On-farm Experiment (OFE) with Focus on Large Strip Trials

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SAGI West, Curtin University
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WHO WE ARE

SAGI
Statistics for the Australian Grains Industry
National | North | West | South

GRDC

Curtin University

SAGI West houses a team of five staff who are dedicated to promoting and improving statistical awareness amongst GRDC contracted researchers through education initiatives and mentoring.

Professor Adrian Baddeley

As a leading academic researcher in statistical science, my role is to develop new statistical methodology for difficult problems in spatial data analysis. I work mainly on the analysis of spatial patterns of events and develop open-source software that can be used by other statistical researchers.

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Dr Katia Stefanova

For the past 25 years, my research interests have been directly linked to my consultancy work, which is focused on the application of linear mixed models, spatial statistics, experimental design, multivariate techniques in plant breeding and agricultural, biological and environmental sciences. I have experience in teaching statistics and training in experimental design, statistical analysis and the use of a number of statistical packages.

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Dr Kefei Chen

I have experience in statistical modelling. This includes generalised linear and additive modelling to build dynamic yield prediction systems and decision tools, used to optimise fertiliser rates. My experience also extends to experimental design and linear mixed model analysis in the areas of agronomy, pathology and farming systems. I also bring to the team an advanced knowledge of molecular genetics, comparative and evolutionary genomics and environmental health, and experience in programming using R, Stata and SAS software.

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Dr Karyn Reeves

My experience is in the design and analysis of agricultural trials, with a particular focus on the impact of frost on cereal crops and foliar and root diseases of wheat, including fitting complex linear mixed models to trial data. I also have advanced knowledge of methods used to control for population structure in host-viral association studies, and experience in statistical modelling and programming using R software.

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Dr Suman Rakshit

Experienced Researcher with a demonstrated history of working in the research industry.
Professional Biometrician and Data Scientist with a PhD in Statistics from Monash University.
My research interests are spatial statistics, nonparametric statistics, machine learning algorithms, and experimental design.
Skilled in R, Python, C, C#, SQL, Power BI and Tableau.

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Talk Outline

- Statistical thinking is important
- OFE categories
- Comparative OFE (For large target region)
- Site-specific crop management (SSCM) trials
- Global and local estimation of the treatment effect
- Strip trials vs small plot experiments
- Proposed method for statistical inference
- Questions/comments

Why statistics is important?

- Why we need experimental design?
  Why we need rigorous and robust methods of analysis?
  How do we know a new crop variety is better than the standard?
- Experiments are expensive!
  You like to generate most reliable data that can provide the correct
  information. Confounding can be a big problem if not considered.
- What questions to ask, how to test, and how to interpret the results?
  Extrapolation of the results is a big problem in many fields.

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Design and Analysis of Agricultural Field Trials

- *Spatial variability is common in a field – unless accounted for, may result in seriously biased treatments estimates and inflate standard errors.*
- *Can be addressed by sound experimental design, careful trial manage appropriate statistical analysis.*
- *Good design is cornerstone of field trials – RCBD, BIB, PBIB, α-design, row-column, augmented, neighbour-balanced, p-rep design.*
- *For analysis: Linear Mixed model and REML technique*

OFE Categories

- Comparative OFE
  - Objective is to compare the mean performance of the treatments for a large target region.

- Site-specific management trials
  - Objective is to compare the treatments for future management of the same field.

Comparative OFE

- *The farm is considered a single replication*
- *Single replicated trials on large strips*
- *Simple designs used in these OFEs*
- *Conducted at a large number of locations than OS experiments*
- *The data from OFE are unbalanced*
- *There are not many studies comparing OF and OS experiments*
- *Two studies (Yan et al., 2002; Schmidt et al., 2018) compared data from OF and OS experiments in the context of cultivar evaluation*

Site-specific Trials (Global Estimation)

- Objective is to estimate treatment effects only for the field (global estimation)

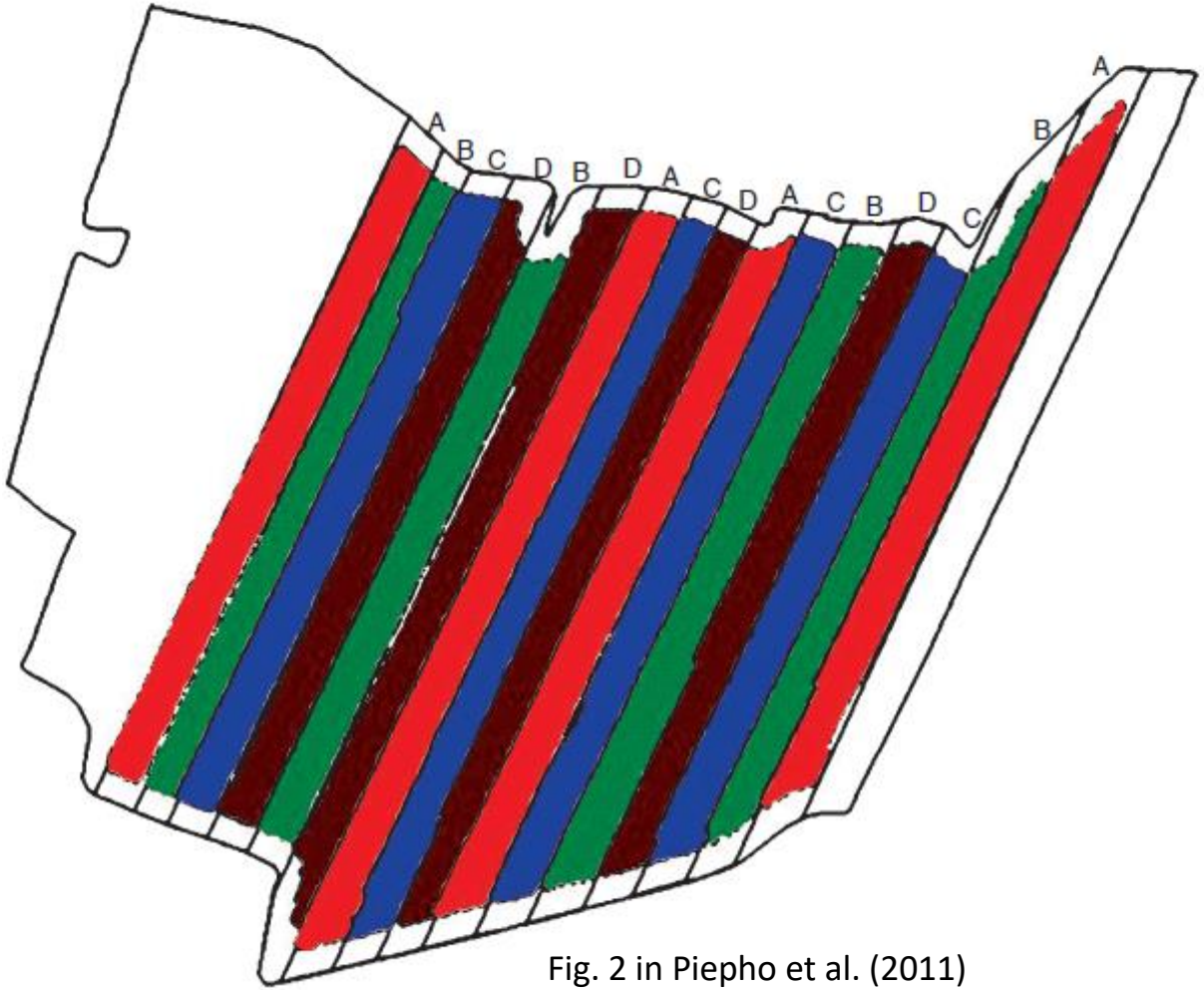

Fig. 2 in Piepho et al. (2011)

Site-specific trials (local estimation)

- *Management-class experiments and local-response experiments.*

- *Objective of the management-class experiments is to compare how a crop responds to the applied treatments between and within different spatial zones/management classes in the field*

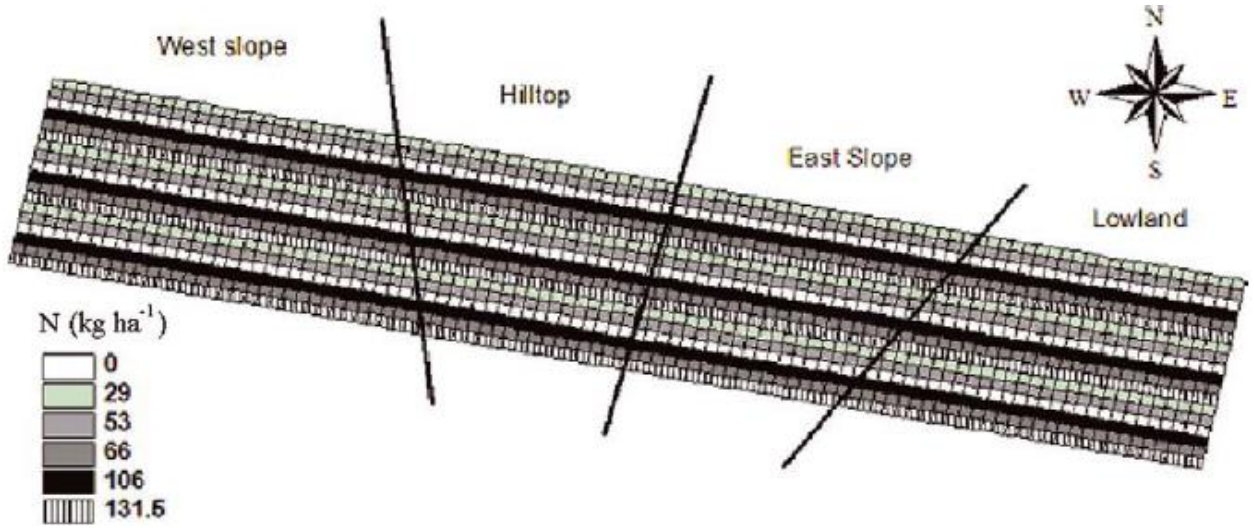

Fig. 1 in Lambert et al. (2004)

SSCM trials seeking local estimation

- Objective of the local estimation is to obtain a fine-scale spatially variable optimum rate of the inputs

- Based on the hypothesis that the treatment and environmental effects are not additive across the entire field

- Localised inference (estimation and significance testing) for the treatment effects

Strip Trials versus Small-plot Experiments

- *The yield data are correlated in large-strip trials. Can not use classical ANOVA methods for estimation. Geo-statistical models are typically used to handle the autocorrelation.*

- *No true replication of treatments 2 and 3. Multiple observations per plot. Need to take into account the issue of pseudo-replication while hypothesis testing.*

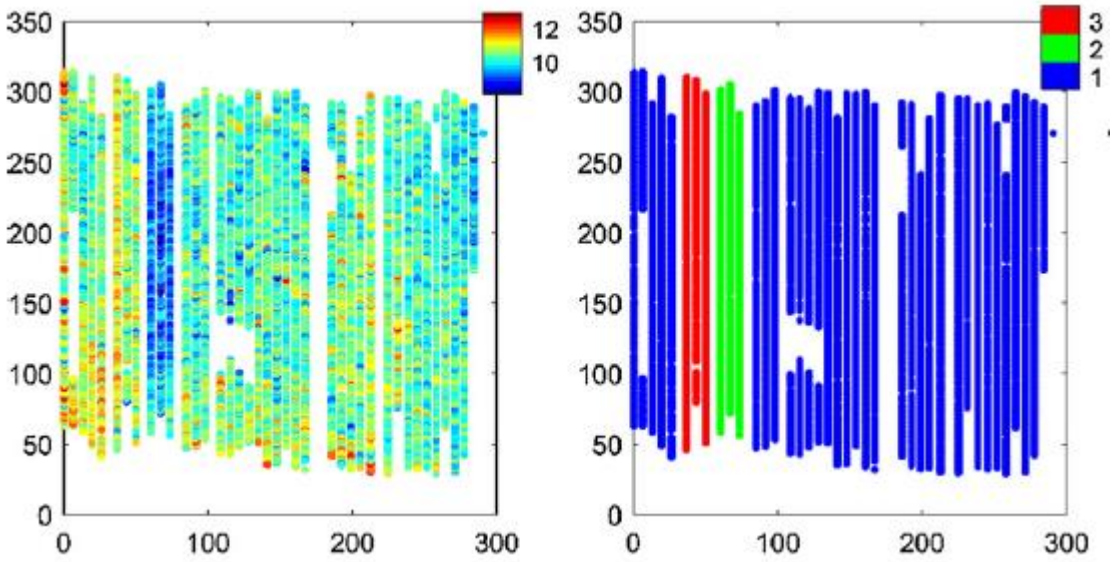

Fig. 7 in Merchant et al. (2019)

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Inference for the Large-strip Trials

- *Two papers Merchant et al. (2019) and Lawes and Bramley (2012) have recently analysed strip trials.*

- *Two broad questions are:*

(1) Which is the overall best treatment?

Model: $\boldsymbol{y} = \boldsymbol{X\beta} + \boldsymbol{\varepsilon}$ **where** $\boldsymbol{\varepsilon} \sim \boldsymbol{N(0, V)}$

REML estimate: $\hat{\boldsymbol{\beta}} = (\boldsymbol{X}' \hat{\boldsymbol{V}}^{-1} \boldsymbol{X})^{-1} \boldsymbol{X}' \hat{\boldsymbol{V}}^{-1} \boldsymbol{y}$ **with estimated variance**

$$\sum = \widehat{var(\hat{\beta})} = (X' \hat{V}^{-1} X)^{-1}$$

Test statistic: $\hat{\beta}_j / \hat{\sigma}_j$

where $\hat{\sigma}_j$ **is the** j**th diagonal entry of** $\sum$

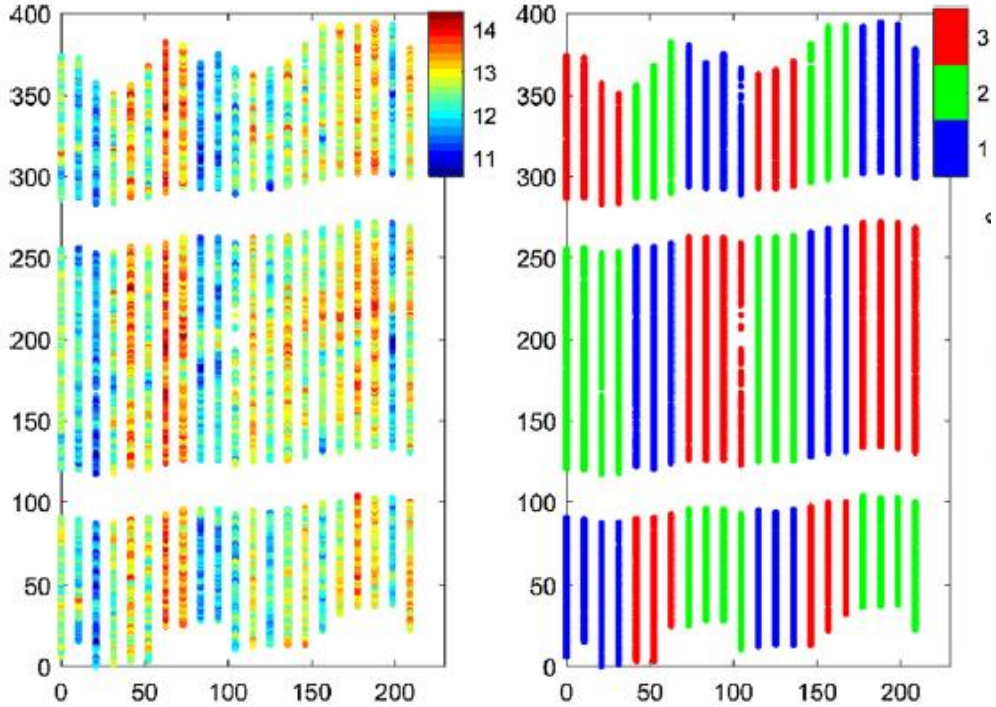

Fig. 6 in Merchant et al. (2019)

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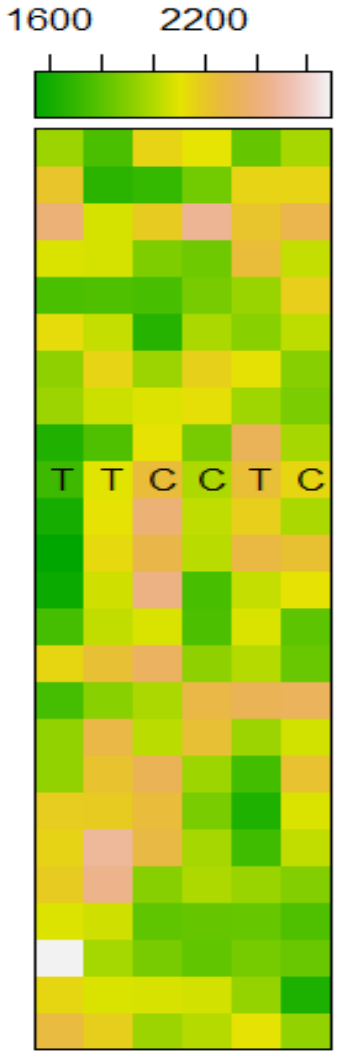
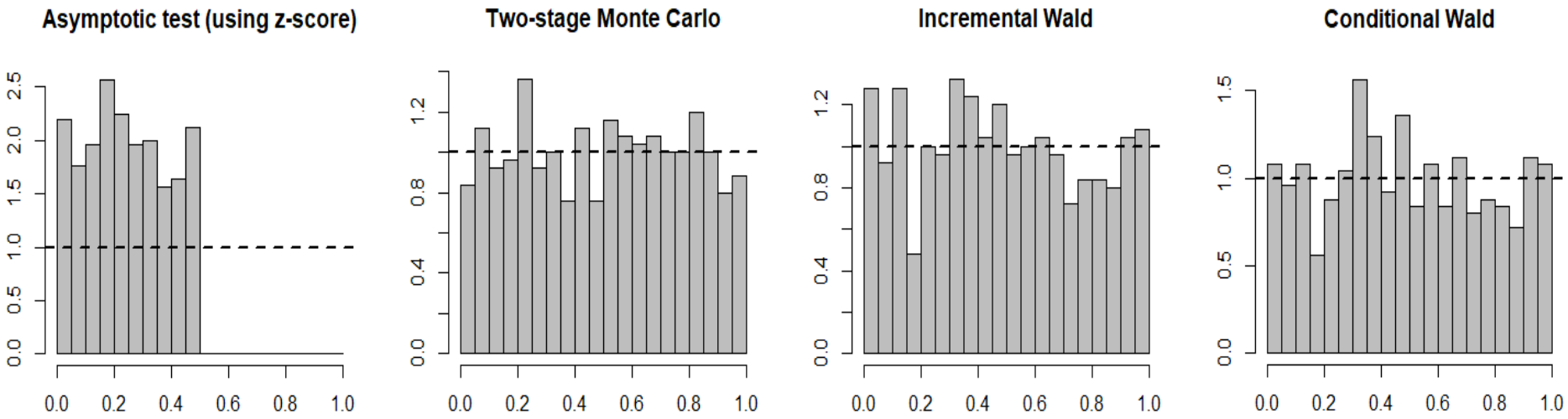
Testing for overall mean effect

How good is this asymptotic test?



- 6-columns (2 treatments (T & C) with 3 reps each)
- Simulated from the null distribution (nsim = 500)
- Average yield: 2000
- Spatial variation: AR1 x AR1 with

$$\sigma^2 = 50{,}000\,, \quad \rho_r = 0.5, \quad \rho_c = 0.3$$



Type-I error rate

α				
0.05	0.110	0.042	0.064	0.054
0.10	0.198	0.098	0.110	0.102

Two-stage MC test

Algorithm 2 (*Balanced Independent Two-Stage Test*).

Given data $\boldsymbol{x}$ and significance level $\alpha = (k+1)/(n+1)$ where $k \in \{0, \ldots, n-1\}$,

$t \leftarrow T(\boldsymbol{x})$; $\hat{\theta} \leftarrow \hat{\theta}(\boldsymbol{x})$

First stage: For $i = 1$ to $i = m$

  Generate a realization $\boldsymbol{x}_i$ from $\boldsymbol{P}_{\hat{\theta}}$

  $t_i' \leftarrow T(\boldsymbol{x}_i)$

Compute $p \leftarrow (m+1)^{-1}(1 + \sum_{i=1}^{m} \mathbf{1}(t \leq t_i'))$

Second stage: For $i = 1$ to $i = n$

  Generate a realization $\boldsymbol{y}_i$ from $\boldsymbol{P}_{\hat{\theta}}$

  $t_i \leftarrow T(\boldsymbol{y}_i)$; $\widehat{\theta}_i \leftarrow \widehat{\theta}(\boldsymbol{y}_i)$

  For $j = 1$ to $j = m$

    Generate a realization $\boldsymbol{y}_{ij}$ from $\boldsymbol{P}_{\widehat{\theta}_i}$

    $t_{ij} \leftarrow T(\boldsymbol{y}_{ij})$

  Compute p_i from (4)

Compute $\hat{p}$ from (5), resolving tied values by imposing a random ordering

Reject $\mathcal{H}_0$ at level α if $\hat{p} \leq \alpha$.

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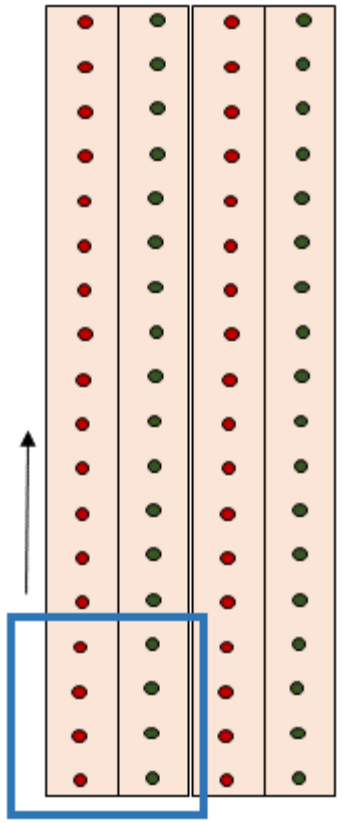
Moving Window Analysis for Localised Inference

(2) What is the best treatment in different parts of the field?

Here we seek to measure the spatial variation of treatment effects or interaction between treatment and spatial windows across the strips.



- *Pairwise t-statistic and corresponding p-value are computed using the observations within the window.*
- *The window is moved one row up to compute localised t-statistics and p-values.*
- *Note that a systematic treatment application*

Moving Window Analysis

- *These localised t-statistics or the treatment effects can be plotted and compared against the overall treatment effect for the entire field/zone.*
- *In the paper Lawes and Bramley (2012), the authors plotted the yield differences under two treatments.*
- *Such localised analyses are useful to the farmers.*
- *There is no study assessing the validity of this method.*

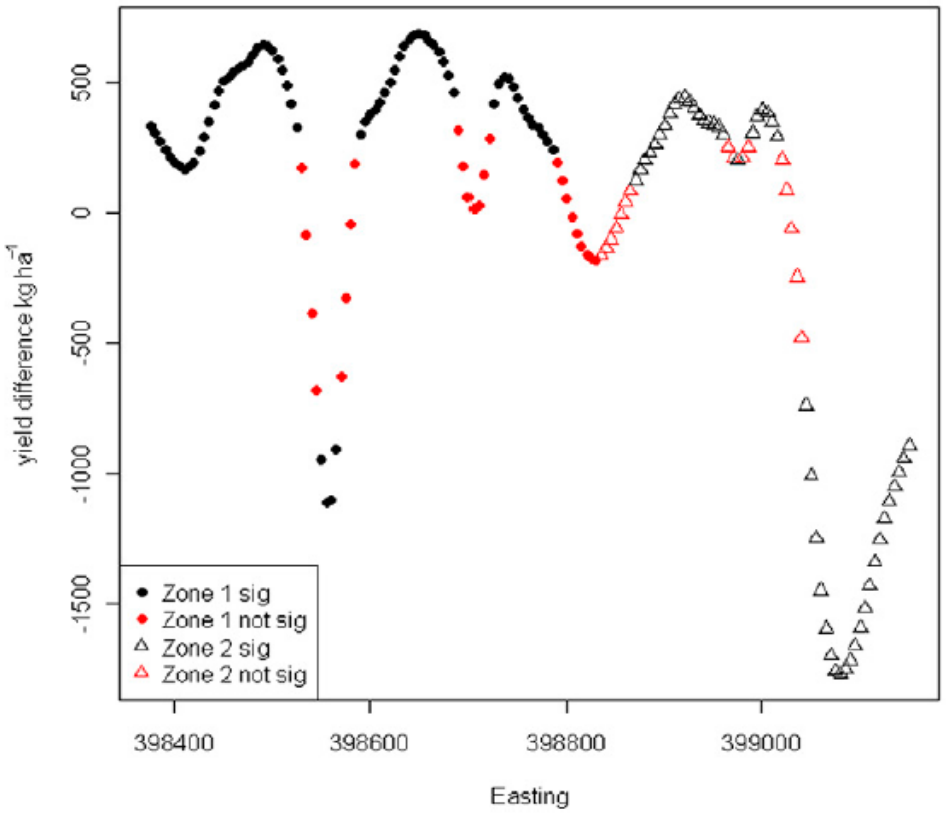


Figure 3 from Lawes and Bramley (2012) showing the yield difference between two treatments against the centre of the moving window in the field.

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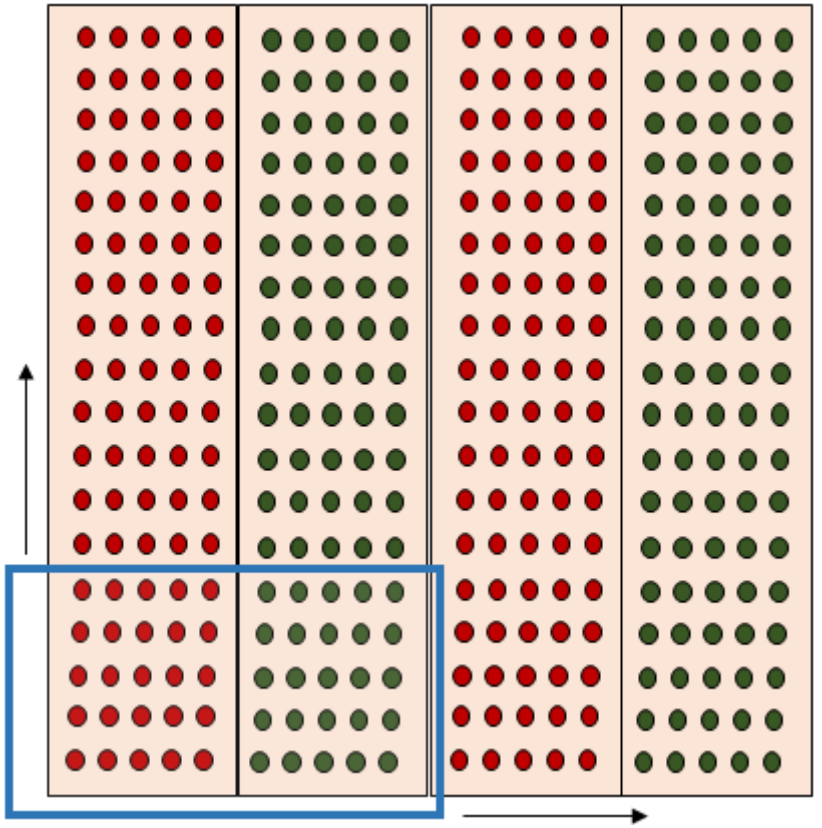
Few comments on the Moving Window Analysis

- *The method assumes one grid value in one of the directions.*
- *This method computes the localised pairwise t-statistics by treating the observations within the window as independent observations.*
- *Using the standard normal critical value to calculate p-value, and using that p-value for concluding significance may not provide correct inference.*
- *Because the tests are correlated, the problem with multiple comparisons and false discovery rates may arise.*



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How to Test for the Localised Optimum Treatment?

- *Because strip trials are usually non-randomised and comprised of plots of large sizes, the analysis should take into account any possible spatial trend before estimating localised treatment effects.*
- *Since the observations within windows are correlated, methods that take into account this correlation shall provide better inference.*
- *Improved methods are required for concluding significance at grid locations in the field.*
- *We plan to study geostatistical simulations in the context of localised estimation of the effects.*

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Thank You!