Abstract

Dryland wheat farmers in northern NSW are faced with both spatial and temporal variability. The temporal variability between seasons is likely to exceed the spatial variability between soils. WHEATMAN was used to simulate the relative value of information on soil water holding capacity or in-crop rainfall when making N fertiliser decisions. Although information on the soil and the season would be useful, the general shape of the response surface of wheat to nitrogen fertiliser was flat around the optimum. This is due to economics (the payment for protein) and the biology (shape of yield response and higher protein when the yield is limited by water). As a consequence a strategy of getting nitrogen rates roughly right compared to precisely optimal may be adequate for many growers.

Introduction

For growth and nourishment the climate is the most important factor and in general the character of the season as a whole. For when rain, fair weather and storms occur opportune, all crops bear well and are fruitful, even if they be in a soil which is impregnated with salt or poor. Wherefore it is an apt proverbial saying that it is the year which bears and not the field. Theophrastus c.a. 300 B.C.

Precision Agriculture (PA) addresses spatial variability in crop production. An enduring challenge of dryland farming in Australia is temporal variability primarily due to the erratic climate. Cook and Bramley (2000) argued that variability becomes an opportunity for improvement when the link between control and outcome becomes certain enough to be acted upon. After decades of research into the response of wheat to nitrogen (N) in northern NSW, the relationship between N supplied by soil and fertiliser and N demand from the crop is well understood. However, each autumn as farmers apply N, they face uncertainty in knowing what level of crop demand to target. Even though 45% of farmers in NSW take some account of seasonal climate forecasts in their management decisions (White 2001), the probabilistic nature of these forecasts (60% chance of exceeding the median) highlights the fact that climate remains a source of irreducible uncertainty for fertiliser decisions. This study used simulation modelling to investigate the interaction of temporal and spatial variability for N on wheat decisions on the Liverpool Plains.

The erratic rainfall – a challenge for interpreting yield maps

Nix (1975) drew attention to the relative importance of rainfall as a climatic constraint in Australian crop production compared to cold temperatures in North America, Europe and Asia and high temperatures and high humidity in India. Temperature variation is seasonal and can often be well predicted by topography. This is a useful application of spatial climate information as shown in the South Island of New Zealand (Hutchinson 2000) and for management zones based on topography and frost risk for wheat crops in northern NSW (Kelleher et al 2001).

The challenge of rainfall variability for agriculture in general and precision agriculture in particular is the irregularity from season to season. One consultant expressed his experience as follows: The reaction to a yield map in the first year is “Wow I didn’t expect it to be so different to last year”, the reaction to the second yield map is “Wow I didn’t expect it to be so variable!”, the reaction to the third yield map is “Wow I didn’t expect it to be so different to last year” and the reaction to the third yield map being different again is an expletive. Boottink et al (1996) commented that studies on precision farming appeared to look back to past growing seasons whereas farmers had to look forward to a new season with unknown weather conditions.

The challenge of temporal variability for precision agriculture is well documented. Cook et al (1996) drew attention to climatic uncertainties in a study on phosphorus in Western Australia. Porter et al (1996) used data from long term field trials in Minnesota and Wisconsin to study the interaction between temporal and spatial variability of 10 years of corn and soybean yields. They found that season to season variability was 3 x greater than plot to plot variability in corn yields and 4 x greater in soybean yields. They warned that emphasising yield map variability during poor growing seasons (when the field range is very large relative to the field average) may lead to erroneous conclusions. Felton and Nash (1998) questioned the cost effectiveness of site-specific nutrient management in the NE grains belt of Australia because differences between seasons were likely to be greater than differences within fields. Using a water use efficiency calculation and historical rainfall records they determined that regions that received about 600 mm annual rainfall had roughly an equal probability of achieving wheat yields of <2, 2-3 or >3 t/ha.

McBratney et al (2000) proposed an opportunity index for site-specific crop management. In essence this index considers the magnitude and spatial structure of the field variability to justify the cost of a shift from uniform to site specific management. One of the findings of their study was the temporal instability of the index especially for wheat crops in northern NSW. The three years they report covered two La Ninas (1996 and 1998) and one El Nino year (1997) (Couper-Johnston 2000). They recommended that data on crop variability would have to be collected for several years before a true indication of the opportunity index was known. What is not clear is how many more years are required for dryland wheat in northern NSW compared to irrigated cotton in the same region or dryland corn in Minnesota or wheat in Western Australia.
(1994) argued that all continents have deserts where rainfall is rare and unpredictable, or areas where rainfall does not vary predictably on an annual basis, but that Australia was the only continent where the overwhelming influence on climate is non-annual. He maintained that this was due to the impact of the El Nino Southern Oscillation ENSO on Australian rainfall. Flannery maintains that adaptations to ENSO explain many of the unique features of Australian ecology. Examples are the lack of deciduous trees, intermittent flowering of eucalypts, irregular breeding cycles of fauna and the kangaroo carrying its joey as a dormant embryo. Flannery (1994) warned against importing farming systems from more stable climates of North America and Europe, this mismatch has been discussed in reviews of the history of farming in Australia (Davidson and Davidson 1993, Barr and Carey 1992).

The year to year variability is reflected in wheat production at a national and farm level. The coefficient of variation of de-trended Australian wheat yields from 1960 to 1997 was 19% compared to 7% for the United States (Podbury et al 1998). Australian national wheat yields are more strongly related to broad-scale ENSO indices than any other major grain crop in the world (Garnett and Khandekar 1992). Within Australia, farms on the NE grains belt face more variable rainfall and higher evaporation and consequently higher variability in wheat yields (CV 40%) compared to WA and parts of Victoria (CV 33%) (Wright et al. 1994).

Seasonal variability is by no means a reason to reject PA. The problems of increasing efficiency while minimising off-site pollution are a major challenge and it is foolish to overlook some form of site specific management as part of the solution. Nevertheless, as PA is adapted to local conditions, climate variability needs to be explicitly addressed.

### Precision Agriculture in the NE grains industry

Precision agriculture may be in its infancy in NE Australia but it is wrong to refer only to future potential. An impressive local example is the do-it-yourself development of a system for precision farming by Mike Smith, a farmer at Gurley, south of Moree in northern NSW (reported by Reppel 2000).

The farmer interest in site specific management in the northern grains belt is driven in part by the availability of yield maps, the experience of farmers who are using the technology and the considerable success of controlled traffic farming. According to Boydell et al (2000), applications in the grains industry are equal to or ahead of the cotton industry. Cook and Bramley (2000) claimed that the most advanced adoption in Australia is in dryland grains, which contrasted to the US where adoption in the small grains sector is reported to be slow compared to US corn growers. The interest (if not widespread adoption) in site specific management in the NE grains belt is likely to continue for a number of reasons.

1. **Most farmers would choose to be an engineer rather than an agronomist as a second career.**

A common experience at field days is to see agronomists looking at crops but farmers crowding around machinery. Farmers’ interest in machinery and scale of operations is justified. In an ABARE study of farm productivity in the grains industry, the NE region achieved a gain of 2.7% per year from 1977 to 1988. This was only partially explained by increases in wheat yields (1.1% per year from 1977 to 1998). The main sources of increase in productivity in the region were listed as reduced tillage, precision farming and economies of scale from farm amalgamation and tram-lining (Knopke et al 2000 p 66).

2. **Paddocks are getting larger and running across soil types**

The recent floods in northern NSW have increased the emphasis on paddock layout to minimise peak water flows and erosion. This has involved removing fences and in some cases down-slope farming. This trend towards larger paddocks or at least longer strips that cross topographic features will increase the chance of non uniform paddocks. Even within existing paddocks, the increase in deep soil sampling and measurement of water holding capacity has increased the awareness of within paddock variability and sub-surface limitations (Dalgleish and Foale 1998).

3. **Nitrogen fertiliser is necessary but expensive.**

A survey of 400 wheat farmers in northern NSW in April 1997 (Hayman and Alston 1999) showed a dramatic increase in reported rates of N used. Although most respondents had been growing wheat since the 1960s, regular applications of N only commenced in the mid 1980s. Initially only low rates of N were applied, but in the 1990s, the rates of N were increased substantially. These changes are notable because until the last decade, most farmers in the region were content to rely mainly on mineralisation of soil organic N, whereas, now, half the respondents in the survey planned to add about as much N in fertiliser in one year as was removed in the previous year’s wheat crop. Although N rates have increased, farmers are very aware of this emerging cost which is squeezing their margin and are looking for efficiencies.

Rather than a revolution, precision agriculture can be viewed as an evolutionary step in the application of information to agriculture (Lowenberg-DeBoer and Boehlje 1996). In the NE region the fitness to the environment is still being tested. Before adopting a new technology, farmers will ask two questions; does it pay? If so, what are the risks and returns over what I am doing now? This study falls well short of being an economic feasibility study, however, the aim is to raise some issues that could be considered in such feasibility studies. I have used the decision support system WHEATMAN (Woodruff 1992) to consider an imaginary paddock in Gunnedah, NSW which had an even mixture of the 6 soil types covered in the model. As stated earlier, the purpose is to investigate the value of knowing about the spatial and temporal variability. In other words the soil and the season, or to use Theophrastus, the year or the field.

### Methods and results

WHEATMAN is a computerised decision support system for farmers and advisers in the North Eastern wheatbelt. It is based on a daily time-step simulation model, the DSS is described in detail in Woodruff (1992). The philosophy of WHEATMAN is that while science explains the past, farmers
have to make future crop management decisions under uncertainty. For a decision such as fertiliser rates, this involves a range of outcomes depending on the season.

Although WHEATMAN concentrates on seasonal variability, the user specifies soil type and starting conditions. Table 1 shows the six soil types available in northern NSW, these were selected in the mid 1990s by agronomists and farmers as broadly representative of water holding capacity of soils in the region. The purpose of this simulation exercise was to examine the interaction between soil water holding capacity and in-crop rain on yield, grain protein and optimal fertiliser N rate. The scenario considered was a paddock with all 6 soil types present in even proportions. The level of water stored in each soil at sowing was set at 100 mm and the N content in each soil was set at 50 kg/ha. This meant that the profile of the shallow red soil was full of water whereas the deep black soil was half full. The median yields might be considered low compared to those achieved in recent years on the Liverpool Plains, however most of the high yields have been achieved on heavy clays when up to 200 mm of water has been stored at sowing rather than the 100 mm in this study. In this simulation, a medium maturity length variety was sown on the 10th of June. The median yields reported in Table 1 are for 225 kg of fertiliser N (i.e. N unlimited)

Table 1. Water holding capacity, rooting depth and simulated median yield for 6 soil types in Gunnedah for wheat sown on 10th June with 100 mm stored soil water and N supply > 275 kg/ha (unlimited).

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>ASW (mm/m)</th>
<th>Depth root zone (m)</th>
<th>Capacity (mm)</th>
<th>Simulated yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep black soil</td>
<td>160</td>
<td>1.25</td>
<td>200</td>
<td>3.8</td>
</tr>
<tr>
<td>Deep grey or brown brigalow clay</td>
<td>140</td>
<td>1.2</td>
<td>168</td>
<td>3.3</td>
</tr>
<tr>
<td>Deep red brown and red earths</td>
<td>125</td>
<td>1.2</td>
<td>150</td>
<td>2.9</td>
</tr>
<tr>
<td>Shallow black soil</td>
<td>160</td>
<td>0.8</td>
<td>128</td>
<td>2.7</td>
</tr>
<tr>
<td>Shallow grey/brown brigalow clay</td>
<td>140</td>
<td>0.8</td>
<td>112</td>
<td>2.5</td>
</tr>
<tr>
<td>Shallow red brown and red earths</td>
<td>125</td>
<td>0.8</td>
<td>100</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Range (max-min) 100.0 1.9

Variability (range/mean) 70% 67%

The range in water holding capacity of the soils leads to a similar range in median wheat yields. It is important to emphasise that the change in simulated median yields are due to water holding capacity. N supply, starting soil water, historical in-crop rainfall data, phosphorus, and micronutrient levels are constant across soil types.

Table 2 shows the yields for the 10th, 30th, median, 70th and 90th percentile. The average yield range from season to season (3t/ha) exceeds the range from soil to soil (1.9t/ha). The variability between seasons increases as the quality of the soil deteriorates (74% for the deep black soil to 142% for the shallow red soil). The variability between soils increases as the seasons get drier (34% for the 90th percentile season and 103% for the 10th percentile season). In both cases the increase is in relative variability and is due primarily to the reduction in the mean.

Table 2. Simulated yield of 6 soil types in each of 5 seasons from poor (10%ile) to good (90%ile)

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<tbody>
<tr>
<td>10%ile</td>
<td>2.2</td>
<td>2.3</td>
<td>1.2</td>
<td>1.1</td>
<td>1.1</td>
<td>0.8</td>
<td>1.5</td>
<td>103%</td>
</tr>
<tr>
<td>30%ile</td>
<td>3.3</td>
<td>3.3</td>
<td>2.2</td>
<td>2.1</td>
<td>2.0</td>
<td>1.4</td>
<td>2.4</td>
<td>80%</td>
</tr>
<tr>
<td>50%ile</td>
<td>3.8</td>
<td>3.8</td>
<td>2.9</td>
<td>2.7</td>
<td>2.5</td>
<td>1.9</td>
<td>2.9</td>
<td>65%</td>
</tr>
<tr>
<td>70%ile</td>
<td>4.3</td>
<td>4.3</td>
<td>3.2</td>
<td>3.1</td>
<td>3.0</td>
<td>2.4</td>
<td>3.4</td>
<td>56%</td>
</tr>
<tr>
<td>90%ile</td>
<td>5.0</td>
<td>5.0</td>
<td>4.6</td>
<td>4.4</td>
<td>4.1</td>
<td>3.5</td>
<td>4.4</td>
<td>34%</td>
</tr>
<tr>
<td>Range</td>
<td>2.8</td>
<td>2.7</td>
<td>3.4</td>
<td>3.3</td>
<td>3.0</td>
<td>2.7</td>
<td>3.0</td>
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</tbody>
</table>

Variability 74% 71% 117% 122% 120% 142% 108%

Table 3. Simulated median yield, associated protein and N harvested.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Yield t/ha</th>
<th>Protein %</th>
<th>N in grain kg N/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep black soil</td>
<td>3.8</td>
<td>12.9</td>
<td>86</td>
</tr>
<tr>
<td>Deep grey/ brown brigalow clay</td>
<td>3.3</td>
<td>13.2</td>
<td>76</td>
</tr>
<tr>
<td>Deep red brown and red earths</td>
<td>2.9</td>
<td>13.6</td>
<td>69</td>
</tr>
<tr>
<td>Shallow black soil</td>
<td>2.7</td>
<td>13.7</td>
<td>65</td>
</tr>
</tbody>
</table>
Shallow grey/brown brigalow  
2.5  
13.9  
61
Shallow red brown earths  
1.9  
15  
50
Range  
1.9  
2.1  
35.9
Variability  
67%  
15%  
53%

The yield data in Table 3 is the same as Table 1, the added information is the protein for the median yield and the amount of nitrogen removed in the grain at harvest. The variability in grain nitrogen harvested is smaller than the variability in yields. This is because under adequate nitrogen, as water supply decreases the grain protein content increases.

Grain protein content is an essential aspect of wheat production in northern NSW. Not only does it have potential as a diagnostic tool for N supply in precision agriculture in the region (Kelly et al 2001), it is essential for calculating gross margins (GM). Malzer et al (1996) studying corn in Minnesota, and Cook and Bramley (1998) studying wheat in WA multiplied yield by a single crop price and subtracted the cost of N. This linear relationship between a yield and GM is not valid for the NE region. Due to the compensation of higher protein on yields that are limited by water, a GM map constructed from yield and protein is likely to be considerably dampened compared to one that was constructed from yield alone.

The economic optimum N rate can be defined as the point where the marginal cost is equal to the marginal return. Although this does not take into account the opportunity cost of the money invested in fertiliser, it is consistent with other studies on the economics of site specific management (Malzer et al 1996, Cook and Bramley 1998). By definition, this is the N rate that leads to the highest GM. The GM was calculated as per NSW Agriculture budget books (Scott 2001). The essential assumptions were as follows

- Price of Wheat at 10% protein to be $140/t and a sliding scale of $0.50 for each 0.1% grain protein above and below 10%.
- Growing cost apart from N and harvest cost = $100.00/ha
- Cost of N = $1.00/kg
- Harvest cost = $25.00/ha for first 2.5t and $1.30/ha for each additional 0.1t.

Figure 1. GM vs N rates for (a) 10th, (b) 30th, (c) Median, (d) 70th, (e) 90th percentile and (f) probability weighted average of 5 season types. Shallow red brown earth (open circles), shallow grey/brown brigalow clay (cross), shallow black soil (open square), deep red brown earth (closed triangle), shallow grey/brown brigalow clay (open triangle), shallow black soil (closed circle). The vertical line in (f) at 75 kg/ha of N is the average optimum rate.

Table 4. N rate and GM for 5 different management options on 6 soil types. Management options are explained in the text.

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<tbody>
<tr>
<td>N rate kg/ha</td>
<td>GM $/ha</td>
<td>N rate kg/ha</td>
<td>GM $/ha</td>
<td>N rate kg/ha</td>
<td>GM $/ha</td>
<td>N rate kg/ha</td>
</tr>
<tr>
<td>68</td>
<td>271</td>
<td>68</td>
<td>263</td>
<td>68</td>
<td>215</td>
<td>68</td>
</tr>
</tbody>
</table>
Discussion

The difference between option F and option E (i.e including the soil information) is of more value in the poor years than the good years.

Option F

(Marshall et al 1996) adjusting for soil type with no knowledge of seasons. Adjusting based on imperfect seasonal forecasting has been shown to be worth about $3.50/ha. Might occur, a farmer could adjust for season type. This results in about $10.00 extra in return. Interestingly, this is worth about the same as option E. If a different approach would lead to an extra $10.00/ha return above the optimum uniform treatment (option C).

N.

Option D

approach would lead to an extra $10.00/ha return above the optimum uniform treatment (option C).

75 units across the paddock. This would lead to a GM that was $23 better than assuming that the paddock was uniformly a poor red soil (option B2), but only 67c better off than using a basic WUE calculation or soil types in WHEATMAN. After a long consultation with WHEATMAN and some subsequent averaging they would come up with Figure 1f and apply 125 units across the paddock which would lead to higher GM than option A on the better soils and lower GM on the poorer soils. The overall outcome as a deep black soil but incorrectly estimated the whole paddock to be uniform. The result of a consultation with WHEATMAN would be to apply 125 units, the fertiliser N requirement is 67 kg/ha. Table 3 shows that under this first option there is a $150 range in GM from the best to the poorest soil and that the overall GM is $207.75. An alternative approach is to just use historical yields which have integrated yield variability across the paddock.

As a variant on option B1, a farmer might mistake the soil to be uniformly a shallow red soil, the application would be reduced to 25 units, and that the overall GM is about 2.8t/ha.

This is likely to provide a similar result as the average of the 5 seasons types and 6 soils at moderate N supply for 100mm of starting soil water is about 2.8t/ha.

Table 3 shows that under this first option there is a $150 range in GM from the best to the poorest soil and that the overall GM is $207.75. An alternative approach is to just use historical yields which have integrated yield variability across the paddock.

$19 better than assuming that the paddock was uniformly a good black soil (option B1) but only 67c better off than using a basic WUE calculation or paddock history (option A).

In this case 125 units would be applied to the 2 best soils, 50 units to the next three soils and 25 units to the poorest soil.

This site specific approach would lead to an extra $10.00/ha return above the optimum uniform treatment (option C).

In the highly unlikely and theoretically dubious event that climate science could tell a farmer with certainty which of the 5 season types might occur, a farmer could adjust for season type. This results in about $10.00 extra in return. Interestingly, this is worth about the same as adjusting for soil type with no knowledge of seasons. Adjusting based on imperfect seasonal forecasting has been shown to be worth about $3.50/ha (Marshall et al 1996)

Option F The perfect knowledge scenario which adjusts for both soil and season. In this case the information is worth an extra $33/ha. The difference between option F and option E (i.e including the soil information) is of more value in the poor years than the good years.

<table>
<thead>
<tr>
<th>Option</th>
<th>Avg</th>
<th>10%ile</th>
<th>20%ile</th>
<th>30%ile</th>
<th>40%ile</th>
<th>50%ile</th>
<th>60%ile</th>
<th>70%ile</th>
<th>90%ile</th>
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<tbody>
<tr>
<td>A</td>
<td>150</td>
<td>175</td>
<td>200</td>
<td>225</td>
<td>250</td>
<td>275</td>
<td>300</td>
<td>325</td>
<td>350</td>
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<tr>
<td>B1</td>
<td>125</td>
<td>175</td>
<td>200</td>
<td>225</td>
<td>250</td>
<td>275</td>
<td>300</td>
<td>325</td>
<td>350</td>
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<td>B2</td>
<td>25</td>
<td>275</td>
<td>190</td>
<td>165</td>
<td>140</td>
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<td>90</td>
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<td>D</td>
<td>125</td>
<td>175</td>
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<td>225</td>
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<td>275</td>
<td>300</td>
<td>325</td>
<td>350</td>
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<tr>
<td></td>
<td>30%ile</td>
<td>50</td>
<td>246</td>
<td>50</td>
<td>230</td>
<td>50</td>
<td>190</td>
<td>50</td>
<td>175</td>
</tr>
<tr>
<td></td>
<td>50%ile</td>
<td>50</td>
<td>264</td>
<td>50</td>
<td>250</td>
<td>50</td>
<td>238</td>
<td>50</td>
<td>226</td>
</tr>
<tr>
<td></td>
<td>70%ile</td>
<td>150</td>
<td>353</td>
<td>150</td>
<td>353</td>
<td>150</td>
<td>209</td>
<td>150</td>
<td>196</td>
</tr>
<tr>
<td></td>
<td>90%ile</td>
<td>150</td>
<td>387</td>
<td>150</td>
<td>385</td>
<td>150</td>
<td>379</td>
<td>150</td>
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This study provided a cursory investigation of the relative value of information about soil water capacity and seasonal rainfall. Under N unlimited conditions, the variation in GM due to the season was greater than the variation in yield due to the soil. This supports Theophrastus (B.C.) when he reminded us that it is the year that bears and not the soil. However, perfect knowledge of the soil (attainable at a cost) was worth about the same as perfect knowledge of which of 5 season types would occur (unattainable at any cost). Perfect knowledge on both the soil and the season was worth three times as much as knowing one in isolation.

Rather than perfect knowledge, the information age had delivered data, and lots of it. Ideally, this data can be transformed into information which reduces uncertainty, however as pointed out by Cook and Bramley (2000) a typical wheat paddock will generate 30,000 estimates of yield whereas previously there was one. Given the trend towards including protein estimates and the need to collect data from a range of seasons many growers are likely to experience information dazzle. Given this amount of data, even with appropriate software, it may be better to be roughly right with rules based on paddock history than precisely wrong with technology.

Although it adds to the amount of information, the interaction between temporal and spatial variability cannot be ignored, especially in the NE region. Temporal variability makes it more difficult to realise the benefits of managing spatial variability. Similarly a paddock that is spatially variable creates problems for the application of seasonal climate forecasts. Simulation modelling and historical climate records are likely to be useful to put yield and protein maps from individual seasons in context. Perhaps the opportunity index for site-specific management for dryland crops could be presented as a probability distribution rather than a single number.

In an economic feasibility study of site specific management of weeds Pannell and Bennett (1998) suggested that rather than focussing on the strengths and weaknesses of the technology it was important to closely examine the nature of the farm management problem being addressed. The simple analysis in this paper highlights two points about N fertiliser decisions.

**First**, N fertiliser decisions are characterised more by uncertainty than complexity. Furthermore, a major source of this uncertainty is irreducible. Contrasting an industrial activity (the production of a motor car) with dryland farming, Cox (1993) argued that producing a car was complex because there are many choices but certain because once a choice is made you know the precise outcome. Dryland farming, however, has relatively few choices (crop and variety choice, and dates and rates of planting and fertiliser), but the outcomes are very uncertain. The nature of the uncertainty may be a problem when delivering the level of precision common in manufacturing to broadscale crop production.

**Second**, a related issue is that when it comes to fertiliser decisions, the shape of the response surfaces are relatively flat on top so that changes to N rates (x axis) have limited impact on GM (y axis). A consequence of this is that a simple WUE model or historical yields (Option A) led to a rate of fertiliser that was almost identical to knowing the exact proportion and response surfaces of 6 soil types in the paddock. Furthermore this back of the envelope calculation was only $10.00 different to varying the rate for soil or season. The analysis in this study is under a productivity paradigm and there may be environmental reasons for precision agriculture. However, as shown by Keating et al (1999) on the environmentally sensitive issue of nitrogen fertiliser on sugar cane, it is only supra optimal rates that lead to leaching. It may be that for managing N in the environment, it is important to be roughly right, i.e. avoid heavily over fertilising. This may require zone management rather than precise variable rate site specific management.

The finding of insensitivity or flatness in response around the optimum is not a new finding. Anderson (1975) showed the generality of flat response surfaces on any continuous response function with decreasing marginal returns. He concluded that, "in pursuits and discussing optimal levels of decision variables, precision is pretence and great accuracy is absurdity." These observations are not exclusive to economists: Colwell et al. (1970) commenting on his work in northern NSW stated, "The typically low curvature of response in the vicinity of the optimum fertiliser requirements mean that great precision in the estimation of fertiliser requirements is not warranted."

Although this issue of flatness of response is discussed in contemporary agricultural economics, in my limited and biased reading of the literature on precision agriculture and site specific management few references are made. As shown by Hayman and Turpin (1998) and Turpin et al (1998) this insensitivity of wheat GM to N rates is disappointing to advocates of precision in either season or soil. Nevertheless it is good news for farmers faced with temporal and spatial uncertainty when making N fertiliser decisions. It may be that considering the nature of the problem reveals a relatively large solution space and hence being approximately right may be good enough.

### References


Precision Agriculture is about managing field variability by matching layouts. Past landforming has been limited in terms of cut and fill to assist in fertiliser recommendations, regardless of nutrients applied.

Precision Agriculture Adaptation to Rice Based Farming Systems
Brian Dunn and Geoff Beecher.

Precision agriculture experiments we have conducted in this region show that in heavy cut sites, in one field the manure treatments were incorporated before three flush irrigations then applying permanent water. Times the nitrogen and times the phosphorus of the feedlot manure. Causes and prediction of changes in extractable phosphorus during flooding. Soil acidity levels for a range of soil profiles at levels for sites from six fields. I love a sunburnt country, a land of sweeping plains, of ragged mountain ranges, of droughts and flooding rains. Get our daily newsletter. Upgrade your inbox and get our Daily Dispatch and Editor’s Picks. Forthcoming generations of Australians will know ever more sunburnt, drought-stricken and flooded lands, if the predictions of a report from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Bureau of Meteorology are realised. Those sweeping plains, especially in the country’s centre, will become much hotter and their soil will degrade. The report, rel