are exceeded by wind loading.)

- In the yellow region above the parabola, and to the left of the minimum stem lodging velocity line, only root lodging occurs (Anchorage strength is reduced as soil becomes increasingly saturated with water, leading to root lodging even at mean wind velocities less than the root lodging velocity, $\overline{U}_{LR}$.)
- Only stem lodging is predicted in the blue region below the curve and to the right of the minimum stem lodging velocity line. (Stem strength is exceeded.)
- Both stem and root lodging are predicted for velocity-rainfall data pairs in the green region above the curve and to the right of the minimum stem lodging velocity line. (Both stem and anchorage strength are exceeded.)

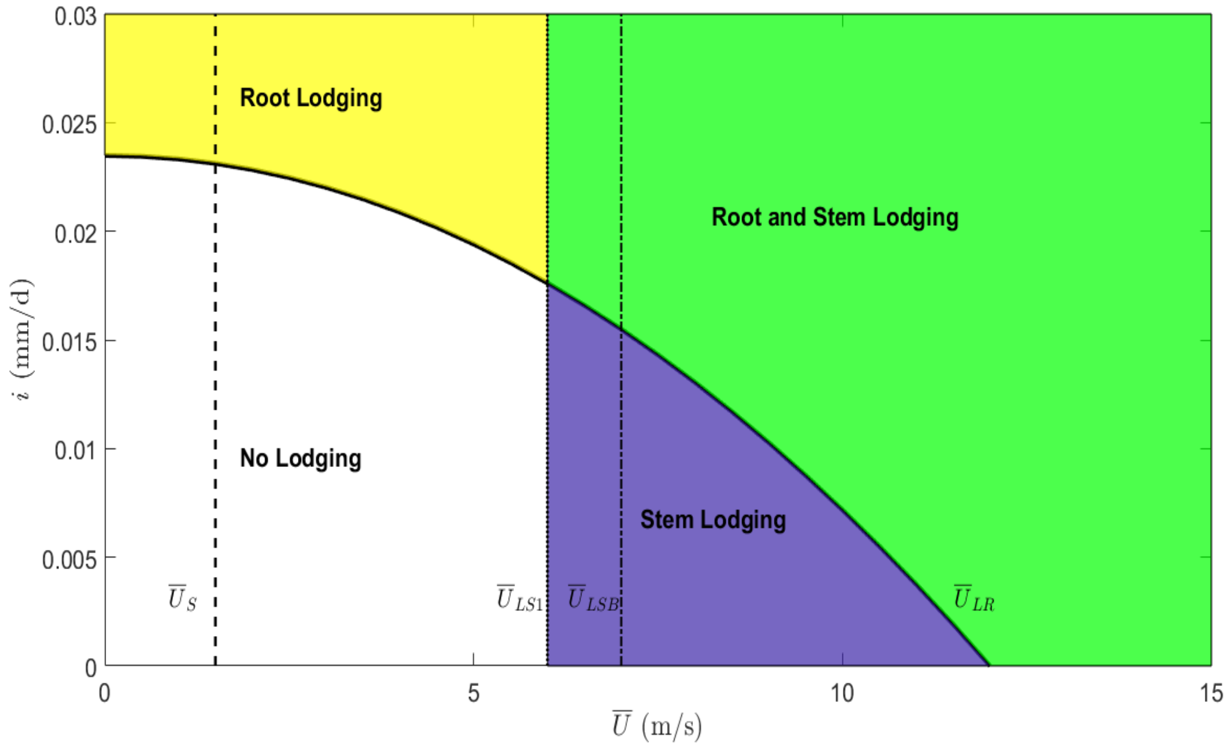

Figure 3: Generalised model of crop lodging

Calibrating and testing the model

Calibration of the generalised lodging model for a particular crop leads to the derivation of a formula for lodging risk. The model has been extensively tested for wheat grown in the UK and is 80% accurate in predicting the occurrence of lodging. Field and laboratory experiments have been conducted to calibrate the model, specify crop parameters such as drag coefficient, damping ratio and natural frequency, and examine the spatio-temporal variability of lodging-associated plant characters. Field measurements of site meteorology, namely realistic probability distributions of wind speed and rainfall, are required to determine lodging risk. To this end, a team of wind engineers at the University of Birmingham have developed novel techniques for capturing the wind speed above the crop canopy and the corresponding crop displacement. Figures 4 and 5 illustrate the instrument configuration employed in the field. This consists of two research grade 3D sonic anemometers positioned at 2 m above the crop canopy (reference height) and at crop height respectively.

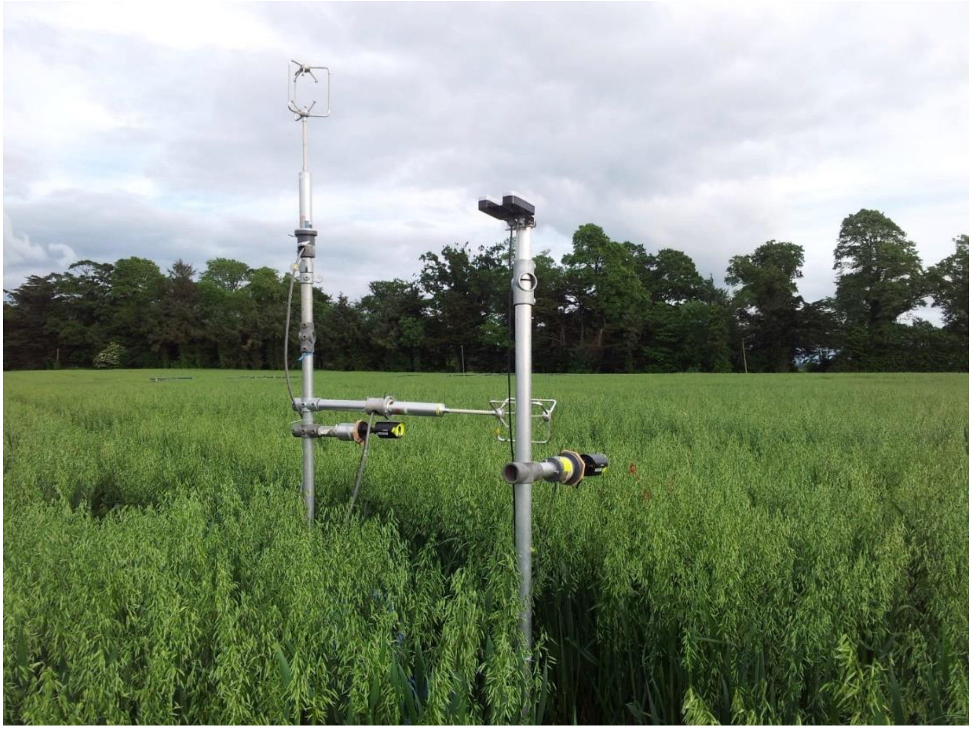

Figure 4: Instrument set up to measure wind speed, rainfall intensity and crop displacement above the crop canopy for oilseed rape.

Figure 5: Instrument set up to measure, wind speed, rainfall intensity and crop displacement for maize grown in the UK.

Figure 6 illustrates the use of two orthogonally mounted CCTV cameras to record the displacement of a painted oilseed rape target plant in two perpendicular planes. Rainfall intensity is measured using a rain gauge.

Figure 6: Painted target crop in two viewing planes (North-south and East-West).

Figure 7 provides an example of the output from one campaign of field measurements for a maize crop grown in the UK. Here, the displacement of a target plant is calculated from video footage using a customized MATLAB code which tracks crop movement in each video frame in pixel units. The pixel displacement obtained from the tracking procedure is subsequently converted to displacement in length units relative to the initial position of the plant. In Figure 7, the time series for the two horizontal components of wind velocity are compared to the corresponding displacements of a target crop over a 10 minute period.

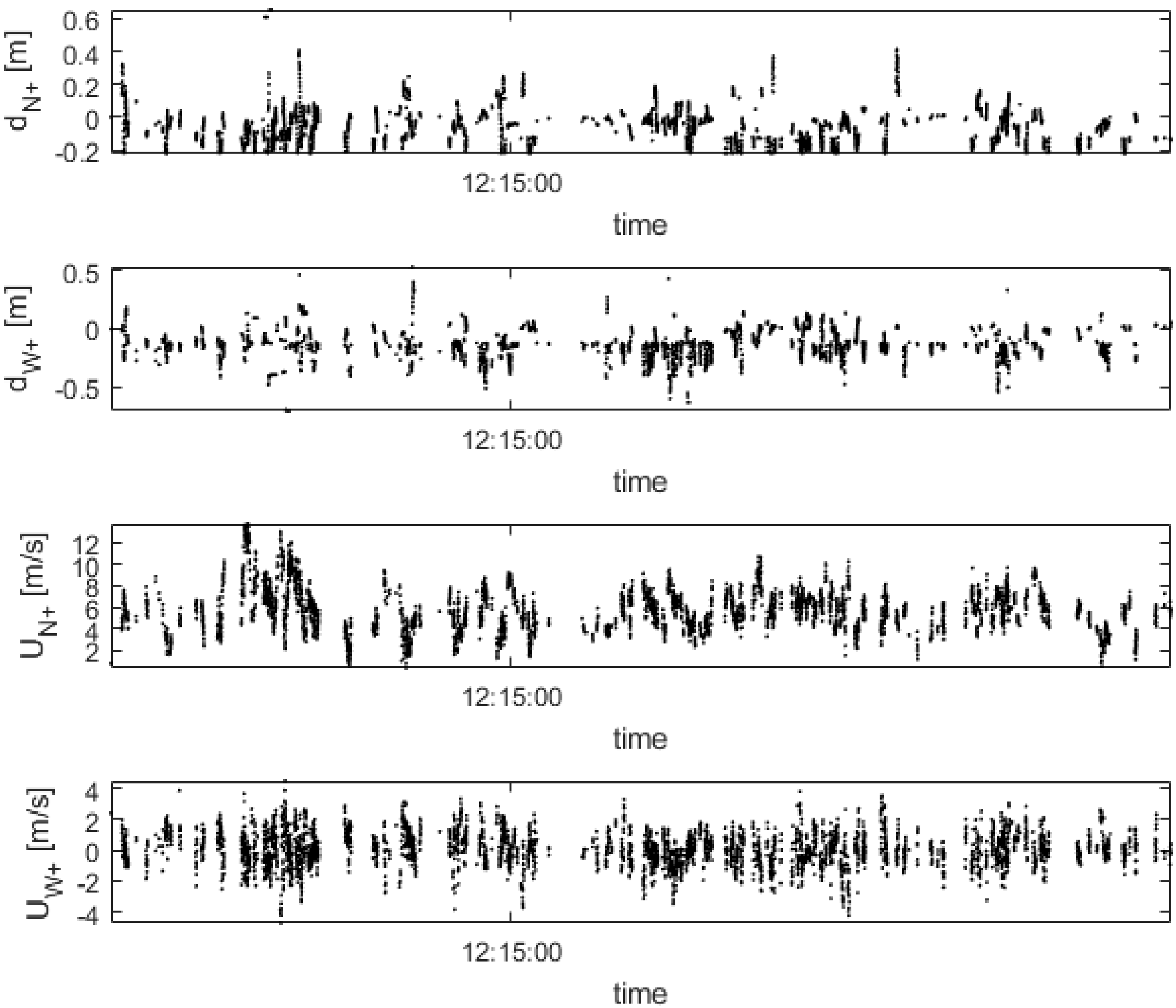

Figure 7: Displacement time series in North-South and East-West planes and corresponding velocity time series for a maize crop (Mansfield, UK).

Lodging Project Funding

Under a BBSRC/GCRF grant for the project "**Understanding and reducing lodging in rice and maize**" and the BBSRC/NERC SARIC funded programme entitled "**Increasing the resilience of cereal and oilseed rape production to weather damage**", the conceptual model which has been extensively tested for wheat will be optimized and calibrated through further laboratory and field experimental campaigns to accurately represent the plant morphologies and mechanical properties of oilseed rape, rice and maize respectively. The research programmes will adopt a multi-disciplinary approach, incorporating Remote Sensing and geospatial technologies, crop science and wind engineering. Under the BBSRC/NERC SARIC programme, the lodging model developed for UK cereal and oilseed rape crops will be integrated with an Earth Observation framework and heterogeneous terrain flow field resolution software FLOWSTAR, resulting in an agronomic decision making package CROPFALL. The BBSRC/GCRF programme will seek to produce a further iteration of the model with global transferability to rice and maize crops in China and Mexico - CROPFALL-GT.

It is envisioned, that the lodging model will provide early warning of lodging events, identifying areas of fields which are susceptible to lodging, thus serving as an agricultural decision making tool which will allow agronomist and farmers to develop and strategically implement crop husbandry techniques which mitigate lodging risk. The model will contribute to climate change resilience of agricultural practices through its ability to account for lodging risk associated with increased frequency of extreme wind and rainfall events brought about by climate variability.