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Consequence of spatial variability in the field on the uniformity of seed quality in a barley seed crop

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Abstract. *Spatial variation is known to affect cereal growth and yield but consequences for seed quality are less well-known. Intra-field spatial variation occurs in soil and environmental variables and these are expected to affect the crop. The objective of this paper was to identify the spatial variation in barley seed quality and to investigate its association with environmental factors and the spatial scale over which this correlation occurs.*

Two uniformly-managed, commercial fields of winter barley (cv Cassia, 4 ha, 2013; cv. California, 9 ha, 2014) in south east England, were assessed for spatial variation in germination, vigor, thousand grain weight and seed moisture content. Variable features within the fields included soil type (gravel terraces, clay cap and moisture retentive gullies) as well as an undulating topography. Unbalanced nested sampling design were designed based for each field based on pre-existing spatial data. The unbalanced sampling design included five spatial scales (1-81 m) with 138-150 sampling points per field. Canopy variables and soil samples were assessed at each point. Seed quality variables varied more over long (i.e. > 20 m) than over short (i.e. < 20 m) distances. Although germination and vigor tests were correlated at a 2.7m spatial scale with some canopy and soil variables, variation over this distance is not manageable by the farmer although it may assist in understanding intra-field variations. Correlations of seed quality with canopy and environmental variables also tended to be stronger over the longer distances. Some seed quality characteristics such as seed moisture content at final harvest, varied over long distances (>60 m). In terms of precision management of the field, seed producers might be able to harvest and dry seeds separately from different parts of the field.

Site-specific management in the field can therefore be proposed depending on the spatial variability of seed quality variables.

***Keywords**. seed germination, thousand grain weight, nested sampling, barley seed production*

Introduction

Variation in environmental conditions occurs within individual fields and from one season to another (Kumhalova et al., 2008; Diacono et al., 2012). This variation includes soil conditions, environmental factors and their interactions with the crop (James and Godwin, 2003). Determining within-field variation of these factors may contribute to improving crop management and agronomy in order to maximize crop yield and quality and hopefully, gross margins (Kumhalova et al. 2008; Oliver et al., 2013 It is well-known that soil, environment and crops seldom uniform over space and time, whereas commercial fields are generally managed uniformly (Webster and Oliver, 2007; Schmidhalter et al., 2008; Oliver et al., 2013). Research on precision cereal agronomy (Oliver and Carroll, 2004; Rajala et al., 2007) has mainly been focused on spatial variability of the cereal yield. To our knowledge, no research has evaluated spatial variability of seed quality, especially at different spatial scales. Within-field spatial variability of seed quality is likely to affect the achievement of high seed quality. This variation is also expected to lead to variation in the harvested yield (Ajeigbe and et al., 2008). Factors such as soil properties can vary at numerous spatial scales and the relationships with other factors can also vary at different spatial scales (Corstanje et al., 2007). Therefore, soil properties and microclimate of the crop environment ought to be investigated at different spatial sales (Frogbrook and Oliver, 2000; Kerry and Oliver, 2007; Heege, 2013). Spatial information of seed quality within field will possibly permit growers to regard production from the perspectives of quality or yield, or the association of both (Whelan and Taylor, 2013). Using a nested sampling design is an effective way to get information about variables at different spatial scales in the field (Lark, 2011). This paper evaluates the influence of the spatial distribution of environmental factors such as microclimate and soil properties on barley seed quality. An important objective was to identify the spatial scales at which barley seed quality and environmental factors varied. Then, make recommendations for improving uniformity in barley yield and seed quality through more precise management of the field.

Materials and methods

Study site and sampling scheme

Two uniformly-managed, commercial fields of winter barley (cv. Cassia, 4 ha, 2013; cv. California, 9 ha, 2014) in south east England were selected. The first experiment was conducted at Radbrooks field in Dunsden Green, near Reading in 2013, while the second experiment was conducted at Harts Hill Gull field in Thatcham, Newbury, near Reading in 2014.

An unbalanced nested sampling design with nine and ten main stations were used in Radbrooks and Harts Hill Gull fields, respectively. The design was unbalanced to limit locations to 14 per main station. The spatial scales for the nested design were based on prior information from a yield map and a green pixel analysis of a Google Earth satellite image in Radbrooks and Harts Hill Gull fields, respectively. Two equilateral triangles were included (Figure 1.). Point 1 was treated as the main station from which 13 additional sample points were derived. Points 6-10 branched from point 2, while points 11-14branched from point 3 of the bigger triangle. Spatial scales used in the design were on a geometric series of increasing distances, that is, 1.0, 2.7, 7.3 and 20m in Radbrooks and 1, 3, 9 and 27 m in Harts Hill. Distances between main stations were fixed approximately 55 and 81 m in Radbrooks (Figure 2) and Harts Hill, respectively. Angular separations from point 1 at each main station were chosen at random (including the orientation of the two equilateral triangles, Figures 1, 2) to determine positions of the 14 sampling points within a given main station. An additional 12 points, were included for mapping (M. Oliver and A. Milne, personal communication). Overall there was a total of 138 and 150 sampling points in Radbrooks and Harts Hill, respectively. The area of each plot at each point used for sampling and measurements was 0.25 m^2 (0.5 x 0.5 m) such that four crop rows were included in each plot.

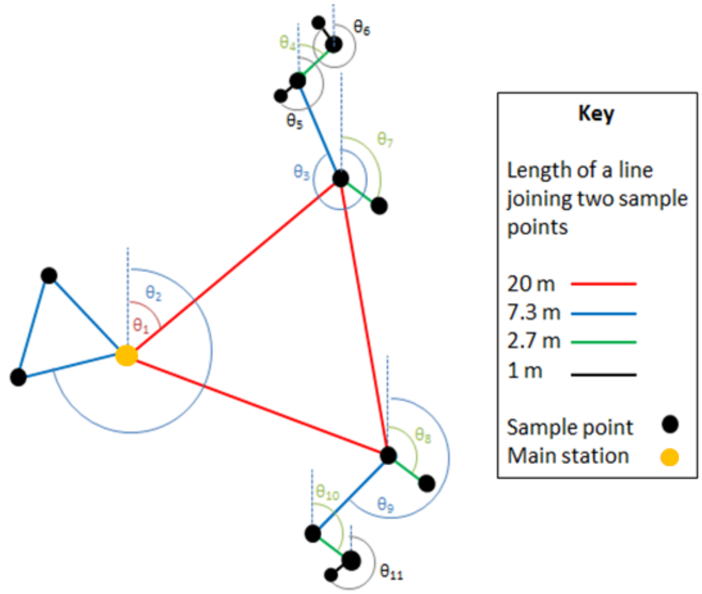

Fig 1. Basic design of the nested sampling scheme in Radbrooks field with vertices labelled with numbers. The lines with different colours on the legend key shows the various spatial scales used in the design in the first field, while in the second field these distances were 1, 3, 9 and 27m, respectively. Each angle shown ($\Theta_{1\text{-}11}$) were chosen randomly relative to north for each main station. The grey dotted lines are directed north.

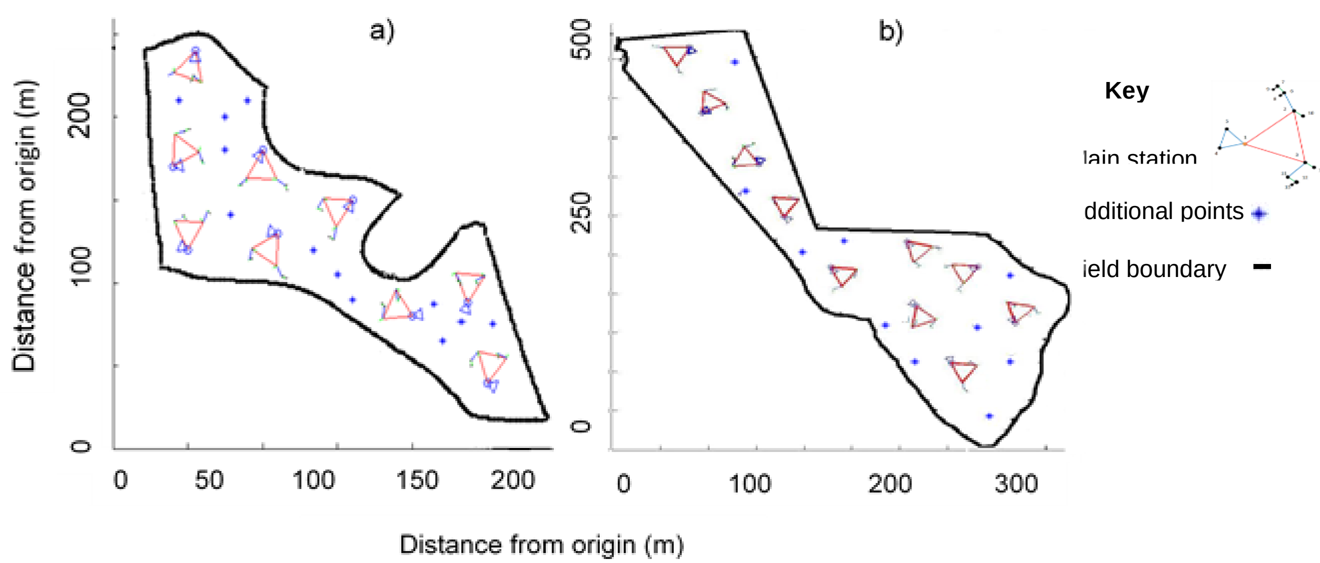

Fig 2. Sketch of the nested sample design used in a) Radbrooks field and b) Hart Hill Gull fields. Blue circles show the locations of position one of the nine main stations at the first field and ten main station at the second field, while blue stars represent additional sampling points. This scale drawing uses an arbitrary origin, the X and Y-axes being distances east and north, respectively.

Measurements

The measurements were conducted and soil samples collected in all plots. Crop canopy measurements at different growth stages included solar radiation interception and leaf area index (LAI) by using Ceptometer AccuPAR model LP-80 and crop cover estimated from green pixel analysis (WD3-WinDias software) of images captured using a Nikon D90 digital SLR camera. Crop canopy measurements were taken in April, May and June. The measurements of soil variables were included soil volumetric moisture content, soil pH, electrical conductivity (EC), soil texture, soil organic matter, and available soil phosphate (P), potassium (K), magnesium (Mg) and calcium (Ca). Palintest Soil Test Model 10 (Palintest Ltd, Palintest House, Kingsway, Team Valley, UK) was used to measure soil pH, electrical conductivity (EC) and soil nutrients. Barley seed measurements during seed development and at final harvest as applicable included seed moisture content, seed germination, seedling vigor and thousand grain weight (TGW). Grain yield for each plot was measured by hand-harvesting the central two rows of each plot (0.125 m^2 (0.25 m x 0.5 m)). For geostatistical analysis, each plot was geo-referenced with a differential GPS (Topcon Positioning Systems, Inc., 7400 National Drive, Livermore, CA USA 94550) with a quoted resolution of 5 cm. The latitude and longitude data for each plot in decimal degrees were converted to the UK national grid reference for mapping.

Germination was tested using rolled paper towels moistened with deionized water at 10°C for 14 days. Four replicates of 50 seeds were tested from each plot. Germination was counted after 14 days from the setting up the germination test, and seedlings were evaluated as normal, abnormal or dead seeds according to the ISTA (International Seed Testing Association) rules for germination tests. The test was maintained until all seeds had either germinated or died/gone moldy. Seedling vigor using a plumule growth test, also in rolled paper towels, at 20°C for 14 days. Two replicates of 25 seeds were tested from each plot in each case. Seed moisture content was tested using two replicates of ground samples dried for two hours at 130-133°C. These tests were also implemented according to the ISTA rules. Thousand grain weights are estimated on dry weights of samples.

Data analysis

Pearson's correlation coefficients were calculated using GenStat, regardless to the scales of the sampling scheme, to indicate the overall relationships between seed quality and environmental variables within each field. Residual Maximum Likelihood (REML) analysis of the nested sampling design estimated the variance and covariance for pairs of sampled variables at each spatial scale of the hierarchical design. The REML outputs of variances and co-variances were used for correlations between pairs of variables for each spatial scale (equation 1).

$$\text{Corr (V1,V2)}=\frac{\text{Cov (V1,V2)}}{\sqrt{\text{Var}}\text{(V1*V2)}} \quad (1)$$

Where, Corr= correlation of the two variables, V1 and V2; Cov= covariance of the two variables;

Var (V1* V2) = combined variance of the two variables

Confidence intervals for the correlations were calculated by Fisher's z-transform, with degrees of freedom appropriate to the number of sampled pairs at the corresponding level of the design. For each variable the components of variance were accumulated starting at the finest scales and plotted with the variograms.

In addition, variograms were estimated and modelled to quantify the spatial structure in the variance of the measured variables across the whole field using GenStat. The variables were then mapped across the field by ordinary kriging then contoured using the predictions in ArcMap (ESRI). Before analysis, values of some variables such as seed moisture content were found to have skewed distributions. These data were transformed (logarithm base (10)) to minimize the skewness and get more normally distributed data, which is desirable for geostatistical analysis (Kerry and Oliver, 2007). The spatial dependency of the data for each variable was estimated by the ratio of the nugget and sill semi-variances, such that a low value indicated high spatial dependency.

Results and Discussion

Except where specified to the contrary, the results presented here relate to the first field (Radbrooks) and the main focus is on seed moisture content at harvest. Descriptive statistics of the seed quality variables, yield, and some of the studied variables showed that the values for most of the variables were distributed normally while seed moisture content at final harvest and solar radiation interception May were skewed.

The coefficients of variation (%CV) - a measure of spatial variability within the field – ranged from approximately 2 to 58 % for seed quality variables such as germination and seed moisture content at final harvest. Pearson's correlation coefficients between variables were calculated and their significance checked by Fisher's z-transform. Although many of these correlations were weak, most correlations with seed moisture content at final harvest were significant. For example, its correlations with soil moisture and clay content were 0.70 and 0.54, respectively although it is not possible to make any inferences about possible causal relationships between these variables and seed moisture content. The only significant correlations with germination at final harvest was with leaf area index during June (-0.20). Significant correlations with seedling vigor were always negative, the highest being -0.56 with crop cover during June. A significant positive correlation, 0.35, was observed between thousand grain weight and clay content while grain yield was only correlated significantly with solar radiation interception during May which was 0.30. These results indicated that relationships between barley seed quality variables, especially seed moisture content, and soil variables were stronger than the relationships with crop canopy variables.

From geostatistical analysis of, the spatial variation of the studied variables. The spatial dependencies were strong for thousand grain weight and seed moisture content while other barley seed quality variables showed weak spatial dependency (based nugget and sill semi-variances). The variogram models differed between the studied variables as did the lag distance to reach the sill. The variograms of studied variables all reached a sill which implies the variation in these variables is patchy producing areas in different parts of the field. These results confirm that sampling protocol was sufficient to determine the variogram, nugget effect, sill values and the average extent of variation. For example, the variograms of log seed moisture content at final harvest was fitted with a double spherical model, while TGW was fitted with a circular model, indicating that there were different patterns of spatial variation in seed quality variables.

The calculated components of variance according to the sampling scheme (Fig. 1) for barley seed quality showed the obvious spatial structure in the data with the increase in the accumulated components of variance similar to that shown by the variograms as function of the increase of spatial scale or lag distance (data not shown). The components of variance therefore generally increased with increase in spatial scale (i.e. 1, 2.7, and 7.3 m). Where the components of variance were negative, for example at 7.3 m, the implication was that points separated by 7.3 m were less variable than those over shorter distances. Although these effects were sometimes observed over short spatial scales, the variances were not significantly less than that at shorter spatial scales. The main point is that variances increased greatly over the larger spatial scales (20 and 55 m) for seed quality variables such as seed moisture content at final harvest and TGW, showing more spatial variability at these spatial scales especially > 55 m (data not shown).

These are potentially interesting results in terms of the practical management implications seed crops. For example, since seed and grain moisture contents correlated with soil moisture and clay contents, a farmer could divide the field into zones likely to have lower or higher moisture contents. If the seed or grain was likely to need drying after harvest, the field could be harvested by zone so that the moister seeds could be dried separately. In addition, the results indicated most of the variations occurred at spatial scales of more than 20m, which is approximately equal to the width of the harvester and the tractor, harvesting and transferring the seeds, including the distance between them. Harvesting by zone would avoid mixing seeds at various moisture contents and might therefore avoid unnecessary use of energy to dry seeds. The correlations between barley seed quality variables such as seed moisture content and TGW, and soil moisture and clay content were weak and not significant in Harts Hill Gull field, whereas the variogram and accumulated components of variance of these variables were similar to the same variables in Radbrooks field in terms of increasing variance over spatial scales (results not shown).

The kriged maps of seed quality variables show different spatial distribution for these variables. However, in some parts of the field some variables show a similar pattern of variation. For instance, the high seed moisture content in the north-west and south east of Radbrooks field were associated with higher soil moisture. While correlation does not prove causation, the moisture retentiveness of the soil may be affecting seed moisture content at final harvest. The maps of seed quality and soil properties may therefore guide the farmer in field management more precisely. Seed moisture content showed similar variability in the second field (results not shown).

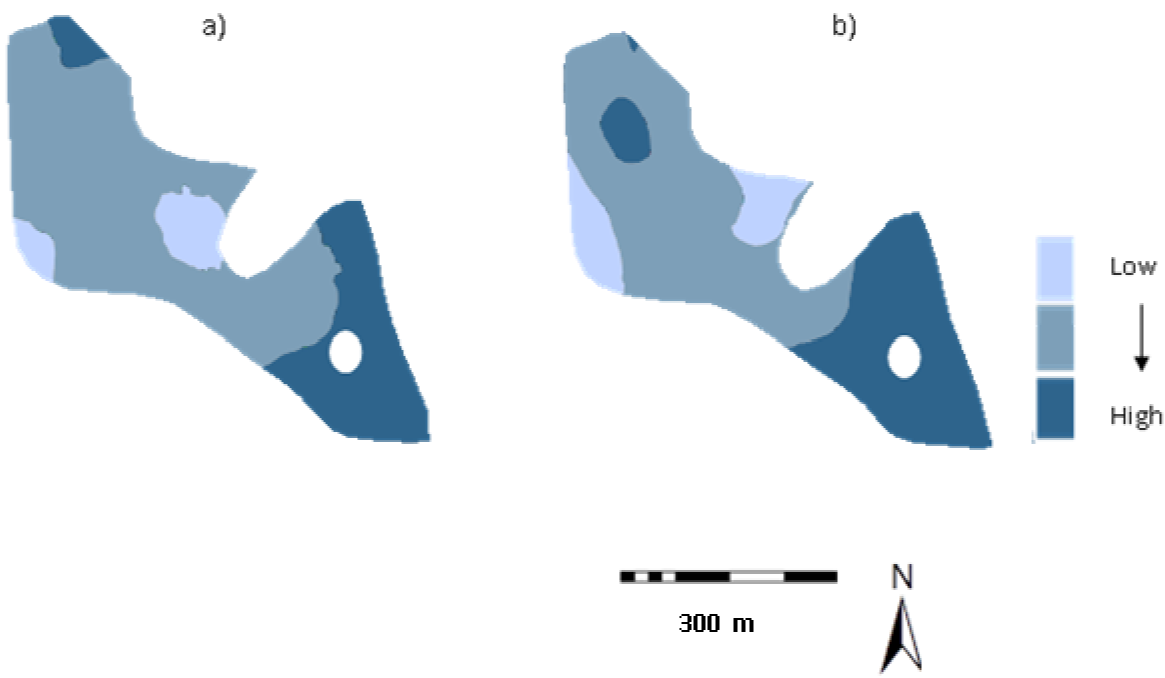

Fig 3. Kriged maps of Radbrooks field, Radbrooks, for seed quality variables a) seed moisture content (%) at final harvest and b) soil moisture content (%). The white circle is the area of a tree in the field.

Conclusion

The majority of spatial variation was accounted by sampling protocol in Radbrooks field, and it was sufficient to model the variogram and quantify the nugget effect, sill value and the average extent of the variation. Seed quality variables were correlated with crop canopy and soil variables but correlations with soil factors appeared to be greater than for crop canopy variables. Therefore, spatial variations of canopy variables were less useful as predictors of seed quality and soil moisture content are more highly correlated with seed quality variables. As expected, variation over long distances was higher than at the short distances for most variables. On the other hand, variation at short distances needs more investigation to find out the relationships which may be affecting seed quality although it is unlikely that a farmer would attempt to manage the seed quality of cereals like barley at spatial scales lower than 20 m.

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