Placement, Timing and Source of Nitrogen Fertilizer on Yield of Irrigated Russet Burbank Potato in Manitoba

By

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ABSTRACT

Efficacious timing and rate of synthetic fertilizer nitrogen (N) application can reduce the amount of N needed to be applied for potato production. The purpose of this study was to compare combinations of source, timing, and application methods of different synthetic N fertilizers on yield and quality of irrigated Russet Burbank, processing potato in Manitoba. Source, timing, and application method combinations were examined to provide a range of N availability over the growing season. This study was conducted at two sites over two years. Split applications of granular urea or Super-U, addition of ESN at planting and split application of granular urea at planting and fertigation were the most consistent treatments for highest marketable yield and nitrogen use efficiency. ESN was advantageous in wet site conditions. The results indicate split application of granular urea and split granular urea and fertigation that growers of processing irrigated potato primarily use in Manitoba are sound management practices.

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1. INTRODUCTION

Potato (Solanum *tuberosum* L.) is the most important vegetable crop grown in Canada. In the 2012-2013 production year, Canada exported an estimated $1.15 billion worth of fresh potato or potato products. Manitoba production accounts for 21% of potatoes grown in Canada, with an average yield of 34.75 t ha^{-1}. However, production in Manitoba has been on a slight decline due to changes in production contracts, with 28 329 ha planted in 2013 (AAFC 2014), down from the 29,948 ha planted in 2011 (Stats Canada 2011). In 2013, approximately 81% of Manitoba grown potatoes were destined for processing, 10% went for seeds and 8% were consumed fresh (AAFC 2014).

1.1 Potato Production

The most common potato cultivar used in the Manitoba processing market is Russet Burbank. It accounted for 68% of the irrigated processing potato acreage, while dryland occupied 25% of the acreage grown in 2014 (MASC 2014). Russet Burbank is a medium to high yielding variety, with a late to very late maturity period (CFIA 2013), requiring approximately 1000 Physiological Days (p-days) (Western Potato Council 2003). When it comes to growing potato, there are many controllable and uncontrollable variables which producers must try to manage effectively. Potato grows well in a variety of acidic and basic soils types. Deep, well drained and crumbly soils are ideal for potato production (PAA 2010). For irrigated land, it is ideal to have soil with a higher water holding capacity, but which does not form clods. Clod forming soils are less preferred over sandier soils as the clods can damage the tubers during harvest (PAA 2010). In irrigated soils, the water holding capacity is less critical as the water can be more closely managed by applying sufficient amount as needed while avoiding runoff, saturation, and leaching of nutrients. Sandy soils, soils high in clay, and those high in organic matter, can all produce high quality potatoes under proper management practices (PAA 2010).

Potato is considered a short day, cool season crop that yields well under high temperatures with adequate and even water supply throughout the growing season, with the highest water use occurring during tuber bulking (PAA 2010). Proper water management is vital to ensure leaf stomates remain open during the hottest parts of the day. Yield is a function of the amount of photosynthate produced and the amount used by the living plant during respiration (PAA 2010). Proper crop rotations will typically lead to reduced use of fertilizer and pesticides, while also resulting in higher yields. Short rotations will increase soil borne diseases and pests (PAA 2010, Mohr et al. 2011).

The ability of potato to produce adequate yield and quality and its ability to withstand environmental and pest induced stresses, is partly determined by proper plant nutrition. The three primary nutrients for potato growth are N, potassium and phosphorus. The soil is capable of providing these nutrients but often not in the amounts required. The soils physical, chemical or biological properties can impact plant available nutrients. Therefore, to achieve proper potato yields, additional plant available nutrients must be supplied. These nutrients may come from commercial synthetic fertilizers, compost, or manure (PAA 2010).

1.2 Nitrogen Fertilization

The earth's air is comprised of approximately 78% nitrogen gas. Nitrogen, as N_2 cannot be used by many organisms or plants; therefore it must be transformed to nitrate (NO_3^-) to be made available for plant uptake. Nitrogen can be metabolized and cycled in its variable chemical forms through the nitrogen cycle (Delwiche 1970).

With the exception of crops capable of biological nitrogen fixation, such as soybeans, peas, and lentils, fertilizer is the most expensive crop input for all other crops (Manitoba Agriculture, Food and Rural Development 2014). Therefore, maximizing N use and efficiency can be critical to increasing farm yields and profit, while aiming to keep input costs down. Nitrogen can either come from synthetic or organic sources, but in both cases it must be transformed into the inorganic forms of NO_3^- or (NH_4^-) to be utilized by plants (O'Leary et al. 2002). Ammonium is usually converted quickly to NO_3^- following application to warm and moist (not saturated) soils. Nitrate is an anion and soluble in water and repelled by negative charges of soil particles and organic matter. When growing crops in coarse textured soils (typical for potato production), proper management of N application is critical to reduce the risk of environmental losses, which can lead to degradation of water quality, while also maximizing the efficiency of the applied N on potato yield (Rosen and Eliason 2005).

Nitrogen is commonly the limiting nutrient for potato grown on sand soils (Zebarth et al. 2009, Davis et al. 2014). These soils typically contain insufficient residual NO_3^- and most N is tied up in previous crop year residues and what little organic matter is present.

Through microbial breakdown, organic N in crop residues and organic matter can eventually be released; however, release is much slower than the rate at which the crop requires it to grow (Rosen and Eliason 2005). For maximum fertilizer efficiency, crop yield and quality, N management and application rates should be based on the amount of N required during the growing season and applied when it is required (Westermann and Kleinkopf 1985, Zebarth et al. 2012, Davis et al. 2014). Nitrogen application rates can be determined by using residual soil NO_3^- testing close to the time of planting and target yields (Davis et al. 2014, Westermann and Kleinkopf 1985), such as the basis for recommendations in the Manitoba Soil Fertility Guide (Manitoba Soil Fertility Advisory Committee 2007).

1.2.1 *Nitrogen Fertilizer Sources*

Common synthetic N fertilizer sources available in Canada are: anhydrous ammonia (82-0-0-0), urea (46-0-0), urea ammonium nitrate (UAN) (28-0-0) , calcium ammonium nitrate (27-0-0-0), ammonium sulphate (20-0-0-24), monoammonium phosphate (11-52-0), and diammonium phosphate (18-46-0) (Statistics Canada 2013). The most common forms in western Canada are: anhydrous ammonia, urea, and urea ammonium nitrate (Saskatchewan Soil Fertility Committee 2014). It is not uncommon for a polymer or sulphur coating to be applied to urea granules to act as a method in controlling the release of N (Zebarth et al. 2008). Different N sources can also be treated with nitrification or urease inhibitors, which include but are not limited to: dicyanamide or 2-chloro-6-(trichloromethyl) pyridine (Subbaro et al. 2006). In addition, N-(n-butyl) thiophosphoric triamide (NBPT) has continuously shown an ability to inhibit the activity of the urease enzyme (Trenkel 2010). These two inhibitors can be added to N fertilizer together or individually to create a stabilized N fertilizer (Trenkel 2010).

The different fertilizer sources available all have advantages and disadvantages for growing potato. Urea is recommended as a favoured fertilizer for applications at planting, UAN has half of its N supplied as NO_3^- and may be lost in the spring due to leaching. Anhydrous ammonia can delay the potential of leaching losses, however it is difficult to position accurately in potato hills (Rosen and Bierman 2008).

1.2.1.1 Urea

Urea (46-0-0) has the highest N concentration amongst granular fertilizers. It is produced by combining ammonia and carbon dioxide under pressure (20 684 kPa) and at a temperature of 177^{o}C (International Consulting Group 2006). This can be illustrated by the chemical reactions below (Prasad 1998):

$$2NH_3 + CO_2 \leftrightarrow NH_2COONH_4$$

(ammonium carbamate)

$$NH_2COONH_4 \leftrightarrow NH_2CONH_2 + H_2O$$

(Urea)

In soil, the above reaction is reversed to produce ammonium carbamate, by the hydrolytic action of urease enzymes present in the soil. Ammonium carbamate is not stable and rapidly degrades into CO_2 and NH_3. Under moist warm soil conditions, the hydrolysis of urea occurs quickly (Pauly 2003). Urea may be broadcasted or banded; however, incorporation into the soil should follow a urea broadcast application to reduce volatilization losses. If banded at seeding, urea should be placed at least five centimeters from the seed to reduce the risk of ammonia toxicity. Urea is also highly soluble in water which can also allow for liquid foliar application. However, to prevent ammonia volatilization loses; urea should be incorporated with irrigation following a foliar or broadcast application (Pauly 2003).

1.2.1.2 Controlled release urea

A slow or controlled release fertilizer is where the nutrient(s) in a form in which it will have a delayed or extended release period for plant uptake and use.. This delay or extended period can be achieved through a variety of methods including; controlled water solubility of the material by semi-permeable coatings, occlusion, and protein materials as some examples (Trenkel 2010). The discharge of nutrients from a controlled release fertilizer product can be more accurately predicted (Trenkel 2010). The thickness and coverage of the polymer coating will have a large impact on how quickly the urea will diffuse from the granule (Du et al. 2006). Soil temperature and moisture increase the rate at which the urea is released from these granules (Trenkel 2010).

Environmentally smart nitrogen (ESN) is an example of a polymer coated urea. When tested in a laboratory setting, it was found to have a release period of 7-42 days (Cahill et al. 2010). Environmentally smart nitrogen released 90% of nitrogen 93, 86, and 104 days after planting (DAP) for preplant, planting, and emergence applied ESN, respectively, to potato (Wilson et al. 2009). Wilson et al. (2009) estimated 100% of the N would be released 110 and 125 DAP for preplant and planting applied ESN respectively. However, 147 DAP were required for 95% of the N to be released from the emergence applied ESN (Wilson et al. 2009). Environmentally smart nitrogen was found to significantly reduce leaching of NO_3^- compared to two Urea Split applications (Wilson et al. 2010).

Environmentally Smart Nitrogen is better suited toward longer season crops due to the sustained release rate; therefore is likely better suited to potato than shorter season crops.

1.2.1.3 Stabilized Nitrogen

Urea fertilizers which are applied to soil must be hydrolyzed, by the urease enzyme, ubiquitous in soils (Franzen 2013). Urease inhibitors are products which inhibit the ability of the urease enzyme to hydrolyze urea. N-(n-butyl) thiophosphoric acid triamide (NBPT), is a urease inhibitor; it acts by blocking the active site of the enzyme (Manunza et al. 1999). Hydrolysis of urea can be delayed 2-10 weeks through the use of hydrolysis inhibitors (Jones et al. 2007). Delaying the rate of hydrolysis will maintain more of the nitrogen in the urea form, which will delay the rate that it can be fully converted to NO_3^- and possibly lost from the soil. Agrotain is an example of a commercially available NBPT product.

Urea granules can be formed containing urease and/or nitrification inhibitors. Super-U is a commercially available product urea granule which has its nitrogen stabilized with NBPT and a nitrification inhibitor, dicyandiamide (DCD) (Koch Agronomic Services 2015). Nitrification inhibitors reduce the ability of *Nitrosonomas* bacteria to convert ammonium to nitrite, therefore impacting the rate at which ammonia is oxidized to nitrite (NO_2^-) (Trenkel 2007). Nitrapyrin (2-chloro-6-(trichloromethyl)-pyridene) and DCD are the two nitrification inhibitors commercially available in many parts of the world (Trenkel 2007), including Canada.

1.2.1.4 Urea Ammonium Nitrate (UAN)

Urea ammonium nitrate (UAN) is a liquid fertilizer available a with nitrogen concentration of 28%. Urea accounts for half the total N of UAN, the other half coming from ammonium nitrate (International Plant Nutrition Institute 2015a). The ammonium may be immobilized by plants, or soil organisms, fixed by clay particles, or it may also be nitrified. Urea ammonium nitrate may be applied as a fertigation solution onto crops, dribble or surface banded on the soil, or injected into soil. Mechanical incorporation or infiltration with rain or irrigation water should be used following a surface application of UAN to reduce the volatilization risk of the urea portion of the fertilizer (Weiss et al. 2009).

1.3 Fertilizer Application Methods

Synthetic nitrogen fertilizers can be applied with a variety of methods, and at different timings depending on the chemical form (Westermann 2005). Pre-plant and starter fertilizer may either be applied prior to or at the same time as planting, respectively. Top-dressing fertilizer post planting of potato involves broadcasting the fertilizer onto the soil surface to be incorporated with hilling. Sidedress application involves injecting the fertilizer into the potato hill. Post plant applications are typically done early in the growing season before canopy closure has occurred (Westermann 2005, Davis et al. 2014). Fertigation is another method for applying nutrients in season, or correcting a nutrient deficiency (Westermann 2005).

1.3.1 *Banding and Broadcast*

In Manitoba, the main granular nitrogen application methods are banding and broadcasting (Manitoba Soil Fertility Guide 2007). Banding and broadcasting of nitrogen are the two placement techniques listed by Waterer and Heard (2003) for prior to or at plant nitrogen application. The relative efficiency of these fertilizers application methods compared to spring broadcast can be found in Table 1-1.

Table 1-1 Banding and Broadcasting nitrogen application relative efficiency (Manitoba Soil Fertility Guide 2007).

Time and Method	Relative Efficiency
Spring broadcast	100
Spring banded	120
Fall broadcast	80
Fall banded	100

Nitrogen fertilizer which is broadcast onto the soil surface should be incorporated as soon as possible following application by either tillage or an appropriate amount of water to dissolve the granules and move the nutrients into the soil. Incorporation of granular urea and other urea containing fertilizer will reduce the risk of volatilization losses (Manitoba Soil Fertility Guide 2007, Overdahl et al. 2013). Banding of fertilizer will result in closer, higher concentration of nitrogen for the crop root system when compared to incorporated broadcasted nitrogen (Zebarth et al. 2012). Malhi and Nyborg (1991) found that incorporated or unincorporated broadcasting of urea resulted in a lower plant N recovery than banding in barley. Olson (1987) found that subsurface banding of UAN led to increased plant uptake when compared to surface and incorporated UAN or surface banding of UAN. Westermann and Solka (1996) found that banding of nitrogen increased dry matter yield, total tuber yield, nitrogen uptake by 6, 9, and 28% respectively when compared to broadcasting. The rate of nitrification can be decreased due to the high salt and ammonia concentration surrounding the banded fertilizer as well as an increase in soil pH. Keeping the applied nitrogen in the less mobile ammonium form can reduce losses from leaching (Zebarth and Milburn 2003). Saffigna et al. (1976) found water infiltration to be higher in the furrow then in the hill, therefore leading to less leaching of hill banded nitrogen.

Banding of N fertilizers at planting or hilling is currently not a common practice in Manitoba potato production. Banding of a portion of the urea to be applied at planting is recommended in other regions of North America such as Prince Edward Island and New Brunswick, and Maine (Zebarth et al. 2004, Zebarth et al. 2012). There, 100% of applied N is commonly provided at planting (Zebarth et al. 2004) as a band, 5 cm to the side and 5 cm down from the potato seed piece (Westermann 1993).

1.3.2 *Nitrogen Fertigation*

Application of nitrogen may also be done throughout the season using liquid UAN or granular nitrogen sources, with either top-dressing with tillage or fertigation for incorporation (Manitoba Soil Fertility Guide 2007). Fertigation is the term given to the process of applying liquid nutrients through the irrigation system. This system allows the producer the ability of adjusting the rate of nitrogen applied with each pass of the irrigator.

1.4 Rate of Nitrogen Application

As previously mentioned, proper nitrogen management is a fundamental practice for achieving high tuber yields and high quality. At planting, split nitrogen applications must be large enough to supply the crop throughout the initial growing phases. However, excessive amount of soil nitrogen over the growing season can decrease specific gravity, delay tuber set, and potentially decrease yield (Davis et al. 2014, Zebarth et al. 2012). These large amounts can also lead to nitrogen losses from leaching of NO_3^- or emission to the atmosphere as nitrous oxide (N_2O) (Davis et al. 2014, Zebarth et al. 2012). Applying nitrogen in split applications can lessen N loss versus full rate at planting (Rosen and Eliason 2005, Davis et al. 2014).

The amount of nitrogen required will vary depending on the variety of potato being grown and the intended market for the potatoes (University of Nebraska 2014). Producers must consider the previous crop and the amount of nitrogen its residue may supply. In addition, any manure that was previously applied to the field may be mineralized (Zebarth and Rosen 2007). Therefore, soil sampling (0-60 cm) of each field in the fall following harvest or in the spring prior to planting will provide growers with NO_3^- levels in the soil. Knowing the level of residual NO_3^- allows for the calculation of the appropriate rate of nitrogen needed for the variety of potato being grown based on the targeted crop yield (Manitoba Soil Fertility Guide 2007). Additionally, N rates can be increased during the season based on petiole and soil testing (University of Nebraska 2014). These tests may indicate an increase or decrease in the rate of nitrogen needed for split applications.

1.5 Phases of Nitrogen Uptake by Potato

Potato nutritional requirements change as the crop progresses through its five growing stages; I., sprout development; II., vegetative growth; III., tuber initiation; IV., tuber bulking; and V., maturation (Westermann 1993). The duration of these growing phases varies depending on climatic/environmental circumstances and the potato cultivar being grown (Zebarth and Rosen 2007). High rates of nitrogen can discourage or slow tuber bulking during growth stages I and II, this is due to increasing yield of undesirable tubers while reducing marketable yield (Westermann 1993, Errebhi et al. 1998). The N fertilizer applied during these stages is at risk of being lost due to nitrous oxide emissions as well as NO_3^- leaching. During growth stage III (50-70 days after planting) vegetative growth as well as nitrogen uptake quickly increase (Zebarth and Rosen 2007). Excessive plant available nitrogen during stage IV can lead to unnecessary vegetative growth, leading to potential reductions in tuber growth and quality (Westermann 1993). When stage V begins nutrient uptake has almost ceased, senescence has begun and during this phase nutrients in the tops and roots are solubilized and moved into the tubers (Westermann 1993, Zebarth and Rosen 2007).

1.6 Objective

The objective of this thesis research was to determine N yield response at a reduced application rates, and also to determine the optimal use of N for maximal yield and quality of irrigated Russet Burbank processing potato based on different combinations of sources, timing, and placement methods. The sources of N in this study were Urea, Environmentally Smart Nitrogen (ESN), Super-U and UAN. Placement methods were broadcasting, banding, and broadcasting of liquid N as a simulated fertigation. Timings studied were placement at planting, hilling, and fertigation at tuber development. These treatment combinations were designed to provide a full range of N availabilities with some being more upfront early in the growing season such as the broadcasted Urea treatment, some mid-season such as the Urea and Super-U splits, as well as ESN and 50%ESN:Urea and fertigation treatments applying early and late in the growing season. It is acknowledged that factors such as weather conditions can affect the availabilities of N from the treatments and temporal N requirement pattern of potato, thus the study was conducted over two years. Soil conditions may also affect the treatment N availabilities and temporal N requirement patterns, thus the study was done at two sites in each year.

1.7 Thesis Structure

This thesis is composed of an introduction chapter (Chapter 1) describing considerations for management of synthetic N fertilizer application to potato, concluding with the project objectives and this section on thesis structure. Chapter 2 outlines the field study conducted over two years, at two different sites each year in Manitoba to determine the optimal use of N for maximal yield and quality of irrigated Russet Burbank processing potato based on the different combinations of N sources, application timing, and placement method. Chapter 2 is formatted as a publication in the Canadian Journal of Soil Science. It should be noted that I lead every aspect of the field research and data analysis for this thesis. Chapter 2 is then followed by an overall synthesis (Chapter 3). In that chapter, other factors investigated not presented in Chapter 2 will be examined as well. In addition, practical and economic considerations, grower recommendations, and recommendations for future research are also provided in Chapter 3. A fourth chapter will contain the general conclusions, summarizing the important results and practical significance coming from this study. An appendix follows containing additional data and reports on other experiments conducted over this study.

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2. PLACEMENT, TIMING AND SOURCE OF NITROGEN FERTILIZER EFFECT ON YIELD OF RUSSET BURBANK POTATO IN MANITOBA

2.1 Abstract

Timing and rate of nitrogen (N) application in conjunction with when it is required can reduce the application rate of nitrogen, as well as reduce the potential of NO_3^- leaching to ground water. The purpose of this study was to compare combinations of source, timing, and application methods of different synthetic N fertilizers on yield and quality of irrigated Russet Burbank, processing potato in Manitoba. Source, timing, and application method combinations were examined to provide a range of N availability over the growing season. This study was conducted at two sites over two years, in which the Urea and Super-U Split Banded treatments and ESN resulted in significantly higher marketable yields. These results indicate no significant increased marketable yield from the use of stabilized nitrogen products, controlled release products, or extending the period of nitrogen application through the use of fertigation, when compared to urea. The banding of fertilizer showed a potential placement benefit over broadcasting regarding marketable yields.

2.2 Introduction

Potato (*Solanum tuberosum* L.) is the most important vegetable crop grown in Canada. In the 2012-2013 production year, Canada exported an estimated $1.15 billion worth of fresh potato or processed potato products. Production in Manitoba has been on a recent slight decline due to reductions in production contracts with 28 329 ha^{-1} planted in 2013

(Agriculture and Agri-Food Canada (AAFC) 2014). Manitoba potato production accounts for 21% of the potatoes grown in Canada, with an average yield of 34.75 t ha^{-1}. In 2013, approximately 81% of Manitoba grown potatoes were destined for processing with 10% for seed potato and 8% consumed fresh (AAFC 2014).

The potato variety Russet Burbank dominates the processing market in Manitoba, accounting for 68% of the irrigated processing potatoes acreage, while for dryland it occupied 25% of the acreage grown (MASC 2014). Most potato land (> 90%) is irrigated in Manitoba (Mario Tenuta, personal communication). Russet Burbank is a medium to high range yielding variety, with late to very late maturation (CFIA 2013) requiring approximately 1000 physiological days (P-days) (Western Potato Council 2003). Potato is typically grown in coarse textured, sandy, and well-draining soils (Rosen and Eliason 2005) and is a crop for which synthetic (N) fertilizer can improve tuber yield and quality (Davis et al. 2014).

The internal quality of tubers can be evaluated through the use of tuber specific gravity. It is one of the largest used measurements for internal quality; there is also a good relationship between specific gravity and tuber starch content, mealiness, and total solids. Due to these properties it is used by potato processors for evaluating suitability of shipments from producers (Laboski and Kelling 2007). Increased rates of N fertilization can lead to decreases in specific gravity, varied results have been found on the effect of application timing on specific gravity (Porter and Sisson 1993, Zebarth et al. 2004).

Hollow heart is described by the Canadian Food Inspection Agency (2015) as "irregular cavities of varying size within the potato and is usually lined with light-brown to brown dead tissue". This condition can be brought about by irregular or fast growth. It can be more persistent in wet growing seasons, especially for potatoes grown in highly fertile or heavily irrigated soils (CFIA 2015).

In soil, ammonium (NH_4^+) based fertilizers will convert to NO_3^-, which is not as tightly bound to soil particles, making it more susceptible to movement in soil with water. Proper management of N fertilizer on sandy well-draining soils is needed to maximize N efficiency while reducing environmental damage (Rosen and Eliason 2005). The timing, method of application and source of the N fertilizer can all play an important role in reducing losses due to leaching (Shrestha et al. 2010).

The three most commonly used N sources in Western Canada are anhydrous ammonia (NH_3), urea, and urea ammonium nitrate (UAN). Urea is the preferred nitrogen source used at planting as a starter for potato. With UAN, half of the N from NO_3^-, early season leaching becomes an increased risk with application at planting (Rosen and Bierman 2008). While using anhydrous ammonia can delay NO_3^- losses, proper positioning with the potato hill is difficult (Roseb and Bierman 2008). Reductions in NO_3^- losses have been found from using controlled release or stabilized N sources, which may include polymer coated urea, or products treated with nitrification and/or urease inhibitors (Trenkel 2010).

To achieve maximum fertilizer N use efficiency, while aiming to minimize environmental losses and damage, split applications are recommended for potato production (Rosen and Bierman 2008). This may be done by applying about half of the N at planting followed by the remainder either at hilling, or with fertigation from tuber initiation to bulking (Westermann 1993). Nitrogen application at hilling will typically occur in the vegetative growth stage (stage II). However, when fertigation is used, the applications typically occur in the tuber bulking stage (stage IV) (Westermann 1993).

The objective of this study was to determine the best use of N fertilizer on irrigated Russet Burbank processing potato. This was done by designing treatments to provide a range of temporal N available from planting to tuber bulking, based on a combination of source, timing, and placement on the yield and quality of irrigated Russet Burbank potato for a total of 10 treatments examined and an untreated check. The N sources included urea, Super-U, ESN, and UAN, timing of application included at plant, split applications at planting and hilling, and delayed fertigation applications and placement included broadcasting and banding. The broadcasted Urea at planting treatment provided early season N availability, Urea and Super-U splits, ESN, and 50%ESN:Urea providing early to mid-season availability and simulated fertigation treatments providing N availability early and later in the growing season. Treatments with early and mid-season N availability would be more advantageous in dry spring years, while in wet springs the later N availability would be expected to be advantageous as it is at less risk of loss after planting.

2.3 Materials and Methods

2.3.1 *Sites*

Field plots of potato were established in 2013 and 2014 at the Canada Manitoba Crop Diversification Center (CMCDC) Offsite location at Carberry, MB located at 49.932434, -99.391529. A secondsite was located north of Carman, MB on a commercial production field, located at 49.598685, -98.023010 in 2013, and at 49.578330, -98.009536 in 2014. In both 2013 and 2014 the trials at CMCDC Carberry were conducted on Hallboro-Stockton soil series (Manitoba Agriculture, Food and Rural Initiatives 2010). The Hallboro-Stockton is a loamy fine sand with a pH in water of 5.5, EC of 0.32 dS m^{-1}, OM of 3.0 g kg^{-1}, residual N of 54 kg ha^{-1} in 0-60 cm, and 51 kg ha^{-1} residual phosphorus (P) in 2013, while in 2014 the pH in water was 5.5, EC was 0.28 dS m^{-1}, OM was 2.2 g kg^{-1}, residual N of 22 kg ha^{-1} in 0-60 cm, and 53 kg ha^{-1} residual P. In 2013, the trial located north of Carman was conducted on a Reinland coarse loamy soil with a pH of 6.5, EC of 0.37 dS m^{-1}, OM of 21 g kg^{-1}, residual N of 19 kg ha^{-1} in 0-60 cm, and 7 kg ha^{-1} residual P. In 2014 it was conducted on Hochfeld-Kronstal group coarse loamy soil with a pH of 7.35, EC of 0.58 dS m^{-1}, OM of 30.0 g kg^{-1}, residual N of 62 kg ha^{-1} in 0-60 cms, and 22 kg ha^{-1} residual P (Michalyna et al. 1988**)**. The Reinland and Hochfeld-Kronstal soil series are in close association with each other (Manitoba Agriculture, Food and Rural Initiatives 2010). Each year a new experimental area was chosen, this reduces the risk of carryover of residual N from the previous year.

2.3.2 *Experimental Design*

The trials were a randomized complete block design, consisting of 11 treatments (Table 2-2) and four blocks totaling 44 plots per site. Each block was separated by a 3 m fallow buffer area. Combinations of sources (urea, ESN, Super-U, 50%ESN:Urea, and urea ammonium nitrate (UAN) as a simulated fertigation), timings (at planting, split applied (at plant and at hilling or tuber development)), and placements (broadcast, banding) of N fertilizer comprised 10 treatments to provide a gradient of N availability over the growing season and were evaluated for their effect on yield and quality of irrigated Russet Burbank potatoes.

Plots consisted of four, one meter wide rows, which were 12 meters long; the two center rows were used for plant tissue sampling and harvest. All four rows received the same treatment, but the outside two rows functioned as guard/border rows. Spray rows were incorporated into the design of the plots to allow application of fertilizer and pesticides from a tractor mounted boom. Spray rows decrease the risk of crop damage to the two treatment rows.

2.3.3 *Production Practices*

Phosphorus as triple superphosphate (0-45-0) and potassium chloride (0-0-60) were broadcasted over the whole site prior to pre-plant tillage at rates recommended from the Manitoba Soil Fertility Guide based on a composite site soil sample. A one-row planter was used to plant Russet Burbank at 0.336 m seed spacing with a row spacing of 1 meter; planting dates are given Table 2-1. Stand and stem counts were performed following full crop emergence. Pesticide and herbicides were applied as needed based on site conditions, industry standard fungicide applications were made over the growing season. Irrigation in Carberry was supplied by a lateral irrigator, while at the Carman site it was supplied with a labour intensive to setup and maintain, travelling gun. Trial harvest occurred in mid-September; these dates along with the corresponding days to harvest after planting can be found in Table 2-1. Historical temperature and precipitation values were obtained from Environment Canada (2015). The data for Carberry were reported from the weather station located at (49°54'20.900" N, 99°21'26.800" W) and the Carman University of Manitoba station (49°29'53.200" N, 98°01'47.100" W).

Table 2-1 Production information for the study.

	2013		2014	
Action	Carman	Carberry	Carman	Carberry
Spring Tillage	Roterra	Roterra	Roterra	Roterra
Planting Date	May. 16	May. 22	May. 27	May. 17
Row/Seed Spacing (m)	0.336	0.336	0.336	0.336
Fertilizer Rate (kg ha^{-1})				
N	159	119	123	168
P_2O_5	159	92	92	115
KCl	419	71	252	112
Hilling Date	June. 21	June. 25	June. 26	Jun.e 24
Fertigation				
Start	July. 17	July. 16	July. 21	July. 18
Finish	Aug. 07	Aug. 06	Aug. 11	Aug. 06
Precipitation (mm)				
Rainfall	287	356	338	326
Irrigation	102	293	76	190
Total	389	649	414	516
Harvest Date	Sep. 13	Sep. 18	Sep. 30	Sep. 22
Harvested in Days After Planting	120	119	126	128

Total precipitation refers to the amount of rainfall and supplemental irrigation which was added at each site (Table 2-1). Total precipitation for Carman and Carberry in 2013, were more dissimilar than in 2014. In both years, irrigation was responsible for the majority of the total precipitation difference between sites. Irrigation began earlier in

Carberry; therefore more applications occurred resulting in more mm being applied, while in Carman irrigation began with fertigation applications. Water levels at the pump site became a factor controlling the amount of irrigation applied for both years at Carman. Total precipitation and mean daily temperature values can be seen in Fig. 2-1.

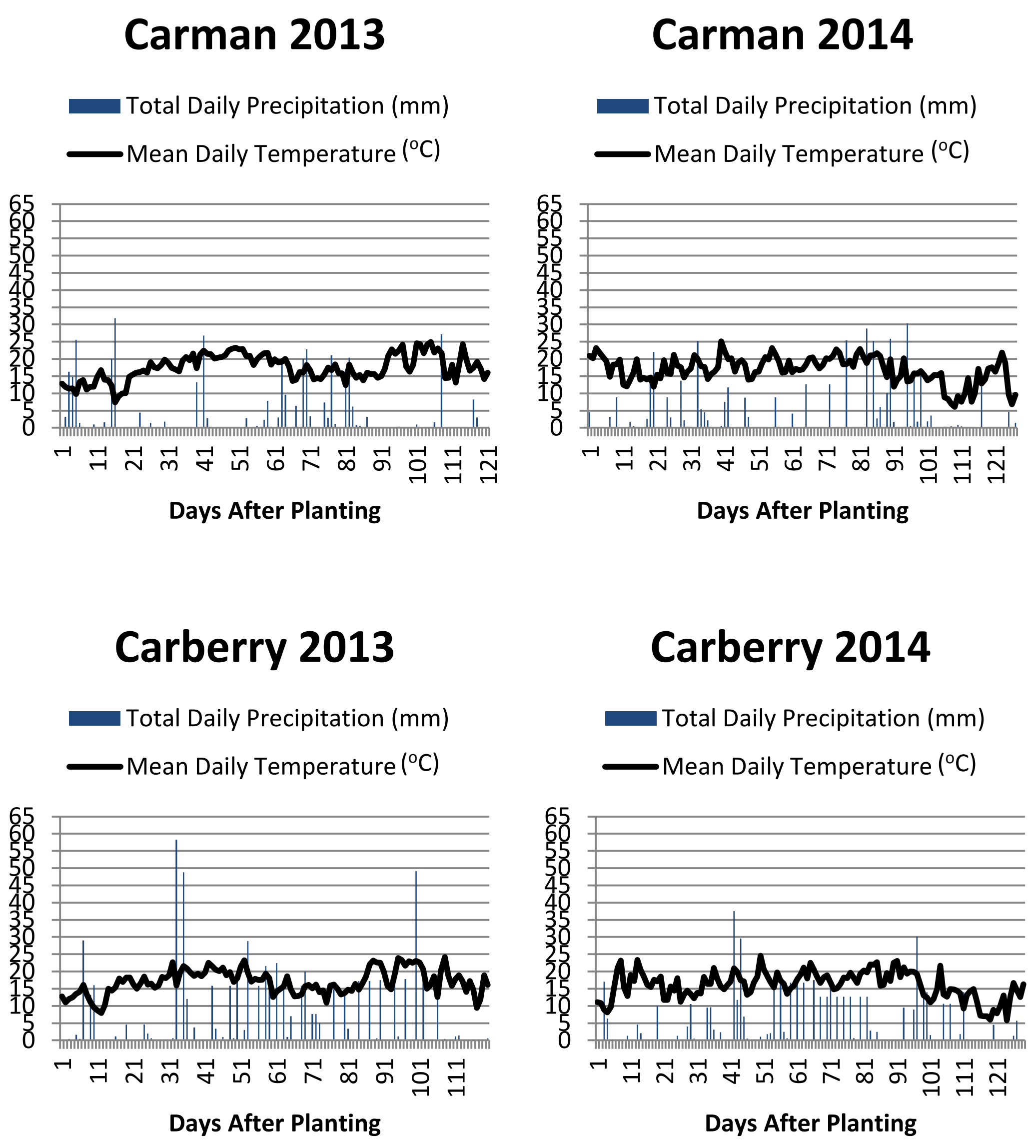

Fig. 2-1. Total daily precipitation and mean daily air temperature from planting to harvest over both sites and years (data source: Environment Canada 2015).

In the spring of each year, both sites were soil sampled (0-15cm and 15-60cm) and analyzed at the University of Manitoba Soil Ecology Lab. For each soil sample, a 5 g subsample was placed into a 50 ml conical centrifuge tube, then 25ml of 2M KCl extracting solution was added. The tube was capped and placed on a reciprocating shaker for 1 hour at 150 excursions per minute. A centrifuge was then used to spin the tubes for 3.5 minutes at 3,000 rpm. The resulting clear supernatant was then transferred to labeled scintillation vials for storage at 4 °C prior to analysis for the inorganic N ions.

Ammonium concentration of extracts was determined using a Technicon™ Autoanalyzer II System (Pulse Instruments, Mequon, WI) using the automated phenate method. Nitrate analysis was also done with an Autoanalyzer II System but using the automated cadmium reduction azo-dye method. Nitrite analysis was done with a similar procedure as for NO_3^- except the reduction step was omitted.

The Manitoba Soil Fertility Guide gives N rate applications based on soil N residual and a target yield. The NO_3^- content (kg N ha^{-1} to 60 cm) and a target yield of 42,000 kg ha^{-1} were used for application rate determinations. The recommended rate was then reduced by 20% so that 80% of the recommended N was applied, the different percentages can be seen below in Table 2-2. This was done in an effort to be further down on the N response curve in hopes of observing treatment differences in plant available N. Split applications were broadcasted onto the appropriate plots and then incorporated into the hill using a three-point mounted hiller.

All broadcast applications occurred prior to pre-plant tillage, and then incorporated into the soil. The two banded treatments occurred at planting, using a double hooked-shank side bander, attached to a cone applicator. The side bander localized the fertilizer within the hill, targeting 5-7 cms to the side and below the seed piece; the cone ensured the fertilizer was banded evenly over the length of the plot. The remaining 40% of the split applications was broadcasted prior to hilling (late June) onto the appropriate plots and then incorporated into the hill by a three-point mounted hiller. Fertigation treatments began in mid-July; timing was based on targeting 1.8 cm to 2.1 cm sized tubers. Urea ammonium nitrate was applied with a three-point mounted sprayer using SJ7-04 drenching nozzles. Following application, the UAN was infiltrated into soil with 13 mm of irrigation water.

Table 2-2. Nitrogen application as a percentage of total N applied based on 80% of recommended rate for each treatment

	Treatment	Broadcast @ Plant	Banded @ Plant	Hilling Split	Fertigation Applications				Total
					1	2	3	4	
1	Untreated Check								0
2	Urea	100							100
3	Urea Split - I	40		60					100
4	Urea Split - B		40	60					100
5	Super-U Split - I	40		60					100
6	Super-U Split - B		40	60					100
7	ESN	100							100
8	50% ESN:Urea	100							100
9	Fertigation A (28-0-0 diluted 1:10)	60			17	13	10		100
10	Fertigation B (28-0-0 diluted 1:10)	40			20	17	13	10	100
11	Fertigation C (28-0-0 dilution) (50% ESN:Urea)	60			17	13	10		100

I - Broadcast and incorporated
B - Banded at plant

2.3.4 *Soil Nitrogen Analysis*

Fifteen soil samples, five samples from each side of the hill and five from the top of the hill, at each two depths (0-15 and 15-60 cm) were taken from the westerly treatment row in each plot prior to the beginning of the fertigation treatments. These samples were submitted to the University of Manitoba Soil Ecology Lab for extraction and analysis of inorganic N by the same techniques described previously. Repeat soil sampling was then performed again after the completion of fertigation. Following harvest each plot was then soil sampled again to 120 cm at 30 cm increments (0-30, 30-60, 60-90, and 90-120 cm); these were also submitted to the University of Manitoba Soil Ecology Lab for inorganic N analysis to measure residual soil N level after harvest.

2.3.5 *Tuber Yield and Grading*

Immediately prior to harvest, the center rows of each plot were mechanically topped to remove vines from the hill. A single row potato harvester was then used to dig each row and place tubers on the soil surface. The middle section of each row was initially handpicked for a minimum 22.5 kg subsample, for grading marketable yield and quality analysis. The rest of the plot was then handpicked after the sample and weighed for total plot yield.

Size grading was done by weighing and separating each tuber into the following size categories; undersize (<85g), small (85-170g), medium (170-340g), and bonus (>340g). All tubers >85g are considered marketable tubers. Fry colour and sugar ends were analyzed on ten fries at the beginning, middle and end of storage. Tuber were stored in the Gaia Consulting Ltd potato storage, under commercial storage conditions of approximately 9^{o}C and 95% humidity.

2.3.6 *Petiole and Plant Analysis*

Prior to the beginning of fertigation, thirty petiole samples (fifteen from each treatment row) were hand picked per plot for NO_3^- analysis conducted by Agvise Laboratories (Northwood, North Dakota, U.S.A.). Plots were petiole sampled again following the completion of fertigation.

Prior to senescence, four plants were sampled from the westerly most row of each plot, weighed, and dried for total above ground biomass yield and total N analysis. Total N analysis was completed by commercial laboratory Farmers Edge, Winnipeg, MB, using the total Kjeldahl Nitrogen method on ground subsamples. Plants had to match the target spacing to avoid potential of misrepresentation from collecting larger or smaller plants due to spacing. Tuber N analysis was also done on ten potato strips selected from the middle of each tuber at the initial fry color testing, strips were weighed, dried, and ground for total N analysis.

2.3.7 *Specific Gravity and Hollow Heart*

Specific gravity was determined using the weight in air less weight in water method, at grading shortly after harvest. A minimum 4.5 kg market grade sample was randomly selected, weighed in air, then each tuber was cut in half to check for hollow heart. The tuber pieces where then reweighed in water. Specific gravity was then calculated as (weight in air (kg))/(weight in air (kg)-weight in water (kg)).

2.3.8 *Apparent Fertilizer Uptake*

Total apparent fertilizer N uptake was estimated from the total N content of above ground biomass and total tuber N in relation to those of the control treatment.

Total Apparent Fertilizer N Uptake in percent was calculated by ((Treatment N total above ground uptake (kg N ha^{-1}))–(Control N total uptake (kg N ha^{-1})))/N fertilizer added (kg N ha^{-1}) x 100%.

2.3.9 *Statistical Analysis*

All statistical analyses were performed with the Statistical Analysis Software (SAS) (SAS Institute, Cary, NC; release 9.3 for Windows). The data sets were analyzed using PROC GLIMMIX, with treatment, site and year being considered a fixed effect, while block was considered a random effects. Treatment effects were considered significant when $P < 0.05$. Fishers Protected LSD was used to compare treatment means. Slices of the data by year and/or site were used to separate out least squares of the treatment means. Contrasts were used for testing the significance of difference between groups oftreatment means.

2.4 Results

2.4.1 *Total Tuber Yield*

Analysis of variance of total yield indicated there were significant Trt x Year (P = 0.0002) and Trt x Site (P = 0.0366) and Site x Year (P = <.0001) interactions (Table 2-

3). The Trt x Year interaction was likely because in 2013 the best performing treatments were ESN and Fertigation A whereas in 2014 it was the Urea Split Incorporated, Urea Split Banded and Super-U Split Incorporated treatments (Fig. 2-2). The Trt x Site interaction was likely because the treatment yields at Carman tending to be higher than those at Carberry. The untreated control was the significantly lowest yielding treatment for both sites and years of this study (Fig. 2-2 and Fig. 2-3). Total yields were increased with the use of N fertilizers by 34-45% compared to the Untreated Check.

Table 2-3. Mean total yuber yield (Total), marketable tuber yield (Market), tuber size categories (Under, Small, Medium and Bonus), nitrogen use efficiency (NUE), specific gravity (S.G.), hollow heart (H.H.) and residual soil nitrogen (Resid Soil N) as affected by nitrogen treatment, site and year in this study. Also shown are ANOVA main and interaction effects P-values.

Effect	Total	Market	Under	Small	Medium	Bonus	NUE	S.G.	H.H.	Resid Soil N
	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	%		%	kg ha^{-1}
Treatment (Trt)										
Untreated Check	35430	30951	4479	15835	13092	2024	-	1.0903	17	20
Urea	49166	45621	3545	17030	23448	5144	45 bc	1.0900	10	25
Urea Split - I	51065	47270	3794	15712	26161	5396	54 ab	1.0909	20	24
Urea Split - B	51170	47589	3581	16472	24816	6301	51 ab	1.0908	16	26
Super-U Split - I	51373	47245	4128	15398	25586	6262	57 ab	1.0896	18	26
Super-U Split - B	50081	46461	3620	15391	24022	7048	63 a	1.0901	21	26
ESN	51132	47570	3562	15647	25079	6844	56 ab	1.0905	16	28
50% ESN:Urea	47772	44237	3536	15865	23111	5261	34 c	1.0910	18	27
Fertigation A	50937	47002	3936	16239	23103	7659	57 ab	1.0883	10	27
Fertigation B	48245	44977	3268	15117	23588	6271	48 b	1.0892	13	24
Fertigation C	49815	46021	3794	15636	24734	5652	49 b	1.0897	17	27
Site										
Carman	50909	46464	4445	17065	24039	5361	55	1.0896	11	25
Carberry	46579	43526	3054	14634	22641	6251	48	1.0905	22	26
Year										
2013	49962	46466	3496	16234	25088	5144	47	1.0894	8	26
2014	47526	43523	4003	15465	21592	6467	56	1.0907	24	24
					P-values					
Trt	<.0001	<.0001	0.1545	0.9618	<.0001	0.0011	<.0001	0.2123	0.1749	0.4648
Site	0.0137	0.0815	<.0001	0.036	0.202	0.2423	0.5068	0.5112	0.0002	0.8224
Year	0.1306	0.081	0.0564	0.4693	0.0055	0.0926	0.3836	0.3696	<.0001	0.4976
Trt x Site	0.0366	0.0268	0.628	0.3465	0.0883	0.0279	0.0985	0.0019	0.4771	0.9551
Trt x Year	0.0002	0.0002	0.6282	0.9097	0.276	0.1088	0.0522	0.122	0.1683	0.9082
Site x Year	<.0001	0.0003	0.0005	0.0018	0.0067	0.8276	0.4798	0.0609	<.0001	<.0001
Trt x Site x Year	0.0535	0.0011	0.0047	0.6805	0.0009	0.1024	0.9814	0.6989	0.001	0.9786

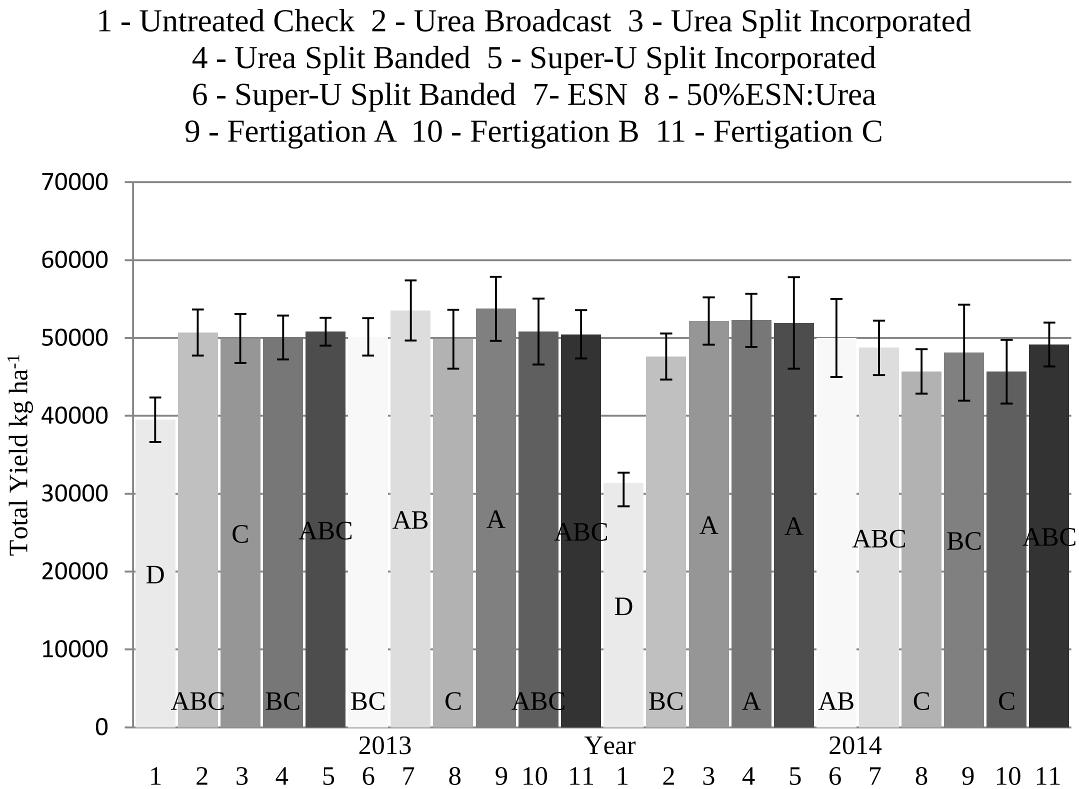

Fig. 2-2. Total yield (kg ha^{-1}) as affected by nitrogen treatments over both years. For a year, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

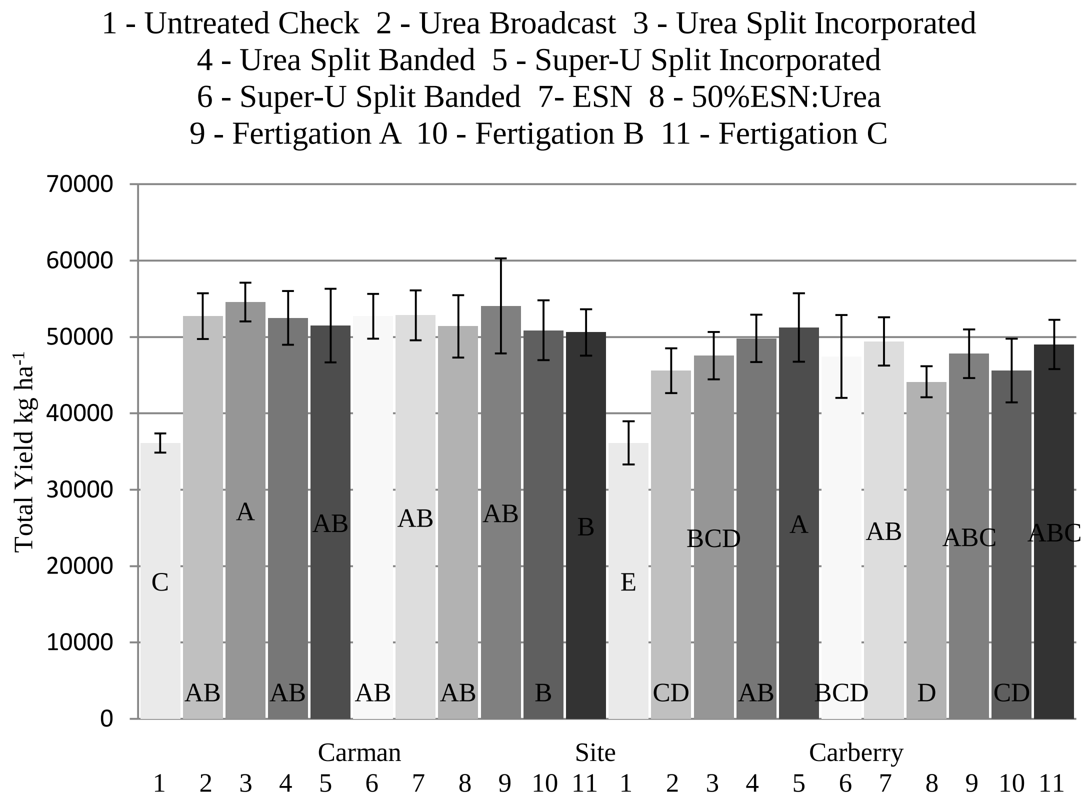

Fig. 2-3. Total yield (kg ha^{-1}) as affected by nitrogen treatments at both sites. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

Contrast analysis indicated that there was significantly higher total yield with the urea treatments than the 50%ESN:Urea treatment (Table 2-4). Further, Urea Split Incorporated yielded 6% higher for total yield, while the Urea Split Banded yield was 7% higher than the 50%ESN:Urea (Table 2-5).

Table 2-4. Total Yield Contrast Analysis

Contrast	Pr>F
Urea vs Fertigation	0.2794
Urea vs Super-U	0.7527
Urea vs Enhanced	0.5929
Urea vs Urea:ESN	0.0019
Band vs Broadcast	0.5121

Table 2-5. Total yield of the urea treatments contrasted to the 50%ESN:Urea treatment.

Contrast	Pr>F
Urea Broadcast vs 50%ESN:Urea	0.2770
Urea Split Incorporated vs 50% ESN:Urea	0.0111
Urea Split Banded vs 50%ESN:Urea	0.0089

2.4.2 *Marketable Tuber Yield*

Marketable tuber yield accounts for all of the tubers harvested greater than 85 g. A three-way interaction between Trt x Site x Year (Table 2-3) was found to be significant (P = 0.001) for marketable tuber yield. The three-way interaction effect likely resulted because in 2013 the best performing treatments were ESN and Fertigation B at Carman and ESN, Fertigation A and Fertigation C at Carberry (Fig. 2-4), but in 2014 it was Urea Split Incorporated and banded at Carman and Urea Split Incorporated and banded, and Super-U Split Incorporated at Carberry (Fig. 2-5). Similar to total yield, the Untreated Check had marketable yield significantly lower than any of the N fertilizer treatments (Fig. 2-4 and 2-5).

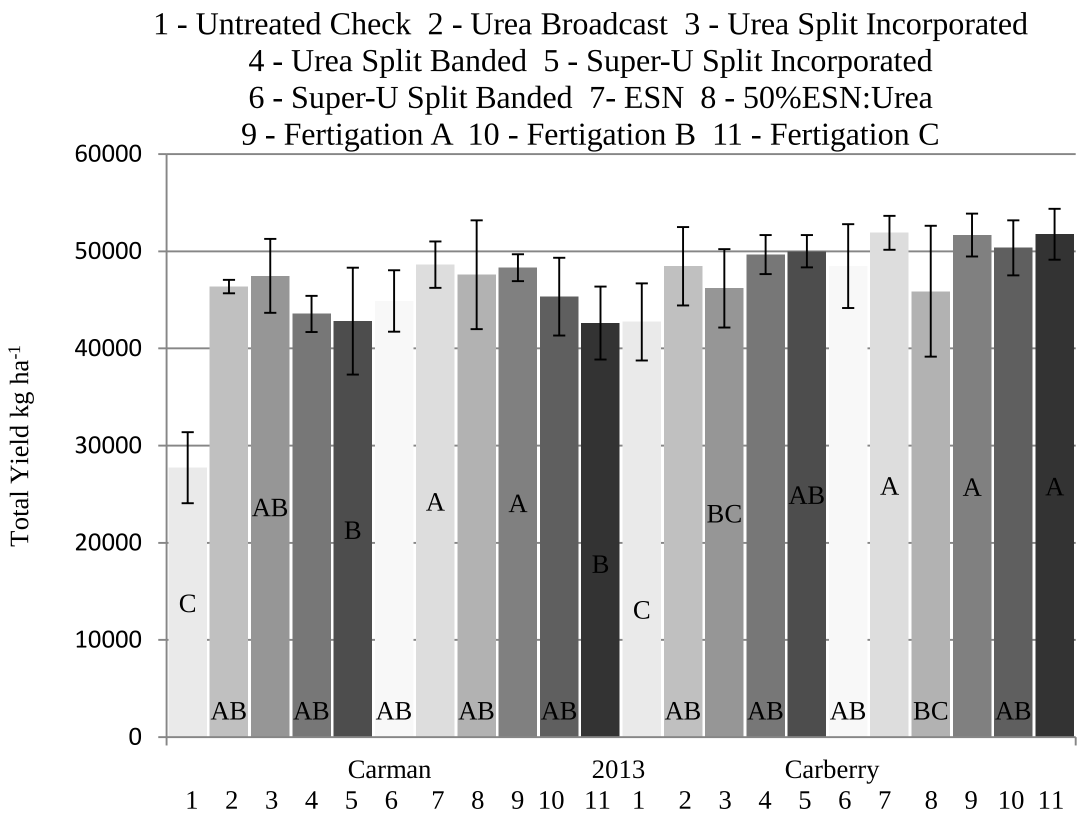

Fig. 2-4. Marketable yield (kg ha^{-1}) as affected by nitrogen treatments at both sites in 2013. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

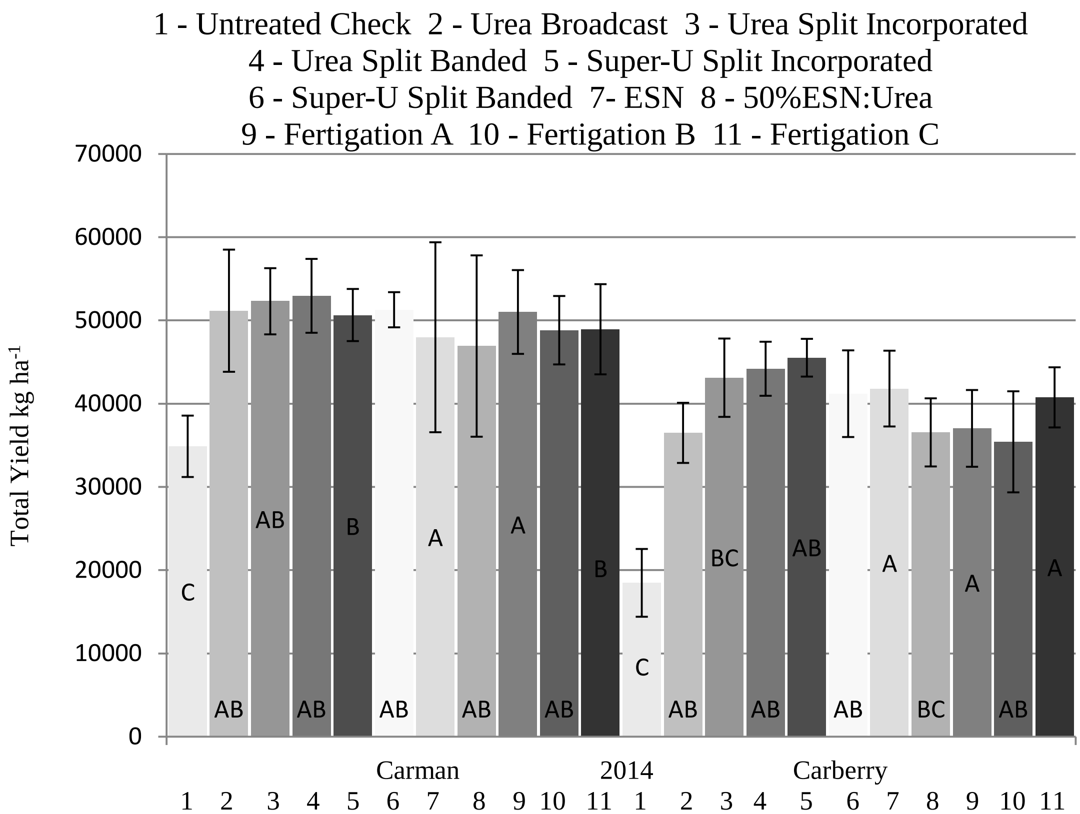

Fig. 2-5. Marketable yield (kg ha^{-1}) as affected by nitrogen treatments at both sites in 2014. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure ($P > 0.05$). Error bars represent one standard deviation of the mean.

Contrast analysis indicated a difference in marketable yield between the Urea and the 50% ESN:Urea treatments (Table 2-6). When these were investigated further we again see that the two Urea Splits differ significantly from the 50%ESN:Urea treatment (Table 2-7), with both the Urea Split being higher than the 50%ESN:Urea marketable yield.

Table 2-6. Marketable yield contrast.	
Contrast	Pr>F
Urea vs Fertigation	0.2683
Urea vs Super-U	0.9747
Urea vs Enhanced	0.7217
Urea vs Urea:ESN	0.015
Band vs Broadcast	0.798

Table 2-7. Marketable yield of urea treatments contrasted against yields of 50%ESN:Urea treatment	
Contrast	Pr>F
Urea Broadcast vs 50%ESN:Urea	0.24
Urea Split Incorporated vs 50% ESN:Urea	0.02
Urea Split Banded vs 50%ESN:Urea	0.01

2.4.3 *Tuber Size Classification by weight*

2.4.3.1 Undersized (<85 g) tubers were found to have a significant (P = 0.0047) three way Trt x Site x Year interaction (Table 2-3). This three way interaction occurred because in 2013 at Carman, the Untreated Check produced the highest yield of under sized tubers, while at Carberry it was the Urea Broadcast and the Untreated Check. However, in 2014 the best preforming treatments were the Urea Split Incorporated and the Untreated Check at Carman, while at Carberry it was the Untreated Check. The Untreated Check produced the largest amount of undersized tubers, over both sites and years.

2.4.3.2 Small tubers (85-170 g) were found to have a significant (P = 0.0018) Site x Year interaction (Table 2-3). Over both years Carman produced a significantly higher amount of small tubers than Carberry.

2.4.3.3 Medium tubers (170-340 g) were found to have a significant (P = 0.0009) three way interaction between Trt x Site x Year (Table 2-3). This interaction effect likely occurred due to the Urea Broadcast having the highest yield of medium tubers at Carberry in 2013, while at Carman this occurred in Urea Split Incorporated (Fig. 2-6). In 2014, the Urea Split Incorporated produced the highest yield at Carman, and the Urea Split Incorporated at Carberry (Fig. 2-7).

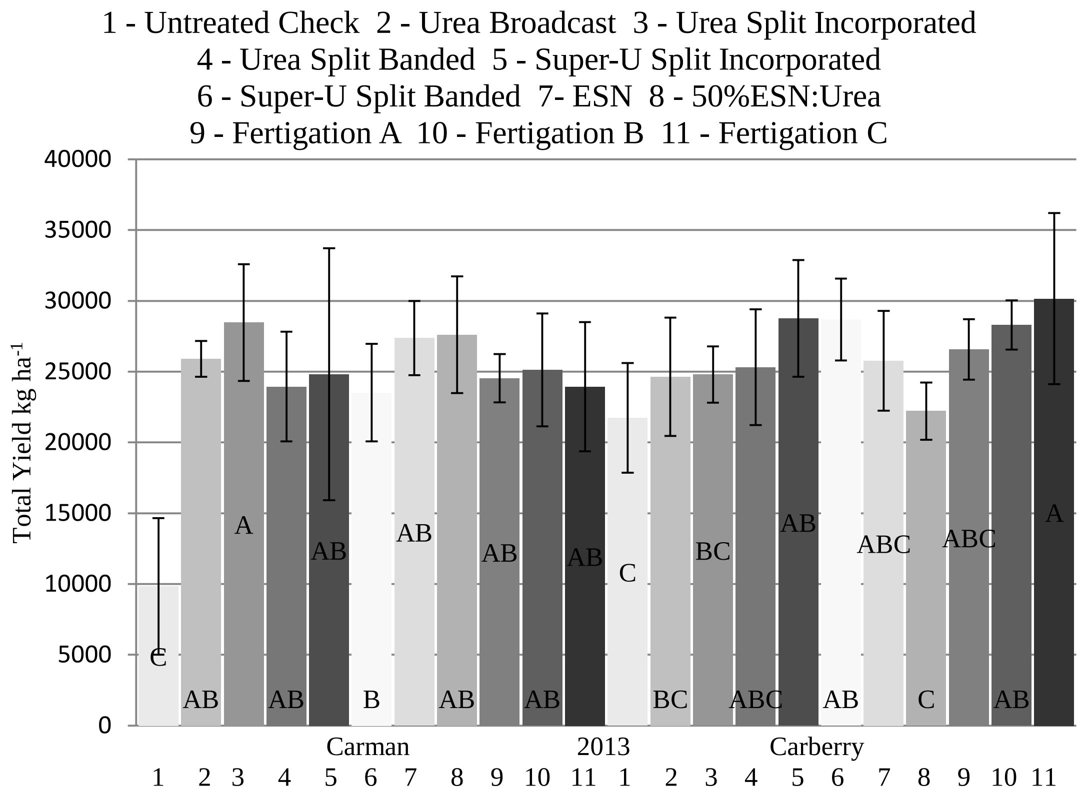

Fig. 2-6. Medium tuber class yield (kg ha^{-1}) as affected by nitrogen treatments at both sites in 2013. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation errors of the mean.

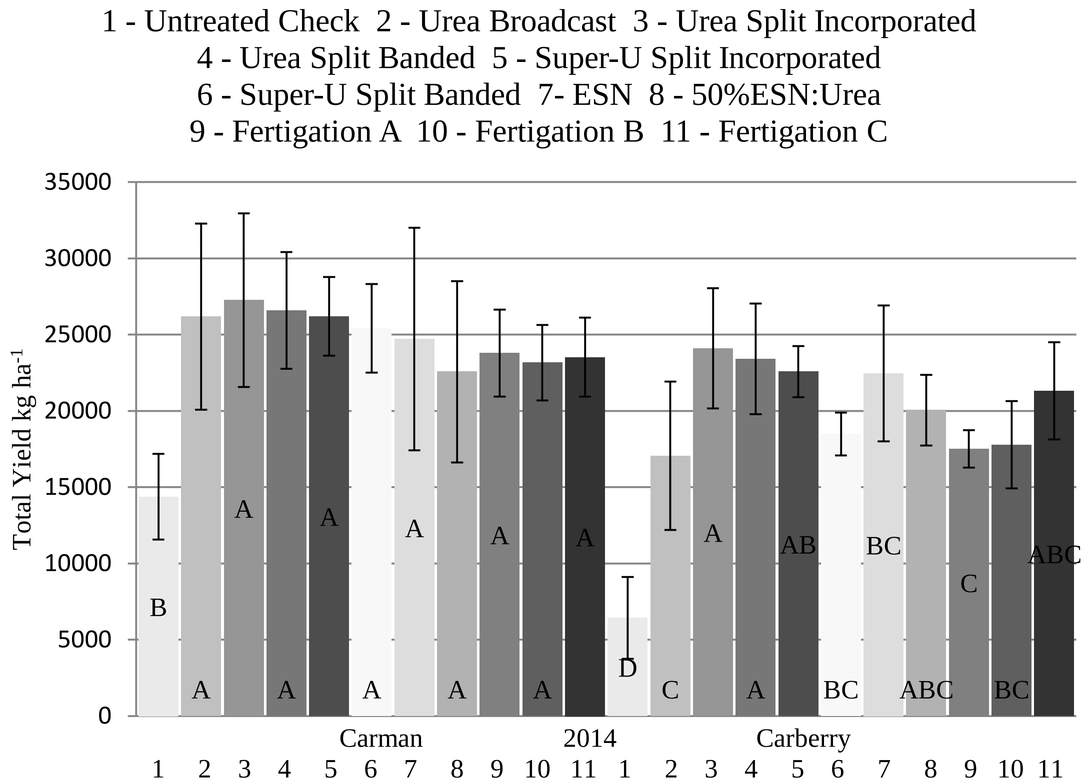

Fig. 2-7. Medium tuber class yield (kg ha^{-1}) as affected by nitrogen treatments at both sites in 2014. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

2.4.3.4 Bonus tubers (>340g) was found to have a significant (P = 0.0279) Trt x Site interaction (Table 2-3). This interaction occurred due to the treatment yields being higher at the Carman site than at the Carberry site (Fig. 2-8).

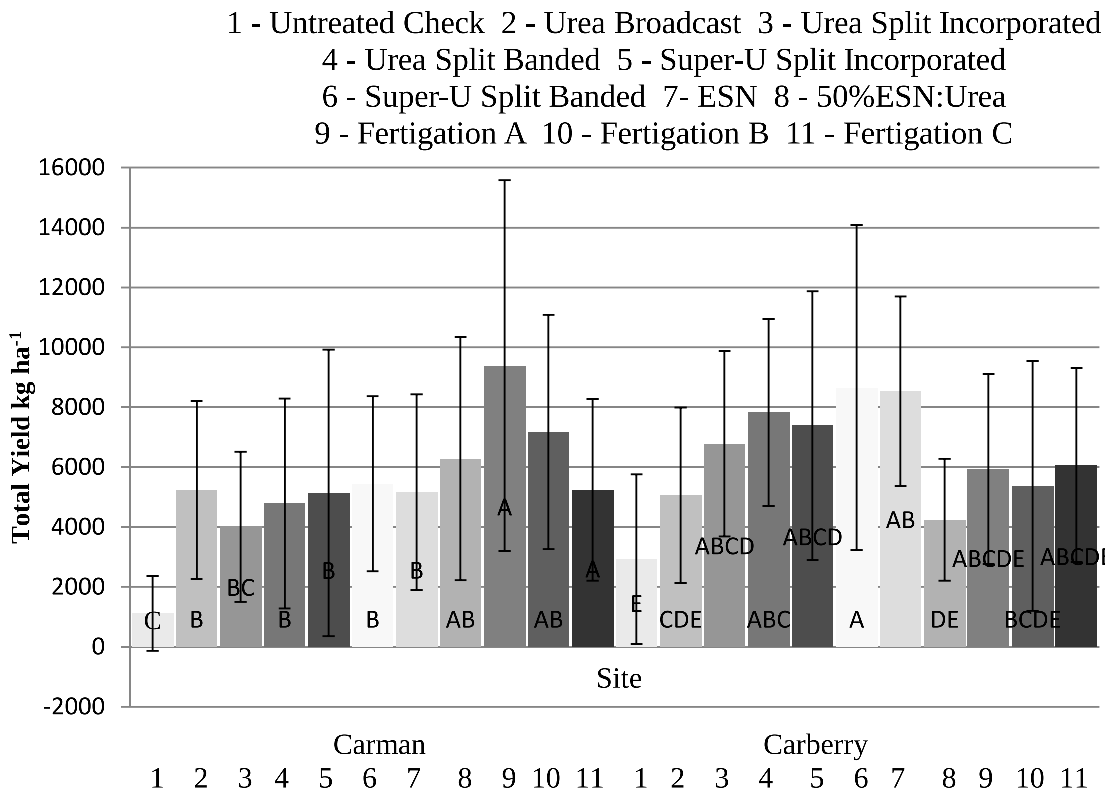

Fig. 2-8. Bonus tuber class yield (kg ha^{-1}) as affected by nitrogen treatments at both sites. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

2.4.4 *Tuber Size Classification by Percent of Marketable Yield*

2.4.4.1 Small sized tubers as a percent of marketable yield were found to have a significant (P=0.0003) Trt x Site x Year three-way interaction (Table 2.9). In 2013 at Carman, the Untreated Check had the significantly highest percent of small tubers at 64%, there was no significant differences between the other treatments. While at Carberry, the 50%ESN:Urea produced the numerically highest percentage of small tuber at 40%, but there was no significant differences between the treatments (Fig. 2-9). In 2014, at the Carman site the Untreated Check again produced the significantly highest percentage of small tubers at 54%. There were no significant differences found between the other treatments. At Carberry in 2014, the Untreated Check produced the significantly highest small tuber at 64% (Fig. 2-10).

Table 2.9 Tuber size classification % based on Marketable Yield

Effect		Small	Medium	Bonus
		%	%	%
Treatment (Trt)				
	Untreated Check	54.77	39.84	5.39
	Urea	38.09	50.90	11.01
	Urea Split - I	32.95	55.30	11.75
	Urea Split - B	34.32	52.22	13.46
	Super-U Split - I	32.72	53.70	13.41
	Super-U Split - B	32.88	51.63	15.49
	ESN	32.37	52.72	14.92
	50% ESN / 50% Urea	35.60	52.46	11.94
	Fertigation A	34.93	49.14	15.94
	Fertigation B	33.91	52.38	13.71
	Fertigation C	34.07	53.51	12.42
Site				
	Carman	37.47	51.28	11.25
	Carberry	34.64	51.26	14.10
Year				
	2013	35.74	52.53	10.74
	2014	36.37	49.02	14.61
			P-value	
Trt		<.0001	<.0001	0.0049
Site		0.1332	0.9832	0.101
Year		0.7281	0.0007	0.0325
Trt x Site		0.0781	0.7209	0.044
Trt x Year		0.3787	0.7743	0.1696
Site x Year		0.3954	0.705	0.4826
Trt x Site x Year		0.0003	0.0015	0.0553

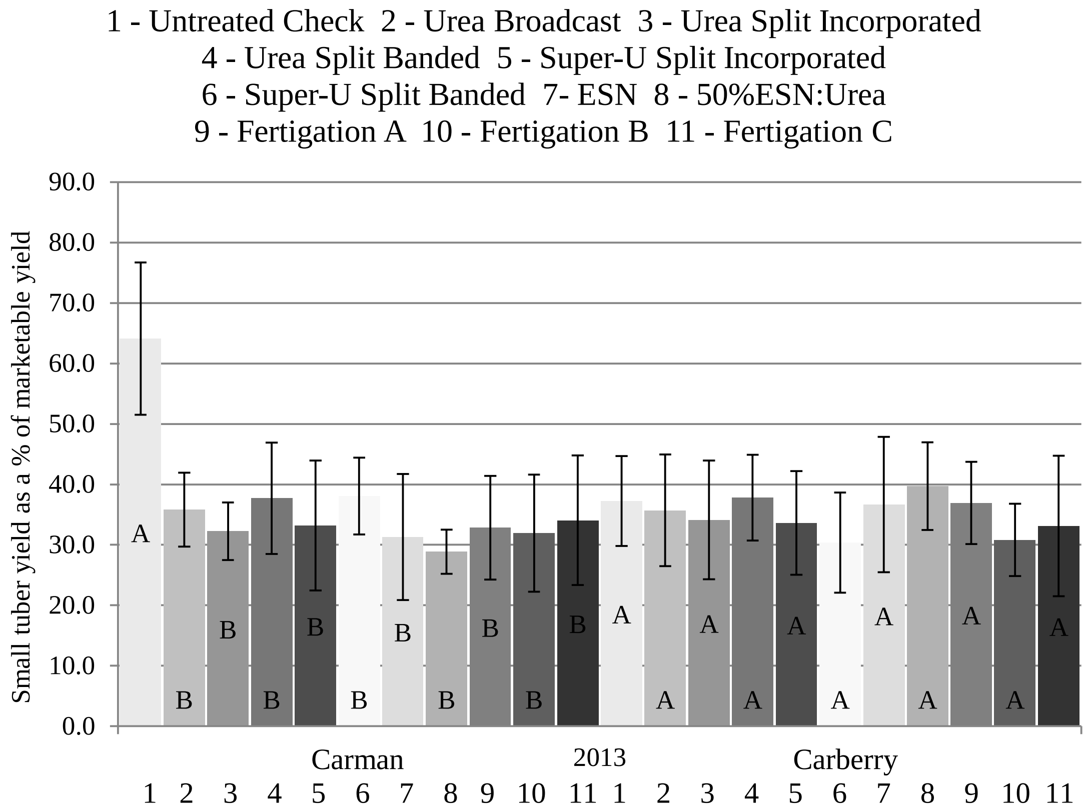

Fig. 2-9. Small tuber yield (kg ha^{-1}) as a percentage of marketable yield, as affected by nitrogen treatments over both sites for 2013. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

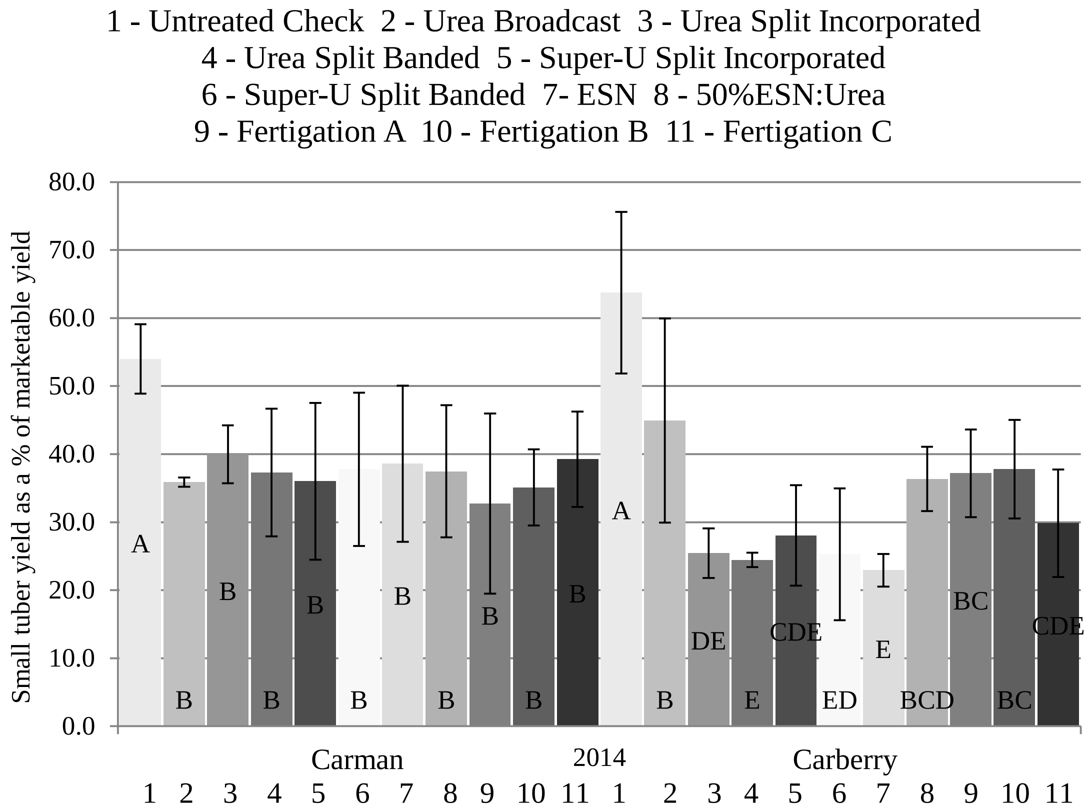

Fig. 2-10. Small tuber yield (kg ha^{-1}) as a percentage of marketable yield, as affected by nitrogen treatments over both sites for 2014. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

2.4.4.2 Medium sized tuber percentage of marketable yield was found to have a significant (P=0.0015) Trt x Site x Year three-way interaction (Table 2.9). In 2013 at Carman, the Urea Split Incorporated produced the significantly highest percentage of medium sized tubers at 60 (Fig. 2-11). While at the Carberry site, the Super-U Split Banded produced the significantly highest percentage of medium tubers at 60%. At the Carman site in 2014, the Urea Broadcast, both Urea Splits, Super-U Split Incorporated and ESN produced the significantly highest medium tuber yield at 51, 52, 50, 52 and 52 % respectively (Fig. 2-12). At Carberry, the Urea Split Incorporated and the 50%ESN:Urea treatments produced the significantly highest medium tuber percent at 56 and 55 % respectively (Fig. 2-12).

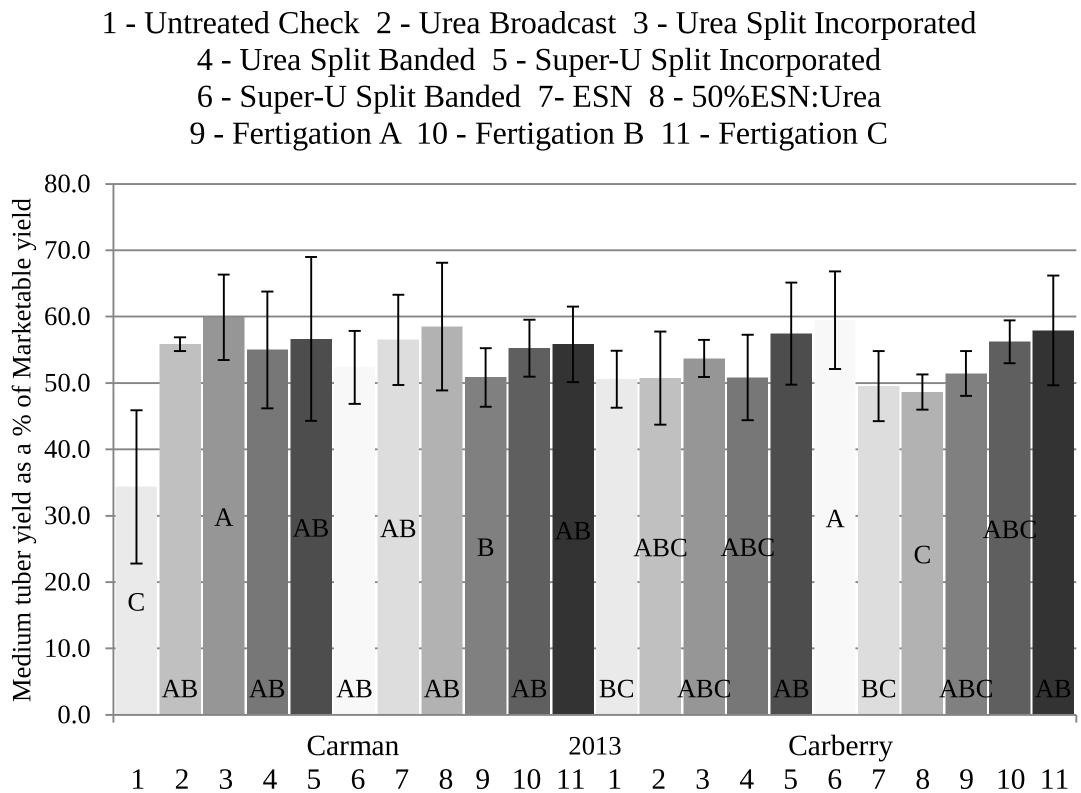

Fig. 2-11. Medium tuber yield (kg ha^{-1}) as a percentage of marketable yield, as affected by nitrogen treatments over both sites for 2013. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

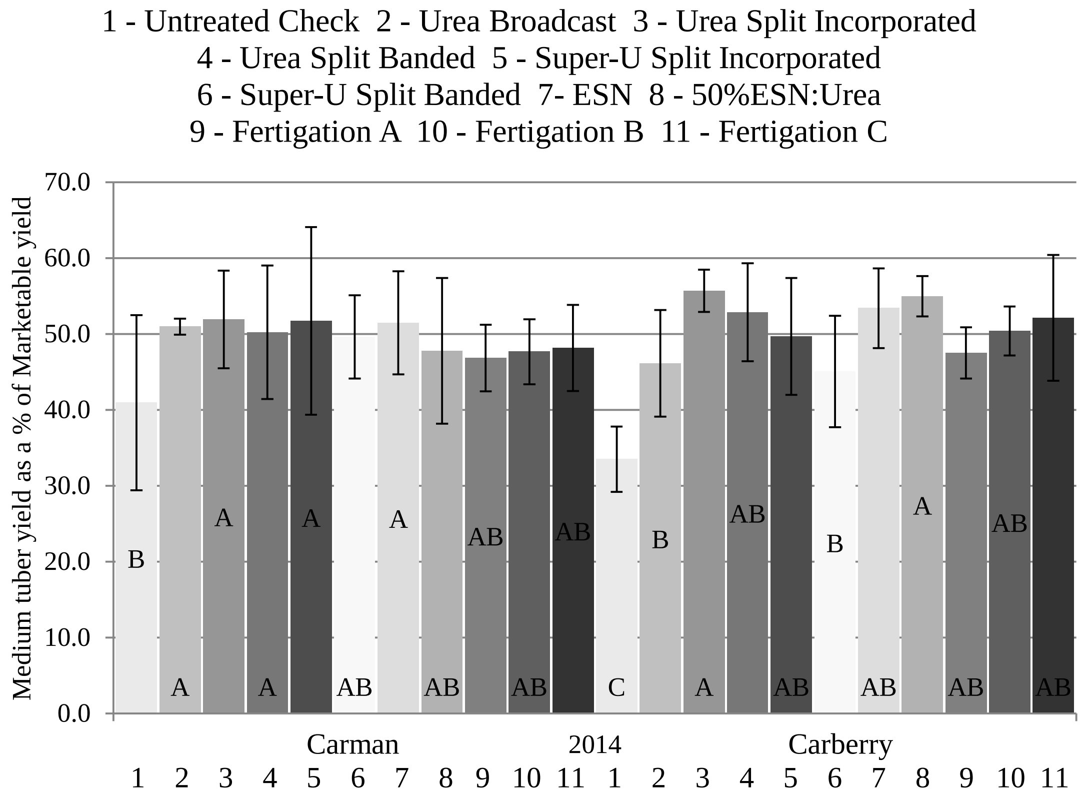

Fig. 2-12. Medium tuber yield (kg ha^{-1}) as a percentage of marketable yield, as affected by nitrogen treatments over both sites for 2014. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

2.4.4.3 Bonus sized tuber yield as a percentage of marketable tuber yield was found to have a significant (P=0.44) Trt x Site interaction (Table 2.9). Fertigation A produced the significantly highest bonus yield percentage of 18% at Carman. While at Carberry the Super-U Split Banded produced the significantly highest bonus yield percentage at 20% (Fig. 2-13).

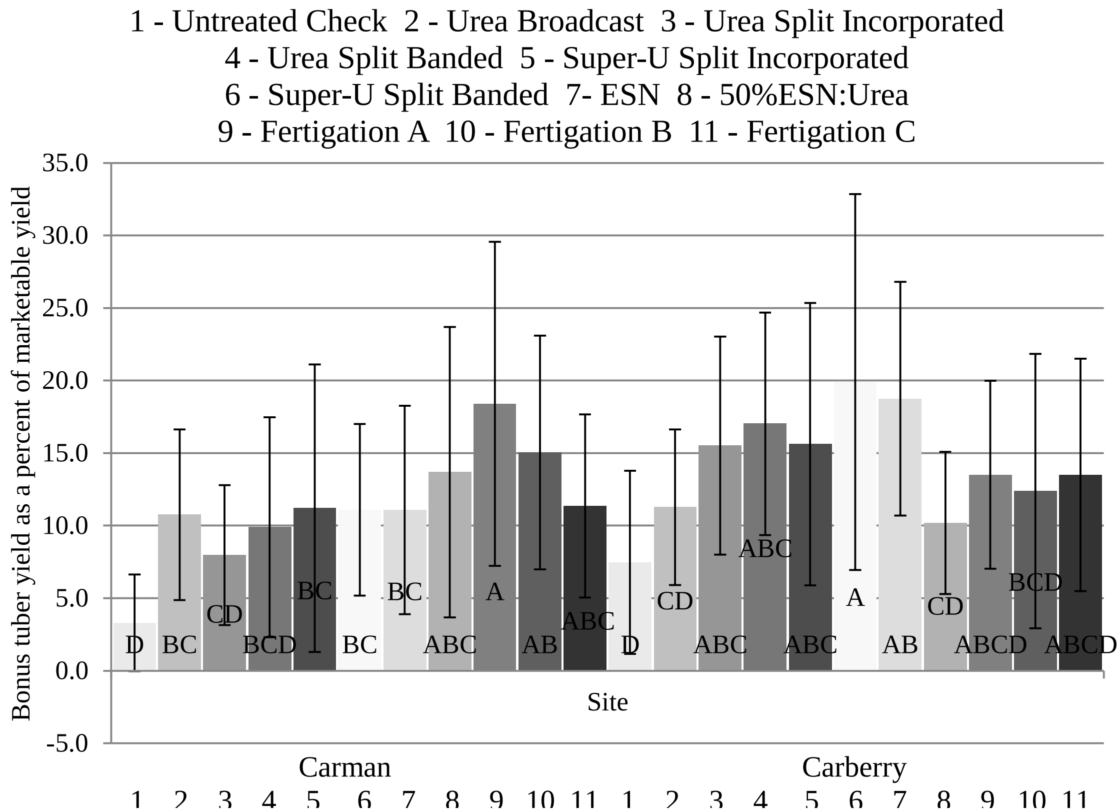

Fig. 2-13. Bonus tuber yield (kg ha^{-1}) as a percentage of marketable yield, as affected by nitrogen treatments over both sites. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

2.4.5 *Nitrogen Use Efficiency*

The treatment effect was significant (P = 0.001) for nitrogen use efficiency (Table 2-3). This indicates that site and year did not significantly affect nitrogen use efficiency. The Super-U Split Banded treatment had the highest nitrogen use efficiency at 63% (Fig. 2-14). Nitrogen use efficiency was higher but not significant in 2014 (55%) then 2013 (47%), and also higher but not significant at the Carman (55%) site, than in Carberry (48%).

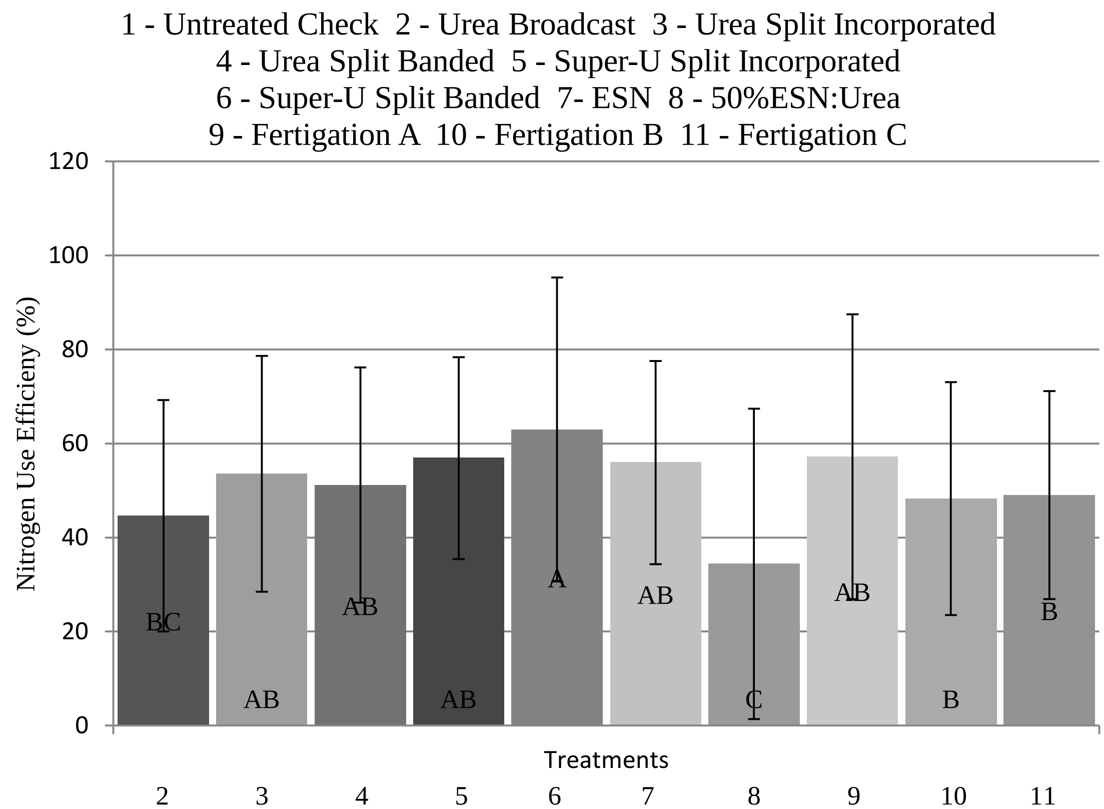

Fig. 2-14. Nitrogen use efficiency (%) as affected by nitrogen treatment. For treatments, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

Table 2-8. Nitrogen use efficiency contrasts.	
Contrast	Pr>F
Urea vs Fertigation	0,6494
Urea vs Super-U	0.0171
Urea vs Enhanced	0.0204
Urea vs 50% ESN:Urea	0.0045
Band vs Broadcast	0.6870

The contrast analysis indicated significant differences between the Urea vs Super-U, Enhanced Fertilizers (Super-U and ESN), and the 50%ESN:Urea mix (Table 2-8). The Super-U and ESN treatments had a higher NUE then the Urea treaments, while the 50%ESN:Urea NUE was lower than the Urea treatments.

2.4.6*Specific Gravity and Hollow Heart*

2.4.6.1 Specific gravity had a significant (P = 0.002) Trt x Site interaction (Table 2-3). This effect was due to at the Carman site, the Urea Split Incorporated resulted in the highest specific gravity, while at Carberry it was the Untreated Check and the 50%ESN:Urea (Fig. 2-15).

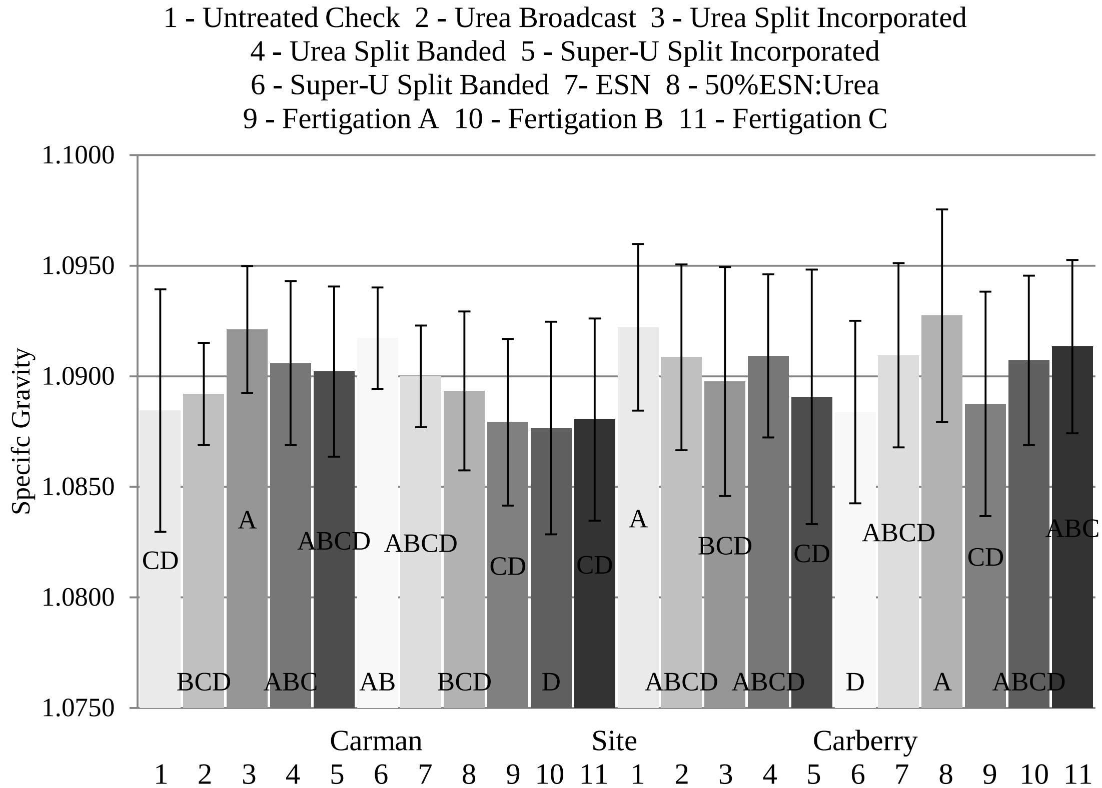

Fig. 2-9. Specific gravity as affected by nitrogen treatment. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure ($P > 0.05$). Error bars represent one standard deviation of the mean.

Contrast analysis was used to further investigate the treatments, with significant differences being found between the Urea Broadcast, both Urea Split treatments and Fertigation A, B, C treatments (Table 2-9), with the average specific gravity of 1.0905 for the Urea Broadcast and both Urea Split treatments being higher than the average specific gravity from the Fertigation A, B, C of 1.0891.

Table 2-9. Marketable tuber specific gravity contrasts.	
Contrast	Pr>F
Urea vs Fertigation	0.0091
Urea vs Super-U	0.2537
Urea vs Enhanced	0.3662
Urea vs 50%ESN:Urea	0.5676
Band vs Broadcast	0.8754

2.4.6.2 Hollow heart incidence had a significant (P = 0.001) three-way interaction, between Trt x Site x Year (Table 2-3). This interaction likely occurred because in 2013 at Carman, there was no significant differences between treatments, while at Carberry the Untreated Check resulted in the highest hollow heart incidence (Fig. 2-16). In 2014, there was again no significant differences at the Carman site, however, at Carberry the Urea Split Incorporated, Super-U Split Incorporated, Super-U Split Banded, ESN, and 50%ESN:Urea produced the highest incidence (Fig. 2-17).

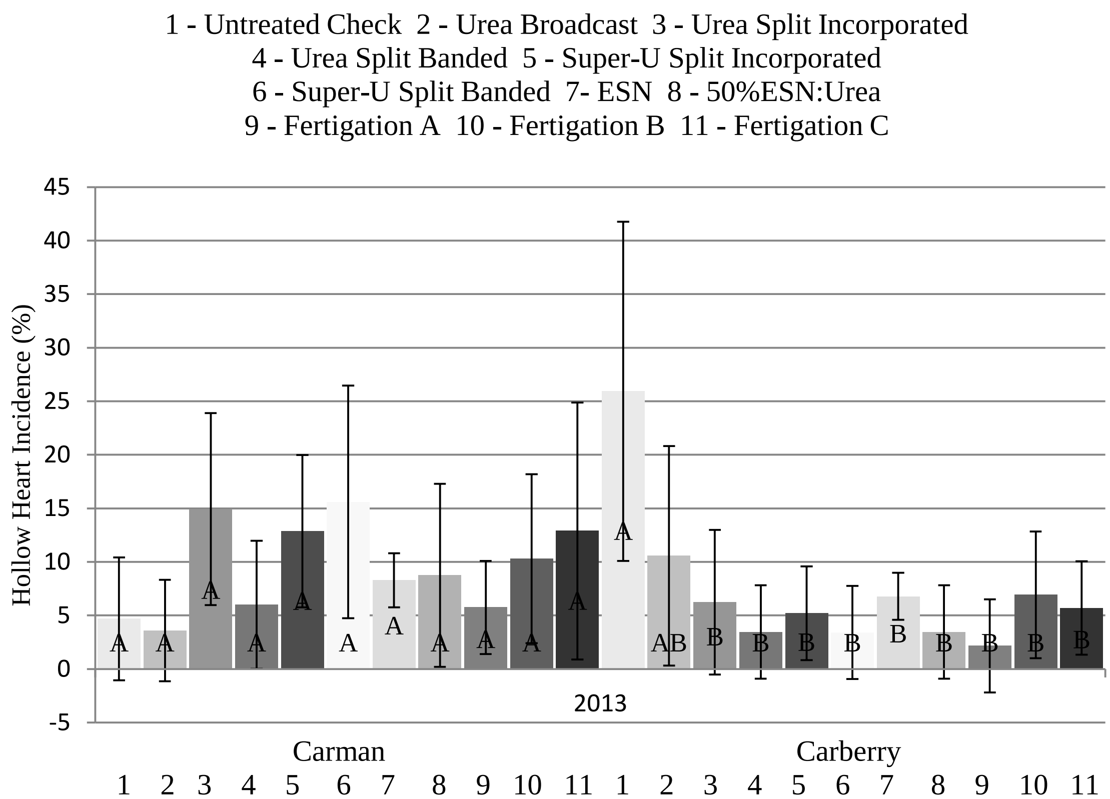

Fig. 2-106. Incidence of hollow heart as affected by nitrogen treatment at both study sites in 2013. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure (*P* > 0.05). Error bars represent one standard deviation of the mean.

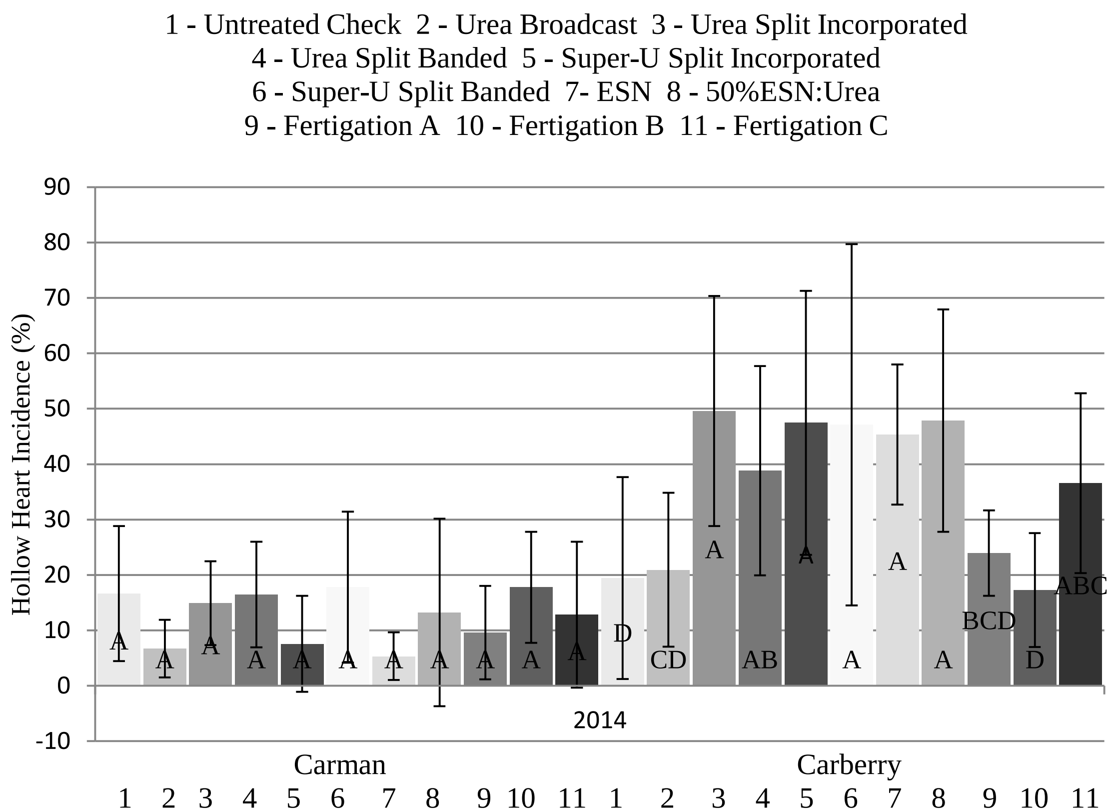

Fig. 2-17. Incidence of hollow heart as affected by nitrogen treatment at both study sites in 2013. For a site, columns with the same letter are not significantly different according to the LSD mean comparison procedure (*P* > 0.05). Error bars represent one standard deviation of the mean.

2.4.7 *Soil Residual Nitrogen*

Residual N after harvest had a significant (P = <.0001) Site x Year interaction (Table 2-4). ESN had the highest average residual N level (28 kg ha^{-1}) in the top 60 cms, for both sites and years; this was only significantly higher than the Untreated Check (20 kg ha^{-1}).

2.4.8 *In Season Nitrogen Analysis*

Plant and soil nitrogen concentration were measured during the growing season through petiole and soil sampling prior to, and after the completion of the fertigation treatments.

2.4.8.1 Prior to fertigation petiole sampling was found to have a significant Trt x Site x Year interaction with a p-values of 0.0003 (Table 2.10). This three-way interaction occurred because in 2013 at Carman the Urea Split Banded produced the highest petiole-N value of 21 989 ppm, while at Carberry, both of the Urea Splits, the Super-U Split Banded along with ESN produced the highest petiole-N values of 26 735, 27 281, 26 577, and 26 920 ppm respectively (Fig. 2-18). However, in 2014 at Carman both Urea splits and the Super-U Split Banded had the highest petiole-N value, while at Carberry it was the Super-U Split Banded (Fig. 2-19).

2.4.8.2

Table 2.10. Prefertgation petiole (Petiol 1), post fertigation petiole (petiole 2), prefertigation soil (Soil 1), post fertigation soil (Soil 2), as affected by nitrogen treatments.

Effect	Petiole 1	Petiole 2	Soil 1	Soil 2
	NO_3^- -N ppm	NO_3^- -N ppm	kg ha^{-1}	kg ha^{-1}
Treatment (Trt)				
Untreated Check	2828	864	36.7	21.0
Urea	16435	1779	84.4	24.7
Urea Split - I	18646	1710	83.2	25.6
Urea Split - B	20342	1764	93.4	22.6
Super-U Split - I	18698	1652	71.4	24.6
Super-U Split - B	20149	2578	84.8	28.0
ESN	17312	1540	81.2	26.1
50% ESN / 50% Urea	17051	1610	66.8	23.2
Fertigation A	11715	1731	54.1	24.4
Fertigation B	7073	2858	45.9	24.2
Fertigation C	11069	1607	60.2	23.8
Site				
Carman	10185	1425	75.62	27.9382
Carberry	19146	2155	62.956	20.816
Year				
2013	18431	2105	65.9	21.6
2014	10899	1476	72.6	27.1
		P-value		
Trt	<.0001	<.0001	<.0001	0.0533
Site	<.0001	0.1217	0.0085	0.0016
Year	<.0001	0.1765	0.1215	0.0091
Trt x Site	0.0008	0.0371	0.7708	0.322
Trt x Year	0.0028	0.1874	0.7307	0.1707
Site x Year	0.5283	0.0926	0.0009	<.0001
Trt x Site x Year	0.0003	0.014	0.4107	0.0042

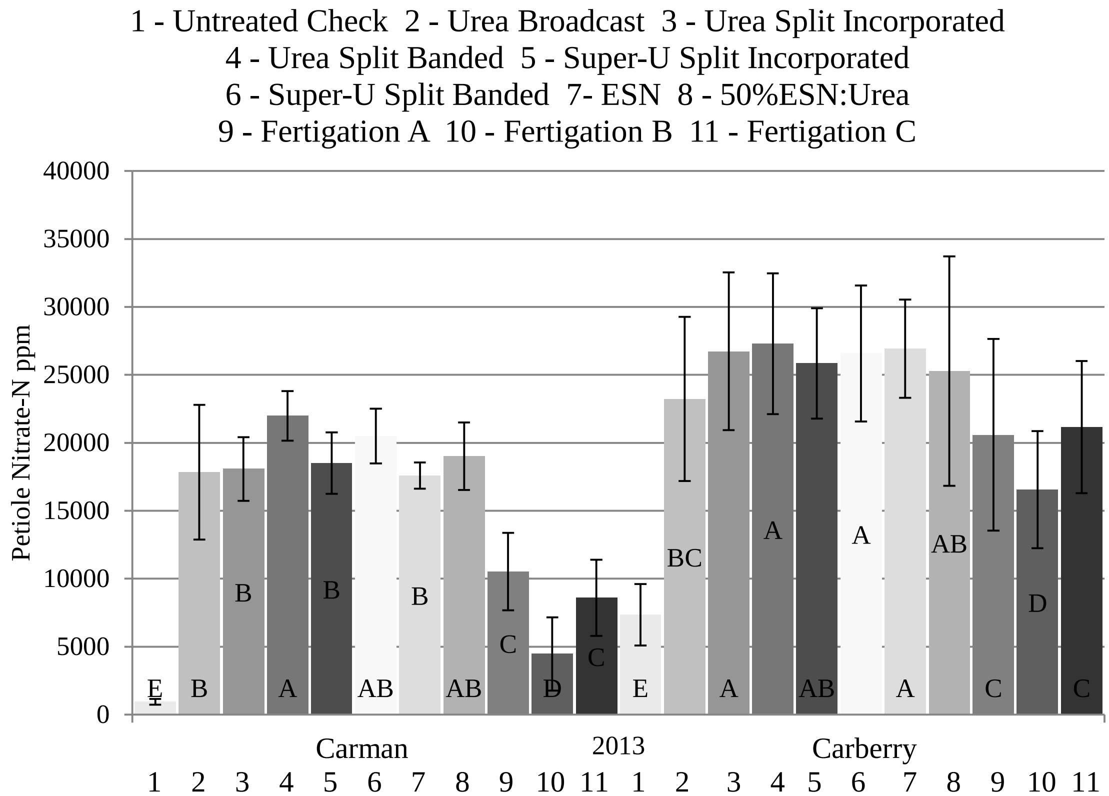

Fig. 2-18. Pre-fertigation petiole NO_3^- -N (ppm) as affected by nitrogen treatments at both locations in 2013. For a location, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

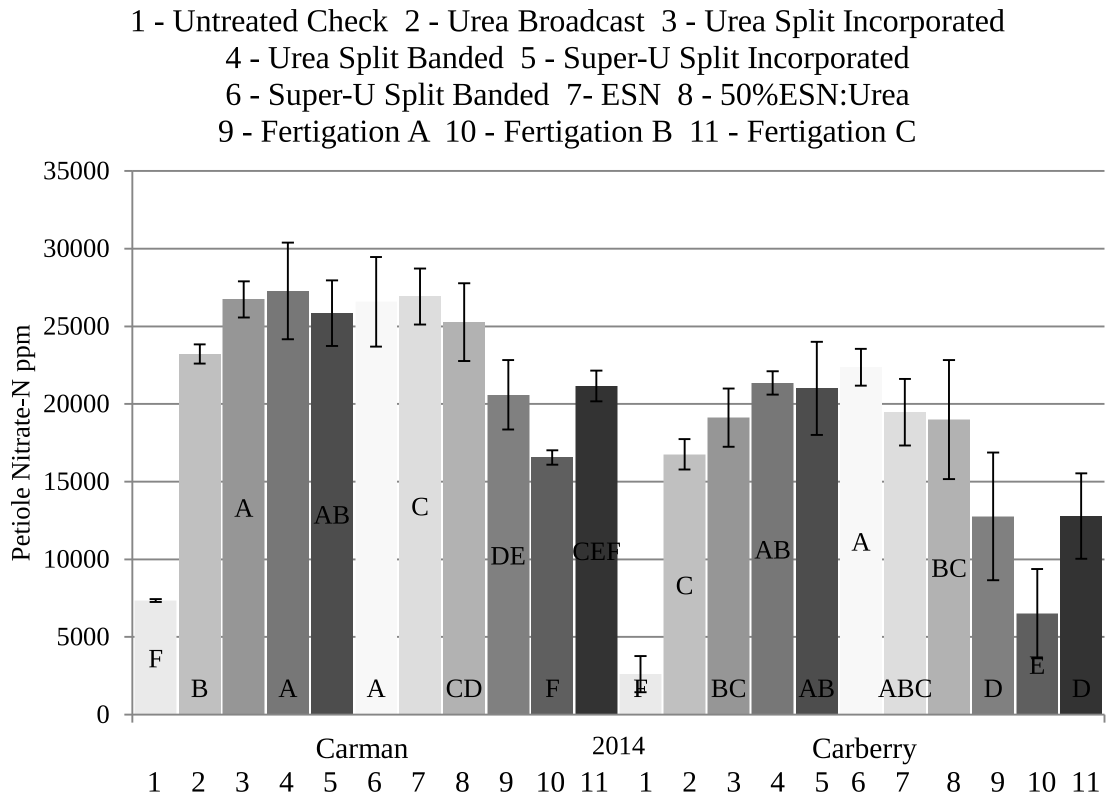

Fig. 2-19. Pre-fertigation petiole NO_3^- -N (ppm) as affected by nitrogen treatments at both locations in 2014. For a location, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

2.4.8.3 Post fertigation petiole-N level had a significant (P=0.014) Trt x Site x Year interaction (Table 2.10). In 2013, post fertigation petiole-N values were significantly highest under the Super-U Split Banded treatment at 2 544 ppm at the Carman site (Fig. 2-20). While at Carberry, the Urea Broadcast, Urea Split Incorporated, Super-U Split Banded, ESN, and Fertigation B all had the significantly highest petiole-N values of 3 251, 3 646, 3 446, 3 575 and 3 445 ppm in 2013 (Fig. 2-20). At Carman in 2014, there were no significant differences between any treatments (Fig. 2-21). However, at

Carberry in that year Super-U Split Banded and Fertigation B produced the significantly highest petiole-N values of 3 446 and 3 816 respectively. (Fig. 2-21).

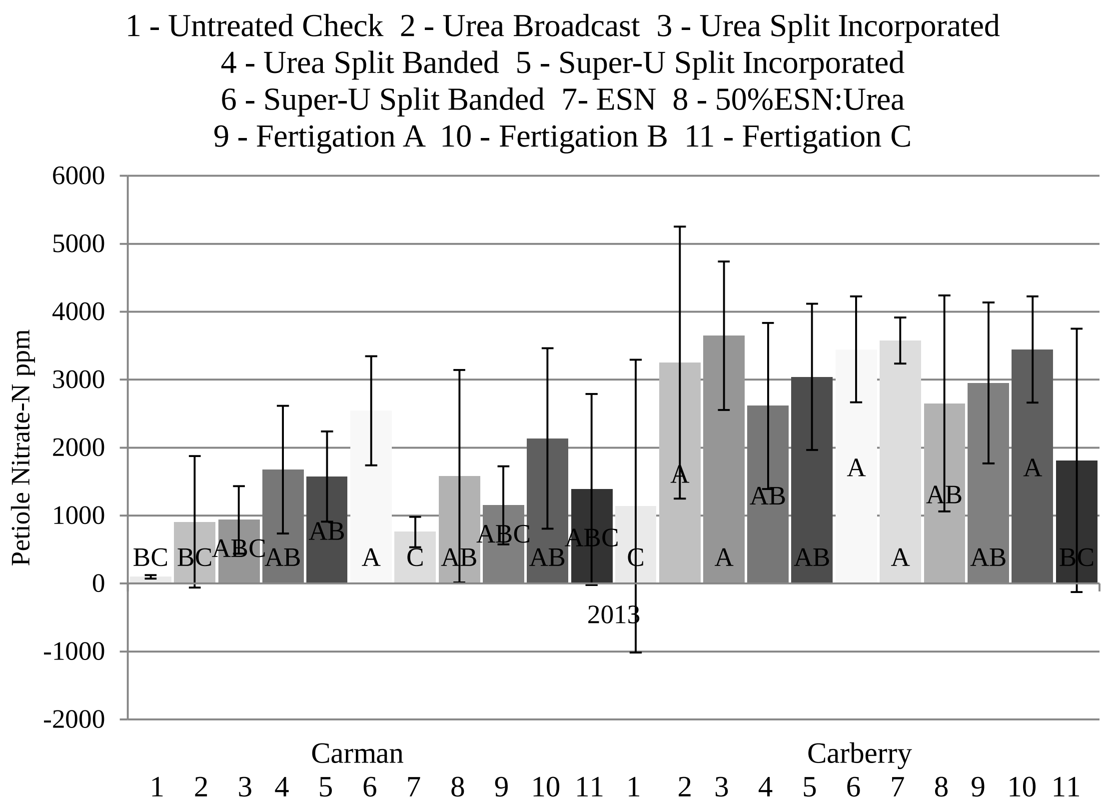

Fig. 2-20. Post fertigation petiole NO_3^- -N (ppm) as affected by nitrogen treatments at both locations in 2013. For a location, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

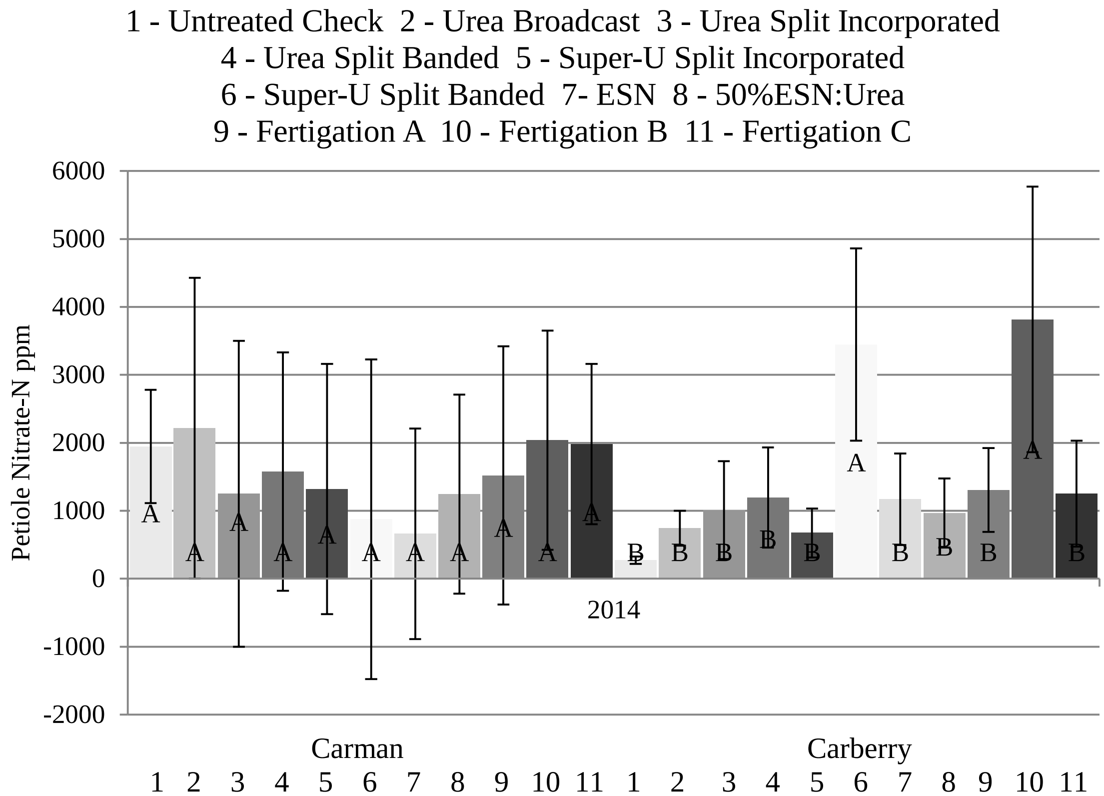

Fig. 2-21. Post fertigation petiole NO_3^- -N (ppm) as affected by nitrogen treatments at both locations in 2014. For a location, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

2.4.8.4 Prior to fertigation soil NO_3^- was found to have a significant Site x Year interaction (P=0.0009) (Table 2.10). This was due to the average soil NO_3^- level of 88 kg ha^{-1} for the Carman site in 2014 being significantly higher than the average soil NO_3^- for the other three site years, which did not show any significant differences.

2.4.8.5 Post fertigation soil NO_3^- had a significant (P=0.0042) Trt x Site x Year interaction (Table 2.10). In 2013, at Carman the Urea Broadcast has the significantly highest post fertigation soil NO_3^- level at 25 kg ha^{-1}, while at the Carberry site the Urea Split Incorporated, and ESN had the significantly highest soil NO_3^- at 29 and 28 kg ha^{-1} respectively (Fig. 2-22). At both locations the Untreated Check had the significantly lowest soil NO_3^- level; at both sites this was not significantly lower than some of the nitrogen treatments. In 2014, at the Carman site ESN produced the significantly highest soil NO_3^-, with 42 kg ha^{-1} post fertigation (Fig. 2-23). However, at the Carberry site in the same year, Super-U Split Banded produced a soil NO_3^- value of 30 kg ha^{-1} which was the significantly highest (Fig. 2-23).

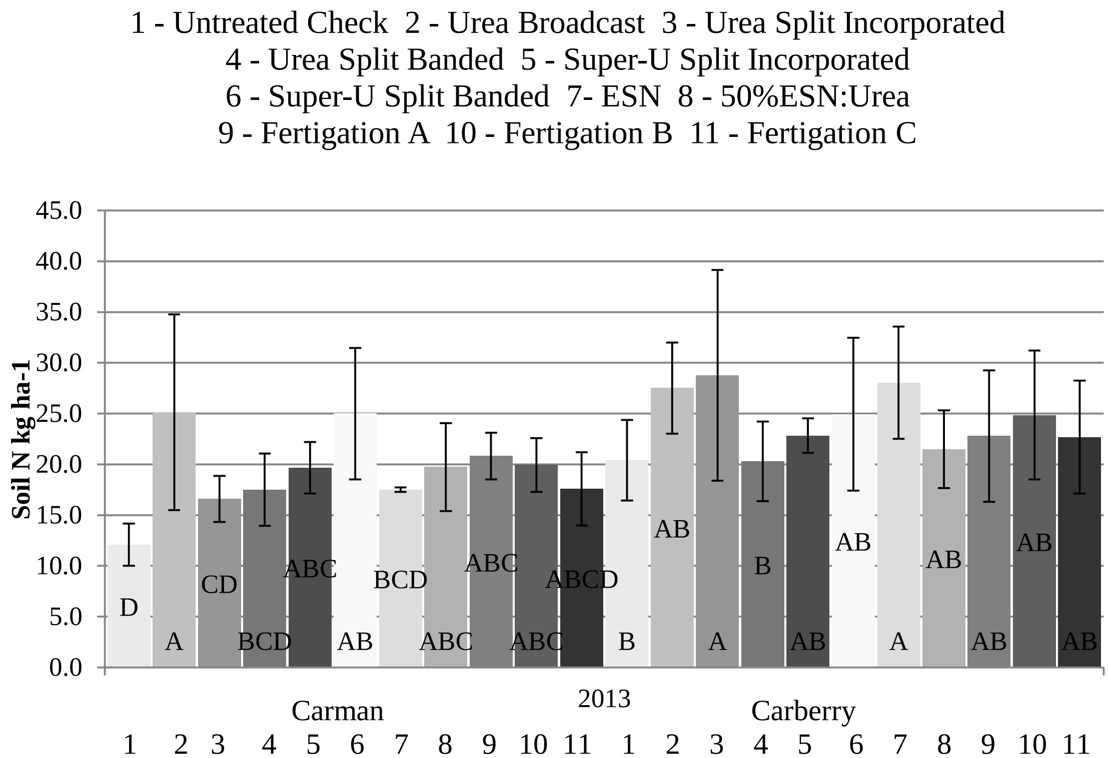

Fig. 2-22. Pre-fertigation Soil N (kg ha^{-1}) as affected by nitrogen treatments at both locations in 2013. For a location, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

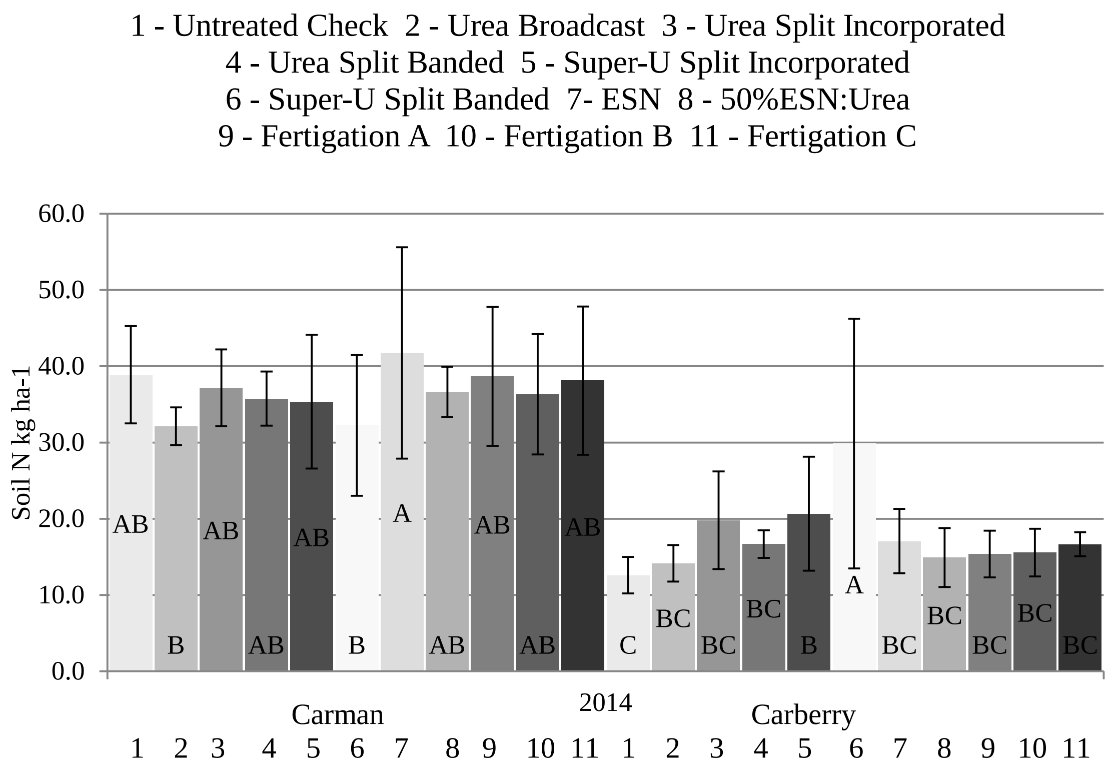

Fig. 2-23. Post fertigation Soil N (kg ha^{-1}) as affected by nitrogen treatments at both locations in 2014. For a location, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P > 0.05). Error bars represent one standard deviation of the mean.

2.5 Discussion

Treatment yields were expected to be higher under the stabilized, controlled release and fertigation treatments, as they delay N availability or application longer into the growing season when N uptake by the plant is higher. The placement technique of banding was expected to increase yields over the broadcast placement technique. These expectations were not observed over both sites and years. An increase in yield was found to occur in response to N application over the Untreated Check. This increase in yield from N application was expected and similar with other studies observing the effect of N on potato (Painter and Augustin 1976, Porter and Sisson 1991, Belanger et al. 2000, Arsenault et al. 2001, Zvomuya and Rosen 2001, Wilson et al. 2009, McPharlin and Lancaster 2010, Kelling et al. 2011, Ziadi et al. 2011). The treatments differences are going to be discussed based on their significant interaction effects.

2.5.1 *Treatment Variation*

2.5.1.1 Nitrogen use efficiency (NUE) was found to be highest for the Super-U Split Banded treatment at 63%. This was significantly higher than the Urea Broadcast, 50%ESN:Urea, and Fertigaion B and C. Both of the Super-U splits were numerically higher than the Urea Split, which may indicate a fertilizer source benefit. The Urea Split Broadcast was numerically higher than the Urea Split Banded, while the Super-U Split Banded was higher than the broadcast treatment; this indicates no benefit to banding over broadcast. The 50%ESN:Urea treatment produced the significantly lowest NUE, indicating no benefit from mixing ESN and Urea for an at planting fertilizer. Fertigation A had a numerically higher NUE than Fertigation B and C, this indicates no increase in NUE from applying less N at plant and more as a delayed application, or from using 50%ESN:Urea as an at planting fertilizer. The nitrogen use efficiency results for the Urea Broadcast, both Urea Splits, and ESN responded with similar results to those found by Zvomuya et al. (2003) and Wilson et al. (2010) regarding polymer coated urea and urea. In both cases urea has values lower than or equal to that of the polymer coated urea. However, the differences are not always significant.

2.5.2 *Treatment Variation with Year*

2.5.2.1 Total yields in 2013 were higher for the controlled and delayed release treatments over the split and at planting treatments. While in 2014, the split applications produced higher total yields than the controlled release or delayed applications, although not always significant. Heavy rainfalls post planting would be expected to affect the Urea treatments most as they would be the most susceptible to leaching due to not being stabilized with inhibitors, having controlled release due to a polymer coating, or having a delayed application period such as the fertigation treatments. If this occurred at Carman in 2013, it only resulted in numerically lower total yields than in Carberry for the Urea treatments. In 2013, there was a larger numeric difference between the total precipitation levels, with Carman being 260 mm lower than Carberry, while in 2014 Carman was 102 mm lower than Carberry. The amount of total precipitation did not match to the highest total yielding treatments. Carman, in 2014, produced the significantly highest yield while having the third lowest amount of precipitation; it did not yield significantly higher than Carberry in 2013, but was significantly higher than Carman in 2013 and Carberry in 2014. This indicates that although precipitation levels varied over sites and years, it was not likely a yield limiting factor due to a lower amount of precipitation in 2013 and 2014.

The broadcast and banded split applications of both Urea and Super-U did not yield significantly different total yield than the broadcasted Urea in 2013, while in 2014 the broadcasted Urea yield was not significantly different than the Super-U Split Banded, but it was significantly lower than the two Urea Splits and the Super-U Split Incorporated. This indicates that split fertilizer applications can improve yield (Porter and Sisson 1993), even if the increase is not always significant. The total yields for the Urea and Super-U splits only had a significant difference in 2013, at Carberry; with the Urea Split Incorporated being significantly lower than the Super-U Split Incorporated. There were not any other significant differences between these treatments in 2013 or 2014, this agrees with what Kelling et al. (2011) found when comparing the use of DCD, a nitrification inhibitor found in Super-U, with different N sources. The use of the inhibitor in a few cases resulted in a yield increase and at no point did the use of an inhibitor significantly decrease yield. This may indicate little significant benefit from the nitrification and urease inhibitors found within this product.

In 2013, ESN significantly out yielded the Untreated Check, Urea Split Incorporated and 50%ESN:Urea, by 14,026, 3,592, and 3,690 kg ha^{-1},, while not being significantly higher than any other treatment. These results differ from those found by Burke (2009), where ESN was compared to urea at the same rate for yield on corn, barley, and potatoes, and for all three no significant differences were found in yield between the urea and ESN treatments. However, in 2013, ESN produced 213 kg ha^{-1} less yield than the highest yielding Fertigation A. This difference was not significant though. In 2014 however, ESN only had a significantly yield gain of 17,738 kg ha^{-1} over the Untreated Check. The ESN at planting was never significantly different then the highest total yielding treatments in 2013 or 2014. This indicated ESN's ability as an N source to produce consistently high total yields. Ziadi et al. (2011) hypothesized that increased yield and N use efficiency from ESN were related to the N release pattern being closely linked to N uptake, which is supported by the yield results found in this study. The total yields found from the Fertigation A, B, C, were never significantly different from each other over both years. The little variation between fertigation treatments agrees with results found by Lauer (1986), who found total and U.S. No. 1s yields to be significantly lower when N was not applied at planting, but more similar when the rates were split over the season. Increased N rates at planting were found to increase total yield one of three years with the other two showing no timing effect (Zebarth et al. 2004), which is similar to the findings in this study where Fertigation B which only received 40% of the N rate at planting resulted in significantly lower yields overall in 2014, when compared to the highest yielding treatment, and numerically lower then both Fertigation A and C. Contrast analysis indicates significant treatment differences between the 50%ESN:Urea and the other urea treatments. This difference was further investigated and it was found that the two Urea Splits yielded 3,300 and 3,400 kg ha^{-1} respectively significantly higher than the 50%ESN:Urea over both sites and years.

2.5.2.2 Hollow heart incidence was significantly higher in 2014 at 24%, while in 2013 it was only 8%. In 2013, there were no significant differences found amongst all treatments; the Untreated Check had the highest numeric level of incidence at 15%. However, in 2014, the Super-U Split Banded resulted in the significantly highest incidence of hollow heart at 32%, this was 14, 19, 17, and 15 percent higher than the Untreated Check, broadcasted Urea, Fertigation A and B respectively. Results from

2013, in which the application of nitrogen did not result in significant differences, agree with the results found by Silva et al. (1991), but disagree with Wilson et al. (2009) who found nitrogen application to significantly increase hollow heart incidence. This agrees more with the findings from 2014 where hollow heart incidence increased by 16% over 2013.

2.5.3 *Treatment Variation with Site*

2.5.3.1 Total yield for Carman was 50,909 kg ha^{-1}; this was significantly higher than the 46,579 kg ha^{-1} total yield for Carberry. The Carberry site in 2014, experienced significantly lower stand numbers (26 vs 32 plants $12m^{-1}$) than were experienced at that site in 2013. This may have affected the total yield which was achieved at this site. The total precipitation was lower at Carman over both years; this did not appear to affect the yield when averaged over both sites. At the Carman site, the Urea Split Incorporated yielded the significantly highest at 54,579 kg ha^{-1}, although only significantly higher than the Untreated Check and Fertigation B & C which yielded 36,138, 50,891, and 50,605 kg ha^{-1} respectively. The Super-U Split Incorporated produced a yield of 51,261 kg ha^{-1}, which was found to be the highest yielding treatment at the Carberry site. It was, significantly higher than the Untreated Check, broadcasted Urea, Urea Split Incorporated, Super-U Split Banded, 50%ESN:Urea, and Fertigation B, by 16,539, 5,678, 3,711, 3,817, 7,119, and 5,663 kg ha^{-1}. At both sites the significantly highest treatments were incorporated split applications of urea at Carman, and Super-U at Carberry, this indicates no significant benefit for banding over broadcasting with incorporation. Fertigation B and C were significantly lower than the highest yielding treatment at Carman, while ESN and Fertigation A were not. This indicates a potential planting rate difference, as Fertigation A received 60% of the application rate at planting, while Fertigation B only received 40% of the application rate. This agrees with Zebarth et al. (2004) who found higher nitrogen rates at planting applications increased total yield one of three years. There is also a potential N source effect, as Fertigation C yielded significantly less than Fertigation A, while receiving the same N rate at planting. Fertigation C received a 50%ESN:Urea application at planting, which yielded significantly less than the regular urea used at planting in Fertigation A.

Bonus tuber yield for Fertigation A yielded 9 383 kg ha^{-1}, which was the significantly highest treatment at Carman. Fertigation A at Carman was not significantly different than the 50%ESN:Urea or Fertigation C. The Super-U Split Banded produced the significantly highest bonus tuber yield at Carberry. This was significantly higher than the Untreated Check, Urea Broadcast, 50%ESN:Urea and Fertigation B. Fertigation A was not significantly different than Fertigation B at either location, and Fertigation A was only different from Fertigation C at Carman; this may indicate that the fertigation applications occurred at the proper time during the tuber bulking phase (growth stage IV). This stage is when majority of the nutrients are taken up by the potato (Westermann 1993). Carman had experienced heavier rains fall in the 2013 season. This would have given additional benefit to the delayed N applications from fertigation and may be why the split treatments were significantly lower than Fertigation A and numerically lower than Fertigation B. All other nitrogen treatments at Carman were not significantly different; the Urea Split Incorporated was numerically the lowest nitrogen treatment, and was not significantly higher than the Untreated Check. The Super-U Split Banded bonus tuber yield was 8 652 kg ha^{-1}, which was the significantly highest treatment at Carberry. Total precipitation values were higher for Carberry than Carman and they tended to be more evenly dispersed over the growing season. This more even distribution of precipitation may have resulted in less leaching which is why we see the Urea and Super-U splits yielding numerically higher than the fertigation treatments at Carberry. Temperature and moisture can have a significant effect on the nutrient release of polymer coated controlled release products such as ESN (Trenkel 2010). This even distribution of precipitation may have resulted in a more consistent release from the ESN granules resulting in an increase of bonus tubers. Carberry tended to have more significant variation between the treatments than Carman. This could be related to the seed rot experienced at this location in 2014. Seed rot can lead to changes and inconsistencies in the spacing between the emerged tubers. Larger spacing typically leads to larger tuber sizes, while smaller spacing result in smaller tubers (Love and Thompson-Johns 1999). The results from Carberry support the findings that split applications of nitrogen can lead to an increased in tuber yield at the same rate (Roberts et al. 1982). Having both Urea and Super-U Split Banded treatments showing numerically higher yields at Carberry may be indicative of a nitrogen fertilizer placement benefit, over nitrogen source, when comparing them to broadcasting.

2.5.3.2 Bonus tuber yield as a percentage of marketable yield is also an important property as when the percentage is 15% or higher there is a dockage penalty applied to producers. At the Carman sites, over both years, Fertigation A produced the significantly highest bonus tuber yield as a percentage of marketable yields. At Carberry thou, the Super-U Split Banded produced the significantly highest bonus tuber yield as a percentage of marketable yields. At both sites, as expected the untreated check produced the lowest percentage of bonus tubers as a percent of marketable yield. At Carman, both Fertigation A and B produced bonus tubers yields of 18 and 15% of their marketable yield respectively. While at Carberry, both the Urea and Super-U splits, and ESN produced bonus tubers yield of 16, 17, 16, 20 and 19%, which are all higher than the value of 14% for which no financial penalties will apply.

2.5.3.3 Specific gravity at Carman was significantly highest under the Urea Split Incorporated with a value of 1.0921. This was not significantly different than the Urea Split Banded, both Super-U splits, and the ESN treatments. Fertigation B produced the significantly lowest specific gravity, thou it was not significantly different than the Untreated Check, Urea Broadcast, 50%ESN:Urea, Fertigation A and C. The Untreated Check and 50%ESN:Urea produced the significantly highest specific gravities at Carberry with values of 1.0922 and 1.0927 respectively. These were not significantly different from the Urea Broadcast, Urea Split Banded, ESN, 50%ESN:Urea Fertigation B and C. The Super-U Split Banded produced the lowest specific gravity at Carberry, but was not different from the Super-U Split Broadcast, and Fertigation A. There were no significant differences between the Urea Broadcast, the Urea and Super-U splits and the ESN. The fertigation treatments also had no significant variation between them at either site. Specific gravities affect yield of fries, with higher gravities resulting in higher yields, than those with lower gravities (Scanlan 2003). However, at both sites no treatment was below the specific gravity level of 1.086 considered to be ideal by processors (AAFC 2012). This is important to note for producers as monetary penalty's began at specific gravities of 1.084 and lower, while bonuses exist for producing tubers with specific gravities of 1.086 and higher (Dan Sawatzky, personal communication). The fertigation treatments were the significantly lowest in Carman along with the Untreated Check and Urea Broadcast. The fertigation treatments appeared to behave like a treatment with a higher rate of N, than the other treatments, as specific gravities tend to either have no change, or tend to decrease with increasing nitrogen rates (Painter and Augustin 1976, Westermann and Kleinkopf 1985, Lauer 1986, Porter and Sisson 1991, Joern and Vitosh 1995, Belanger et al. 2002, Laboski and Kelling 2007). However, the Untreated Check had no N applied but still a lower specific gravity which disagrees with the previous author's findings. At both sites, the Urea and Super-U split applications were never significantly different, neither were the full application at plant treatments of broadcasted Urea, ESN, and 50%ESN:Urea. This agrees with the findings by Zebarth et al. (2004) and Wilson et al. (2009) who stated that specific gravity was found to be significantly unaffected by application timing when the same total N rate was applied.

Ojala et al (1990) found that as nitrogen levels increased the tuber specific gravity decreased. This study maintained the same rate, but at Carman the fertigation treatments had the significantly lowest specific gravities. This may be an indication that the delayed application can behave similar to a higher N rate with respect to specific gravity. Specific gravity was found to be significantly unaffected by timing when the same total N rate was applied (Zebarth et al. 2004, Wilson et al. 2009). This study had similar findings, with treatments which had similar N availabilities not having significant differences between them.

2.5.4 *Variation between Site and Year*

2.5.4.1 Small sized tubers had a significant Site x Year interaction (P= 0.0018). This indicates that there was no treatment effect on small sized tubers. Small sized tubers yielded the significantly highest at Carman in 2014, while Carberry in 2014 produced the significantly lowest small sized tuber yields. Carberry in 2013 was not significantly different from Carman in 2013 or 2014.

2.5.4.2 Soil residual NO_3^- after harvest had only a significant Site x Year interaction (P= <.0001). This indicates that the treatment had no effect on the amount of NO_3^- left in the top 60 cms of soil after harvest. Soil residual NO_3^- was highest at Carberry in 2013, but not significantly different from Carman in 2014. Carberry in 2014, was not significantly different from Carman in 2013, thou these were both significantly lower than the highest soil NO_3^- values. resulting in less remaining in the soil post-harvest. Belanger et al. (2003) found fall soil NO_3^--N residual levels increased as the rate of nitrogen application also increased. However, in this study all treatments received the same amount of nitrogen over the growing season. This may be why a treatment effect did not occur. The authors stated that $\leq$70 kg NO_3^--N ha^{-1} is an acceptable level at postharvest for the 0-90 cm depth. The values from this study fall well beneath for the 0-60 cm depth which may be an indication that over application of nitrogen did not occur.

2.5.4.3 Soil NO_3^- values prior to fertigation was not found to be significantly different for Carman in 2013, and Carberry in 2013 or 2014. Carman in 2014, was significantly higher than the other three site years. This may have been caused by the upward water pressure caused by the irrigation dug out which this trial was situated close to. This upward pressure may have slowed the rate and which N would have been lost from the soil.

2.5.5 *Treatment Variation by Site and Year*

2.5.5.1 Marketable yield observed a nitrogen treatment response, with the Untreated Check yielding the significantly lowest over both sites and years. In 2013, at Carman the ESN and Fertigation A treatments yielded the significantly highest marketable yields at 48 615 and 48 304 kg ha^{-1}. This was significantly higher than the Untreated Check, Super-U Split Broadcast and Fertigation C. At Carberry in 2013, ESN and Fertigation A and C treatments were significantly highest yielding treatments, higher than the Untreated Check, Urea Split Broadcast, and 50%ESN:Urea. However, in 2014 at Carman, the Urea Split Banded and Broadcast produced the significantly highest yielding treatments, higher than the Untreated Check and the 50%ESN:Urea. The Urea Split Broadcast, Urea Split Banded, and Super-U split Broadcast produced the significantly highest yields at the Carberry site in 2014.

When a wet spring is experienced such as in 2013 at both sites, significant increase in marketable yield with the controlled release N and numerical increases with Fertigation A, B, and C, over all other treatments except for the broadcasted Urea was observed. The broadcasted Urea being numerically higher than Fertigation C in 2013 was unexpected. The heavy precipitation events experienced after planting would have been expected to effect the broadcasted Urea treatment the most as it had the full application of nitrogen prior to planting. Yields from both sites in 2014 indicate that in a dryer spring, the effects of either broadcasting (with incorporation) or banding of Urea or Super-U to be just as effective, or in the care of the Urea Split Incorporated, to be significantly higher than controlled release nitrogen or delayed nitrogen applications. The little variation between the broadcast and banding of nitrogen disagrees with results found by Painter and Augustin (1976), who found banding of ammonium sulfate to have a negative effect on yield and quality. However, this lack of variation is supported by Timm et al. (1983) who, over a three year study, found banding fertilizer to produce higher total and No. 1 potatoes in the first year of study. While in the second year there were no significant differences with regard to total yield, but broadcasting producing higher yields of No. 1 potatoes. In the third year of study, no significant yields differences were observed between the broadcasting or banding treatments (Timm et al. 1983). Dicyamide (DCD) was found by Kelling et al. (2011) to cause reductions in the yield of U.S. No. 1 tubers, although not significantly. Results similar to this were not witnessed in this trial when comparing Super-U to other nitrogen sources. The authors attributed this to the DCD being used with all ammonium or ammonium-forming N sources. Results from 2014 disagree with the findings of Joern and Vitosh (1995), who found that four applications of an aqueous solution of ammonium sulfate to be an ineffective N fertilization technique, when compared to the other techniques studied.

In 2013 across both sites, ESN had the significantly highest marketable yield of 50,249, while in 2014 the Urea Split Banded resulted in the significantly highest marketable yield of 48,572 kg ha^{-1}. The yield results from the urea treatments and ESN have a similar trend with those found by Zvomuya et al. (2003) who tested a 70-day release polyolefin-coated urea. In both studies, the controlled release products tended to have higher marketable and total yields then urea. However, this is not always the case, and the differences are not always significant (Wilson et al. 2009). No additional yield benefit was noticed from a longer delay of nitrogen application. No benefit was also found from applying a blend of 50%ESN:Urea at planting.

Larger percentages applied at planting in split application treatments was found to increase yields over applying small amounts at planting and a larger percentage over the growing season (Zebarth et al. 2004, Love et al. 2005). These results may help explain why Fertigation B was the significantly lowest yielding fertigation treatment at Carberry in 2014, and numerically lower then Fertigation A at Carman and Carberry in 2013 and 2014, and Fertigation C at Carberry in 2013 and Carman in 2014. Fertigation B only had 40% of the recommended rate applied at planting with 60% coming through fertigation, while the other two fertigation (Fertigation A and C) received 60% at planting and 40% through fertigation. However, smaller amounts of N fertilizer applied at planting, was found by Errebhi et al. (1998) to improve marketable yield.

Yield increases for the nitrogen treatments ranged in 2013 at Carman 54% to a high of 75% for the Super-U Split Incorporated and ESN respectively over the Untreated Check. At Carberry in 2013, the yield increases over the Untreated Check were lowest at 8% for the Urea Split Broadcasted and highest at 21% for ESN, Fertigation A and C. At both sites in 2013, ESN yield 8% higher that the Urea Broadcast treatment, while in 2014, ESN yielded 9% lower at Carman, but 28% higher at Carberry than the Urea Broadcast. This increase in 2013, was not as high as the 12% increase found by Ziadi et al. (2011) when ESN was compared to calcium ammonium nitrate, while in 2014 the increases were not as consistent as 2013. For both total and marketable yield, the results from this study differ from those found by Wilson et al. (2009), who did not find significant differences between different N sources at similar rates.

2.5.5.2 Undersized tuber yields are more beneficial when found to be significantly lower than higher, as these tubers are not used by processers. In 2013, at Carman the Untreated Check produced the significantly highest yields of undersized tubers at 4 964 kg ha^{-1}, while in the same year at Carberry, the Super-U Split Incorporated produced the significantly highest undersized tuber yields at 4 469 kg ha^{-1}. In 2013, the 50%ESN:Urea produced the significantly lowest yield at Carman, while Fertigation B yielded the significantly lowest at Carberry in the same year. However, in 2014 at Carman, the Urea Split Incorporated and at Carberry the Untreated Check yielded the significantly highest amount of undersized tubers. The results from Carman and Carberry in 2013, and Carberry in 2014 agree with the findings of Belanger et al. (2002) who found average fresh tuber weight to increase with application of nitrogen, only at Carman in 2014 did the nitrogen treatments tend to yield more undersize tubers than the Untreated Check. Painter and Augustin (1976) also found tuber yield and size to increase with nitrogen application. The Untreated Check had no nitrogen applied therefore would be expected to have the least amount of tuber bulking, resulting in the highest amount of under sized tubers. The Untreated Check has the significantly highest undersized tuber yield at Carman in 2013, and Carberry in 2014, while it was numerically higher than some treatments at Carberry in 2013 and Carman in 2014. These results are to be expected as the addition of N has been shown to increase tuber yield and size (Painter and Augustin 1976, Westermann and Kleinkopf 1985, Belanger et al. 2002).

2.5.5.3 Medium tuber yields in 2013 were significantly highest at Carman under the Urea Split Incorporated treatment at 48 474 kg ha^{-1}, which was significantly higher than the Untreated Check, and the Super-U Split Banded which yielded 9 832 and 23 517 kg ha^{-1} respectively. While at Carberry Fertigation C was the significantly highest yielding treatment at 30 154 kg ha^{-1}, significantly higher than the Untreated Check, Broadcasted Urea, Urea Split Incorporated, and the 50%ESN:Urea. At Carman in 2014, the Untreated Check was significantly lower than all of the nitrogen treatments, which were not significantly different. In 2014, at Carberry, the two Urea Splits produced the significantly highest medium tuber yields at 24 105 and 23 419 kg ha^{-1} for the incorporated and banded treatments respectively. Over both sites and years, the Untreated Check produced the significantly lowest medium tuber yield. This is expected as tuber size has been found to increase with nitrogen application (Painter and Augustin 1976, Belanger et al. 2002). The controlled and delayed nitrogen applications treatments tended to result in numerically higher yields in 2013 over both sites. However, over both sites in 2014, the split applications tended to have numerically higher yields. Over both sites and year thou these differences were not always significant.

2.5.5.4 Small sized tuber yield as a percent of marketable yield was significantly highest at Carman over both years for the untreated check. Unlike medium and bonus sized tubers, the percentage of small sized tubers does not have a bonus or dockage associated with them. Little significant variation was seen between the treatments over both years at the Carman site, with the Untreated Check being the significantly highest and no differences between all other treatments. While at Carberry in 2013, there was no significant difference between the treatments. However, in 2014, the Untreated Check yielded the significantly highest, while both Urea and Super-U splits, ESN and Fertigation C being the significant lowest. The Untreated Check yielding the highest at three of four site years is not surprising, as tuber weight and size has been found to increase with nitrogen application (Painter and Augustin 1976, Westermann and Kleinkopf 1985, Belanger et al. 2002).

2.5.5.5 Medium sized tubers are a percent of marketable yield is an important factor for producers as it comes with bonus incentives from processors. The target is to have yields with greater than 45% of tubers in the 170-340 g range. With 45% or higher tuber yield in the 170-340 g range results in a financial bonus for producers.

Over both sites and years the Untreated Check was the only treatment which resulted in medium tuber yield percentage under 45%, this occurred at Carman in 2013, and Carman and Carberry in 2014. As Carman in 2013 the Urea Split Incorporated produced the significantly highest percentage of medium sized tubers based on marketable yield at

60%. This was only significantly higher than the Untreated Check, and Fertigation A. At Carberry in 2013, the Super-U Split Banded produced the significantly highest percent of medium tubers as a percent of its marketable yield at 60%. This was significantly higher than the Untreated Check, ESN, and 50%ESN:Urea. At Carberry in 2014, the Urea Split Incorporated and the 50%ESN:Urea treatments resulted in the significantly higher percentage of medium sized tubers based on their marketable yield.

At the Carman site in 2014, Broadcast Urea, both Urea Splits, Super-U Split Incorporated, and ESN all produced the significantly highest percentage of medium sized tubers based on their marketable yield at 51, 52, 51, 52 and 52% respectively. These however were only significantly different from the Untreated Check.

2.5.5.6 Hollow heart incidence was not significantly different for any treatments at Carman in 2013, but the Super-U Split Banded resulted in the numerically highest incidence. However, at Carberry in 2013, the Untreated Check produced the significantly highest incidence was 26%, this was significantly higher than all treatments except the Urea Broadcast. The other N treatments at Carberry were not significantly different from each other. The Carman site had similar results in 2014, with there being no significant differences between treatments, with ESN producing the numerically lowest at 5% and the Super-U Split Banded and Fertigation B being the numerically highest at 18%. However, at Carberry in 2014 the Super-U Split Incorporated produced the significantly highest level of incidence at 50%. This was not significantly different from the Urea Split Banded, both Super-U split, ESN, 50%ESN:Urea, and Fertigation C. Results from the Carman site in 2013 and 2014, and Carberry in 2013, in which the application of nitrogen did not result in significant differences, agree with the results found by Silva et al. (1991), but disagrees with Wilson et al. (2009) who found nitrogen application to significantly increase hollow heart incidence. The results found in 2014 at Carberry tend to agree more with Wilson et al. (2009) as the nitrogen treatments except for Fertigation B had numerically and significant higher levels of incidence than the Untreated Check. The higher levels of incidence at Carberry in 2014, may be related to the seed rot which was experienced there, as the tubers which did emerge would have more space in the hill for growth. Reducing the seed spacing has been found to be an effective control in reducing hollow heart, which supports the possibility that increased spacing in Carberry may be responsible for increased hollow heart incidence (Nelson 1970, Nelson et al. 1979, Rex and Mazza 1989). The higher rates of total precipitation at Carberry in 2013 and 2014 may also have increased the incidence of hollow heart as excess irrigation during August and September was found by Silva et al. (1991) to increase hollow heart incidence.

2.5.5.7 Petiole sampling occurred prior to the beginning of the fertigations treatments, sampling then occurred after the completion of the fertigation treatments. In 2013 at Carman, the Urea Split Banded had the significantly highest prior to fertigation petiole-nitrate value at 21 989 ppm. The lowest values at this site during this year occurred for the Untreated Check, while the three fertigation treatments were significantly lower than the other seven N treatments. Similar results were observed for the Carberry site in 2013, with the Untreated Check again being the significantly lowest treatment, and the fertigation treatments being numerically lower than other N treatments, and in some cases this difference was significant. The Urea Split Banded and Super-U split Banded both had numerically higher petiole-N values than the same split which was incorporated. These differences however were not significant. The ESN treatment was significantly lower than the highest petiole-N value at Carman in 2013, while at Carberry this difference was not significant. For both sites in 2013, Fertigation B was lower than Fertigation A and C at the initial smapling, prior to fertigation beginning. This can be explained by that treatment only receiving 40% of its N application at planting, while Fertigation A and C both received 60%.

Post fertigation petiole-N values at Carman in 2013 were highest under the Super-U Banded treatment. However, this was only significantly higher than the Untreated Check, Urea Broadcast, Urea Split Incorporated, and ESN. At Carberry in 2013, the Urea Split Incorporated produced the significantly highest petiole-N value, this was only significantly higher than the Untreated Check and Fertigation C. After fertigation was completed, we see much less significant differences between petiole-N values. At both sites, and sampling period in 2013, the Untreated Check was the significantly lowest petiole-N value. Post fertigation at both Carman and Carberry in 2013, resulted in the Fertigation treatment no longer being the significantly lower than the highest petiole-N treatment, except for Fertigation C at Carberry in 2013.

Prior to the start of fertigation in 2014 at Carman and Carberry the Super-U Split Banded had the significantly highest petiole-N value. At Carman, this value was significantly higher than the Untreated Check, Urea Broadcast, ESN, 50%ESN:Urea and the three fertigation treatments. While at Carberry it was significantly higher than Untreated Check, Urea Broadcast, Urea Split Incorporated, 50%ESN:Urea and the three fertigation treatments. At both sites prior to fertigation, the Untreated Check had the significantly lowest petiole-N value. At Carman however, this value was not significantly different than Fertigation B and C. Post fertigation at Carman in 2014 showed no significant differences between all treatments. While at Carberry, Fertigation B had the significantly highest petiole-N value, this was not significantly different than the Super-U Split Banded thou. All other treatments at Carberry in 2014 were not significantly different.

At both Carman and Carberry in 2013 and 2014 the Untreated Check was either significantly or numerically the lowest treatment, except for the post fertigation sampling at Carman in 2014. In 2014, the Urea and Super-U Split Banded treatments were higher than the incorporated treatments, except for the Super-U treatments at Carman. These differences were not always significant. The ESN treatment at Carman in 2014 was significantly lower than the highest petiole-N treatment, while at Carberry it was not. This lack of significant difference at Carberry over both years may be due to the higher level of precipitation which occurred there. This added moisture may have increased the amount of N which exited the ESN granule earlier in the season. Over both sites and years the fertigation treatments were always significantly lower prior to fertigation, which were expected as these treatments had only received 40-60% of their N application. After the finals 40-60% of N was applied these treatments were no longer significantly different from the higher petiole-N treatment at Carman in 2013 and 2014. While at

Carberry in 2013, only Fertigation C was lower, and in 2014 Fertigation A and C were lower.

2.5.5.8 Soil NO_3^- following the end of the fertigation treatment was significantly highest at Carman and Carberry in 2013 under the Urea Broadcast treatment at 25 and 29 kg ha^{-1}. This was only significantly higher than the Untreated Check, both Urea splits, and ESN at Carman which has post fertigation soil NO_3^- values of 12, 17, 18, and 18 kg ha^{-1} respectively.. However, at Carberry this was significantly higher than the Untreated Check and the Urea Split Banded, which had 20 kg ha^{-1} for both treatments.

In 2014, ESN produced had the highest soil NO_3^- at Carman with a value of 42 kg ha^{-1}, while at Carberry it was the Super-U Split Banded with a value of 30 kg ha^{-1}. At Carman ESN was significantly higher than the Urea Broadcast and Super-U Split Banded. While the Super-U Split Banded was significantly higher than all other treatments at Carberry. The soil NO_3^- values at Carman in 2014 tended to be higher than values observed at any other site year. This may have been caused by the proximity of this trial to an irrigation dug out. This dug out caused upward water pressure which may have slowed the N losses at this site, resulting in higher soil NO_3^- values.

There was no consistent pattern between the broadcast and banded Urea and Super-U treatments, this may indicate that neither source or placement were having an effect on soil NO_3^- post fertigation. The fertigation treatments were never consistently significantly lower or higher than the split applications. This indicates no significant positive or negative effect from delaying the N applications through fertigation.

2.6 Conclusion

Yield results varied by treatment from year to year and site to site, with there being a significant (P=0.001) Trt x Site x Year effect for marketable yield. For marketable yield, ESN, Urea Split Banded, and Super-U Split Banded were the only treatments which did not statistically vary from the highest yielding treatment for all years and sites. This may indicate a benefit from the polymer coating controlling the release of N from the ESN, but also a timing and placement benefit from the split applications of banded Urea and Super-U. The ESN treatment received the full rate of N at planting; this is of added convenience to the producer due to not having to worry about reapplying at hilling or through fertigation. In 2013, where Carman experienced a large amount of precipitation shortly after planting, ESN yielded the highest, this may indicate that the controlled release properties of that nitrogen source were effective, while the other non-controlled sources may have been more susceptible to losses.

Both of the banded treatments (Urea and Super-U) were splits with banding at plant followed by a second application at hilling. These treatments resulted in higher yields when rainfall amounts were lower following planting. Banding fertilizer at planting may require modification of equipment if not already designed for that method of N fertilizer application. Applying fertilizer at planting requires less pre-plant field work, in wet years this may be an additional benefit to the producer, reducing the amount of field work and time spent on the field. Due to Super-U being urea based N stabilized with inhibitor products, it did not demonstrate a yield benefit to justify the increase in cost over regular urea based on the same application techniques.

The simulated fertigation did not show an added benefit to delaying the applications of N later in the season. This is of importance as it requires additional equipment specialized for this application method, which based on the results found in this study, this additional equipment and applications did not produce significant yield gains.

ESN and the fertigation treatments may offer protection during wet springs as they yielded numerically higher at Carman in 2013 when this was experienced. These methods may come at an increased cost over regular Urea Splits, but may offer more consistent yields when heavy precipitation events are experienced following planting.

The tuber sizing as a percentage of the marketable yield is an important factor for consideration. Of the highest marketable yield treating (Urea and Super-U splits, and ESN), ESN was the only treatment to be significantly lower from the highest medium tuber percentage, in 2013 which occurred at Carberry. While in 2014, this occurred for the Super-U Split Banded. In both cases thou the percentage of medium tuber yield was still higher enough to result in an additional financial bonus for producers. When looking at the bonus tuber yield of these treatments, at the Carman site they did not produce a higher enough percent of bonus tuber yield to result in a financial penalty. However, at Carberry those five treatments all produced bonus tuber yield which would have resulted in financial penalties. In general thou the benefit from the higher medium tuber yield would be able to balance out the penalty from the higher bonus yields.

The results from this study tend to agree with those of Belanger et al. (2000) who stated that "Our results indicate that the response to two of the most significant factors of potato production, irrigation and N fertilization, varies greatly with sites and climatic conditions, and that field specific recommendations are required for the optimum management of N and irrigation".

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3. OVERALL SYNTHESIS

3.1 Introduction

Potato as an agricultural crop, is one of the most important in Canada (Agriculture and Agri-Food Canada (AAFC) 2014). Nitrogen can be a yield and quality limiting nutrient during the growing season (Zebarth et al. 2009, Davis et al. 2014). In season plant analysis can be conducted to help evaluate the success of pre and post plant fertilizer application. It may also be used to help assess the nutritional levels of crop during the season. Soil sampling during the season can be used to help evaluate the level of nutrients currently available in the soil. Plant and soil sampling can both be used to assess further nutrient requirements during the growing season (Westermann et al. 1994). Potato petiole sampling can be used to help gauge crop nutrient status. Peak nutrient levels in the vegetation typically occur during tuber initiation (growth stage III). Sampling prior to this stage can be done to indicate if further nutrients are required (Westermann 1993).

Nitrogen management is of both environmental and economic importance (Errebhi et al. 1998). The practice of applying nitrogen fertilizer as split applications is regarded as the most efficient practice (Westermann 1993). Increasing the rate of N applied at planting has been found to result in increased N uptake, decrease NO_3^- losses to leaching as well as improve marketable yield (Errebhi et al. 1998). Soil and plant sampling during the growing season will allow producers to modify future application rates based on in field measurements.

3.2 In Season Nitrogen Measurements

3.2.1 *Petiole*

Potato petiole sampling is a technique commonly used to gauge potato N adequacy (Ziadi et al. 2012). Petiole samples were collected and the beginning and end of fertigation applications (Table 5-1), with responses to nitrogen application being seen. Petiole NO_3^- -N (ppm) levels, prior to fertigation were significantly in Carberry (19 145 ppm) greater than at Carman (10 185 ppm); and for 2013 (18 431 ppm) compared to 2014 (10 900 ppm) (Table 5-1). Nitrogen treatments had higher values at pre-fertigation sampling than at post fertigation three out of four site years; the one exception was the Untreated Check at Carman in 2014. These results agree with findings from MacKerron et al. 1995, Love et al. 2005, and Wilson et al. 2009. Significant differences were found between the treatments, those which had received the full rate of N earlier in the growing season (Urea Broadcast, both Urea and Super-U splits, ESN, and the 50%ESN:Urea) being higher than Fertigation A, B, C which had only received 40-60% of N by the sampling time. Following fertigation applications, petiole values were numerically lower with less significant variation between them.

The pre-fertigation petiole levels at Carman, were 4,401 ppm significantly lower for ESN than the highest petiole-N values, which were found for the Urea Split Banded in 2013. In 2014 at Carman, ESN was 5,890 ppm significantly lower than the highest ppm of 11,159 found for the Super-U Split Banded. The observed variation was gone after the fertigation period though, this could be due to the controlled release properties of ESN, and all of the nitrogen not having been release at the pre-fertigation sampling. This may also indicate that the Urea and Super-U treatments are more quickly available for uptake by plants than the ESN treatment. Post-fertigation petiole-N levels in 2013 at Carman, were significantly highest in the Super-U Split Banded at 2 544 ppm, this was significantly higher than the Untreated Check, Urea Broadcast, Urea Split Incorporated, and ESN with values of 99, 907, 937, and 757 ppm, respectively. For the same location in 2014, there were no significant differences found between the treatments.

The treatments which had higher average petiole-N values such as Super-U Split Banded, also tended to have higher NUE values. However, this does not seem to be the case for Fertigation A. This could be due to missing the maximum value of petiole-N in that fertigation treatment due to only sampling before and following fertigation. This theory is supported by Porter and Sisson (1993) who found petiole-N values to increase immediately following side-dressed applications of nitrogen. Looking at the model effects in Table 5-3 for pre-fertigation sampling we see a significant (P=0.0003) Trt x Site x Year interaction effect on the model.

Petiole concentrations can be affected by a variety of factors including, days after planting, development stage of the plant, potato cultivar, water availability and the application of nitrogen fertilizer (Ziadi et al. 2012). Utilizing petiole nitrogen analysis as a potential yield predictor could lead to misinterpretations without extensive, continuous and consistent sampling. Over applications of nitrogen may lead to increasing levels of petiole-N above the rate needed for maximum yield (Ziadi et al. 2012). This can lead to increased cost, nitrogen losses, and possible environmental damage. From this study significant differences which occurred in the petiole analysis did not always translate to similar significant differences in total or marketable yield.

3.2.2 *Soil*

Soil tests are typically used to estimate the soil nitrogen supply, which is then used for computing or altering crop nitrogen fertilizer rate (Ziadi et al. 2012). These same tests can be completed during the growing season as a tool to gauge crop N supply. These tests do not assess the nitrogen demand of the crop, or how much nitrogen may be mineralized or immobilized over the remainder of the growing season (Ziadi et al. 2012).

In season soil testing was completed at the same time as petiole sampling. Samples were taken from 0-15 and 15- 60 cm for analysis at the University of Manitoba Soil Ecology lab. The soil sample results from 2013 (Table 5-5), indicate similar results to that found from petiole-N results. Prior to fertigation occurring, the three fertigation treatments had significantly lower soil-N levels than the other treatments except for the Untreated Check. As was stated with respect to petiole analysis, significant differences which occur between treatments with respect to soil NO_3^- do not translate to significant differences in yields. Post fertigation soil sampling resulted in fewer significant differences at both sites and years.

Due to potato being grown in hills, it can make in season soil sampling difficult and the results can be misleading depending on the fertilizer techniques used. If a nitrogen band is heavily sampled in a field setting it could give results which tend to be higher due to the sampling of the nitrogen band. While under a broadcast and incorporated system, one would expect to have lower soil nitrogen values due to the fertilizer being mixed throughout the whole field, and not just the hill to which the tubers were planted.

3.2.3 *Plant Root Simulator™ (PRS) Probes*

The full report from an experiment using PRS probes can be found in Appendix II. The three above techniques allow for in-season measurements of; plant-N levels, or soil-N levels, or potential amount of nitrogen that can be absorbed by the roots from the soil. This can allow the producer to get in-season measurements, in some cases the next day. These tools can prove themselves valuable should the field or region experience heavy or continuous rainfall over a period of time and the producer is worried about potential losses. Implementing some of these techniques allows them to get a feeling of how much nitrogen they may need to apply in split applications to help the crop through the remainder of the growing season.

3.3 Practical and Economic Considerations

Split applications of nitrogen fertilizer are a recommended practice, with the ability to decrease losses and improve yields with splits that have less nitrogen being applied at planting and more in a following side-dressed or fertigation application (Westermann 1993; Errebhi 1998). The initial application of these fertilizers can occur prior to, or at the same time as planting. Broadcasted N fertilizer must be incorporated into the soil to reduce the risk of volatilization or denitrification losses. Broadcasted N fertilizer prior to planting removes the need for equipment designed for N application at planting, also allowing more management and focus to the planting process as a whole (Westermann 1993). The remaining N fertilizer is typically applied as a side-dress at hilling, or as several smaller amounts applied as fertigation (Westermann 1993). The latter of these requires additional equipment for injection into the irrigation water, as well as man-power and time for monitoring of this equipment.

In Manitoba, the price point for different N fertilizers varies throughout the year. In the spring of 2015 prices were $1.40, 1.39 and 1.81 per kg of N for UAN, urea, and ESN (Munro Farms Supplies, personal communication). Super-U has an additional cost of $0.35-0.37 per kg of N, added on top of the cost of urea (Koch Fertilizer Canada, personal communication). This would bring the total cost of Super-U to $1.74 - 1.76 per kg of N. Using ESN or Super-U as a nitrogen fertilizer would have an additional cost of $0.42 and $0.36 per kg of N over the price of urea, while the use of UAN results in a $0.01 increase in cost per kg of N.

The increased marketable yield benefit of Urea Split applications over the full broadcasted Urea was found to be significant only at Carberry in 2014, while the other sites and years were not significantly different. However, overall the Urea Split Incorporated averaged 1 648 kg ha^{-1} more yield over the broadcasted Urea, and the Urea Split Banded yielded 1 967 ka ha^{-1} more. This increase in marketable yield when considered for a commercial potato operation would be of benefit even if not statistically different. A significant difference only occurred at Carberry in 2014 for the percentage of medium tubers based on marketable yield with the broadcasted Urea being significantly lower than the splits. The Urea Split Incorporated was generally numerically higher than the banded treatment with regard to medium tuber yield percent, while also tending to produce less bonus tubers. This indicates a potential for an increased financial bonus to producers with a lower risk of penalties.

When considering the $0.36 per kg of N increased cost of Super-U over regular urea, Super-U did not demonstrate in this study to be advantageous. Only the Super-U Split Incorporated was found to be significantly different than the full rate of broadcasted Urea, at Carberry in 2014. All other sites and years did not see significant differences between the broadcasted Urea and the Super-U splits. Broadcasted Super-U Split Incorporated and Super-U Split Banded averaged over both sites and years, had marketable yield increases of 1 624 and 840 kg ha^{-1} over the broadcasted Urea, these increases are not higher than either of the Urea Splits, which indicates no yield benefit or economic benefit to the use of Super-U. The Super-U Split was not significantly different from the Urea Splits with regard to the percentage of medium tuber or bonus tuber yield. While at both sites, Super-U did produce a numerically higher bonus tuber yield. This could result in increased penalties due to the use of Super-U fertilizer over Urea.

Environmentally Smart Nitrogen broadcasted at planting resulted in significantly higher yields at Carberry in 2014 over the broadcasted Urea, with no other significant differences being observed. The use of ESN resulted in overall yield increases of 1 949 kg ha^{-1} over the broadcasted Urea. This is just slightly less than the overall increase of 1 967 kg ha^{-1} seen with the Urea Split Banded. This indicates there may be an economic benefit to using ESN broadcasted at planting, when compared to just broadcasting Urea at planting. However, it does not show an increase higher than the Urea Split Banded therefore it may not be a smart economic decision verses the Urea Split Banded, as ESN has an increased cost of $0.42 per kg of N over regular urea. The use of ESN at planting may be a smarter choice in wet spring years. The controlled release ability of this product may provide protection to the encased urea during heavy rains early in the growth stages (I and II) when nitrogen is in lower demand by the crop. Regular broadcasted Urea has no protection and is at risk of environmental losses during those periods. The ESN was not significantly different from the Urea Splits with regard to the percentage of medium tuber or bonus tuber yield. While at both sites ESN did produce a numerically higher bonus tuber yield. This could result in increased penalties due to the use of ESN fertilizer over Urea.

The use of an 50%ESN:Urea applied as a full rate at planting did not show any benefit. It resulted in 1 385 kg ha^{-1} less yield than the broadcasted Urea. This treatment would also have the added cost of ESN, but did not show any benefit. The 50%ESN:Urea was not significantly different from the Urea Splits with regard to the percentage of medium tuber yield. While at Carman, the 50%ESN:Urea did produce a significantly higher bonus tuber yield, however at Carberry this different was not significant, and the 50%ESN:Urea was lower than the Urea splits. At both locations however, the 50%ESN:Urea bonus tuber yield was under the percentage which will cause a financial penalty to be applied.

The use of fertigation was only overall significantly higher than the 50%ESN:Urea. Fertigation B had an additional application of fertigation and a smaller amount of urea applied at planting, it tended to yield the lowest of the three fertigation treatments. Fertigation A and C resulted in average marketable yield increase over the Urea Broadcast at plant of 1 380 and 400 kg ha^{-1}, while Fertigation B resulted in a decrease of 644 kg ha^{-1}. The use of fertigation offers the producers the advantage of being able to adjust nitrogen application rates during the growing season. It also adds the increased cost of equipment for injecting the UAN into the irrigation, and also potential for increased cost of staff to manage such equipment. The fertigation treatments were never significantly different between the percentage of medium or bonus tubers yielded. However, in 2013 at Carman, Fertigation A yielded significantly lower percentage of medium tubers than the significantly highest Urea Split Incorporated. Fertigation A and B produced a percentage of bonus tubers at Carman which have resulted in a financial penalty. While at Carberry, the percent of bonus tubers yield were all below the penalty level. Based on the results from this study there was no benefit to the use of fertigation over split applications of urea.

3.4 Grower Recommendations

The added expense of purchasing Super-U fertilizers over urea did not result in significantly increased marketable yields averaged over both 2013, 2014 and the Carberry and Carman sites. The use of Fertigation A or C did not result in significantly higher marketable yields when compared to the Urea Split applications, while Fertigation B yielded overall significantly lower than then Urea Split Banded. Environmentally Smart Nitrogen showed numerically higher marketable yields over the full rate of broadcasted Urea, Urea Split Incorporated, and just slightly below the Urea Split Banded application, these differences were not found to be significant. This indicates that the increased cost of that product may not be a smart economic decision. If heavy rains are expected to following planting there may be a yield benefit from the controlled release ability of ESN over regular urea products, or from the delayed applications associated with fertigation. The environmental benefit from these different N fertilizers sources was not investigated in this study.

3.5 Recommendations for Future Research

This study is currently into its third year with the treatment list remaining the same. This will allow an economic study to be done on benefits of the different products used. With further investigation into how the size portfolio of the treatments results in financial benefit and penalties for the producers. It will also allow more information to be gained on how these treatments continue to perform over varied climatic conditions.

The next step for this project would be to drop treatments which have not shown any increase benefit, specifically the 50%ESN:Urea, as well as Fertigation B. It would be interesting to investigate the benefit of utilizing ESN in a split application program, for example; applying ESN at planting followed with a urea application at hilling. The ESN will give the urea protection from potential heavy moisture events after planting, while also reducing the cost due to not applying the full N rate as the most expensive source, ESN. The urea at hilling would aim to provide a nitrogen boost at the start of tuber initiation (growth stage III), when demands of the crop are at their highest.

Investigation the timing of the fertigation applications may also result in higher yields. Having a range of timings may give an indication of the most accurate time to start fertigation applications, to maximize nitrogen use and yield.

The addition of a 100% N rate would be interesting to investigate as this may give an indication if the current N recommendations are too high. This may open up the opportunities to investigate further N reductions. Also, adding a treatment which simulates the application practices of what producers are currently practicing would allow comparisons to the higher yielding treatments from this study. The use of irrigation early in the growing season could be used to simulate early season N losses.

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4. CONCLUSION

One of the goals for this project was to make sure we were achieving an N response, as well as looking to find response differences within our treatments. This was achieved due to the significantly lower total and marketable yields being found in the Untreated Check over both site years. Over both sites and years, different treatments resulted in higher yields. This indicates that there is more than just a nitrogen source, timing or placement effect present. This is supported by the fact for both total and marketable yield, Trt had a significant (P=<0.0001) effect on the model, as well did the Trt x Year (P=0.0002) and Site x Year interactions (P=<.0001 and P=0.0003). The Trt x Year and Site x Year interaction being significant indicates that more than just the treatment is affecting the model. This extra effect is most likely coming from the weather which each site experiences. Marketable yield had a significant (P=0.0011) three-way Trt x Site x Year interaction.

Weather is the unpredictable and uncontrollable variable which producers have to contend with. The increased use of irrigation gives them the ability to reduce the drought effect during times of limited or no rainfall. However, aside from increasing their fields ability to drain through tile drainage they have no control over when, how much, and how quickly precipitation may fall. This is something producers and agronomist need to consider when making agronomic decisions for fertilizer application.

The controlled and enhanced efficiency products used in this study come at an increased cost when compared to conventional urea, which add another consideration when choosing fertilizer to apply. At different sites and years these products did respond with higher yields than just the conventional urea, the increases though were not always significant. The placement technique of banding vs. broadcast did not show a significant difference when contrasted; this indicates that a significant benefit may not be seen from the banding over broadcasting of fertilizer. Fertigation treatments performed as well as the others or worse, indicating no increased benefit to delaying the split applications and applying them as fertigation later into the growing season.

Based on the results from 2013 and 2014 at both locations of this study, Urea Split Banded, Super-U Split Banded and ESN were the consistently highest marketable yielding treatments. While not always the highest yielding, these three were always in the significantly highest yielding grouping. In 2013, when heavy rainfalls were experienced following planting at Carman and Carberry experienced high total precipitation ESN resulted in 3 746 and 5 065 kg ha^{-1} and 3 403 and 2 223 kg ha^{-1} increases in marketable yield over the Urea Split Banded and Super-U Split Banded at Carman and Carberry respectively. However, in 2014 when precipitation was spread more over the growing season at both locations the Urea Split Banded and Super-U Split Banded applications resulted in marketable yield increases over ESN of 4 974 and 3 315 kg ha^{-1} at Carman. At Carberry, the Urea Split Banded increased marketable yield over ESN by 2 387 kg ha^{-1}, while ESN increased yield by 601 kg ha^{-1} over the Super-U Split Banded. The agronomics of using these products were not explored in this study and are something that must be considered before recommending either Super-U or ESN over regular urea, as the increased cost of these products may not make their use a smart economic decision. Marketable yield differences which occur between the Urea Split Banded, Super-U Split Banded and ESN were never significant and are likely related to the different growing conditions experienced, especially with regard to precipitation amounts and times. This study will be continuing for three more years, this will help increase the amount of data being available, which may lead to a better understanding of which treatments are most effective at increasing yield of irrigated Russet Burbank processing potatoes in Manitoba.

5. APPENDICIES

Appendix I. Report from Plant Root Simulator™ experiment: PRS Probes Compared to Soil Nitrogen Testing based on Marketable Potato Yield in a Nitrogen Management Study

A1-1 Highlights

-Highest averages for total inorganic-N PRS values were in both banding treatments

-Control had the lowest total inorganic-N PRS values on average

-Significant positive correlation between NO_3^- and total inorganic-N between PRS and soil samples at first of two in season sampling times (prior to fertigation)

-Significant positive correlation between PRS probes and marketable yield for NO_3^- and total inorganic-N at first of two in season sampling times (prior to fertigation)

-Significant correlation was also found between soil NO_3^- and total inorganic-N verses yield at the first of two in season sampling times (prior to fertigation)

- PRS probe NO_3^- and total inorganic N seems promising to be an in season evaluator of available N to set fertigation scheduling verses using soil or petiole sampling

A1-2 Introduction

The earth's air is comprised of approximately 78% nitrogen gas as N_2. Nitrogen is very important for many biological functions but it is typically the limiting resource regarding plant growth, it is required by potatoes in sufficient quantities in order to achieve proper yield and quality. Potatoes also require adequate amount of water for proper growth, this water can lead to the nitrogen being carried below the root zone making it in accessible to plants. The leaching of nitrogen can lead to water to environmental issues as well as being a lost input cost to the producer. The amount of nitrogen needed prior to be planting can be estimated through soil testing, the amount that may be lost or made available by the soil to the plant is unknown.

The Guidelines for Estimating Crop Productions Costs 2014 in Western Manitoba, provides estimated costs associated with growing certain crops. Without factoring in soybeans, peas, and lentils, fertilizer is the most expensive crop input for all other crops (Manitoba Agriculture, Food and Rural Developments 2014).

A1-3 Methods

Soil samples were collected from the Nitrogen Management studied located at the CMCDC Carberry, Manitoba offsite location at a depth of 0-30 cm. The samples were collected from 9 different treatments in each of the 4 block trial area, and then taken back to the University of Manitoba for analysis using PRS Probes.

Samples were measured into containers, inserted with two cation and two anion probes, following which they were placed in a germination chamber where they were allowed to sit for two weeks before extraction. Probes where extracted on August 8, 2014, following guidelines provided by Western Ag, after which they were store chilled for shipping. The main interest of this experiment is focusing on the nitrogen uptake by the probes as a result of the different nitrogen treatments applied to the trial area that spring.

The PRS probes after analyzed produce NH_4^+ and NO_3^- soil nutrient supply values, which are combined for a total inorganic-N value, these probes can also test for a range of other soil nutrients. The 9 treatments tested can be seen below in Table A1-1.

Table A1-1. Treatment list and nitrogen application as a percentage of total N applied based on 80% of recommended rate for each treatment

	Treatment	Broadcast @ Plant	Banded @ Plant	Hilling Split (side dress)	Fertigation 1	Fertigation 2	Fertigation 3	Fertigation 4	Total
1	Untreated Check								0
2	Urea	100							100
3	Urea Split - I	40		60					100
4	Urea Split - B		40	60					100
5	Super-U Split - I	40		60					100
6	Super-U Split - B		40	60					100
7	ESN	100							100
8	Fertigation A (28-0-0 diluted 1:10)	60			17	13	10		100
9	Fertigation C (28-0-0 diluted 1:10) (50% ESN)	60			17	13	10		100

I - Broadcast and incorporated

B - Banded

I - Indicates nitrogen fertilizer was surface applied and then incorporated prior to planting

B -Indicates nitrogen fertilizer was applied in a double band at planting

A1-4 Results and Discussions

The nitrogen values (NO_3^-, NH_4^+, total inorganic-N) were graphed against the soil test results for the same sampling period, the resulting graphs can be seen in Fig. A1-1 to A1-3.

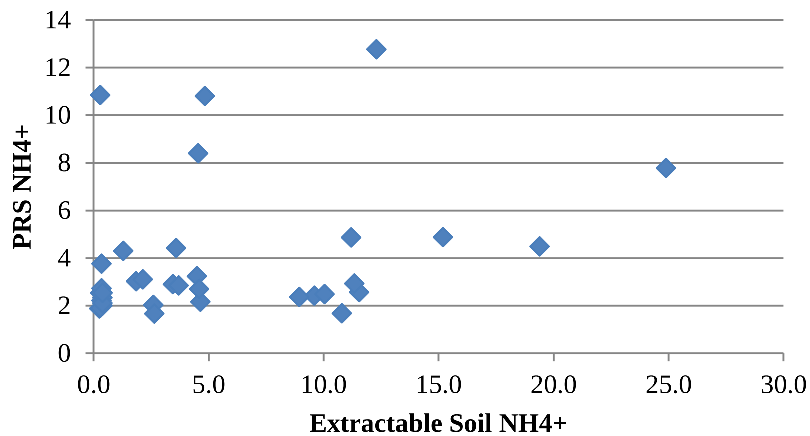


Fig. A1-1. July soil extractable NH_4^+ vs PRS NH_4^+.

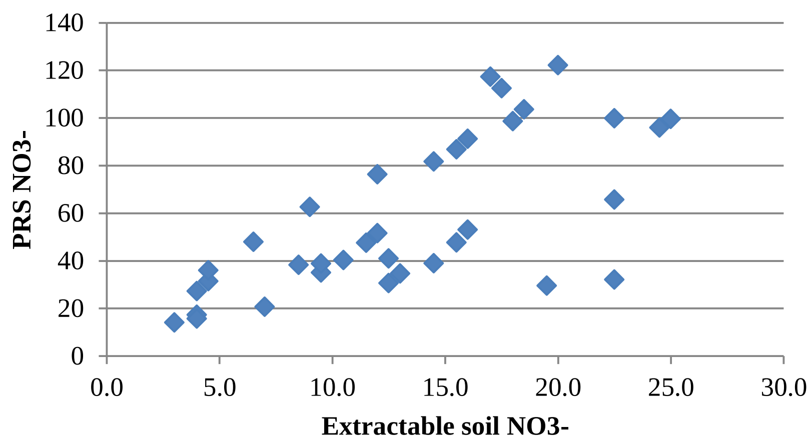


Fig. A1-2. July soil extractable NO_3^- vs PRS NO_3^-.

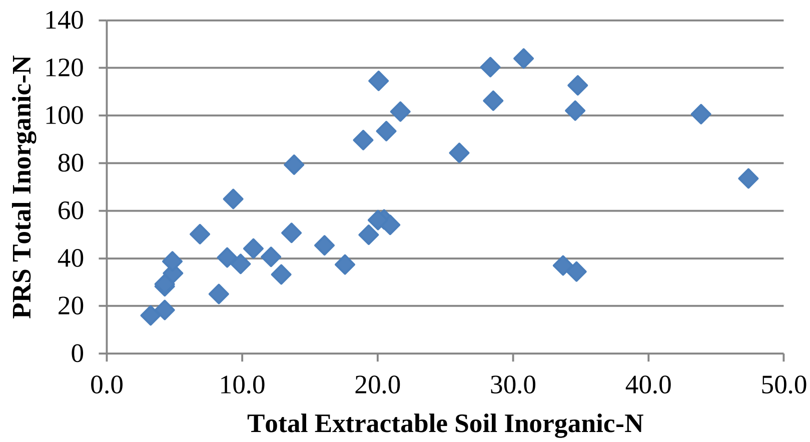
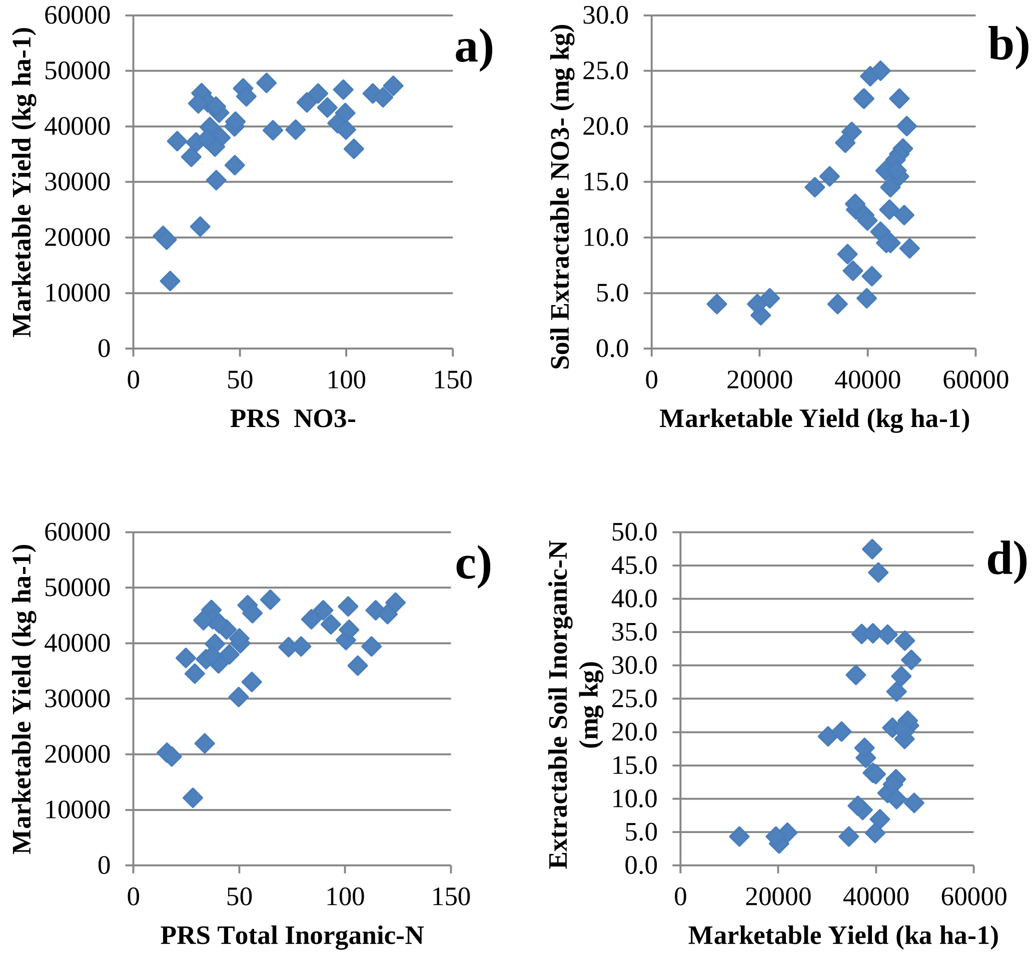


Fig. A1-3. July soil extractable Total Inorganic-N vs PRS Total Inorganic-N.

Looking at the above Fig. A1-3 we see the strongest correlation between the extractable NO_3^- and total inorganic-N values for both the soil and the PRS probes. Extractable NH_4^+ had also had a more positive correlation, just not as tight as the NO_3^- or total inorganic-N.

Pearson correlation analysis was run on the PRS data against soil test results from the same soil, and the marketable yield (ka ha^{-1}) from the 2014 growing season. This resulted in positive and significant correlation from NO_3^- and total inorganic-N for both PRS results and the soil test with respect to yield (Fig. A1-4 to A1-7).



a) **Fig. A1-4** PRS NO_3^- vs Marketable Yield (kg ha^{-1}),
b) **Fig. A1-5** Extractable Soil NO_3^- vs Marketable Yield (kg ha^{-1}),
c) **Fig. A1-6** Extractable Soil Total Inorganic-N vs Marketable Yield (kg ha^{-1}),
d) **Fig. A1-7** PRS Total Inorganic-N vs Marketable Yield (kg ha^{-1})

The positively correlated PRS graphs from above have an interesting trend to them, they seem to plateau instead of continuing to increase. A similar pattern is seen with the soil sample graphs, with yield plateauing over a varied range of nitrogen values. This could be a sign especially for NO_3^- and total inorganic-N that there is a surplus in the soil. This surplus may be used by the plant of the remainder of the growing season. NO_3^- and total inorganic-N results from PRS probes may be able to be used as a method to help producers decide when and how much to fertigate during the growing over using soil or petiole testing. Being able to monitor plant root uptake may lead to being a better indicator of nutrient shortage then the amount of NO_3^- or total inorganic-N in soil or the petiole NO_3^- level.

Comparing the NH_4^+ results to marketable yield did not show significant correlation for the soil test values, but for the PRS values the results were significant, but negatively correlated. This can be seen in Fig. A1-8.

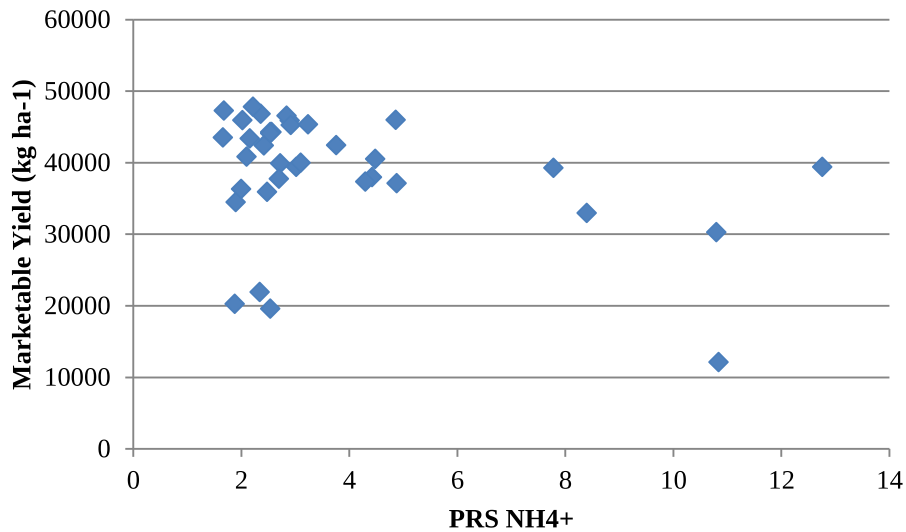


Fig. A1-8. PRS NH_4^+ vs Marketable Yield.

A1-5 Conclusion

PRS probe monitoring is another tool available for researchers and producers alike. Unlike soil testing these probes help indicate how much of each nutrient may be taken up by the plant versus how much is in the soil. Nutrients in the soil especially nitrogen can be tied up in the organic matter and not always available to plants. Use of these probes allows an indication of how much of the different nutrients was available to the plant. Based on the correlation results from this study, NO_3^- and total inorganic-N have a slightly higher correlation with marketable yield then the results from the soil testing. Further testing would be needed at various times in the growing season to confirm the use of PRS probe results being an accurate yield indicator.

Appendix II. Tuber Emergence and Size

Table A2-1. Average tuber size (g)

Treatment	Average Tuber Size (g)									
	2013				2014					
	Carman		Carberry		Carman		Carberry		Mean	
Untreated Check	120	C	156	AB	141	AB	110	E	132	B
Urea	161	AB	164	AB	158	AB	149	DE	158	A
Urea Split - I	166	AB	168	AB	154	AB	180	ABC	167	A
Urea Split - B	155	B	163	AB	151	AB	177	ABC	162	A
Super-U Split - I	157	AB	154	B	147	AB	184	AB	160	A
Super-U Split - B	152	B	169	AB	141	AB	190	A	163	A
ESN	170	AB	164	AB	138	B	193	A	166	A
50% ESN / 50% Urea	178	A	158	AB	141	B	163	BCD	160	A
Fertigation A	165	AB	160	AB	162	A	159	DC	162	A
Fertigation B	168	AB	176	A	153	AB	160	DC	165	A
Fertigation C	158	AB	167	AB	150	AB	176	ABC	163	A
Mean	161				158					

Effect	P-value
Trt	<0.0001
Site	0.0134
Year	0.4183
Trt x Site	0.0161
Trt x Year	0.2427
Site x Year	0.1004
Trt x Site x Year	<0.0001

Table A2-2. Average stand count (plants 12m^{-1})		
Treatment	Average Stand Count (plants 12m^{-1})	
	2013	2014
Carman	28	34
Carberry	32	26

Effect	P-value
Trt	0.0649
Site	0.0062
Year	0.6272
Trt x Site	0.1495
Trt x Year	0.4412
Site x Year	<0.0001
Trt x Site x Year	0.5952

Table A2-3. Average stem counts (stems 12 m^{-1})		
Treatment	Average Stem Counts (stems 12 m^{-1})	
	2013	2014
Carman	74	144
Carberry	155	95

Effect	P-value
Trt	0.0649
Site	0.0062
Year	0.6272
Trt x Site	0.1495
Trt x Year	0.4412
Site x Year	<0.0001
Year x Trt x Site	0.5952