Advanced Field-Scale Experimentation for Grain Growers

A guide to using precision agriculture to improve trial results

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ABOUT THIS GUIDE

Applying the precision agriculture (PA) philosophy to crop management requires access to site-specific information. The amount and pattern of variability in soil, landscape attributes and production output, the reasons for the variability, the agronomic implications and the management opportunities all ultimately need to be identified locally on each farm and in each field.

When each farm and field is explored in this detail it is desirable to obtain information on any variability in crop yield in response to different application rates of inputs across an entire site in order to identify if worthwhile production gains and increased profit can be made by implementing spatially variable application rates.

This guide is designed to complement the earlier GRDC publication Designing your own on-farm experiments: how PA can help. With the now widespread use of global navigation satellite systems (GNSS) for autosteer vehicle navigation and variable-rate application of inputs, it is hoped that further discussion on design criteria and analysis provided here will stimulate more on-farm research and help grain growers get the most out of PA.
Grains industry R&D continues to contribute significantly to improvements in crop production across the country. Results and recommendations are often targeted for use at the regional or district level. With an increasing understanding of the variability in production at the local level, many growers and farm advisers are keen to take the general principles and results from grains industry R&D and test them in their own production systems.

On-farm experimentation allows the impact of changes in the production process to be measured right down to the individual field scale so growers can more accurately judge any benefits for themselves.

With increased use being made of precision agriculture (PA) technologies for vehicle navigation and managing inputs, grain growers also have a greater opportunity to use PA to run their own field-scale trials. Being able to run field-scale trials on any/every field is one of the major benefits of growers adopting PA technologies, and work continues on practical trial design and analysis to ensure meaningful results can be achieved by grain farmers.

There are essentially two different field-scale experimental types/questions that can be asked by grain farmers.

- **Approach-response experiment**
  Is there a change in production response to different rates of an input (for example, nutrient application rates, irrigation water, seeding rates)?

- **Rate-response experiment**
  Is there a difference in production response to two or more alternative management practices or products (for example, cultivation versus minimum or no-till, alternative chemicals, crop varieties, fertiliser products)?

The first question is more easily dealt with in terms of experimental design and analysis. The second question is more complex and the design and analysis potentially becomes more involved. This guide targets design and analysis for rate-response experiments but the techniques can also be applied to designing approach-response experiments.
For a field-scale rate-response experiment it is best to test rate changes in one single input or practice at a time, to avoid potential confusion about the cause of any detected change in yield or profit. It keeps the design, analysis and interpretation of results simple and allows for a greater number of treatment rates or replications of treatment rates within a given area. In order to get the best results from a rate-response experiment for a single input or practice, it is important that the field has been investigated for variability in factors that may affect the production response to the input. Site-specific sampling should have been carried out as part of a whole PA plan to diagnose causes of historic production variability and ameliorate any obvious soil issues (for example, areas of hostile soil pH) or rectify management-induced issues such as areas of significant weed burden (see the GRDC Precision Agriculture Manual, Applying PA Education and Training Modules for information on the stepwise implementation of PA into grain crop management to explain this process in detail).

Variation in production potential that remains after this step can be mainly attributed to natural variation in production prospects (for example, due to changes in soil depth or texture within the field) in combination with weather conditions. Weather conditions are generally considered to be uniform over a field but in any case are difficult to predict before an experiment. What can be assessed and documented is any pattern in the variation of the natural yield potential within a field. It is important that this step is carried out before designing the field experiment as it can be crucial to achieving an agronomically useful result. At present the most effective way to achieve this is to apply the potential management class (PMC) approach.

Potential management class (PMC)

Fields are divided into areas (classes) that have shown differences in production potential which may require different management treatments. A management class can be assigned to one or more management zones within a field.

Figure 1 shows how this process breaks the production variability into a number of relative categories, with more classes increasing the ability to describe the range of potential production variability.

The boundaries of the classes/zones can be drawn using a wide range of methods and initial information. The methods range from growers drawing them by hand using their knowledge of a field, such as in Figure 2, to statistical processes that use one or more whole-field maps of variability in yield/soil/terrain/reflectance (examples of which are in Figure 3) to partition the production potential. Figure 4 shows the result of combining a number of the layers in Figure 3 in a statistical process to form PMCs.

Using previously gathered maps of variability and statistical processes takes the guesswork out of setting boundaries, but it is important to ensure that any maps that are used correctly reflect the variability in the field and don’t have any problems caused by poor management or collection errors. As can be seen from the legends in Figures 1 and 4, when the number of PMCs is increased the differences between the production potential in each PMC decreases. As these differences decrease, the potential benefits of managing the classes differently are also reduced. So any decision on how many management classes to use should be made with consideration of both maintaining an agronomically and financially significant difference in production potential and ensuring the pattern of variation is not overly broken up into many small zones.

In practice, one to four management classes for a particular operation are used across Australia. Most commonly one to three management classes are identified:

- one – uniform production potential;
- two – a division between high and low;
- three – high, medium and low production potential identified.

**FIGURE 1** The number of management classes affects the way variability is categorised.

**FIGURE 2** Hand-drawn class/zone boundaries of potential production variability within a field.
**FIGURE 3** Individual maps that may be used to help define boundaries of PMCs: crop yield maps (a and b), elevation (c) and soil apparent electrical conductivity (d).

![Individual maps](image)

**FIGURE 4** Two (a) and three (b) potential management classes (PMCs) built using the soil ECa, elevation and crop yield information for the field shown in Figure 3.

![Potential management classes](image)
DESIGNING RATE-RESPONSE EXPERIMENTS

This diagnostic process undertaken to describe/explain the extent of production variability within a field should help define which input is the most useful candidate for including in a rate-response experiment. As an example, a marked build-up or depletion of a soil nutrient identified between classes could be used as a criterion, along with the magnitude of contribution the required input makes to the variable costs of production. This might involve testing the profitability of increasing nutrients in some parts of the field, reducing (or even eliminating) the amount added in other parts, or examining the financial benefit of redistributing the same total amount of nutrient across the different PMCs; in each case, the aim might be to better match input rate to the water-limited crop potential.

Treatment rates

Once the input of interest has been chosen, it is time to decide on the number of treatment rates. The traditional or current best practice application rate that will be applied to the majority of the field becomes one treatment. More than one alternative treatment rate is preferable, otherwise the best that can be hoped for is a decision that one treatment is preferable to another. At least two alternative treatments can help provide information to decide the ‘best’ treatment rate.

So while the majority of the field is to be treated with a rate that is the current best practice, the alternative treatments could be calculated as multiples of that application rate (for example, 0.25x, 0.5x, 1.5x, 2x). The information from the experiment will be greatest when there is a good size difference between the treatment rates. Where possible a zero rate (or very low) treatment should also be included to help show the full scale of response.

Using a low treatment rate obviously depends on the input being tested and the actual range of rates over which the input would be applied in practice. However, it is important to have low treatment rates where the experiment is testing whether a reduction in input rate is viable.

Field plan

The location and size of the applied treatments within the field should consider the capability and width of input application equipment, the method of measuring the production response and the incorporation of any PMC pattern. Depending on the range of treatment rates, it may also be desirable to minimise the area/financial impact of the experiment.

Application equipment

Treatments can be applied with traditional application equipment using manual switching or multi-pass applications to achieve different input rates. Alternatively, variable-rate technology (VRT) is available for many rate-based input operations. Using VRT makes the job less stressful and allows more sophisticated positioning and rate adjustments of the treatments.

When using VRT, the smallest area in a field that can be treated differently is related to:
- the minimum independent section width of the application equipment;
- the speed at which a rate change can be relayed to the equipment;
- the time it takes for the equipment to change up and down rates; and
- the speed of travel.

This means that each equipment set-up and its operation will provide a unique minimum area of application. So by choosing/changing equipment and speeds, growers have a variety of options available to them for controlling the scale of treatment application.
Measuring the production response
Usually the production response being measured is crop yield, but it may be a quality parameter or biomass production. Whatever the measured response, it is important to understand the resolution of the chosen measurement system so that treatment plots are large enough to be successfully monitored.

For grain crop yield, a harvester-mounted yield monitor is ideal as it allows the whole field to be monitored automatically. The impact of the resolution of the yield monitor on design and analysis are discussed later. A weigh wagon or truck scales can be used where a yield monitor is not available, but the harvesting of treatments needs to be performed carefully.

Treatment plot type
This type of experiment can be run using field-length treatment strips, where each treatment rate is applied as a strip over the length of the field (Figure 6a). Many grain growers have experience with this design as it is often used for variety trials. Field-length strip designs are not reliant on VRT as the treatment rates can be set manually at the start of a strip and adjusted again at the beginning of the next run. However, where VRT is available the application of small strip treatment plots is very feasible (Figure 6b).

The minimum length of the ‘small strips’ will be constrained by the rate-command response of the application equipment and the resolution of the production-response measurement equipment. For example, when...
using a harvester-mounted yield monitor a significant amount of internal grain mixing occurs inside the harvester as it travels along its operational path. This means that yield data gathered at the beginning and end of each strip should be regarded as contaminated by surrounding treatments (usually standard field treatment). To compensate for this and to cover the majority of VRT response specifications, the small strips should be a minimum of 100 metres long. Twenty metres of yield data from each end of the harvested treatment strips should be discarded from the analysis to remove potential treatment contamination. This leaves a minimum analysable ‘small strip’ length of 60m.

Whether field-length or small strip plots are chosen, the plots must be laid out in the direction of sowing and harvesting if a harvester-mounted yield monitor is being used. The width for both plot types should be at least three harvester widths to ensure that one full cutting width can be obtained from each strip without the possibility of contamination from adjoining treatments. Therefore, the minimum width for either strip type will be determined by the minimum multiple of the application machinery width that will meet this target.

If the crop response is to be determined by canopy sensing instead of harvester-mounted yield monitors then the resolution of the canopy sensor (proximal, aerial or satellite) needs to be considered in determining the ‘small strip’ length and the width of either type of plot.

Treatment replication and randomisation
Replication refers to the repetition of the treatment rates in more than one plot within a field. Randomisation is the process of allocating the different treatment levels to different field plots without any conscious choice or favour. These two operations help to ensure the observed response from a particular treatment is not specifically influenced by other sources of variation and that it is representative of the experimental area and not biased by decisions to put high or low rates in a particular spot(s). For example, in an experiment where a field is divided in half and one treatment is applied to one half and an alternative treatment to the other, it is impossible to tell if any difference in response between the treatments reflects real treatment effects and not inherent differences between the two halves of the field. Replicating and randomising treatments across the two halves of the field helps solve this problem.

However, with field-length strips the design can start to take over the field and, where low or very high treatment rates are included in the design, some significant loss of production may be encountered in the name of experimentation. This is where the use of small strips becomes advantageous. The small strip plots allow a larger number of true replications within a given area (increasing the potential statistical value of the trial), more flexibility in location of plots and greater coverage of the conditions within each PMC in the field, and often result in less area being subjected to potential yield-reducing treatments.

Implementation
With either plot type, a minimum of two alternative treatment rates (that is, three treatments in total including the current best practice applied to the rest of the field) and two replications per PMC are strongly recommended, regardless of the other constraints imposed on the production system.

Using the design parameters described, the number of plots required for harvester-monitored rate-response experiments with varying treatment and replicate numbers can be calculated from Table 1. The minimum experimental area required for the alternative treatment plots can be calculated as:

\[ \text{Field-length strip area (m}^2\text{)} = \text{plot number} \times 3 \times \text{harvester width (m)} \times \text{field length (m)} \]

\[ \text{Small strip area (m}^2\text{)} = \text{plot number} \times 3 \times \text{harvester width (m)} \times 100 \text{ (m)} \]

<table>
<thead>
<tr>
<th>Replicates</th>
<th>Number of alternative treatments (excluding rest-of-field treatment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two</td>
<td>4/6 8/12 12/18 16/24</td>
</tr>
<tr>
<td>Three</td>
<td>6/9 12/18 18/27 24/36</td>
</tr>
<tr>
<td>Four</td>
<td>8/12 16/24 24/36 32/48</td>
</tr>
</tbody>
</table>

TABLE 1 Minimum number of plots required for a given combination of treatments and replicates for a field with either 2 or 3 management classes. Left-hand value indicates the number of plots required for 2 management classes and the right-hand value the number of plots for a 3-management-class field.
Summary

The important points to consider when planning and designing any rate-response experiment where the production response is going to be measured by a harvester-mounted yield-monitoring system are:

- Test changes in one single input or practice at a time. It is preferable to increase the number of different rates in the experiment, rather than include additional variables.
- Use more than one alternative treatment rate, otherwise the best that can be hoped for is a decision that one treatment is preferable to another. At least two alternative treatments (plus the standard rate) can help to decide the ‘best’ treatment rate.
- There should be a good size difference between the treatment rates. Multiples of the traditional application rate (for example, 0.25x, 0.5x, 1.5x, 2x) are suitable. A low rate should be included if possible to better describe the response.
- The design should consider the capability and width of application equipment, any management class pattern and the method of measuring the production response, and should aim to minimise the financial impact of the experiment. The experiments can be run using whole-field treatment strips, but with variable-rate technology setting up small strip experiments is easy. Small strips provide the opportunity for greater independent replication of treatments, more flexibility in location and greater coverage of the conditions in the field, and often result in less area being subject to potentially yield-reducing treatments.
- Any strips should be at least 100 m long and at least three harvester widths wide.

ANALYSIS OF RATE-RESPONSE EXPERIMENTS

The interpretation of the output from these experimental designs focuses on two main questions.

1. **Is there a difference in the production response to the different treatment rates?**
2. **What is the input application rate that optimises production or profit?**

**Question 1: Is there a difference in production response?**

Two commonly applied ‘standard’ statistical analyses can be used to answer question 1. They are:

- **t-test** – used to compare two different treatments; and
- **analysis of variance (ANOVA)** – which can be applied to test for differences between more than two treatments.

When used to compare two treatments, it is the same as the t-test.

Both these tests assess the overall variation in the response data and calculate how much can be attributed to effects from the treatments and how much is occurring between the individual measurements for each treatment. The result is then expressed according to whether or not there is a ‘significant difference’ between the average response for each treatment.

The finding of a ‘significant difference’ is an assessment that the average results from the treatments are statistically different enough that the probability of such a difference happening by chance is below a set threshold. The thresholds are known as ‘levels of significance’. Common levels of significance are 5% (p=0.05), 1% (p=0.01) and 0.1% (p=0.001). For example, if someone argues that ‘there is only one chance in a thousand this could have happened by chance’, a 0.001 (high) level of statistical significance is being implied. Choosing a level of significance is an arbitrary task, but for many agricultural applications, a level of 5% is common. However, grain growers may be content to operate at lower levels of significance (10% to 20%). The higher the significance level, the stronger is the required evidence of a difference.

Using these tests on the types of field-scale response experiments described here requires some caution. The tests use the average response to each treatment for comparisons, and include an assessment of the accuracy of the averages when making a decision on significance. The accuracy is assessed by the amount of variation in all the measurements and the number of measurements used to calculate the averages. In these tests, as the number of measurements increases, the accuracy of the estimates for the averages and the overall variation is deemed to increase, and therefore it is easier to find significant differences.

However, each measurement is expected to be from an independent sample of the property being measured (for example, crop yield). When measuring the yield response using a harvester-mounted yield monitor, the internal mixing of grain during mechanical harvesting means that neighbouring samples taken by the monitor are correlated and so each measurement does not constitute a new piece of information in a statistical sense. Given that yield monitors can collect quite a number of measurements in most treatment plots, if this is not recognised and each yield measurement is considered independent in a statistical analysis, then the chance of finding statistically significant treatment effects is artificially inflated simply by using a yield monitor to harvest the experiment.

One way to improve the reliability of the results obtained from using these tests on field-length strip experiments is to break the response data into sections and then use the average response values in each section for analysis. When the response measurements are yield-monitor data, the sections can be created by imposing 20-metre buffers along the strip at 50-metre intervals (Figure 7). While this does not fully...
address the statistical issues, by using averages of separated sections as the measurements, the number of ‘observations’ is reduced, which helps make the significance assessment more realistic.

To deal with this issue in the small-strip design, the average of the yield-monitor data from within each strip plot (replicate) should be used as an estimate of the production response to the treatment rate. For this reason the greater the number of plots that can be established for each treatment level, the better the chance of discovering a statistical difference.

It should be noted that the discovery of a ‘statistical’ significant difference does not necessarily equate to an agronomically or financially significant difference. Agronomic significance is defined here as a production difference, relative to input rate change, that is large enough to compel crop producers to modify management actions in order to gain the observed benefits. And the reverse is also true. The fact that a statistically significant difference is not found does not necessarily mean that an agronomically or financially significant difference is not present.

So when using the methods described here to analyse both the field-length-strip and small-strip designs for differences in the production response to different treatment rates, a lowering of the level of significance to 10% to 20% or taking a pragmatic ‘agronomic’ significant difference approach to the results may therefore be required.

The latter will introduce some subjectivity into the analysis and should include the opinion of the producer and/or local agronomist. The choice of value for the former will be dependent on the risk profile of the producer. But operating the analysis in this way produces a usable methodology for applying the ANOVA/t-test for commercial field-scale experimentation.

**So, the results of using yield-monitor data in these standard statistical tests can provide information for decisions on rate changes but they should be considered with caution.**

**Question 2: What is the optimum application rate?**

In an experiment where there are at least two alternative treatment rates plus the traditional treatment, the average production response for each treatment rate can be used to build production response functions. These can be used to provide an agronomic assessment of the input application rate that optimises production or profit. In this case it is not the maximum yield that is sought, but the yield that optimises the cost of production and financial returns.

Ordinary least squares (OLS) regression, which is accessible to the general scientific and agronomic communities, is suggested as the method for fitting a function to the production response data. Once a production response function has been defined then the point where production is optimised can be located using marginal rate analysis.

For this analysis the cost of the input and the price received for the crop yield are required to calculate the marginal revenue (MR) and marginal cost (MC) along the production function. MR and MC are defined as either the change in revenue or cost as each additional unit of input is applied. For the majority of agricultural inputs, MC of each additional unit of input is constant (for example, the price of one kilogram of nitrogen) and MR is the amount of money received for the output (yield) gained from using that unit of input.

When the return (MR) for applying an additional unit of input is greater than the cost (MC), then applying the unit of input is profitable. If MR is less than MC, the application of the additional unit of input is not profitable. Since total profit increases when marginal profit is positive and total profit decreases when marginal profit becomes negative, it must reach a maximum where marginal profit is zero – or where MC=MR. This is because the producer has collected positive profit up until the point where MC=MR.

Finally, an ANOVA/t-test analysis or the response function analysis would be aimed at exploring the differences in the production responses between any defined PMCs. However, the analysis can be undertaken at the whole-field scale by aggregating the management class responses. Comparing the whole-field response to the responses in each PMC will allow the assessment of the effectiveness of the PMC process in partitioning production variability.

These processes are best understood through a case study.
Figure 8 shows the actual fertiliser application map and the subsequent yield map for the nitrogen response trial designed in Figure 6b. The traditional application rate for the field was 60 kilograms of nitrogen per hectare. The average yield from each treatment plot was calculated, along with the average for each treatment rate in each class. The values are shown in Table 2.

The results show that the two classes are obviously responding differently to the applied nitrogen fertiliser and the traditional rate may not be best for either class. The season was above average in rainfall, with growing-season rain (June to November) of 350 millimetres, or in the 70th centile.

Figure 9 shows the results of an ANOVA using the individual yield values obtained from the harvester in each treatment strip. In Figure 9a all the treatments are considered statistically different when the trial is analysed as a whole. When the field is analysed in PMCs, all the treatments are considered statistically different in Class 1. Class 2 shows that 0kg/ha and 60kg/ha are statistically different from each other and from the 29kg/ha and 82kg/ha treatments. The response to the 29kg/ha and 82kg/ha treatments are not statistically different from each other.

<table>
<thead>
<tr>
<th>Rate (kg N/ha)</th>
<th>Class 1</th>
<th>Class 2</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Rep 1</td>
<td>Rep 2</td>
</tr>
<tr>
<td>0</td>
<td>3.32</td>
<td>3.76</td>
</tr>
<tr>
<td>29</td>
<td>4.68</td>
<td>4.15</td>
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<tr>
<td>60</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>82</td>
<td>4.97</td>
<td>5.50</td>
</tr>
</tbody>
</table>

When the average yield values for the treatment strips are used in the same tests, the results are less decisive (Figure 10). In the whole-field and PMC analyses it is only the response to the 0kg/ha treatment that can be considered statistically different from the others. The change in the statistical difference assessment is due to the decrease in the number of measurements used and the resultant effect on the calculated accuracy of the averages in the test procedures.

These results highlight the potential issues with using these ‘standard’ statistical tests on this type of practical experimental data. In Figure 9 (page 13), where each yield-data point is treated as an individual measurement, statistical differences between yield values that would probably not be considered agronomically different (4.486t/ha and 4.684t/ha in Figure 9a) are found. When the data is reduced to averages for each treatment and the perceived number of replications is reduced, the reverse is the case. Differences in yield response that would be considered agronomically significant are not identified as statistically different.

These issues aside, it is possible to identify which of the four rates produces the most yield using the ANOVA tests, but not the rate that optimises production. To identify the optimum application rate from the trial, yield response functions for the two classes were built using the average yield data from the strips (Figure 11a, page 15). Applying marginal rate analysis to the two functions using prices for the season (Figure 11b) locates the points where MR=MC and shows that the optimum rates of applied nitrogen fertiliser are 109kg N/ha and 39kg N/ha for Class 1 and 2 respectively.
FIGURE 9 ANOVA of wheat yield (t/ha) by applied nitrogen rate (kg N/ha): (a) individual yield data from the trial plots used as input in the analysis of the trial response over the whole field; (b) management Class 1; and (c) management Class 2.

### Analysis of variance (ANOVA) – whole field

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
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<th>Mean square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
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<tr>
<td>Applied N rate (kg/ha)</td>
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<td>119.13</td>
<td>39.71</td>
<td>181.72</td>
<td>&lt;.0001*</td>
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<tr>
<td>Error</td>
<td>524</td>
<td>114.51</td>
<td>0.22</td>
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<tr>
<td>Total</td>
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<td>233.64</td>
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**Comparison of means (student’s t-test)**

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<th>Rate</th>
<th>Mean (t/ha)</th>
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<td>B 4.486</td>
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<tr>
<td>29</td>
<td>C 4.246</td>
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Rates not connected by same letter are significantly different.

### Analysis of variance (ANOVA) – Class 1

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<td>&lt;.0001*</td>
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<td>Total</td>
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**Comparison of means (student’s t-test)**

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Rates not connected by same letter are significantly different.

### Analysis of variance (ANOVA) – Class 2

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<th>Mean square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
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<td>Applied N rate (kg/ha)</td>
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<td>13.85</td>
<td>113.24</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Error</td>
<td>259</td>
<td>31.69</td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>262</td>
<td>73.25</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Comparison of means (student’s t-test)**

<table>
<thead>
<tr>
<th>Rate</th>
<th>Mean (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>82</td>
<td>A 4.132</td>
</tr>
<tr>
<td>60</td>
<td>A B 4.079</td>
</tr>
<tr>
<td>29</td>
<td>B 3.975</td>
</tr>
<tr>
<td>0</td>
<td>C 3.336</td>
</tr>
</tbody>
</table>

Rates not connected by same letter are significantly different.
FIGURE 10 ANOVA of wheat yield (t/ha) by applied nitrogen rate (kg/ha): (a) average yield data from the trial plots used as input in the analysis of the trial response over the whole field; (b) management class 1; and (c)).
Comparing gross margins
With this response information it is possible to compare the gross margin (GM) under traditional uniform management to the GM achievable under variable-rate management scenarios. The GM for each management scenario can be calculated by multiplying the yield achieved by the grain price and deducting the cost for the quantity of fertiliser applied:

\[
\text{Gross margin (GM) ($/ha) = } (\text{yield (t/ha)} \times \text{grain price ($/t)}) - (\text{fertiliser applied (t/ha)} \times \text{fertiliser cost ($/ha)})
\]

From the case study, two simple management response scenarios can be considered.

Scenario one would maintain the total amount of fertiliser applied to the field, but moves the over-application on Class 2 to Class 1. This would keep fertiliser costs constant and result in yield gains in Class 1 that would improve GM by $11.50/ha across the field when compared with the traditional application of 60kg N/ha across the whole field.

Scenario two would aim to apply the optimum amount to each Class, requiring an additional 1.4t of nitrogen in total to achieve the yield goals of 5.4t/ha in Class 1 and 4.0t/ha in Class 2. However, the increased yield would mean that the GM for the field would be improved by $25/ha over the traditional application of 60kg N/ha across the whole field.

Running rate-response experiments and undertaking a GM analysis will show if there are worthwhile financial gains to be made by exploring the optimisation of fertiliser application rates within a field. Any projected gains will be site-specific, but the management-class response information may be used to help inform decisions on management of class-specific yield targets and fertiliser strategies in subsequent years.

Continued experimentation
By maintaining the treatment plots in position for a number of seasons and measuring the production response to total input level rather than applied input rate, it is possible to better quantify the optimal input level required in each PMC at the time when decisions are made. This is especially useful for nutrient-response experiments and is achieved by pre-season sampling of the treatment plots for resident nutrient and adding the applied treatment quantity to calculate the actual nutrient presented to the crop in each strip.

It is important to wait at least two years to let the zero/low treatment plots reduce in resident nutrient before beginning the in-plot nutrient monitoring. With this approach the higher treatment plots can also be monitored for any build-up in resident nutrient levels due to the experimental treatments.

Operating the rate-response experiments in this manner means that yield response for crops in the management rotation can be examined and information on seasonal conditions can be matched with the responses. An archive of this information over a number of seasons and crops would provide greater information to tailor future application-rate decisions to expected seasonal conditions.

Input response data from individual fields may then also be used as a replacement for generic response models in crop growth simulation programs.

**FIGURE 11** Yield response (a) to applied nitrogen fertiliser from the trial in Figure 6. Traditional field application was 60kg N/ha. Marginal rate analysis (b) shows where MC=MR and that Class 1 optimum = 109kg N/ha; Class 2 optimum = 39kg N/ha.