Production & Economic Benefits of Variable Rate Nitrogen Application in Cropping Systems

By Brendan Torpy

Abstract

This study evaluated the nitrogen (N) fertiliser response of Hyola 601 Roundup Ready® canola across three paddock soil zones (sand, loam and clay) in the Inverleigh district of South West Victoria. Four N levels were applied (0, 65, 115 and 130 kg urea ha\(^{-1}\)) at the rosette growth stage in a strip trial layout which passed through the different paddock soil zones. A 50 kg urea ha\(^{-1}\) blanket rate was applied to the entire trial paddock just prior to flowering. Growth parameter measurements (biomass measurements and plant counts) and yield estimates were completed in all soil zones that the different N treatment strips passed through. The dry weight (DW) results revealed that there was no positive crop growth response as N rate was increased and no significant difference in mean DW levels between the three soil zones. The fresh weight (FW) measurements however displayed an increasing trend as N rate increased. In terms of estimated yields, there were no clear trends of increasing yield as N rate increased and no significant differences between N treatment yield estimates. The sand soil zone however had a significantly higher mean yield estimate (5.60 t ha\(^{-1}\)) compared to the loam (3.59 t ha\(^{-1}\)) and clay (4.16 t ha\(^{-1}\)) soil zones. The trial paddock had a high total available soil N prior to sowing (101.1 – 112.1 kg N ha\(^{-1}\)) and two different row spacing measurements (250 and 500 mm) within the strip trial area. These confounding factors were believed to have affected the validity of the biomass, plant density and yield estimate measurements, however the author still believes correct trends have been shown. Marginal return on investment (ROI) calculations were completed on different N rates in the three paddock soil zones. Within the sand zone a maximum ROI ($3.29 return per $1 spent on urea) was achieved by applying 180 kg urea ha\(^{-1}\) (130 kg ha\(^{-1}\) + 50 kg ha\(^{-1}\)). Within the loam zone the 165 kg urea ha\(^{-1}\) (115 kg ha\(^{-1}\) + 50 kg ha\(^{-1}\)) rate achieved the maximum ROI of $7.82 return per $1 spent on urea, while in the clay zone the maximum ROI of $11.72 return per $1 spent on urea was achieved by applying 115 kg urea ha\(^{-1}\) (65 kg ha\(^{-1}\) + 50 kg ha\(^{-1}\)). Normalised Difference Vegetation Index (NDVI) measurements were taken over the trial paddock to assess potential differences in biomass/yield potential between N treatments/soil zones. NDVI value versus yield estimate value correlations were completed throughout the growing season. Correlations were very weak early in the season and only marginally improved at flowering onset. This weak relationship was believed to be caused by human errors in both pixel NDVI value interpretation and in the yield estimate process. While the trial did not produce conclusive yield estimate differences between N treatments, it still highlighted differences in yield potential between different soil zones and the benefits of variable rate nitrogen applications over spatially variable paddocks.
Introduction

The concept of Precision Agriculture (PA) has grown in the world since the early 1990’s with the inventions of the Global Positioning System, yield monitoring and other associated technologies (Brase 2006; Srinivasan 2006). Precision agriculture comes under many different terms including precision farming (PF), information-intensive agriculture, prescription farming, target farming, site specific crop management (SSCM), variable rate management, variable rate technology (VRT), farming by soil, grid soil sampling agriculture, grid farming, Global Positioning Systems (GPS) agriculture, farming by the inch and farming by the foot (Srinivasan 2006).

The concept of PA however remains the same no matter which definition or term is used to describe it (Srinivasan 2006). PA is defined as a “system approach to managing soils and crops to reduce decision uncertainty through better understanding and management of spatial and temporal variability” (Dobermann et al. 2004). Spatial variability is the variation that can be viewed across a paddock such as yield and soil maps. Temporal variability is seen when yield maps are compared from year to year to allow managers to examine trends showing underlying features (Srinivasan 2006). The driving force for PA is spatial variability because without it, dividing paddocks into management zones/subfield areas is not required (Brase 2006).

The main goal of PA is to vary input amounts to match the spatial yield potential of a particular site and therefore minimise input costs while maximising the economic return to the producer (Schwab et al. 2005). In Australia, pressures to increase the profitability of agricultural production and to a lesser degree, environmental issues such as nitrate leaching have driven PF research (Dobermann et al. 2004).

Variable Rate Application (VRA) is a method of applying varying rates of inputs such as seed, fertiliser and chemicals in appropriately designated zones within a paddock (Grisso et al. 2011). According to Grisso et al. (2011) there are three main goals of VRA:

1) Maximise profit to its fullest potential
2) Create efficiencies in input application
3) Ensure sustainability and environmental safety

According to Grisso et al. (2011) and Kuhar et al. (1997) there are two basic methods for implementing VRA:

1) Map-based VRA
2) Sensor-based VRA

Map-based VRA systems adjust the input application rate based on information contained within an electronic map (prescription map) of a paddock’s properties (Kuhar 1997). This
system is capable of determining the machine’s position within a paddock and relates that location to a desired application rate through reading the map (Kuhar 1997).

Sensor-based VRA systems do not use application rate/prescription maps but instead use data from real-time sensors to electronically control site-specific field operations (Kuhar 1997). Sensors located on the applicator measure soil properties or crop characteristics ‘on-the-go’ and this continual information stream enters a control system, which calculates soil or plant input requirements (Grisso et al. 2011). This information is transferred to a controller, enabling delivery of the input to the specific location which was measured by the sensor (Grisso et al. 2011). Both systems have advantages and disadvantages, and a combination of these systems in VRA will most likely produce the best economic or environmental benefits (Kuhar 1997).

VRA Management Zones (Grisso et al. 2011) or Potential Management Zones (PMZs) (Inchbold, Whelan & Baines 2009) illustrate a paddock’s natural variability and are used to manage the VRA of inputs across the paddock (Grisso et al. 2011). VRA Management Zones/PMZs are useful for writing prescription maps and identifying if VRA of fertiliser is beneficial (Inchbold, Whelan & Baines 2009). VRA Management Zones or PMZs are typically built through the combination of previous paddock yield maps, soil testing or soil ECa (electrical conductivity) from EM (electromagnetic) 38 surveys or gamma radiometric maps and elevation maps (Inchbold, Whelan & Baines 2009).

Prescription maps are electronic data files composed of specific details on input rates to be applied in the different paddock management zones (Grisso et al. 2011). Remote Sensing (RS) in general is a group of techniques used to gather information about an object or area without being in physical contact with it (Kuhar 1997). RS involves measuring energy, known as electromagnetic energy, that is reflected or emitted from objects (Kuhar 1997). The information gathered from RS is then processed and analysed and the information is used in developing a prescription map for VRA application (Grisso et al. 2011).

In theory VRA increases producers’ economic returns through strategically optimising input amounts placed in each zone (Grisso et al. 2011). VRA allows producers to focus inputs on management zones that yield the highest return, while reducing inputs in zones of lower productivity or where past management practices have led to a reduced need for inputs (Grisso et al. 2011).

There are still factors that are beyond the control of farmers/producers that can reduce any potential benefits of VRA (Brase 2006; Kuhar 1997). A major factor is weather particularly rainfall and temperature, and the timing of these events in relation to crop development stages, which can overwhelm crop growth factors and/or all other inputs (Kuhar 1997).

The large variability in soil type across some paddocks can lead to inaccurate nutrient recommendations for particular management zones (Brase 2006) unless highly extensive
soil sampling occurs. The costs of detailed soil sampling and analysing is preventing dense grid soil sampling techniques (Tekin 2010).

If the use of site specific crop management (SSCM) techniques associated with VRA adds time to planting, spraying or harvest operations, the cost of downtime must be taken into account by the farmer (Kuhar 1997). VRA machines tend to be more complicated and thus farmers must take into account how reliable the extra components and systems are and the extra costs and difficulties associated with repairing them in contrast to simpler machines (Kuhar 1997).

Research has been carried out in the past to determine the potential economic benefits of VRA and site-specific management (SSM). Tekin (2010) conducted a study examining the economics of VRA in Turkish wheat production using an investment appraisal and partial budgeting analysis to determine applicable conditions for farmers. It was concluded that applying nitrogen fertiliser considering soil nutrient variation could be economically justified with 1 to 10 % yield increases and 4 to 37 % savings in fertiliser (Tekin 2010). Tekin (2010) also concluded that the key factor for PA implementation is the degree of variability; with higher variability leading to easier implementation. This is supported by Babcock and Pautsch (1998) who concluded that less productive fields in their study possessed more variability in which the value of variable rate technology (VRT) will be higher than for less variable fields.

Koch et al. (2004) conducted on farm studies of two continuous corn (Zea mays L.) fields in north-eastern Colorado, USA, using three different N management strategies: uniform, grid-based, site-specific management zone-constant yield goal (SSMZ-CYG) and site-specific management zone-variable yield goal (SSMZ-VYG). In order to determine the economics of each N management strategy and which N strategy was most profitable “profit and loss software” was used (Koch et al. 2004). Results gathered from three site years consistently indicated that 6-46 % less total N fertiliser was used under the SSMZ-VYG N management strategy in comparison to uniform N management (Koch et al. 2004). Net returns were $18.21 to $29.57/ha higher when using the SSMZ-VYG N management strategy compared to uniform N management (Koch et al. 2004).

Batte (2000) explored the potential impact of site-specific management (SSM) on farm receipts, variable input costs and fixed investment costs along with the likely impact of farm size on profitability of SSM adoption and the potential environmental consequences of SSM for society. Batte (2000) concluded that SSM can potentially improve farm profitability and lessen environmental damages of agriculture. Economic performance of SSM is site-specific and financially its performance will depend on farm soil and resource attributes, inherent variability in production for these resources and previous management decisions (Batte 2000). The idea that economic performance of SSM/VRA is site-specific is supported by Maine et al. (2009) who concluded that the profitability of VR technology is site-specific, and what is profitable in one area is not necessarily profitable elsewhere. Under SSM yield will
likely increase on some field sites while decreasing on others and input usage will also vary unpredictably in comparison to a uniform input strategy (Batte 2000). Farm total fixed costs will increase under SSM due to investments in associated technologies, machinery and human capital and profits from SSM investment will be determined by relative changes in revenues and costs (Batte 2000). The costs and profits of SSM will be impacted by the size of the adopting farm with larger farms having a greater profit potential (greater economies of scale) (Batte 2000). Economies of scale may justify ownership of VRT equipment and allow adoption of this technology for many farming operations (Koch et al. 2004). Batte (2000) also concluded that environmental impacts from SSM adoption are likely due to fertiliser and agrichemical input usage either increasing or decreasing. The adoption of SSMZ and VRT can potentially create a more environmentally friendly, profitable, and sustainable agriculture (Koch et al. 2004).

Babcock and Pautsch (1998) evaluated the potential value of switching from uniform to variable fertiliser rates based on the yield potential model of various soil types in 12 Iowa counties. The results indicated a moderate increase in gross returns over fertiliser costs ranging from $7.43 to $1.52/acre, a reduction in fertiliser costs by $1.19 to $6.83/acre and under the model assumptions applying variable fertiliser rates would increase yield by 0.05 to 0.50 bushels/acre (Babcock & Pautsch 1998). The net profitability of VRT is sensitive to the per acre costs of changing to a VRT program (Babcock & Pautsch 1998). Babcock and Pautsch (1998) demonstrated that applying an optimal uniform rate on 240 fields resulted in 66% of the acreage being oversupplied with N fertiliser and only 4% being undersupplied. Babcock and Pautsch (1998) suggest that by matching fertiliser rates with soil productivity environmental benefits would occur due to less N being available to contaminate water supplies.

One study summarised the results from 17 field crops in terms of PA profitability analyses and of those, five showed PA as unprofitable, six produced mixed or inconclusive results and six produced potential profitability (DeBoer and Swinton 1997, in Maine et al. 2009, pp. 449-450). Another study reviewed and summarised 133 publicly available studies on PA profitability; 108 of these reported on the economics of the associated technology with 63% producing positive net returns, 11% producing negative returns for a specific technology and the remaining reports producing inconclusive results (Lambert and Lowenberg-DeBoer 2000, in Maine et al. 2009, p. 450).

Kahabka et al. (2004) conducted a study to evaluate the spatial structure of yield response to N fertiliser and investigate the potential for SSM of N under maize production in New York on variably drained soils. In contrast to other literature, the spatial yield response analysis from the study displayed limited field-scale regionalisation of both yield and profit response to N and it was suggested that site-specific application of N is impractical (Kahabka et al. 2004). It was observed that the greatest source of variability in N requirement was the annual effects of the weather, which presents a greater potential for precise N application.
Kahabka et al. (2004) noted that annual variations in the optimum N rate did not relate to annual yield differences observed and yield potential on its own does not appear to be a good N requirement predictor.

A common theme in the literature is the concern of high costs associated with grid soil sampling and other sampling procedures often associated with PA strategies. It is seen as a considerable obstacle to the profitability of PF approaches (Dobermann et al. 2004). VR N applications from the study by Koch et al. (2004) based on grid soil sampling were economically unfeasible due to the costs of the soil sampling process and increased N fertiliser application. This is supported by Tekin (2010) who concluded that costs associated with detailed soil sampling and analysing is a barrier preventing soil sample collection from a dense grid of data points and new soil mapping techniques must be developed and used including remote sensing and multispectral photography in order to reduce costs (Tekin 2010). Approaches to manage spatial variability which have minimal-cost and are effective are required (Koch et al. 2004).

Yield maps on their own provide a basis for estimating phosphorus (P) and potassium (K) fertiliser replenishment levels however they are unable to determine a variable N application strategy in a certain season to optimise management (Dobermann et al. 2004). Dobermann et al. (2004) stated that paddock variability can be difficult to predict from using several seasons of yield maps and thus paddocks should also be managed in accordance with the current season conditions instead of using historic yield maps alone.

Grisso et al. (2011) stated that N response patterns are usually paddock and season specific and can vary widely within the same paddock, which further complicates prescription map construction. In future years, an improved understanding of temporal variation in N soil test levels, improved crop simulation models and improved N sensing and application equipment may help farmers to capture the benefits of VRA N management (Grisso et al. 2011). Another approach to site-specific N management entails reacting to the N levels within crop paddocks during the current growing season (Grisso et al. 2011). This process is completed by monitoring crop N status in near-real time and then N is applied only when and where it is needed (Grisso et al. 2011). In this method in order to identify plant N stress, plant or canopy reflectance of light or chlorophyll content is used and these optical methods make it possible to construct in-season N prescription maps based on crop N stress instead of predicted yield (Grisso et al. 2011). The main benefit of this method is that it allows producers to identify plant N stress in the current crop, which may be different to previous seasons due to changes in the season climate. This enables them to take action to optimise N application for that particular season and not just base N application on what has happened in the past (yield maps).

One tool that can monitor crop status in near real time is the normalised difference vegetation index (NDVI). NDVI is calculated as: \( \text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}} \), "where Red and NIR stand for the spectral reflectance measurements acquired in the red and near-
infrared regions, respectively” (Zhang et al. 2011). (Tucker 1979) concluded that IR/red ratio and related IR and red linear combinations were superior to green/red ratio and related green and red linear combinations for monitoring vegetation. Healthier crop canopies absorb more red light and reflect more near-infrared light compared to stressed or unhealthy canopies and thus have a higher NDVI value (Zhang et al. 2011). NDVI satellite imagery is a cost effective method to identify plant N stress and can be easily completed over a large scale. NDVI satellite imagery can be completed commercially for $0.90/ha (Whitlock, pers. comm., 2 April 2011) and produced within 24 hours after satellite capture (precisionagriculture.com.au 2010).

Knowledge gaps still exist in agricultural nutrient application in terms of where, when and what quantity should be applied. Filling this knowledge gap can improve targeted use of inputs, crop productivity, farm profitability and sustainability of farming land. Real-time forms of N management where remote sensing or on-the-go crop sensors are used to complete VR N applications at critical growth stages are emerging, however at the current time these technologies are not commonly used by farmers and available research data on these systems does not allow thorough evaluation (Schwab et al. 2005).

A VR nitrogen trial was set up in a canola paddock on the Murnong Farming operation near Inverleigh, Victoria (30 km west of Geelong). The main objectives of the project were to evaluate the possible production and economic benefits of using VR N in paddocks with a range of soil types (spatially variable paddocks). The project also aims to highlight the benefits of using satellite imagery/crop sensors (NDVI) along with EM38 and yield maps to define paddock management zones and determine in season crop N stress (NDVI).

**Materials & Methods**

**The Trial Paddock**

The paddock used for the project trial was paddock Y09 located on the Murnong Farming operation in the Inverleigh district approximately 30 km west of Geelong, Victoria (-38.14 Latitude, 144.04 Longitude). Paddock Y09 is 43 ha and was sown with Hyola 601 RR canola in 2011. Previous crops sown in paddock Y09 were barley (2010) and wheat (2009).

Commercially available EM38 mapping was completed on paddock Y09 in 2010 to assist in determining the range and area of different soil types. The EM38 map concluded that paddock Y09 has a mixture of sand, loam and clay soils. This information in combination with historical yield maps from the site was used to determine the location of the trial.

**Experimental Design**

A strip trial experimental design was used for the project. The design involved applying four different blanket application urea treatments across a portion of the paddock corresponding with controlled traffic fertiliser application and harvesting passes.
The four urea treatments were 0, 65, 115 and 130 kg ha\(^{-1}\). Each treatment (excluding 0 kg ha\(^{-1}\) treatment) was applied in 60 m wide strips – 3 fertiliser passes. The 0 kg ha\(^{-1}\) strip was 20 m wide – 1 fertiliser pass. These treatment strips ran the total paddock length (approximately 770 m) and each strip crossed different paddock soil types/management zones. Two 115 kg ha\(^{-1}\) treatment strips were made to ensure the treatment crossed different soil types/management zones.

![Figure 1. The Trial Layout (UAN treatment not part of trial)](image)

<table>
<thead>
<tr>
<th>Urea Treatment (kg ha(^{-1}))</th>
<th>N rate (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 + 50</td>
<td>23</td>
</tr>
<tr>
<td>65 + 50</td>
<td>52.9</td>
</tr>
<tr>
<td>115 + 50</td>
<td>75.9</td>
</tr>
<tr>
<td>130 + 50</td>
<td>82.8</td>
</tr>
</tbody>
</table>

Urea was applied via a Bogballe\(^{®}\) spreader and John Deere\(^{®}\) 7930 tractor. The treatment strip locations were recorded via a John Deere GreenStar\(^{®}\) GPS when the urea applications occurred. This data was downloaded onto Farm Works\(^{®}\) software and then uploaded onto a Trimble Nomad\(^{®}\) handheld GPS to be used for biomass and plant density measurement sampling points.
The treatment strip urea applications were completed on 12 August, 2011 at the rosette growth stage. The entire Y09 paddock received an additional 50 kg ha$^{-1}$ blanket urea application following the strip trial applications on 31 August, 2011 prior to flowering. In the estimated yield average comparisons and economic analysis of the different treatments the total urea application is considered (i.e. 50 kg ha$^{-1}$ blanket urea application is added to the treatment strip applications).

**Data Collection**

A sampling plan was constructed on Farm Works® software to complete biomass cuts, plant counts and yield estimates. The sampling plan was constructed by placing 10 sampling points within each treatment strip (5 points in each 115 kg ha$^{-1}$ strip). The sampling points were placed strategically to ensure there were samples taken from each soil type within the treatment strip.

![Sampling plan](image)

**Figure 2. Sampling plan – yellow zone = sand, red zone = loam, blue zone = clay. Numbers represent the sampling points**

The sampling plan was downloaded onto the Trimble Nomad® handheld GPS. Plant counts and biomass cuts were completed on 8 September, 2011 (biomass 1) via use of the
handheld GPS to determine the sampling points. A 50 cm ruler was placed at random in the canola crop at the sampling points. The number of plants on each side of the ruler was recorded (plants/m) and then secateurs were used to cut the plants at the base. The plants were placed into labelled (sampling point ID) paper bags.

![Figure 3. Equipment used during plant count and biomass cutting processes](image)

The biomass cuts were weighed after collection (fresh weight) and the results were recorded. Due to delays in placing the cuts in an oven, plant growth occurred in the bags and thus an accurate dry weight could not be recorded. Biomass cuts were again completed on 17 October, 2011 (biomass 2) using the same process. The cuts were weighed after collection (fresh weight) and the results recorded.

![Figure 4. Biomass cuts being completed](image)
Figure 5. Fresh weights being recorded from biomass cuts

During the second biomass collection process yield estimates were completed on 24 biomass samples. Three yield estimates were completed for each soil type in each nitrogen treatment. In the case where the treatment strip had less than three sampling points in each soil type the yield estimates were simply taken from the number of samples collected in the soil zone. Yield estimates on each sample were completed by using the yield component method.

The number of pods/m², average number of seeds/pod and seed weight measurements were used to determine the yield estimate. The number of pods per sample was determined by selecting three plants from the sample (in sample 7 all eight plants were selected due to counting errors) that represented the plant sample size range and then counting the pods on each of these plants. An average number of pods/plant was then calculated and this value was multiplied by the number of plants in the sample to determine the number of pods in the sample. This number was divided by the crop sample row spacing to determine the number of pods/m². The average number of seeds/pod for each sample was determined by recording the number of seeds in ten of the sample pods to calculate an average. Seed weight was assumed to be 3 grams per 1000 seeds (Nicolas, pers. comm., 4 October 2011).

Yield estimate = pods/m² * seeds/pod * seed weight

(Nicolas, pers. comm., 4 October 2011)

Yield estimates were calculated in grams/m² and converted to tonnes/hectare.
Following the yield estimates the biomass cuts were placed in plant material drying ovens (Labro, Clayson – Microprocessor and Qualtex Thermstat) for approximately 120 hours at 65°C and then removed and weighed (dry weight). The results were recorded and a conversion factor was determined from fresh to dry weight to be used to determine dry weights from the first cut.
A Topcon CropCircle® (crop sensor) was mounted to the front of Murnong Farming tractors during trial paddock passes (when chemical or fertiliser applications occurred). This sensor recorded NDVI crop measurements throughout the season over the different treatment strips. An NDVI satellite image was also captured over the trial site on 16 September, 2011.

Figure 8. Satellite imagery (NDVI) taken over Y09 paddock on 16 September, 2011

Figure 9. Topcon CropCircle® NDVI image taken over Y09 paddock on 30 August, 2011
MATLAB software was used to complete data analysis on fresh and dry biomass weights, plant counts and yield estimates according to soil type/zone and nitrogen rate.

Economic analysis was completed using the marginal return on investment (ROI) method. This method calculated the extra income received by applying a urea treatment above the base (lowest rate) on the three individual paddock soil zones. The extra urea cost was also calculated to determine profit. The profit was then divided by the extra urea cost to determine the ROI ($ return per $1 spent on urea).

Extra Income – Extra urea cost = Profit

\[
\text{Profit} = \frac{\text{Extra urea cost}}{\text{Extra urea cost}} = \text{return per $1 spent on urea (ROI)}
\]

**Results**

**Trial Site Climate Data**

**Table 2. Inverleigh 2011 and long term average Growing Season (April - October) Climate Data.**

<table>
<thead>
<tr>
<th>Month</th>
<th>2011 Monthly Mean Maximum Air Temperature (°C)</th>
<th>Long Term Monthly Mean Maximum Air Temperature (°C)</th>
<th>2011 Monthly Rainfall (mm)</th>
<th>Long Term Monthly Mean Rainfall (mm)</th>
<th>Decile 5 Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>18.3</td>
<td>19.1</td>
<td>20.7</td>
<td>42.3</td>
<td>38.0</td>
</tr>
<tr>
<td>May</td>
<td>13.2</td>
<td>15.0</td>
<td>38.0</td>
<td>36.3</td>
<td>39.4</td>
</tr>
<tr>
<td>June</td>
<td>12.7</td>
<td>12.3</td>
<td>48.8</td>
<td>48.6</td>
<td>45.4</td>
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<td>July</td>
<td>11.7</td>
<td>11.5</td>
<td>73.1</td>
<td>56.0</td>
<td>57.6</td>
</tr>
<tr>
<td>August</td>
<td>14.1</td>
<td>12.7</td>
<td>29.7</td>
<td>61.1</td>
<td>54.7</td>
</tr>
<tr>
<td>September</td>
<td>15.9</td>
<td>14.4</td>
<td>21.8</td>
<td>49.1</td>
<td>44.8</td>
</tr>
<tr>
<td>October</td>
<td>17.6</td>
<td>16.6</td>
<td>63.0</td>
<td>52.2</td>
<td>38.6</td>
</tr>
</tbody>
</table>

| 2011 Growing Season Rainfall (GSR) (mm) | Decile 5 GSR (mm) | 318.5 |

Source: Bureau of Meteorology (2011). Note 2011 monthly mean maximum air temperature, long term monthly mean maximum air temperature, long term monthly mean rainfall and decile 5 rainfall recorded from Colac (Mount Gellibrand) weather station (20.8 km from Inverleigh) and 2011 monthly rainfall recorded from Winchelsea (post office) weather station (11.4 km from Inverleigh).

As seen in Table 2 the 2011 growing season rainfall (GSR) of 295.1 mm is reasonably close to a decile 5 GSR rainfall of 318.5 mm and 2011 monthly mean maximum temperatures are
similar to the long term average. Due to the high sub soil moisture availability at sowing it was assumed that the trial site had experienced a decile 5 GSR and thus there was no substantial climate extremes expected to affect results.

**Biomass Data**

The fresh biomass cuts completed on 8 September 2011 (biomass 1) ranged from 801 – 1875 g/m – mean of 1154 g/m (0 kg urea ha⁻¹), 860 – 1948 g/m – mean of 1449 g/m (65 kg urea ha⁻¹), 804 – 1703 g/m – mean of 1137 g/m (115 kg urea ha⁻¹) and 458 – 1023 g/m – mean of 759 g/m (130 kg urea ha⁻¹). The analysis of variance (ANOVA) indicates a significant difference (p = <0.05) between the fresh biomass weights for the different nitrogen treatments (see Appendix A Table A5). Figure 10 indicates significant differences between the fresh weights in the urea treatments of 0 and 130 kg ha⁻¹ and 65 and 130 kg ha⁻¹.

![Figure 10. Fresh biomass 1 (g/m) range (box plots) for 0, 65, 115 and 130 kg ha⁻¹ nitrogen (urea) applications](image)

The fresh biomass cuts completed on 17 October, 2011 (biomass 2) ranged from 1145 – 2245 g/m – mean of 1706 g/m (0 kg urea ha⁻¹), 1670 - 2585 g/m – mean of 1933 g/m (65 kg urea ha⁻¹), 1000 – 2230 g/m – mean of 1677 g/m (115 kg urea ha⁻¹) and 495 - 2180 g/m – mean of 1403 g/m (130 kg urea ha⁻¹).

The ANOVA indicates a significant difference (p = <0.05) between the fresh biomass weights for the different nitrogen treatments (see Appendix A Table A7). Figure 11 indicates a significant difference between the fresh weights in the nitrogen treatments of 65 and 130 kg ha⁻¹. The p value here (0.03) also indicates a reduced significant difference between the nitrogen treatment fresh weights (biomass 2) compared to biomass 1 (p = 8.6*10⁻⁰.⁰⁰⁵).
Figure 11. Fresh biomass 2 (g/m) level range (box plots) for 0, 65, 115 and 130 kg ha⁻¹ nitrogen (urea) applications

The fresh biomass 1 cuts ranged from 596 – 1206 g/m – mean of 838 g/m (sand), 458 – 1948 g/m – mean of 1307 g/m (loam) and 801 – 1476 g/m – mean of 1135 g/m (clay).

A p value of <0.05 from the ANOVA indicates a significant difference in fresh biomass 1 weights between the three soil types (see Appendix A Table A6). A significant difference is observed between the fresh biomass weights of the sand and clay soil types in Figure 12.

Figure 12. Fresh biomass 1 level range (box plots) for sand, loam and clay soil types/zones
The fresh biomass 2 cuts ranged from 1000 – 2180 g/m – mean of 1540 g/m (sand), 495 – 2585 g/m – mean of 1623 g/m (loam) and 1200 – 2245 g/m – mean of 1829 g/m (clay).

The ANOVA indicates no significant difference (p = >0.05) in the fresh biomass 2 weights between the three soil types (see Appendix A Table A8). There is however a trend of increasing fresh biomass from sand to clay soil.

Figure 13. Fresh biomass 2 level range (box plots) for sand, loam and clay soil types/zones

The dry biomass 1 calculated from the biomass 2 cut fresh to dry weight conversion factor ranged from 152 – 356 g/m – mean of 219.4 g/m (0 kg urea ha⁻¹), 163 – 370 g/m – mean of 275.2 g/m (65 kg urea ha⁻¹), 153 – 324 g/m – mean of 216.1 g/m (115 kg urea ha⁻¹) and 87 – 194 g/m – mean of 144.2 g/m (130 kg urea ha⁻¹).

A p value <0.05 from the ANOVA indicates a significant difference in dry biomass 1 weights between the four nitrogen treatments (see Appendix A Table A1). A significant difference is observed between the dry biomass weights in the 0 and 130 kg urea ha⁻¹ treatments in Figure 14.
The dry biomass calculated from the biomass cuts ranged from 230 – 430 g/m – mean of 336.5 g/m (0 kg urea ha⁻¹), 310 – 465 g/m – mean of 363.5 g/m (65 kg urea ha⁻¹), 175 – 405 g/m – mean of 314.5 g/m (115 kg urea ha⁻¹) and 90 – 400 g/m – mean of 263 g/m (130 kg urea ha⁻¹).

The ANOVA indicated a significant difference in dry biomass weights between the four nitrogen treatments (p = <0.05) (see Appendix A Table A3). A significant difference is observed between the dry biomass weights in the 65 and 130 kg urea ha⁻¹ treatments in Figure 15.
The dry biomass 1 cuts ranged from 113 – 229 g/m – mean of 159 g/m (sand), 87 – 370 g/m – mean of 248 g/m (loam) and 152 – 280 g/m – mean of 216 g/m (clay).

A significant difference was observed in dry biomass 1 levels between the three soil types in the ANOVA (p = <0.05) (see Appendix A Table A2). In Figure 16 a significant difference is observed between the dry biomass weights in sand and clay soil types. Both the loam and clay soil zones have higher mean dry weight levels than the sand soil zone.

![Figure 16. Dry biomass 1 level range (box plots) for sand, loam and clay soil types/zones](image)

The dry biomass calculated from the biomass 2 cut ranged from 175 – 400 g/m – mean of 288 g/m (sand), 90 – 465 g/m – mean of 306 g/m (loam) and 245 – 430 g/m – mean of 354 g/m (clay).

The ANOVA displayed no significant difference in dry biomass 2 levels between the three soil types (p = >0.05) (see Appendix A Table A4). However there was a trend of increasing dry weight moving from the sand to clay soils.
The plant density measurements taken on 17 October, 2011 ranged from 28 – 56 plants/m² - mean of 42 plants/m² (sand), 12 – 84 plants/m² – mean of 40 plants/m² (loam) and 26 – 72 plants/m² - mean of 48 plants/m² (clay).

No significant differences were observed between plant density and soil type or urea rate according to the ANOVA tests (p = >0.05) (see Appendix B). Both the sand and loam soil zones had lower plant densities compared to the clay zone.

Figure 17. Dry biomass 2 level range (box plots) for sand, loam and clay soil types/zones

**Plant Density Data**

Figure 18. Plant density 2 (plants/m²) range (box plots) for sand, loam and clay soil types
**Yield Estimate Data**

Yield estimates completed on the biomass 2 cuts ranged from 1.43 – 5 t ha\(^{-1}\) – mean of 3.66 t ha\(^{-1}\) (0 kg urea ha\(^{-1}\)), 2.55 – 4.5 t ha\(^{-1}\) – mean of 3.64 t ha\(^{-1}\) (65 kg urea ha\(^{-1}\)), 3.52 – 7.11 t ha\(^{-1}\) – mean of 4.99 t ha\(^{-1}\) (115 kg urea ha\(^{-1}\)) and 2.04 – 5.98 t ha\(^{-1}\) – mean of 4.70 t ha\(^{-1}\) (130 kg urea ha\(^{-1}\)). According to the ANOVA there is no significant difference in yield estimates between the four nitrogen treatments (p = >0.05) (see Appendix C Table C1).

![Figure 19](image)

**Figure 19. Canola yield estimate (t ha\(^{-1}\)) range (box plots) for 0, 65, 115 and 130 kg ha\(^{-1}\) nitrogen (urea) applications**

Yield estimates completed on the biomass 2 cuts ranged from 3.96 – 7.11 t ha\(^{-1}\) – mean of 5.60 t ha\(^{-1}\) (sand), 2.04 – 4.99 t ha\(^{-1}\) – mean of 3.59 t ha\(^{-1}\) (loam) and 1.43 – 6.24 t ha\(^{-1}\) – mean of 4.16 t ha\(^{-1}\) (clay).

According to the ANOVA test there is a significant difference in yield estimates between the three soil types (p = <0.05) (see Appendix C Table C2). As seen in Figure 20 yield estimates taken from the sand soil zone are significantly higher than those taken on the loam and clay soil zones.
Figure 20. Canola yield estimate (t ha⁻¹) range (box plots) for sand, loam and clay soil types

The following part of the results addresses the urea treatments in regards to the total urea applied for the season in each treatment (i.e. 115 kg ha⁻¹ + 50 kg ha⁻¹ paddock blanket application = 165 kg ha⁻¹).

The average canola yield estimates in the paddock Y09 sand soil zones are 5.57 t ha⁻¹ (165 kg urea ha⁻¹) and 5.64 t ha⁻¹ (180 kg urea ha⁻¹). According to the standard error bars there is no significant difference between canola yield estimates on sand soil zones in the 165 and 180 kg urea ha⁻¹ treatments. Yield estimates do increase with increasing N rate.

Figure 21. Average canola yield estimate levels (t ha⁻¹) for 165 and 180 kg ha⁻¹ urea application rates on paddock Y09 sand soil zone. Error bars represent standard errors.
The average canola yield estimates in the paddock Y09 loam soil zone are 4.16 t ha\(^{-1}\) (50 kg urea ha\(^{-1}\)), 3.04 t ha\(^{-1}\) (115 kg urea ha\(^{-1}\)), 3.52 t ha\(^{-1}\) (165 kg urea ha\(^{-1}\)) and 3.76 t ha\(^{-1}\) (180 kg urea ha\(^{-1}\)). According to the standard error bars there is a significant yield estimate difference between the 50 and 115, 50 and 165 and 115 and 180 kg urea ha\(^{-1}\) treatments. The yield estimates have not responded positively to increasing N rate here.

![Loam Zone Yields](image1)

**Figure 22.** Average canola yield estimate levels (t ha\(^{-1}\)) for 50, 115, 165 and 180 kg ha\(^{-1}\) urea application rates on paddock Y09 loam soil zone. Error bars represent standard errors

The average canola yield estimates in the paddock Y09 clay soil zone are 3.33 t ha\(^{-1}\) (50 kg urea ha\(^{-1}\)), 4.23 t ha\(^{-1}\) (115 kg urea ha\(^{-1}\)) and 4.90 t ha\(^{-1}\) (165 kg urea ha\(^{-1}\)). According to the standard error bars there is a significant yield estimate difference between the 50 and 165 kg urea ha\(^{-1}\) treatments. Yield estimates increase with increasing N rate.

![Clay Zone Yields](image2)

**Figure 23.** Average canola yield estimate levels (t ha\(^{-1}\)) for 50, 115 and 165 kg ha\(^{-1}\) urea application rates on paddock Y09 clay soil zone. Error bars represent standard errors
Marginal Return on Investment Data

115 and 130 kg urea ha^{-1} treatment strips passed through the paddock Y09 sand zone. Therefore from a base rate of 165 kg urea ha^{-1} (including 50 kg ha^{-1} blanket application), the extra income received by applying 180 kg ha^{-1} equates to $37.94/ha. The extra urea cost is $8.85/ha equating to a profit increase of $29.09/ha and a marginal return on investment of $3.29/$1 spent on urea.

![Marginal Return on Investment - Sand Zone](image.png)

Figure 24. Marginal return on investment ($ return per $1 spent on urea) for urea application rates of 165 and 180 kg ha^{-1} (above base rate of 165 kg ha^{-1}) in paddock Y09 sand zone. Note marginal return on investment based on average estimated yields, urea price of $590/tonne and canola price of $542/tonne

All four urea treatment strips (0, 65, 115 and 130 kg ha^{-1}) passed through the paddock Y09 loam zone. Therefore from a base rate of 50 kg urea ha^{-1}, the extra income received by applying the three higher urea applications is -$607.04/ha (115 kg ha^{-1}), -$346.88/ha (165 kg ha^{-1}) and -$216.80/ha (180 kg ha^{-1}). The extra urea cost was $38.35/ha (115 kg ha^{-1}), $67.85/ha (165 kg ha^{-1}) and $76.70/ha (180 kg ha^{-1}). This equates to a profit increase of -$645.39 (115 kg ha^{-1}), -$414.73 (165 kg ha^{-1}) and -$293.50 (180 kg ha^{-1}) and a marginal return on investment of -$16.83/$1 spent on urea (115 kg ha^{-1}), -$6.11/$1 spent on urea (165 kg ha^{-1}) and -$3.83/$1 spent on urea (180 kg ha^{-1}).
Figure 25. Marginal return on investment ($ return per $1 spent on urea) for urea application rates of 50, 115, 165 and 180 kg ha\(^{-1}\) (above base rate of 50 kg ha\(^{-1}\)) in paddock Y09 loam zone. Note marginal return on investment based on average estimated yields, urea price of $590/tonne and canola price of $542/tonne.

The marginal return on investment excluding the 50 kg urea ha\(^{-1}\) rate on the loam soil zone scenario was examined as it is highly likely that the high 50 kg urea ha\(^{-1}\) loam yield estimate resulting in the -$ return on investment for the 115, 165 and 180 kg ha\(^{-1}\) rates is due to human errors in the yield estimation process.

From a base rate of 115 kg urea ha\(^{-1}\), the extra income received by applying the two higher urea applications is $260.16/ha (165 kg ha\(^{-1}\)) and $130.08/ha (180 kg ha\(^{-1}\)). The extra urea cost was $29.50/ha (165 kg ha\(^{-1}\)) and $38.35/ha (180 kg ha\(^{-1}\)). This equates to a profit increase of $230.66/ha (165 kg ha\(^{-1}\)) and $91.73 (180 kg ha\(^{-1}\)) and a marginal return on investment of $7.82/$1 spent on urea (165 kg ha\(^{-1}\)) and $2.39/$1 spent on urea (180 kg ha\(^{-1}\)).
Figure 26. Marginal return on investment ($ return per $1 spent on urea) for urea application rates of 115, 165 and 180 kg ha⁻¹ (above base rate of 115 kg ha⁻¹) in paddock Y09 loam zone. Note marginal return on investment based on average estimated yields, urea price of $590/tonne and canola price of $542/tonne.

0, 65 and 115 kg urea ha⁻¹ treatment strips passed through the paddock Y09 clay zone. From a base rate of 50 kg urea ha⁻¹, the extra income received by applying the two higher rates was $487.80/ha (115 kg ha⁻¹) and $850.94/ha (165 kg ha⁻¹). The extra urea cost was $38.35/ha (115 kg ha⁻¹) and $67.85 (165 kg ha⁻¹). This equates to a profit increase of $449.45/ha (115 kg ha⁻¹) and $783.09/ha (165 kg ha⁻¹) and a marginal return on investment of $11.72/$1 spent on urea (115 kg ha⁻¹) and $11.54/$1 spent on urea (165 kg ha⁻¹).
Figure 27. Marginal return on investment ($ return per $1 spent on urea) for urea application rates of 50, 115 and 165 kg ha\(^{-1}\) (above base rate of 50 kg ha\(^{-1}\)) in paddock Y09 clay zone. Note marginal return on investment based on average estimated yields, urea price of $590/tonne and canola price of $542/tonne.

**NDVI versus Yield Estimate Data**

The regression analysis of the NDVI values recorded from the Topcon CropCircle® equipment and the estimated canola yield show extremely poor R\(^2\) values of 0.0034 (July 15) and 0.0078 (August 30) indicating very week relationships between NDVI value and estimated yield.

Figure 28. Regression analysis of NDVI values (recorded on 15 July 2011) and estimated canola yield (t ha\(^{-1}\))
Discussion

Biomass

The dry biomass weight/dry weight (g/m) 1 results (DW1) up until 8 September, 2011 displayed distinct differences between the four nitrogen treatments. A significant difference was observed between the 0 and 130 kg urea ha\textsuperscript{-1} treatments (p = <0.05). While the 65 kg ha\textsuperscript{-1} rate had a higher average DW1 (275.2) than the 0 kg ha\textsuperscript{-1} rate (219.4), both the 115 kg ha\textsuperscript{-1} (216.1) and 130 kg ha\textsuperscript{-1} (144.2) rates had lower average DW1 levels than the 0 and 65 kg ha\textsuperscript{-1} urea rates.

The dry weight (g/m) 2 results (DW2) up until 17 October 2011 did show a significant difference between the 65 and 130 kg ha\textsuperscript{-1} treatments, however the differences between the nitrogen treatment average DW2 weights were lower compared to DW1 weights. Just as occurred in the DW1 weights, the 65 kg ha\textsuperscript{-1} urea rate samples had the highest average DW2 result (363.5) compared to 0 kg ha\textsuperscript{-1} (336.5), 115 kg ha\textsuperscript{-1} (314.5) and 130 kg ha\textsuperscript{-1} (263).

This trend is inconsistent with results from a study conducted by Cheema et al. (2001) where canola that was grown with higher N applications consistently had higher dry weight levels/m\textsuperscript{2} than canola grown with lower N applications.

The main reasons that may have led to the unusual trend in dry weights between N rates is both the high available N in the soil prior to sowing and the difference in row spacing (250 and 500 mm) for half the 115 kg urea ha\textsuperscript{-1} samples and 130 kg ha\textsuperscript{-1} samples compared to the 0, 65 and half the 115 kg ha\textsuperscript{-1} samples.

![NDVI versus Estimated Yield - August 30](image)

**Figure 29.** Regression analysis of NDVI values (recorded on 30 August 2011) and estimated canola yield (t ha\textsuperscript{-1})
The northern 115 kg urea ha$^{-1}$ treatment strip and the 130 kg urea ha$^{-1}$ strip both contained canola growing on a 250 mm row spacing compared to the 0, 65 and southern 115 kg urea ha$^{-1}$ treatment strips, which contained canola growing on a 500 mm row spacing. The higher plant densities observed on the wider row spacing most likely led to the increased biomass observed in these treatment strips.

Total available N in paddock Y09 prior to sowing ranged from 101.1 to 112.1 kg N ha$^{-1}$. This relatively high N level may have led to insignificant crop N response between the varying urea treatments. Therefore the unusual trends in biomass could also be caused by the high soil available N prior to sowing and topdressing.

The higher dry weight levels in the 0, 65 and southern 115 kg ha$^{-1}$ urea treatment strips compared to the 130 and northern 115 kg ha$^{-1}$ treatment strips may be due to higher total available soil N in those treatment areas due to waterlogging effects in the previous season. On the heavier clay soils where these strips are located, significant waterlogging occurred last season and thus barley crop failure occurred (2010). Therefore there may be a higher residual soil nitrogen level here due to reduced demand in these waterlogged regions last season (Whitlock 2010).

The DW1 (g/m) levels displayed a significant difference between the sand and clay soil zones. The clay zone had a higher mean DW1 (215.6) compared to the sand zone (159.1), while the loam zone had the highest mean DW1 level of 248.3 g/m. DW2 (g/m) levels however displayed no significant differences between the three soil zones. From this measurement however the highest mean DW2 was recorded in the clay zone (354.3 g/m) followed by loam (305.7) and sand (287.5).

The lower DW levels recorded in the sand zone may be due to the fact sandy soils have a lower capacity to absorb nutrients (cation form) meaning they have a lower cation exchange capacity (CEC) compared to loam and clay soils. Sand particles have a substantially lower surface area per gram of soil compared to loam and clay soils (CSIRO 1979, in Department of Primary Industries 2009, p. 16). The higher the soil particle surface area to absorb cations, the higher the inherent fertility of the soil (DPI 2009, p. 16). Therefore the higher inherent fertility of the clay and loam soil zones of paddock Y09 has likely led to the higher DW/biomass readings observed in these soils compared to the sand zone.

Coarser textured soils (i.e. sandy soils) will usually have higher infiltration rates in comparison to finer textured soils (loam and clay soils), however coarse textured soils have a poor water holding capacity compared to the finer textured soils (DPI 2009, p. 12). In the 2011 season waterlogging was not a major issue in paddock Y09 and therefore the higher water holding capacity of the loam and clay soils may have led to increased DW levels compared to the poorer water holding capacity sand soils.
Fresh weight biomass 2 (g/m) (FW2) levels were assumed to be most indicative of the FW levels at harvest as the measurement was taken 2 – 4 weeks prior to harvest. When mean FW2 biomass levels are converted to g/m² levels according to urea rate they are 3411 (0 kg ha⁻¹), 3866 (65 kg ha⁻¹), 4765 (115 kg ha⁻¹ – mean of FW averages in 250 mm and 500 mm row spacing) and 5612 (130 kg ha⁻¹).

A study conducted by Kazemeini, Hamzehzarghani and Edalat (2010) examined the effects of nitrogen on growth, yield and yield components of canola. While the study had lower biomass levels overall it displayed the same trend with an increase in fresh biomass (g/m²) as N rate was increased.

### Yield Estimates

The yield estimate results calculated from the biomass 2 cuts displayed no significant differences between the four nitrogen treatments. The mean yield estimate from the 65 kg urea ha⁻¹ treatment (3.64 t ha⁻¹) was lower than the 0 kg urea ha⁻¹ treatment (3.66 t ha⁻¹), while the 130 kg urea ha⁻¹ treatment mean yield estimate (4.70 t ha⁻¹) was lower than the 115 kg urea ha⁻¹ treatment yield estimate (4.99 t ha⁻¹). These results are inconsistent with other studies (Kazemeini et al. 2010); (Kazemeini, Hamzehzarghani & Edalat 2010) where canola yield consistently increased with increased N rate.

The yield estimates did however display significant differences between the sand soil zone compared to both the loam and clay zones (p = <0.05). The mean yield estimate for the sand zone was 5.60 t ha⁻¹ compared to the loam (3.59 t ha⁻¹) and clay (4.16 t ha⁻¹) zones.

This result is completely inverse to the DW2 biomass results where the sand zone had the lowest mean DW2 level compared to the moderate clay DW2 level and the highest level in the loam zone. The likely cause of this result is the difference in row spacing between the soil zones. 250 mm row spacing is present across the entire trial sand zone while the 500 mm row spacing is present over a large proportion of the loam and clay soil zones.

Kondra (1975) concluded in a study that in two canola cultivars yield was consistently lower in both 310 and 610 mm row spacing compared to the 230 mm row spacing. Canola yields continued to decrease as row spacing was increased from 150 to 610 mm (Kondra 1975). This information is also supported by GRDC (2011), which concluded that Western Australian canola trials displayed a mean yield reduction of 13.7 % through increasing row spacing from 18 to 36 cm (180 to 360 mm). The extent of the yield reductions ranged from 9 to 27 % (GRDC 2011).

Therefore the higher mean yield estimates observed in the paddock sand zones compared to the loam and clay zones may be due to the narrower row spacing on the sand zone (250 mm) compared to the wider row spacing on the majority of the loam and clay soil zones (500 mm). The difference in row spacing across the trial along with the high soil available N
prior to sowing may also be responsible for no significant differences in mean yield estimates between the 0, 65, 115 and 130 kg urea ha\(^{-1}\) treatment strips.

Potential crop yields can also be calculated via a standard equation that takes into account the growing season rainfall and crop water use efficiency. The trial site was assumed to have received a decile 5 growing season rainfall (GSR) of 318.5 mm (see Table 2). Yield potential for oilseeds (canola) with a growing season rainfall of 318.5 mm can be calculated via the following equation:

\[
\text{Oilseeds: Yield (kg/ha)} = (\text{Growing Season Rainfall (mm)} - 150) \times 12
\]

(Nicolas, pers. comm., 1 September 2011)

\[
\text{Oilseeds: Yield (kg/ha)} = (318.5 - 150) \times 12
\]

\[
\text{Oilseeds: Yield (kg/ha)} = 2,022 \text{ (2.02 t/ha)}
\]

The project manager observed that the yield estimate process has overestimated yield values. However the project manager still believes the appropriate yield trends have occurred.

Since the trial site has received close to an average (decile 5) GSR and monthly mean maximum temperatures are very similar to the long term monthly mean levels, yields have been assumed to have not been largely impacted by climate extremes.

**Economic Analysis – Return on Investment**

The concept of return on investment (ROI) can be defined as the dollar rate of return per unit of input used. In terms of measuring ROI for the different urea rates in this trial, the ROI was calculated from the extra return gained from using a urea rate above the base (lowest) rate used in the particular soil zone.

Within the paddock Y09 sand soil \(^1\) rate displayed the highest ROI with a $3.29 return per $1 spent on urea. The base (lowest) rate applied to the sand zone was 115 kg urea ha\(^{-1}\) (65 kg ha\(^{-1}\) + 50 kg ha\(^{-1}\)).

In regards to the loam soil zone when the 50 kg urea ha\(^{-1}\) rate (0 kg ha\(^{-1}\) + 50 kg ha\(^{-1}\)) is excluded due to the excessively high estimated yield for the rate) the 165 kg urea ha\(^{-1}\) rate (115 kg ha\(^{-1}\) + 50 kg ha\(^{-1}\)) also returned the highest ROI of $7.82 return per $1 spent on urea (115 kg ha\(^{-1}\) base rate = 65 kg ha\(^{-1}\) + 50 kg ha\(^{-1}\)). The higher 180 kg urea ha\(^{-1}\) rate (130 kg ha\(^{-1}\) + 50 kg ha\(^{-1}\)) had a ROI of $2.39.

Within the clay soil zone the highest ROI ($11.72 return per $1 spent on urea) was achieved with the 115 kg urea ha\(^{-1}\) rate (65 kg ha\(^{-1}\) + 50 kg ha\(^{-1}\)) with a 50 kg ha\(^{-1}\) (0 kg ha\(^{-1}\) + 50 kg ha\(^{-1}\)) base rate. By using the 165 kg urea ha\(^{-1}\) rate (115 kg ha\(^{-1}\) + 50 kg ha\(^{-1}\)) a slightly lower ROI was calculated ($11.54 return per $1 spent on urea).
In the case where marginal investment in a variable input (e.g. nitrogen) has uncertain returns, a return on investment (ROI) minimum rate may be required by decision makers to ensure it is acceptable to farmers (International maize and wheat improvement centre (CIMMYT) 1988, in Farquharson, Malcolm and Chen 2009, p. 6). A minimum ROI of 100 % (‘2 for 1’ return) is considered acceptable by CIMMYT (1988) in Farquharson, Malcolm and Chen (2009), p. 6. Therefore for this trial the minimum acceptable ROI is 100 % (i.e. $2 return for every $1 spent on urea).

Therefore in the paddock Y09 sand zone the $3.29 ROI by applying 180 kg urea ha⁻¹ (130 kg ha⁻¹ + 50 kg ha⁻¹) in place of the base rate used in the sand zone (165 kg urea ha⁻¹ = 115 kg ha⁻¹ + 50 kg ha⁻¹) is considered to be an acceptable investment. A peak ROI however was not realised in this zone as a higher urea rate with a lower ROI was not observed. Therefore there are opportunities to apply a higher urea rate to this zone to test where maximum ROI lies.

In the paddock Y09 loam zone (excluding 0 kg urea ha⁻¹ yield estimate) both the 165 kg urea ha⁻¹ (115 kg ha⁻¹ + 50 kg ha⁻¹) rate ROI ($7.82) and the 180 kg urea ha⁻¹ (130 kg ha⁻¹ + 50 kg ha⁻¹) rate ROI ($2.39) are both acceptable under the ‘2 for 1’ return rule. However in terms of applying a urea rate that has the greatest ROI and carries less investment risk, the 165 kg urea ha⁻¹ rate would be the most acceptable.

In terms of an acceptable urea rate under the ‘2 for 1’ return rule in the paddock Y09 clay zone, the 115 kg urea ha⁻¹ (65 kg ha⁻¹ + 50 kg ha⁻¹) rate ROI ($11.72) and 165 kg urea ha⁻¹ (115 kg ha⁻¹ + 50 kg ha⁻¹) rate ROI ($11.54) are both acceptable. However the 115 kg urea ha⁻¹ rate is the most acceptable rate in terms of maximising ROI and carrying the least investment risk.

**NDVI versus Yield Estimate Relationship**

Normalised Difference Vegetation Index (NDVI) data was collected throughout the trial via Topcon CropCircle® equipment and satellite imagery. This data was collected to assess if it recognised differences in crop biomass and vigour between the different urea treatment strips. Specific NDVI values from the yield estimate sampling points were also compared to the yield estimate values to assess if there was a relationship/correlation between NDVI value and estimated canola seed yield.

The first NDVI measurement was taken on 15 July, 2011. The relationship between NDVI value and estimated canola seed yield was very weak ($R^2 = 0.0034$) meaning only 0.34% of the variation in estimated yield can be explained by variation in NDVI value. The second NDVI measurement was completed on August 30, 2011 and again the relationship was very weak ($R^2 = 0.0078$) meaning only 0.78% of the estimated yield variation can be explained by NDVI value variation.
A study completed by Holzapfel (2007) involved establishing if it was possible to use NDVI to estimate canola yield. The overall trend was that at early crop development stages (between cotyledon and two-leaf stages) no correlation was observed between NDVI and grain yield, however the relationship became stronger as the crop continued to develop (Holzapfel 2007). The relationship was strongest as the crop began flowering (R² = 0.629) and during the late bolting stage (R² = 0.529) for two separate sites (Holzapfel 2007).

Holzapfel (2007) observed that the relationship between NDVI and canola seed yield was strongly dependent on crop growth stage at the time of sensing. The general trend was for the relationship to be weak when the canola had four or less leaves and then progressively improving as the season continued until a peak strength was observed between mid-bolting and flowering onset (Holzapfel 2007). As soon as the canola reached full bloom the correlation rapidly declined (Holzapfel 2007). Similar trends were observed by (Lafond, Holzapfel & May 2007).

When the first NDVI image was taken (15 July, 2011), the crop was at an early development stage and therefore this has likely contributed to the weak relationship between NDVI value and estimated yield. The second NDVI image (captured on 30 August, 2011) was taken just prior to flowering onset. According to the literature the relationship should have been much stronger than calculated (R² = 0.0078). Human errors in interpreting the NDVI map pixel colours (and thus values) and accurately locating the pixel on the map where the yield estimate samples were taken may have caused this poor correlation. Human errors in yield estimates may have also negatively affected the relationship.

Lafon, Holzapfel and May (2007) developed a relationship between NDVI and grain yield. The NDVI value was divided by growing degree days (GDD) (using 0°C base temperature) to account for differences in growing conditions over different sites (Lafond, Holzapfel & May 2007). The relationship accounted for 57 % of the observed wheat grain yield variation (i.e. R² = 0.57) between the 4 leaf stage and flag emergence and approximately 55 % of the variation in final canola grain yield with measurements taken between the mid-bolting stage to appearance of the first flowers (Lafond, Holzapfel & May 2007). Lafond, Holzapfel and May (2007) concluded that these relationships could provide an important planning tool as they can calculate reasonably accurate grain yield estimates throughout the growing season and that optical sensors (i.e. GreenSeeker™) can assist producers and agronomists to make more informed decisions about what the optimum N application rate is.

**Evaluation**

The project realised one of the potential risks early (May 2011) when the proposed trial paddock (wheat) suffered severe waterlogging post sowing and subsequently a total crop failure occurred. A willing farm manager was found by industry contacts who agreed to allow for the variable rate nitrogen trial to be conducted on their property.
This event disturbed the project milestone and deliverable order. As this property was not a part of the original Glenelg Hopkins Catchment Management Authority soil acidification project that the original site was, some of the project aims and methodology were altered. pH mapping of the trial paddock did occur but was not included in the project as no variable rate liming occurred for analysis and thus there was less focus on the environmental benefits of variable rate technology (VRT). 0 – 10 and 0 – 60 cm soils tests and the yield testing NDVI via the quad bike system were also not completed.

The remaining relative critical tasks of urea spreading, plant counts, biomass cuts and satellite imagery (NDVI) capture were completed within the allocated planned time frame. However after consultation with industry contacts and the project supervisor, the project manager decided to undertake a second round of biomass cuts and due to an inability to undertake an NDVI yield estimate from the quad bike system (due to high height of canola crop) a manual yield estimate also had to be completed. The yield estimate process has overestimated potential yields, however the project manager still believes the appropriate yield trends have been observed. Due to the project having to be completed prior to crop harvest the actual yield map data could not be included in the report.

The main aspect of the project which was poorly managed was the trial site measurement strategies. After the project proposal had been completed, during the beginning of data acquisition, the project manager discovered more measurements that would be helpful to the project (completing multiple biomass cuts and plant counts along with manual yield estimates). As these extra measurement tasks were not accounted for in the project proposal they were implemented at times which led to delays in data analysis and were likely not implemented at optimum times for accurate measurements. The design of the biomass and plant count sampling plan was statistically poor as there were not a consistent number of samples taken from each soil zone in each nitrogen treatment. The trial site position was also poor as it involved a major confounding factor of a difference in row spacing (250 and 500 mm) from a separate farm trial and all urea treatments did not pass through all paddock soil zones. These confounding factors may have affected results.

An aspect of the project that was well managed was communication with industry contacts and supervisors which allowed problems that occurred throughout the project to be resolved in the best possible way. The urea treatment design of the trial site was well managed as the four urea treatments provided an adequate range of treatments for data analysis and the 0 kg urea treatment allowed full urea response curves to be examined.

Industry contacts advised the project manager that their expectations from the trial were to observe similar results to previous variable rate urea trials conducted on the Murnong Farming property (Whitlock, pers. comm., 24 October 2011). These previous trials displayed positive yield responses to increased urea rates on different soil zones (which were not waterlogged). This project did not consistently display positive yield responses with increasing urea rates, which may be due to the confounding factors of high soil available N.
prior to sowing, mixture of row spacing throughout the trial and each urea treatment not passing through each soil zone. The industry contacts realised the strong influence of these confounding factors as the likely reason for the trial not meeting all their expectations. Murnong Farming manager Josh Walter expected the Y09 canola crop to produce an average yield of 3 t ha$^{-1}$ (Walter, pers. comm., 28 October 2011). The yield estimates from this trial when combined to form a whole paddock average equate to 4.24 t ha$^{-1}$.

The project manager expectations were not met because of the trial’s confounding factors. Appropriate measurements and data analysis were completed however the results were not as expected. However the project manager was satisfied with the communication with industry contacts and project supervisors in overcoming some of the problems faced during the project. The project manager acknowledges better project planning is required in future to ensure trials are statistically sound, operation timing is improved and data has improved accuracy.

Note plant density measurements were not addressed in the discussion as the nutrients applied at sowing/soil nutrient levels would have influenced these measurements, not urea topdressing applications. The measurements were simply used during the yield estimate process.

**Conclusion**

The dry weight (DW) measurements did not indicate a positive crop growth response as N rate was increased, however there were significant dry weight differences between N treatments. The final DW measurements were highest in the 115 kg urea ha$^{-1}$ (65 kg ha$^{-1}$ + 50 kg ha$^{-1}$) treatment (363 g/m). No significant differences in final DW measurements were observed between the three soil zones with mean DW (g/m) levels highest in the clay zone (354.3) followed by loam (305.7) and sand (287.5). The final fresh weight (FW) measurements taken (g/m) indicated an increasing trend as N rate increased.

There were no clear trends of increasing yield as N rate increased and no significant differences between N treatment mean yield estimates. The sand zone however had a significantly higher mean yield estimate (5.60 t ha$^{-1}$) compared to the loam (3.59 t ha$^{-1}$) and clay (4.16 t ha$^{-1}$) zones. Significant yield estimate differences were observed between different N rates within soil zones. The difference in row spacing (250 and 500 mm) within the trial paddock and the high total available soil N prior to sowing is believed to have affected biomass (DW and FW), plant density and yield estimate measurements.

Within the sand zone the 180 kg urea ha$^{-1}$ (130 kg ha$^{-1}$ + 50 kg ha$^{-1}$) rate provided the highest return on investment (ROI) ($3.29 return per $1 spent on urea). The 165 kg urea ha$^{-1}$ (115 kg ha$^{-1}$ + 50 kg ha$^{-1}$) rate within the loam zone provided the highest ROI ($7.82 return per $1 spent on urea) (excluding 0 kg urea ha$^{-1}$ yield estimate). The highest ROI
within the clay zone was provided from the 115 kg urea ha\(^{-1}\) (65 kg ha\(^{-1}\) + 50 kg ha\(^{-1}\)) rate of $11.72 return per $1 spent on urea.

NDVI value versus yield estimate correlations were very weak at early crop growth stages and were still weak just prior to flowering. This may have been caused by human errors in interpreting pixel NDVI values on maps and in calculating yield estimates.

While this study did not provide conclusive differences in estimated yield between N treatments, it did highlight the significant crop yield differences that occur between paddock soil zones. This highlights that VR nitrogen is highly applicable to paddocks with high spatial variability in order to maximise yield and/or ROI in individual paddock zones. NDVI technology is still believed to be an important planning tool to assist producers and agronomists in determining potential crop yields and optimum N rates to maximise yields and/or return on investment in individual paddock zones.

**Acknowledgements**

The project manager wishes to extend sincere thanks to his industry contact and mentor Andrew Whitlock of precisionagriculture.com.au for his substantial assistance and advice throughout the trial along with providing maps and data from the trial site. Your time and support is much appreciated. Many thanks also to the project supervisor Graham Brodie for his advice and helpful assistance throughout the project proposal, literature review and data analysis processes. Finally a big thank you to Murnong Farming manager Josh Walter for allowing the trial to be conducted on the property and providing a large amount of information on crop inputs and crop sensing along with yield estimate knowledge.

**References**


Dobermann, A, Blackmore, S, Cook, SE & Adamchuk, VI 2004, 'Precision Farming: Challenges and Future Directions', *Proceedings for the 4th International Crop Science Congress*.


Nicolas, M 2011, *Crop Production and Management lecturer*, Dookie, 1 September, Lecture nutrient budget handout.


Walter, J 2011, *Murnong Farming Manager*, Inverleigh, 28 October, Email.


## Appendices

Note all ANOVA tables were completed from MATLAB software.

### Appendix A – ANOVA tables for biomass measurements versus urea rate and soil type

#### Table A1. ANOVA for dry weight 1 (DW1) (g/m) versus urea rate

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#### Table A2. ANOVA for dry weight 1 (DW1) (g/m) versus soil type

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#### Table A3. ANOVA for dry weight 2 (DW2) (g/m) versus urea rate

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Appendix B - ANOVA tables for plant density measurements versus urea rate and soil type

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Appendix C – ANOVA tables for yield estimate measurements versus urea rate and soil type

Table C1. ANOVA for yield estimate (t ha⁻¹) versus urea rate

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Table C2. ANOVA for yield estimate (t ha⁻¹) versus soil type

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