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Testing a wheat shoot number model with independent shoot number data (2021)

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CONTENTS

1. Introduction

Wheat bulb fly (WBF) is a serious pest of winter wheat and is most commonly found in the east of England and Scotland. The life cycle of WBF includes egg laying in the summer, particularly on bare ground. These then hatch in the winter and larvae feed on wheat shoots, killing shoots and potentially reducing yield. The risk to the crop depends on the sowing date, the plant population and the level of WBF infestation.

A previous AHDB funded project (AHDB Project 598, Storer *et al.*, 2018; Leybourne *et al.,* 2021) developed a management scheme which considered the risk from WBF based on egg numbers, and estimated the target plant population and sowing date combinations required in order to manage the risk of WBF in the absence of chemical control options. This project set out the theory and structure for an IPM based management scheme for WBF, but there were some limitations which needed improving before it could be widely proposed as a recommendation system for growers, these included: 1. the relevance of the 500 shoots/m^2 maximum shoot number target for higher yielding crops, 2. the inability to predict potential WBF risk prior to the crop being drilled (and consequently removing the option to amend the drilling date in high risk seasons), 3. potential for differences in shoot production among varieties, and 4. the testing of the shoot number model under a range of seed rates, sowing dates, locations and seasons.

In response to the first limitation, the WBF management scheme was further developed for higher yielding crops in AHDB Project 607 (Storer *et al*., 2019) which found that the target maximum shoot number of 500 shoots/m^2 should be sufficient for crops yielding up to 11 t/ha but this should be increased from 500 to 600 shoots/m^2 for crops expected to yield > 11 t/ha (Storer *et al*., 2019). This work also assessed the potential for varietal differences in shoot production among varieties but was found to be inconclusive and therefore requires further work before a varietal factor could be built into the shoot number prediction model. The second limitation was assessed and improved in a recent AHDB project aiming to update and develop a meteorological model which enabled the prediction of WBF egg counts based on the previous seasons weather data. This model was found to have a predictive accuracy of 70% (Leybourne *et al*., 2021; Leybourne *et al*., 2020). The current project is aiming to focus on the fourth limitation of the recommendation system, testing the shoot number model under a range of seed rates, sowing dates and locations.

1.1. Aim

To test if the shoot number model originally developed in AHDB Project 598 and further developed in Leybourne *et al.* (2021) can predict the shoot number of crops from a range of UK sites, with a range of seed rates and sowing dates.

2. Methods & RESULTS

2.1. Site selection

Ten winter wheat sites from a range of geographic locations, with a range of different seed rates and sowing dates were selected for sampling at GS30/31 to assess the plant population and shoot number. Site details are included in Table 1 and Appendix 1. The locations are shown in Figure 1.

Table 1. Site details.

Site #	Latitude	Longitude	Sow date	Seed rate (seeds/m^2)	Sowing date category
1	54.1010	-0.6458	10/09/2020	175	Early
2	54.0258	-0.5584	23/09/2020	364	Early
3	54.0883	-0.6841	06/10/2020	350	Standard
4	53.3390	-1.0257	10/09/2020	315	Early
5	53.2211	-1.0877	16/10/2020	322	Standard
6	52.1492	-2.8723	14/09/2020	300	Early
7	52.1572	-2.4846	28/09/2020	325	Standard
8	51.9599	-2.5349	05/11/2020	400	Late
9	52.1076	0.0695	15/10/2020	353	Standard
10	52.7720	0.3233	05/11/2020	350	Late

2.2. Shoot number assessment

Crop samples were collected at GS30 from each site to assess shoot number. This timing was to coincide with the maximum shoot number and the growth stage at which the current shoot number model is calibrated for. The sites sampled were either existing small plot field trials, or farm crops. From a representative area in the field (at least 12 m away from the headland and at least 2 m away from a tramline) or from an experimental plot (avoiding the outer two rows) all plants were dug up from three 0.5 x 0.5 m quadrats (0.25 m^2 per quadrat). If experimental plots were used, each sample was collected from a different plot, and if a field sample was used, the samples were spread out with at least 2 m gap between samples to ensure the sample was representative. Plants from the three quadrats were bulked forming a single sample per site which was washed and weighed. A 25% subsample of this was then taken, weighed, and the total number of plants, fertile tillers and dead and dying tillers were counted. The number of tillers showing signs of damage from WBF or other stem boring pest were also recorded (e.g. dead hearts). These values were then corrected to the number of plants/m^2 and shoots/m^2. The number of shoots/m^2 including dead and dying tillers were used in the analysis to test if the model is able to predict the maximum shoot number.

Figure 1. Site locations from which winter wheat crop samples were collected. Light blue = early sown crops (September), dark blue = standard sowing date crops (Late September to October), pink = late sown crops (November onwards).

2.3. Model predictions and data analysis

The shoot number production model described in Leybourne *et al.* (2021) was used to estimate the maximum shoot number for each site using two types of model input: 1. Seed rate and sowing date, and 2. Measured plant population and sowing date.

The model outputs were then compared with the measured GS30 shoot numbers using a linear regression analysis in Genstat (v20). The data were also added to the testing data set used in Leybourne *et al.* (2021), and a multiple linear regression was used to analyse the data, with site as Group in Genstat (v20).

3. Results

There was no significant relationship between the predicted and measured shoot numbers when the seed rate and sow date ($P > 0.05$, Figure 2A) or plant population and sow date ($P > 0.05$,

Figure 2B) was used as the model inputs. Excluding the dead/dying tillers did not improve these relationships (P > 0.05 in each case).

When the data from this study were added to the model testing from Leybourne *et al.* (2021), there was a significant positive relationship between observed shoot number and predicted shoot number based on measured plant population when a common line was fitted (P < 0.001, 54.5% of variation explained). There was a further significant increase in the percentage of variation explained, up to 75.3%, if parallel lines were fitted to the data by site (Figure 3, P < 0.001).

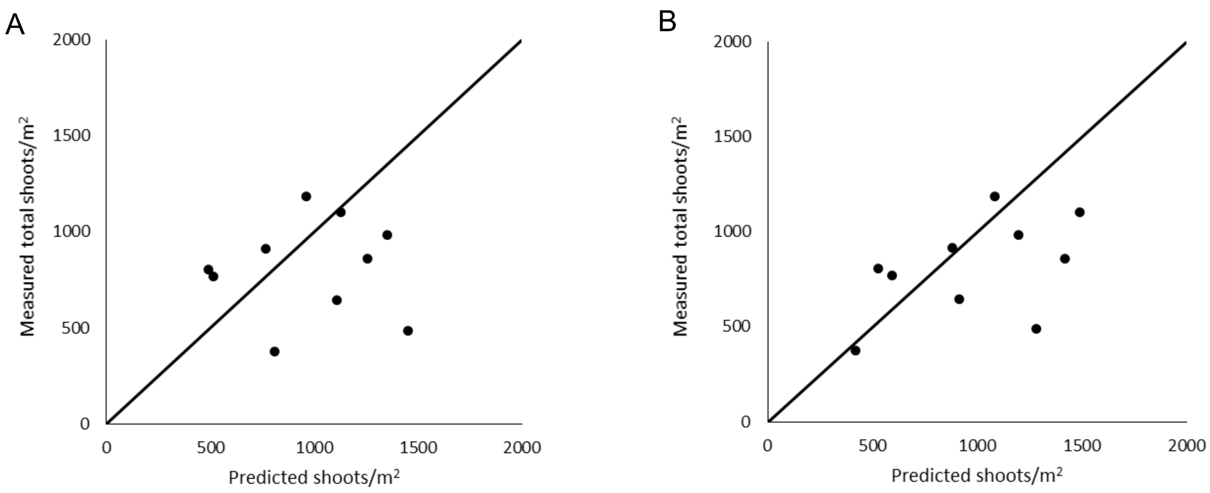

Figure 2. Predicted shoots/m^2 using seed rate (A) or measured plant population (B) plotted against the measured number of fertile shoots. Solid black line is the 1:1 line.

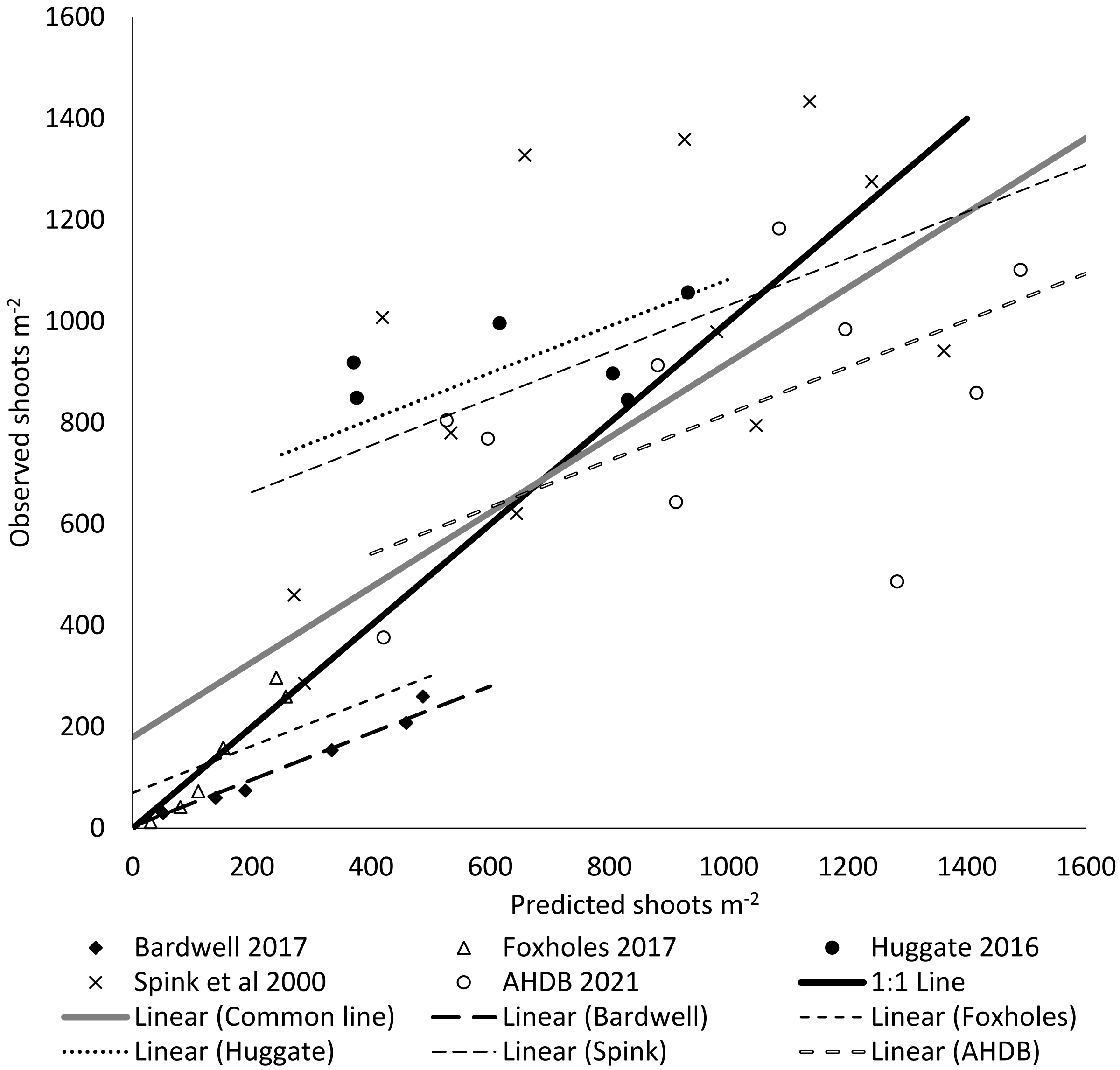

Figure 3. Predicted vs observed shoots/m^2 for a series of winter wheat experiments described in Leybourne *et al.* (2021) with the AHDB 2021 data added in. Black solid line represents the 1:1 line, grey solid line represents the common fit line from the regression across all sites. Separate dashed lines represent fitted individual site relationships from the regression.

4. Discussion

This project aimed to further test the shoot number model developed during AHDB Project 598 to determine if the model can accurately predict maximum shoot number measured at GS30 for a series of ten independent sites across England in 2021. Previous model testing was limited to data from five sites, and three of the experiments used were located in the same field as the trials from which data were collected for model development and calibration (Leybourne *et al*., 2021). This study therefore selected independent data from 10 sites selected to supply a realistic range in sowing date and seed rate for winter wheat for additional model testing.

There was no significant relationship between the measured shoot number at GS30 and the predicted number of shoots/m^2 from the shoot number model when the seed rate was used alongside the sowing date to predict the maximum number of shoots/m^2. Establishment of the plant population can vary significantly among sites for various reasons, including soil type (Blake *et al*., 2003). Therefore, the measured plant population was also used alongside the sowing date to eliminate the risk of establishment effects causing the model to fail. However, while it appeared to slightly improve the prediction, the relationship between the predicted and measured shoot number at GS30 still was not statistically significant, regardless of the inclusion of both fertile and dead/dying tillers. Therefore, the model was unsuccessful at predicting shoot number across these sites in 2021.

The data from this study were then added into the regression analysis completed as part of AHDB Project 598 (Storer *et al*., 2018; Leybourne *et al*., 2021), and this did find a significant relationship between the predicted and measured shoot number, explaining 54.5 % of the variation in the data. However, this was lower than the 65.7% of variation explained in the original regression analysis (excluding these new data). The regression analysis also supported the fitting of separate best-fit lines to each experimental site (for sites where several measurements were made). Note that in 2021, one measurement was made at each site and these were grouped. It seems likely that other factors, such as soil type/conditions may also be influencing the shoot number production, in addition to sowing date and rate. It is difficult to identify clear factors from only 10 sites, and future work with more sites representing a range of soil types/conditions would be required to determine if this is the case. If so, it may be possible to build in a site factor to increase the model reliability in future iterations.

There were a few clear outliers in the data, with the model predicting much higher than observed shoot numbers at some sites. For example, site 4 was an early drilled crop (drilled 10/9/20) and had a predicted shoot number of 1283 shoots/m^2, yet the measured shoot number was only 487 shoots/m^2 which is much lower than expected. A similar trend can be seen at Site 6 which was also sown in the middle of September. In contrast, the two late sown crops (both drilled 5th November) had a predicted shoot number which was lower than the measured shoot number. It's possible that environmental factors, such as the dry September may have delayed establishment of early sown crops (therefore delaying the onset of tillering) and the wet winter may have reduced tillering of some crops (e.g. due to waterlogging). However, these weather factors do not explain why some late drilled crops produced more tillers than predicted.

To test if the thermal time between establishment and GS30 had been significantly higher than predicted by the model at site 10 (late sown), the model was run using the actual thermal time for that site. This did slightly increase the predicted shoot number from 527 shoots/m^2 to 583 shoots/m^2 but this was still well below the measured shoot population of 805 shoots/m^2 (including dead/dying tillers). Future work could further investigate this by running the model using measured thermal time for all sites, to see if the estimates of thermal time required based on Kirby *et al.* (1985) used in the model are appropriate. For example, if a trend for different thermal time values in the East vs the North was observed, it may be possible to build in different thermal time values for different areas in future versions of the model.

Another factor which may influence the reliability for the model for early and later sown crops is that the original model was calibrated using field trial data from crops grown at ‘standard’ timings, to account for plant competition and other in field factors which may limit shoot production. This calibration was limited to relying on data from standard sowing dates as data from late sown or early sown crops was not available to create separate independent calibrations for those timings. However, it is possible that the calibration may need adapting for early and late sown crops, and this may explain some of the variation seen here. Furthermore, where the model is predicting higher shoot numbers than the values counted in the field for later sowing dates, it’s possible that the thermal time from sowing to terminal spikelet (based on Kirby et al. 1999) is an underestimate or phyllochron length used (based on Kirby *et al*., 1985) is an overestimate. There may also be varietal differences in shoot number, phyllochron length or tolerance of environmental factors that trigger the cessation of tillering.

In conclusion, the model prediction of the shoot number for the 2021 data was not strong but these data provide vital information on the reliability of the model and for increasing our understanding of the aspects of the model which have the potential to be further improved. Ideally this study would be repeated for multiple seasons to build up a robust independent dataset to further improve our understanding of how the model is working and identify areas for improvement. Ultimately working towards improving the reliability of the model to the point which growers can make use of it for predicting and tolerating attack by stem boring pests including wheat bulb fly as part of an integrated pest management scheme.

5. References

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6. Appendix 1

Table 2. Additional site data.

Site #	**Modal GS at sampling**	**Sow date**	**Seed rate (seeds/m²)**	**Plant popⁿ (plants /m²)**	**Variety**	**Soil type**	**2020**	**2019**	**2018**	**2017**	**Straw disposal method**	**Pre-sowing cultivations**
1	30	10/09/20	175	243	Graham	Silty Clay loam over chalk (shallow)	Winter oilseed rape	Winter barley	Winter wheat	Potatoes	Incorporated	Cultivated (tines/press), Power Harrow
2	31	23/09/20	364	414	Firefly	Silty Clay Loam over chalk (shallow)	Winter oilseed rape	Winter barley	Spring barley	Winter wheat	Incorporated	Sumo Trio
3	30	06/10/20	350	318	Graham	Silty Clay Loam over chalk (shallow)	Winter oilseed rape	Spring barley	Winter barley	Winter wheat	Incorporated	Sumo, Culti pressing
4	30	10/09/20	315	171	Skyfall	Sandy Loam						Disc, Plough
5	30	16/10/20	322	280	Skyfall	Sand						Disc, Plough
6	31	14/09/20	300	163	Barrel	Silty Clay Loam	Linseed	Winter Wheat	Ryegrass Seed	Ryegrass Seed	Incorporated	Sumo, Harrow
7	30	28/09/20	325	142	Sundance	Silty Clay Loam	Spring Wheat	Grass	Grass	Grass	Baled	Plough, Harrow
8	30	05/11/20	400	322	Barrel	Silty Clay Loam	Grass	Grass	Grass	Grass	N/A	Plough, Harrow
9	30	15/10/20	353	65	Skyfall	Silty Clay Loam						
10	30	05/11/20	350	219	Zulu	Silty Clay Loam					Incorporated	Sumo Trio