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Core ideas (3-5 impact statements, 115 char max for each)

Optimal design for on-farm strip trials — systematic or randomised?

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Abstract

Randomisation is a crucial aspect of agricultural experiments for both agronomists and biometricians. While randomised designs are predominantly used for small trials and large on-farm experiments (OFE), the choice between randomised and systematic designs may depend on the objective of the OFE. Suppose the goal is to produce a smooth map of optimal input levels across a grid covering the entire field, in that case, a systematic design may be preferred for its robustness and reliability. Our simulation study using the Bayesian hierarchical model and geographically weighted regression (GWR) shows that, for large OFE strip trials, the difference between randomised and systematic designs is insignificant when fitting a linear model or ignoring spatial variation. However, for quadratic models, particularly with the presence of spatial variation, systematic designs are superior to randomised designs in terms of smaller true mean squared errors (MSE) of coefficients.

1 Introduction

The principles of randomisation were first expounded in 1925 by Fisher (1934), who analysed a few systematically arranged experiments and pointed out that randomisation can provide valid tests of significance subject to appropriate restrictions, such as experimental units arranged in blocks or in rows and columns of a Latin square (Verdooren 2020). Traditionally, small-plot trials for agriculture are designed to accentuate treatment effects with the completely randomised design (CRD) as the most straight forward, least restrictive experimental design. More complex designs, such as a randomised complete block design (RCBD), a split-plot design, a strip-plot design and a Latin square design, are also widely used in agricultural experiments (Petersen 1994). Following these principles, randomised designs are routinely used for on-farm strip trials, while systematic designs are rarely used.

OFE enables farmers the flexibility to implement large-scale experiments in order to test management practices on their farms (Evans et al. 2020). The goal of OFE is to help farmers better understand uncertainties and leverage their existing strengths in managing translational and structural uncertainty (Cook et al. 2013). In the situation that the goal is to compare yield responses between management classes or to select individuals with the best performance as new market varieties, a randomised design is superior to a systematic design (Pringle et al. 2004; Selle et al. 2019). While randomisation is often considered a crucial prerequisite for obtaining valid statistical inferences (Piepho et al. 2013), this is not always the case when the goal of on-farm experiments (OFE) shifts from the conventional analysis. In the application of precision agriculture (PA), the variable rate applicators (VRA) require a prescription map of the experiment before the start of the operation (Pringle et al. 2004). Therefore, in this scenario, the goal of OFE becomes obtaining a smooth map showing the optimal level of a controllable input, such as nitrogen rates, across a grid made of rows and columns covering the whole field. For this objective, Piepho et al. (2011) stresses that only a single level of treatments can be directly observed at any one point on the grid and the response for other levels at the same grid must be interpolated. If a randomised design is conducted, the interpolation distances to locations with treatment levels of interest will vary throughout the field. Such heterogeneous distances increase the uncertainty in the analysis and reduce the efficiency of local prediction. As a result, a systematic design is preferable to a randomised design in this scenario. Unfortunately, this perspective has often been overlooked by researchers, leading to the widespread use of randomised designs.

Analysing a systematic design for the creation of an optimal treatment map for on-farm experiments (OFE) is a statistically challenging task. The truly localised estimation at each point on the grid is unknown, and the optimum treatment response varies continuously across the field. Cao et al. (2022) implemented a Bayesian approach using spatially correlated random parameters for large systematic OFE strip trials, assuming a quadratic response model with both global and local spatially varying components. However, the Bayesian approach is time-consuming and requires preliminary knowledge of Bayesian statistics for farmers and agronomists. Alternatively, Rakshit et al. (2020) adopt a local regression approach, called geographically weighted regression (GWR), to obtain spatially-varying estimates of treatment effects for OFE. Additionally, Evans et al. (2020) conclude through simulation studies that GWR is a simple method for OFE data analysis and is capable of accurately separating yield variation that is not due to applied treatment from yield response due to treatment. However, their study was limited by the use of a randomised design and the assumption of a linear response to fertiliser treatment. Alesso et al. (2021) simulated corn yield with four nitrogen levels assigned systematically and randomly in the chessboard designs and fitted the true coefficients using GWR. They concluded that systematic designs achieved the best results in most cases. However, in these simulation studies, the use of chessboard design presents a problem: harvesters can smooth over abrupt treatment changes between plots, potentially leading to misleading results unless there are constraints on the field (Pringle et al. 2004). Additionally, the quadratic or plateau feature was not considered a factor in the simulations.

Piepho and Edmondson (2018) demonstrate an example that a linear model is lacking in fitting to the sugar beet data (Petersen 1994). Glynn (2007) show that many curves exist beyond a linear trend for nutrient-response relationships. The curve depends on the current availability of other macro and micronutrients in the soil (Marschner 2011), meaning that a linear relationship is unlikely to be consistent across a large trial. For this reason, it is important to consider models with degrees higher than 1, which means a quadratic model was found to be suitable for relationships (Piepho and Edmondson 2018; Liben et al. 2019).

Our study uses simulation examples to demonstrate that randomisation is not essential for large strip trials. For the purpose of obtaining a treatment map, a systematic design is superior to a randomised design, subject to appropriate restrictions. We also test the power of GWR to determine if it can successfully estimate spatially varying treatment effects for both linear and quadratic responses. Our results show that the optimal bandwidth found by AICc is not the best for GWR. Instead, a fixed bandwidth based on the experimental design is recommended.

The structure of the paper is organised as follows: In Section 2, we describe the statistical model for generating simulated data, which has spatially varying coefficients of treatments, and the GWR model to fit OFE data. In Section 3, we generate simulated data for the combination of the following scenarios: randomised and systematic designs; linear and quadratic response; low and high coefficient correlations; spatial variation among grids is identity (no spatial trend), AR1 ⊗ AR1 and Matérn form. Finally, in Sections 4 and 5, we illustrate the results and discuss

their importance with respect to OFE, and how the findings should influence future trial designs.

2 Methods

This section describes the statistical model used in the simulation study. It outlines the basic model (Subsection 2.1) followed by the methodology for the spatially correlated treatment parameters (Subsection 2.2), and finally GWR (Subsection 2.3).

2.1 Basic statistical model

In a conventional agricultural study, a field experiment can be considered as a rectangular matrix consisting of r rows and c columns, where the total number of plots in the experiment is n = r × c. The notation si ∈ R2, i = 1, . . . , n is a two-cell vector of the Cartesian coordination of the plot centroids, located on a regular grid (Zimmerman and Harville 1991). Hence, y(si) denotes the dependent variable at a query location/grid i.

With the assumption that Y is the vector of the plot data ordered as rows nested within ranges (columns), then the matrix notation of the model is

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|  |  | *( 1 )* |

where b and u are vectors of fixed and random effects, respectively; X and Z are the associated design matrices; and e is the error vector. We further assume that u and e are pairwise independent and that their joint distribution is

2.2 Spatially correlated treatment parameters

3 Results and Discussion

Use tables, graphs, and other illustrations in the Results section to provide the reader with a clear understanding of representative data obtained from the experiments. Call attention to significant findings and special features, but do not repeat what is already clear from an examination of the graphics. If you have minimal results, describe them in the text.

Use the Discussion section to interpret your results. Whether combined with the Results section or standing alone, the Discussion section should focus on the meaning of your findings, not recapitulate them. For more information, please see [chapter 1](https://www.agronomy.org/files/publications/style/chapter-01.pdf) of our style guide.

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Figure 1. This is an example figure legend.

Table 1. This is an example table.

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| Aa | B | C | D | E |
|  | kg ha-1 | | mg | |
| 1 | Asdf | Yes | 12 | Data |
| 2 | Asdf | Yes | 34 | Data |
| 3 | Asdf | No | 56 | Data |

aTable footnote