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Calibrating the wheat bulb fly threshold scheme using field data. Desk Study.

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CONTENTS

1. Abstract

AHDB Final Project Report 598 – *Crop management guidelines for minimising wheat yield losses from wheat bulb fly* (WBF) – described a potential threshold scheme for this serious pest of winter wheat.

The scheme considers the minimum plant population, latest sowing date and need for an insecticide treatment. It uses information from the autumn survey of wheat bulb fly incidence (September egg counts), expected egg viability, the maximum shoot number the crop could achieve by late winter, the number of shoots that a single larvae could destroy, and the minimum final ear number required to achieve the potential yield for the site.

In order for the scheme to be adopted, a more reliable and up-to-date estimate of the minimum final ear number required for high yielding wheat crops was considered necessary. This desk study looked at this aspect, including whether the number changes in different regions and environmental conditions.

A positive association between yield and final ear number was identified for UK wheat crops. For crops expected to yield up to 11 t/ha, a target final ear number of 500 ears/m^2 was deemed a conservative default value. For crops expected to exceed 11 t/ha, a higher target final ear number of 600 ears/m^2 was deemed appropriate.

Although there was evidence that the ear number associated with specific yields may vary between varieties and geographic regions, it was not strong enough to recommend its inclusion in the threshold scheme.

Before the scheme can be adopted, further research is necessary. In particular, it is important to quantify varietal differences in relation to shoot number at growth stage 31 and final ear number.

2. Introduction

Wheat bulb fly (WBF) is one of the most serious pests of winter wheat and is particularly prevalent in the east of England and Scotland. It lays eggs in bare ground during the summer and its larvae hatch during winter and can reduce the yield of wheat by killing shoots and reducing final ear number. The potential yield loss depends on the shoot population in winter, the size of pest population and how much damage an individual larva can cause. AHDB Project 598 (Storer *et al*., 2018) developed a threshold scheme to predict the minimum plant population, latest sowing date and need for an insecticide treatment (seed or foliar) to minimise the risk of yield losses to WBF. The threshold scheme uses information from the autumn survey of WBF incidence in September, egg viability, the maximum shoot number the crop could achieve by late winter, the number of shoots that a single WBF larva could destroy and the minimum final ear number required to achieve the potential yield for the site.

A sensitivity analysis was done to test the impact of the normal variation in each model parameter on the WBF egg threshold. This showed that typical variation in maximum number of shoots in late winter had the largest effect. To account for this, the project developed a tillering model to predict the maximum shoot number using sowing date, seed rate and autumn/winter temperature. Variation in the minimum ear number required to achieve potential yield had a relatively modest impact on the WBF egg threshold. However, it was recognised that underestimating this parameter could result in an over-estimation of the threshold egg numbers, and consequently loss of yield. Previous work has shown that wheat crops achieving typical UK wheat yields of 8t/ha require a minimum of 400 to 450 fertile ears/m^2 to achieve potential yield (Spink *et al*., 2000a). A conservative default value of 500 ears/m^2 was chosen to represent all crops for the WBF threshold scheme. However, recent data collected within the Yield Enhancement Network (YEN) shows a positive association between high yields and ears/m^2. This may indicate that more ears/m^2 are required to achieve high yield potentials. Furthermore, it is not known whether the minimum ear number required for potential yield varies between environments (e.g. region, soil type, soil nutrient status etc.).

The aim of this project was to improve confidence in the WBF threshold scheme by providing a more up-to-date and reliable estimate of the minimum final ear number required for high yielding wheat crops and investigate whether this changes between different environments. This has been achieved by analysing data collected in the YEN project.

3. Materials and methods

3.1. Available data

The YEN dataset was used to investigate the range and mean number of ears/m^2 from 512 YEN entries. The YEN dataset includes data from 2013-2018 and was filtered to only include winter wheat crops, from UK entries. Any data where the unique farm ID was not listed was removed as this could bias the analysis. There were 512 entries included in the analysis, with yields ranging from 5.2 t/ha up to 16.5 t/ha. The mean ear number across these entries was 481 ears/m^2 (Table 1). The ear number was estimated from a crop sample collected a few days before harvest. Approximately 100 randomly selected shoots were collected by the YEN entrants from the field, or area of field (minimum 2 ha) entered into YEN and submitted to ADAS to count and record the shoot biomass, number of fertile (with ear) and infertile (without ear) shoots, grain number the grain weight along with a range of other parameters which are not reported here. Ears/m^2 was calculated by dividing the grain yield measured by the combine (t/ha, 15% moisture content) by grain weight per ear measured from the pre-harvest crop sample from the field or field area entered into YEN. This allows an accurate estimate of ears/m^2 because it uses the grain yield from the whole field or field area entered into YEN and the crop sample is collected from representative locations within this area. There were 63 varieties plus unknown and non-listed varieties in the dataset, but variety data were only included in the analysis if there were 10 or more replicate entries of a given variety (260 entries). This is because it is difficult for the analysis to work with non-replicated data. The data for all varieties (regardless of replicate number) were also summarised by Nabim group, either as Group 1, 2, 3, 4 hard or soft, or Group 1 & 2, Group 3 & 4 soft and Group 4 hard (355 entries). Data from the three Ireland sites were not included in the regional analysis as there were too few replicates for this category. Data from farms where the region was not specified were also excluded.

3.2. Data analysis

The YEN dataset includes over 80 parameters. A subset of these was selected to investigate the relationship between ear number and yield. These included combine yield (t/ha), ear number (ears/m^2), seed rate (seeds/m^2), date of sowing (days since 1st Sept), soil depth to rock (m), region, variety (summarised as described above), status as a 1st or 2nd cereal, cultivation technique, soil class (based on RB209), whether fertiliser P was applied or not, latitude, longitude, rate of nitrogen (N) fertiliser application, fertiliser N product, soil P, K, and Mg index, soil pH, soil organic matter content and soil texture. Where answers to these questions were not provided, the data were classed as either ‘missing’ (for continuous data), or ‘unknown’ (for categorical data). Continuous data were summarised into descriptive traits, and all data (including categorical data) were summarised using histograms.

Correlation analyses were used to determine whether there were any relationships between different measured parameters (Genstat, v16). The YEN dataset was also analysed using the REML directive in Genstat (Payne *et al*., 2017) to assess which factors may contribute to the variation in ear number. Year and farm were included as random factors, and other factors were classed as fixed factors.

4. Results

4.1. Data summary

There was a large range in the reported yields, from 5.2 t/ha, which is well below the UK farm average of approximately 8 t/ha (Defra Statistics), up to 16.5 t/ha (Table 1), which is close to the world record wheat yield (Guinness World Records, 2017). Similarly, there was a large range in ear number, from 208 up to 980 ears/m^2. However, the 5-95 percentile range was substantially smaller, from 305 to 684 ears/m^2. Several other factors which were hypothesised to influence any relationship between ear number and yield, also varied widely giving a good spread of data to test the hypotheses (Table 1).

Table 1. Summary of traits with continuous data.

Trait	Yield (t/ha)	Ear number (ears/m^2)	Seeds/m^2	Day sown (days since 1st Sept)	Soil depth (m)
Mean	10.87	481	332	31.5	1.34
Max	16.50	980	519	75	1.5
Min	5.20	208	180	-23	0.2
5th Percentile	7.83	305	214	13	0.37
95th Percentile	13.93	684	440	51.6	1.5
No. data points	512	460	207	365	507

Several of the most important categorical parameters of interest are summarised in the histograms in Figure 1 to Figure 3. The number of entries included in each one varied depending on whether the YEN entrants provided the information, and whether the data were further rationalised as described in Section 3.1. The region data were biased towards East Anglia, with a reasonably even spread between the other six main categories (Figure 3). Similarly, most crops were first wheats, following an oilseed rape (OSR) break crop and the majority of sites were from medium soils, with deep non-inversion or plough based cultivations being the dominant categories.

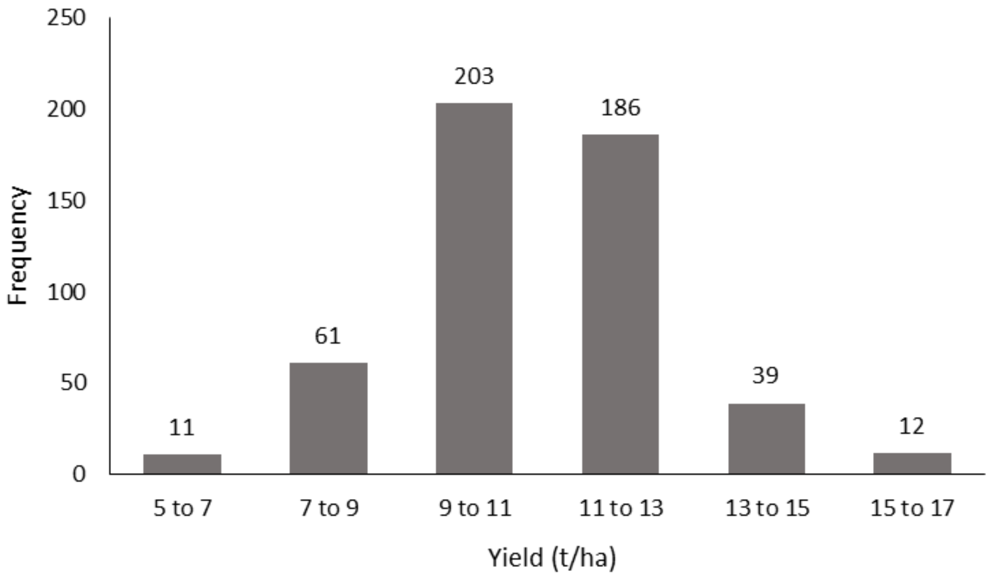

Figure 1. Frequency histogram for yields included in the YEN dataset.

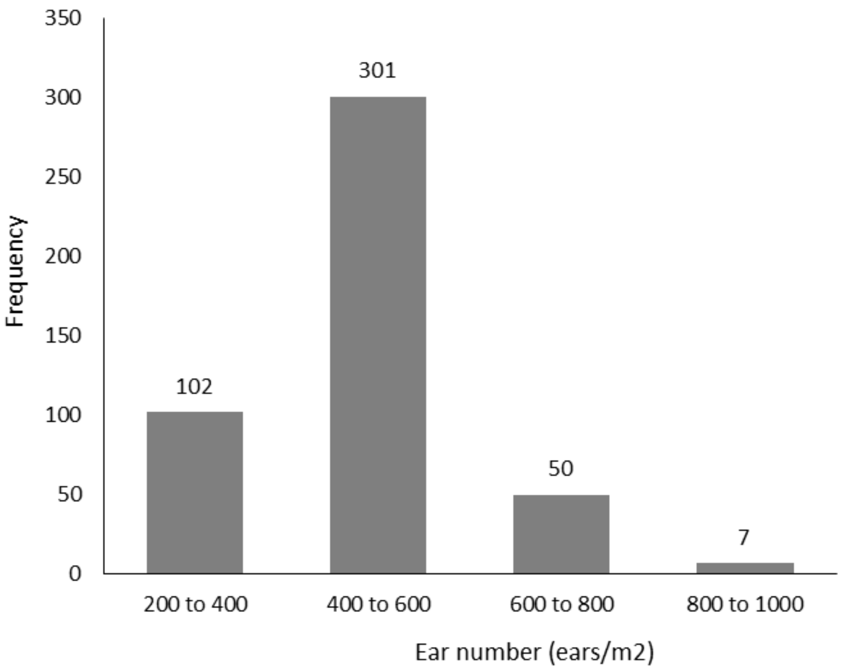

Figure 2. Frequency histogram for ear numbers included in the YEN dataset.

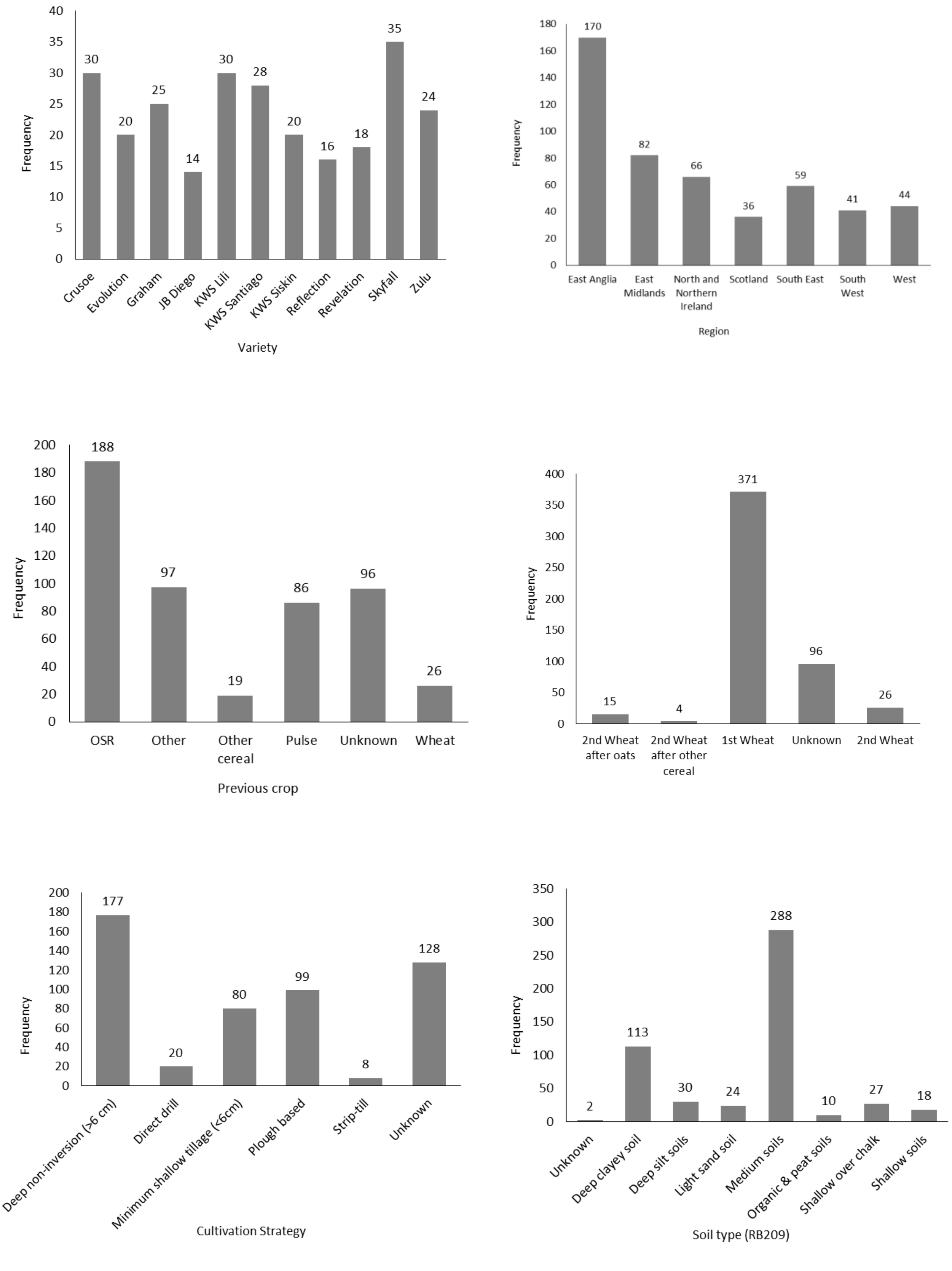

Figure 3. Frequency histograms of traits analysed.

4.2. Relationships between ear number and yield

There was a significant positive correlation between ears/m^2 and yield ($P < 0.001$), and the associated r^2 value was 0.21, suggesting that ears/m^2 explained approx. 21% of the variation in yield. Fitting a logarithmic curve, where the relationship levelled off at high yields, slightly improved the r^2 value to 0.23.

Figure 4 shows the average number of ears associated with yield categories increasing in 2 t/ha increments from 5 to 17 t/ha. Over 90% of the yields were 13 t/ha or less, and the 11-13 t/ha yield category was associated with an average of 510 ears/m^2.

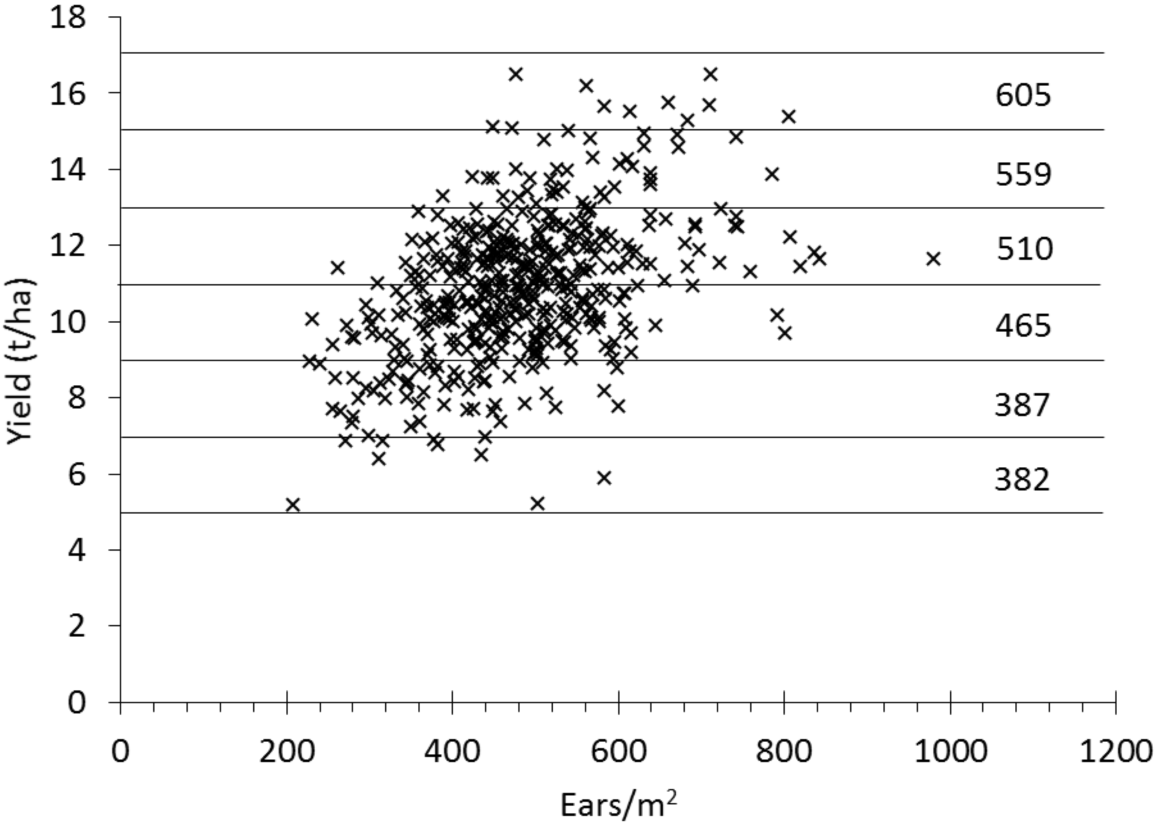

Figure 4. Ears/m^2 plotted against yield (t/ha) with the average number of ears/m^2 presented for each yield group.

4.2.1. Factors describing the associations with ear number

The analysis using the REML directive found that the variation in ear number was significantly associated with the variation in yield ($P < 0.001$). Of the remaining parameters listed in Section 3.2, only region ($n = 446$, $P = 0.012$) and variety ($n = 239$, $P = 0.02$) explained a significant amount of the variation in ear number when analysed using the REML directive. These each remain significant if added into the model sequentially (regardless of order) and therefore appear to be describing different sources of variation in the number of ears/m^2. In contrast, if variety was summarised by Nabim group it did not significantly associate with ear number ($P > 0.05$, n=355). When analysed using a linear regression analysis, fitting fully independent lines (different y-axis intercept, and slope) improved the percentage of variation explained by variety from 20.1 to 26.4 (P = 0.021, Figure 5). Fitting parallel lines (different y-axis intercept) improved the variation explained by region from 21.3% to 24.2% ($P < 0.001$, Figure 6) and was the best model for explaining the influence of region on the relationship between ear number and yield. This indicated that the South West, West, East Anglian regions and Scotland had higher numbers of ears associated with the same yield than other regions. There was also a weak but significant positive correlation between degrees longitude and ear number (n = 447, P = 0.0034, $R^2 = 0.02$), but not between degrees latitude and ear number ($P > 0.05$). Mean ear numbers and yield for each variety and region are shown in Table 2 and Table 3 respectively.

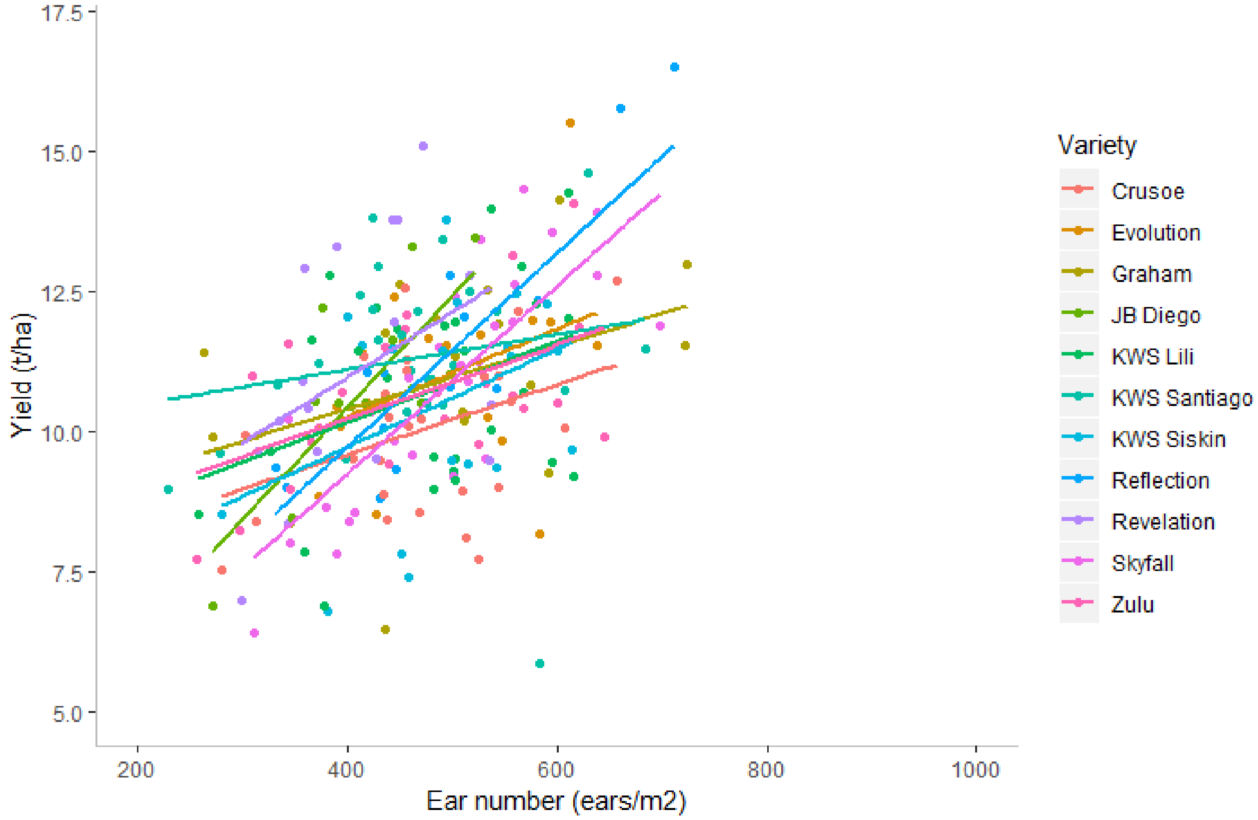

Figure 5. Relationship between ear number and yield for each variety.

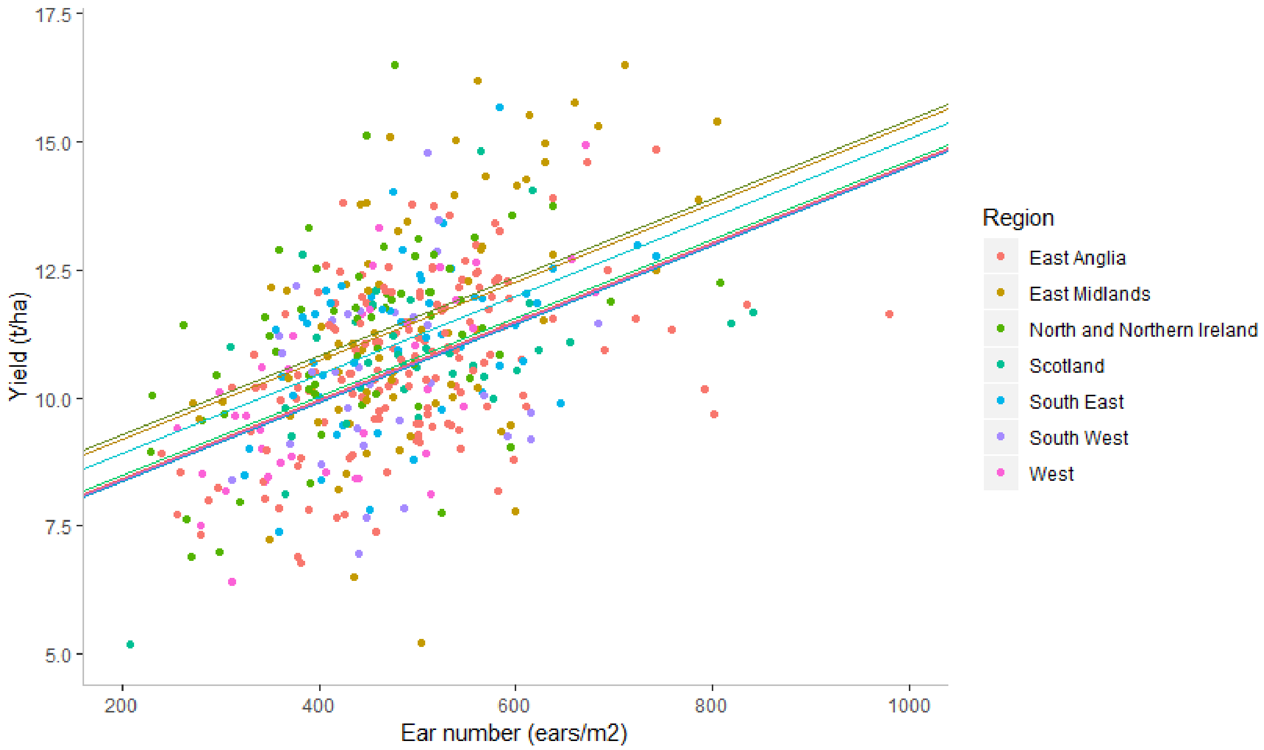

Figure 6. Relationship between ear number and yield for each region.

Table 2. Mean ear number and yield for each variety and number of times that variety is reported in the YEN dataset (N).

Variety	N†	Mean ear number (ears/m^2)	Yield (t/ha)
Revelation	18	413	11.12
JB Diego	13	417	10.76
KWS Santiago	27	462	11.28
Zulu	23	464	10.70
Crusoe	28	465	10.05
KWS Lili	27	481	10.77
Graham	20	488	11.00
Reflection	16	491	11.31
KWS Siskin	19	492	10.64
NA*	221	492	10.93
Skyfall	29	492	10.67
Evolution	19	495	11.01
Grand total	**460**	**481**	**10.87**

*NA = Includes any listed as ‘unknown’, ‘unlisted’ in current RL, ‘not listed’ in any RL, or any varieties where ten or fewer replicates were included.

†N may be lower than the number of variety entries as not all entries submitted ear number data.

Table 3. Mean ear number and yield for each Region and number of times that Region is reported in the YEN dataset (N).

Region	N	Mean ear number (ears/m^2)	Yield (t/ha)
West	40	435	10.33
North and Northern Ireland	61	446	11.07
South West	33	467	10.36
East Anglia	152	492	10.66
South East	52	492	11.13
East Midlands	74	499	11.42
NA*	14	502	11.45
Scotland	34	503	10.79
Grand total	**460**	**481**	**10.87**

*NA= Includes Ireland and any listed as ‘unknown’ regions.

†N may be lower than the number of region entries as not all entries submitted ear number data.

5. Discussion

5.1. Association data

It should be noted that all analyses in this report are relating to associations between variables, and cannot be considered causative effects. Therefore, whilst there is an association between ear number and yield, it may not be the case that yield is directly driven by ear number. Given the method of determination of ear number, it is also important to recognise the possibility of autocorrelation between ear number and yield. However, there were negative correlations between other independent yield components (e.g. ear size, ear length, grains per ear) and ears/m^2, suggesting that the positive relationship between ear number and yield is not caused by autocorrelation. It therefore appears that high yielding crops generally have high ear numbers, and so it will necessary to develop the WBF threshold scheme to minimise the risk of target ear number restricting the yield of higher yielding crops.

5.2. Target minimum ear number

It would not be appropriate to use a simple linear relationship between ear number and yield to adapt the ear number recommendation for high yielding crops. This is because of the high level of variation around the line of best fit between ear number and yield and the high level of variation associated with estimating ear number. A better approach is use categories as shown in to demonstrate the average ear number required to achieve a certain yield.

The results suggest that the original minimum ear number for potential yield of 500 ears/m^2 should be sufficient for the majority of crops, since this is equivalent to the average ear number of crops that yielded up to 11 t/ha, representing 54% of the YEN entrants and exceeding the UK average wheat yield (of ca. 8 t/ha, Defra Statistics) by 3 t/ha. However, due to the positive relationship between ear number and yield, crops that are expected to yield above 11 t/ha may require a minimum ear number greater than 500 ears/m^2. In these cases, the minimum ear number should be increased to 600 ears/m^2 (Table 4), which will exceed the mean ear number for all yield categories up to 15 t/ha. Given the limited number of data points above 15 t/ha (25 entrants), it is not possible to conclude with confidence whether the target ear number for crops within this yield category should be increased above 600 ears/m^2 .

Table 4. Average and recommended minimum ear number for crops summarised by potential yield (t/ha).

Yield (t/ha)	Average ear number (ears/m^2)	Target minimum ear number (ears/m^2)
5 <= 7	382	500
7 <= 9	387	500
9 <= 11	465	500
11 <= 13	510	600
13 <= 15	559	600
15 <= 17	605	600

5.3. Factors associated with ear number

Regression analysis indicated that different varieties may require different ear numbers to achieve specific yields. In contrast, there was no evidence that general Nabim groups affected this relationship. In AHDB project 598 there was a significant difference found for the number of shoots at GS31 between the four varieties studied, with Revelation producing the highest (560 shoots/m^2) and Butler, Evolution and Horatio producing 395, 445 and 470 shoots/m^2 respectively (Storer *et al*. 2018). However, there was no significant difference in final ear numbers produced by these varieties, and the differences in GS31 shoot numbers did not match yield differences. Spink *et al*. (2000b) found similar effects with varietal differences in GS32 shoot numbers, though these also did not translate into yield.

It is important to recognise that the analysis reported here represents an association between variety and the relationship between ear number and yield, but it is not causative. Errors associated with varietal differences in final ears/m^2 at the two sites reported in Project 598 were 24 ears/m^2 (SED) and 51 ears/m^2 (LSD), which were similar to the values reported across all trials in that project (Storer *et al*. 2018). Therefore ear numbers which differ by <50 ears/m^2 are unlikely to represent real differences in ear number.

Thus, given these uncertainties, it is not possible to alter the recommended target shoot number by variety. However, this study has provided evidence that there may be varietal differences in both GS31 shoot number and the final ear number required for a specific yield. It should be recognised that varietal differences in shoot number at GS31 and final ear number may not be consistent. For example, Revelation had the highest GS31 shoot number in Storer *et al*. 2018, whereas it has the lowest final ear number in the YEN dataset. It would be beneficial to investigate further these differences. This could be done by non-destructively assessing GS31 shoot number and final ear number in the recommended list trials. This information could be added as a varietal factor in to the shoot production model of the WBF threshold scheme, and may provide useful data to support integrated crop management strategies as well as enabling a better understanding of physiological characteristics of varieties.

Ear number was also associated with region, with a weak but significant negative trend for lower ear numbers in the west of the country, but there was no significant correlation between degrees latitude within the UK and ear number. The regional effect indicated that the south west, west and East Anglian regions and Scotland had higher ear numbers associated with a specific yield than other regions. However the difference was less than 50 ears/m^2 and not considered large enough to recommend adapting the WBF threshold scheme to take this into account. It was also noted that there was no consistent geographical pattern for differences in ear number, e.g. both Scotland and the south west required more ears to achieve a specific yield. Nonetheless, these relationships were consistent in the regression, REML and correlation analyses, and therefore warrant further investigation when additional years of YEN data are available.

5.3.1. Comparison with the main YEN data analysis

An analysis of the main YEN dataset has also been done separately from this project. This analysis included all cereals (not just wheat), and was not restricted to UK crops. It also investigated associations between a greater number of parameters and yield than the current project. There was no association between variety and yield whereas there was an association between site, weather, soil type and several other husbandry factors and yield. Similar to the current study, there was no yield association with date of sowing, seed rate or cultivation strategy. Large yields tended to be associated with large crops, with both high ear populations and high biomass, and yield did not relate strongly to amount of inputs. This supports the finding that ear number and yield are positively associated, but also demonstrates that ear number is one component contributing to yield, and biomass is also important. Furthermore, it is important to understand that aiming for large crops with high ear numbers will also require careful management of disease and lodging risks.

6. Conclusions

- A target final ear number of 500 ears/m^2 to achieve potential yield for inclusion in the WBF threshold scheme should be sufficient for most UK wheat crops, which are expected to yield up to 11 t/ha.
- For crops expected to exceed 11 t/ha, the target final ear number for the WBF threshold scheme should be increased to 600 ears/m^2.
- Variety was associated with ear number, and explained some of the variation in the relationship between ear number and yield. There was evidence that some varieties may have different ear numbers associated with specific yields, but the evidence was not strong enough to recommend including this as a parameter in the WBF scheme. Further research is required to quantify varietal differences for both GS31 shoot number and final ear number.
- Region was also associated with ear number, and explained some of the variation in the relationship between ear number and yield. However, the evidence was not strong enough to recommend including this as a parameter in the WBF scheme. Further analysis is required, once additional YEN data are available, to understand if these regional trends are consistent and to explore their underlying causes.

7. Acknowledgements

We acknowledge funding from AHDB and thank the YEN entrants and sponsors for making the data available for analysis.

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