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A 'small strip' approach to empirically determining management class yield response functions and calculating the potential financial 'net wastage' associated with whole-field uniform-rate fertiliser application

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ABSTRACT

Site-specific crop management requires site-specific information. The amount and pattern of variability in natural resources and production output, the reasons for variability, the agronomic implications and the management opportunities ultimately need to be identified locally. In this context it is often desirable to obtain information on any variability in production response to different application rates of inputs across a site in order to help identify if worthwhile financial gains can be made by implementing spatially variable application rates. However there has been little development and promotion of practical, considered experimental design and analysis techniques that can be applied at a commercial farm scale to test variability in optimal input rates. Here a stratified, randomised, replicated 'small strip' experimental design is proposed for use in commercial-scale cropping systems that employ a management class approach. The experimental design considers technical, economic, agronomic and non-spatial statistical constraints and seeks to find a compromise between these constraints such that any one constraint is not limiting to adoption or interpretation. A description and rationale for the experimental design and analysis is presented followed by the results from the application of this experimental design to 15 nitrogen and 18 phosphorus response trials on various types of crops, in 3 different regions of Australia, over 6 seasons. Under these conditions, the results show that optimum response data can be obtained using the experimental technique. A gross margin analysis for each experiment was used to calculate the 'net wastage' in fertiliser and yield resulting from the customary, spatially uniform input management. A median 'wastage' of A$39/ha for nitrogen fertiliser and A$48/ha for phosphorus fertiliser was observed. Standardising the individual results to the total, seasonal cost of uniform fertiliser application in each experiment, determined that the median 'net wastage' value equated to 99% of the traditional fertiliser budget for phosphorus and 97% for nitrogen. These figures suggest that the potential financial benefit to be gained over a number of seasons by knowing more about the optimum rates of fertiliser for management classes within a field could be equal to the amount of money traditionally outlaid on fertiliser. The technique does have some statistical limitations that require a practical, agronomic interpretation to be included in an assessment of the results. Although applied to nutrient response experiments in this study, it could be adapted for any crop input or management practice experiment.

1. Introduction

Site-specific crop management (SSCM) aims to identify, seek explanation for, and provide optimal solutions to local variation in production. Investigating the causes of variability and ameliorating to restore/raise production potential where possible is a generic precursory step to exploring variable-rate nutrient management. If investigations indicate variable-rate nutrient management as a potential next step, then decisions on fertiliser requirements and application rate changes need to be made. Traditionally, crop fertiliser requirements are determined using district- or regionally derived yield response functions. This is despite the fact that crop production (yield and quality) and response to nutrient inputs has been shown to vary both within and between fields (e.g. Holford et al., 1992; Kitchen et al., 1995; Mamo et al., 2003; Whelan et al., 2009). In view of this situation, it would appear desirable for producers to determine the degree to which functions that describe yield response to a wide range of applied fertiliser rates may vary

Abbreviations: SSCM, site-specific crop management; VRT, variable-rate technology; ANOVA, analysis of variance; REML, restricted maximum likelihood; OLS, ordinary least squares; MC, marginal cost; MR, marginal revenue; GM, gross margin; OR, optimal input rate.

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across their own production systems. The information obtained would be useful in 'ball-parking' any potential local benefits to variable-rate management and provide a valuable contribution to future decisions on changes to optimal application rates at both the whole-field and within-field scales.

Over the past 20 years there have been significant advances in both vehicle positioning and input placement technologies for broadacre production systems (Bramley, 2009). As a result, producers now have the technical capabilities to establish and harvest numerous agronomic experiments within their own commercially productive fields. However, spatial design-rules and analytical procedures to optimise these 'on-farm' experiments at a commercial scale remain poorly defined, and so informative within-field experimentation remains uncommon (Robertson et al., 2012).

Initial on-farm experimentation studies with variable-rate technology (VRT) and yield sensing systems tended towards the use of highly complex designs, such as checkerboard designs, continuous 2- and 3-dimensional sinusoidal patterns or whole-of-field randomised complete block designs (Bramley et al., 1999; Sadler et al., 2003; Pringle et al., 2004b; Stewart et al., 2005; Panten et al., 2010). These designs are statistically robust and can be applied using VRT but they do require a high level of statistical and agronomic knowledge to design and analyse (Pringle et al., 2004b). The objectives of these designs were to maximise the agronomic information obtained from the experiment. However, their widespread use in broadacre yield response trials may entail considerable production loss and therefore expense, due to the full field coverage, if treatments include rates (high and/or low) that retard production. While a producer may be willing to suffer some economic losses within a field in a 'proof-of-concept' experiment, the trade-off between information gained and production loss must be compelling for the producer to extend such complex, highly invasive studies across the entire production system.

In contrast, and perhaps in response to these highly complex designs, more recent on-farm experimental approaches have tended towards more simplistic designs, in particular field-length strip designs, where an experimental input rate is applied as a strip over the length of the field (Fig. 1) (Hornung et al., 2003; Ebertseder et al., 2005; Khosla et al., 2005; Thoele and Ehlert, 2010; Lawes and Bramley, 2012). Strip designs tend to be more acceptable to producers as they have usually had previous experience with variety strip trials. These designs, particularly where a small number of treatments in unreplicated strips are employed, use less of the field compared with whole of field designs. This minimises the cost of the experiment, especially in lost opportunity when experimental treatment rates are below optimal. Field-length strips also have a distinct advantage in adoption over complex designs in that their implementation is not reliant on a high level of technology. Experimental input rates can be set manually at the start of a strip and then adjusted back to the whole field application rate at the end.

However, simplified strip designs create statistical issues with analysis that can easily generate incorrect or misleading results. For field length strip experiments where the yield is monitored by harvester-mounted sensors, the individual yield measurements do not constitute true replications of a treatment (Gotway Crawford et al., 1997). There is also autocorrelation among observations along the strips, and so the actual number of data values recorded overestimates the number of independent observations that can be used for response analysis. Field-length strips are also strongly spatially constrained. In the example of Fig. 1, the strips are oriented horizontally to capture response within the two defined management classes. However, with no a priori knowledge of production variation in the field and/or if the direction of sowing/harvesting was not east–west, then it would be difficult to align the strips to capture the potential variability in response within this field. Increasing the number of independent observations can be achieved by using

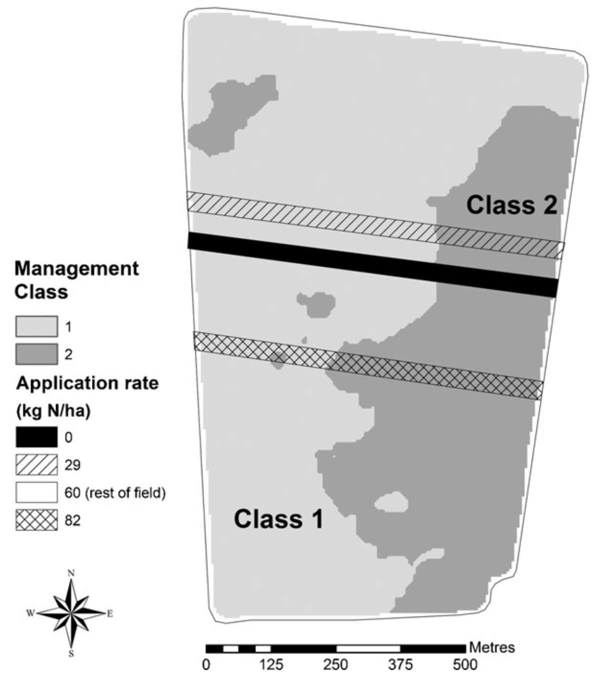

Fig. 1. An example of a whole field strip approach to within-field experimentation. The field has been delineated into two management classes. Three treatment strips have been applied. A fourth rate (60 kg N ha^{-1}), consisting of the producers mean application for the field is applied to the rest of the field.

replicated whole-field strips (e.g. Panten et al., 2010), but this approach moves back towards becoming more invasive.

Regardless of the design, approaches to within-field yield response to fertiliser rate experimentation should operate within the technical, economic and agronomic constraints of a particular production system with the objective of generating useful yield response information. Complex designs generally work within the technical and agronomic constraints but may not fulfil the economic constraints; i.e. they can be used to generate useable response functions but potentially at a cost that is unacceptable to a commercial producer. Meanwhile, simplistic approaches work within the technical and economic constraints but not agronomic constraints; i.e. there is little value or utility in the derived response functions for management at a commercial scale. The balancing act is to derive useful agronomic information without compromising the value of production. If this is not achieved then producers will not adopt these methodologies.

This paper seeks to address this issue by proposing a generic protocol for designing and analysing commercial-scale within-field yield response to applied fertiliser experiments. The approach is based on the use of management classes to stratify the expected production variability and utilises a 'small strip' approach in the experimental design. The objective is to minimise the impact of the experimental design on the production system, both in the cost of establishing and measuring the experiments and the potential cost of lost production, while maximising the agronomic information obtained and the statistical robustness of this agronomic information.

The outcome of such experiments should be the statistically pragmatic identification of agronomically significant yield responses to fertiliser rate changes, and the construction of useful management class-specific yield response functions. A management class design has been deliberately selected as multiple studies have clearly demonstrated that responses to agronomic inputs are management class-specific (e.g. Inman et al., 2005; Whelan and