Effects of Seed Piece Spacing, Nitrogen Rate, and Nitrogen Application Timing on Clearwater Russet

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By

Justin L. Hatch

Major Professor: Jeffrey C. Stark, Ph.D.

Committee Members: Stephen L. Love, Ph.D.; Jonathan L. Whitworth, Ph.D.

Department Administrator: Michael K. Thornton, Ph.D.

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Authorization to Submit Thesis

This thesis of Justin L. Hatch, submitted for the degree of Master of Science with a Major in Plant Science and titled "Effects of Seed Piece Spacing, Nitrogen Rate, and Nitrogen Application Timing on Clearwater Russet," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor: ________________________________ Date: _______________
Jeffrey C. Stark, Ph.D.

Committee Members: ________________________________ Date: _______________
Stephen L. Love, Ph.D.

________________________________ Date: _______________
Jonathan L. Whitworth, Ph.D.

Department
Administrator: ________________________________ Date: _______________
Michael K. Thornton, Ph.D.

Abstract

Clearwater Russet, a new potato variety, released by Northwest Potato Variety Development Program, has garnered favor among producers and processing industries. The objectives of this study were to identify the optimum combination of nitrogen (N) fertilizer rate, N application timing, and seed piece spacing to produce maximum economic returns for this variety. Investigated seed piece spacing's were 25 and 33 cm in 91 cm-wide rows, combined with three N rates, 0, 202, and 269 kg N/ha, and two N application timings; consisting of either 2/3 of N applied prior to tuber initiation (early-loaded) and 1/3 after tuber initiation, or 1/3 of N applied prior to tuber initiation and 2/3 after tuber initiation (late-loaded). Post-harvest assessment of treatments included measurements of total yield, U.S. No 1 yield, tuber size distribution, tuber specific gravity (SG), and economic fry returns. Petioles were analyzed to assess effects of N management on plant NO_3 –N levels. In-season whole plant sampling was conducted to identify tuber density (tubers per unit area), plant N accumulation, and DM partitioning. The 25 cm spacing treatment produced higher total yield, and accumulated more DM, and N in tubers than the 33 cm spacing treatment. However, the economic return for the 33 cm spacing treatment was 11% greater than the 25 cm treatment due to greater yields of large (>397 g) tubers and a higher percent of U.S. No. 1's. The 33 cm spacing produced fewer tubers and stems per unit area. Petiole NO_3- N was positively correlated with N rate and timing. Nitrogen applications, especially when applied early, increased yield of large (>397 g) tubers, reduced the yield of small (114-170 g) and undersized tubers (<114 g). High N rates applied early in the season significantly increased vine DM and N accumulation, while reducing tuber DM and N accumulation. The early-loaded 202 kg/ha N treatment produced the highest economic return. Although the early-loaded 269 kg/ha N treatment resulted in a similar economic return. The results of this study indicate that N rates for Clearwater Russet should be about 25% less than recommended N rates used for Russet Burbank, with 2/3rds of N applied prior to tuber initiation. Seed piece spacing of 33 cm, in 91 cm-wide rows should produce higher economic fry returns than narrower spacing, when size incentives are offered for large tubers.

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Dedication

To my wife Caitlin Hatch, my father Lorin Hatch, my mother Bonnie Hatch, and my son Wade Hatch.

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CHAPTER 1: LITERATURE REVIEW

Introduction

Clearwater Russet, a new potato variety, was released from the Northwest Potato Variety Development Program in 2008. This variety has many favorable processing characteristics, including high U.S. No 1 yield, few external defects, low glucose concentrations, resistance to sugar ends and cold sweetening resistance, which enables it to maintain low reducing sugar concentrations and light fry color during extended periods of storage. Its cold sweetening resistance allows it to be stored at a 7.2°C for up to 250 days without the need for reconditioning (Novy et al. 2010). In full-season trials conducted over a three-year period in California, Colorado, Idaho, Oregon, and Washington, Clearwater Russet produced total yields slightly lower than Ranger Russet and Russet Burbank, but averaged 2% and 30% higher U.S. No. 1 yields, respectively, across all states. Average specific gravity (SG) of Clearwater Russet is comparable to Ranger Russet and significantly higher than Russet Burbank. (Novy et al. 2010). Clearwater Russet has caught the attention of representatives in the processing industry, creating higher demand for this new variety. An increased interest in Clearwater Russet necessitates the need for agronomic research to assist growers in maximizing its potential.

Fertility is an agronomic factor that impacts the yield and quality of the potato crop. Nitrogen (N) is one of 16 essential elements that plants need to complete their life cycles (Westermann, 2005; Uchida, 2000). In potato production systems, N is often the most limiting element, and thereby the crop often responds favorably to additions of this element (Harris, 2012). Manipulating N rates and N application timing can influence how the potato plant partitions nutrients and carbohydrates between vegetative growth and tuber growth. Each potato variety has unique growth and nutrient uptake patterns, necessitating that best management practices be developed for each new variety (Love et al., 2005).

There are five main growth stages of potatoes (Dwelle, 2003). First is “Sprout Development”, wherein buds on potato seed pieces produce sprouts that develop sufficiently to emerge from the soil and form the main stems of the plant. During this stage roots also form at the base of developing sprouts. Second is “Vegetative Growth”, wherein plants begin to form leaves and stems. This stage is critical for maximizing tuber production potential because the plants begin to produce carbohydrates through photosynthesis, which are subsequently translocated to young growing plant parts, including leaves and tubers.

Third is “Tuber Initiation” wherein the stolon tips hook and begin to swell to form tubers. At this point the plants begin to partition some of the carbohydrates that are being produced to the tubers. The fourth growth stage is “Tuber Bulking”, wherein the plants send more carbohydrate to the tubers and less to new foliage. This is a critical production stage because sub-optimal conditions at this stage will result in reduced tuber yield and quality. Some of the key factors influencing tuber bulking are: temperature, fertility, seed physiological age, plant spacing, planting date, irrigation, and pest management. The fifth and final stage is tuber “Maturation” during which photosynthesis declines as foliage senesces and dies. Tuber growth during tuber maturation slows due to vine death, but significant amounts of carbohydrate are still remobilized and translocated from the vines to the tubers. Skin of the tubers begins to thicken or “set” (become firmly attached to the underlying tissue) during tuber maturation, and dry matter within the tubers reaches its maximum. (Dwelle, 2003).

Impact of Nitrogen Fertilization on Potato Growth and Development

Vegetative Growth

Various studies have shown that N supply has a large effect on potato leaf area index (leaf area per unit of ground area), with leaf area increasing as N application increases (Harris, 2012). In addition, the application of N often increases the size and number of leaves throughout the season (Hay and Walker, 1989; Jenkins and Mahmood, 2003). Applications of N also stimulate the growth of leaves, stems, and lateral branches for a longer duration of the season (Millard and MacKerron, 1986) by accelerating canopy development and delaying foliage senescence. Reducing N supply has been shown to reduce the extent of branching of vines (Jenkins and Mahmood, 2003).

A proper balance must be maintained between vine and tuber growth for optimal potato yields. As a result, building an oversized canopy is not beneficial, since the plants cannot efficiently utilize the extra leaf area for production of carbohydrate. The leaf area index sufficiency range for maximum yield of potato is typically between 3 and 3.5, and an increase in leaf area index over 4 will usually not lead to increased dry matter production (Hay and walker, 1989). The goal is to provide the crop with the right amount of early season N which will enable it to maximize leaf area early and maintain it during season.

The canopies of early and late-season varieties respond differently to N applications. Early varieties are relatively unaffected by excessive N levels. On the other hand, late-maturing varieties typically respond to large amounts of N by delaying tuber bulking and leaf senescence. Nitrogen application can result in an increase in late-season leaf area of late-maturing varieties (Hay and Walker, 1989), a state that may allow the crop to continue bulking late into the season, as long as suitable growing conditions remain. Late-season bulking could be beneficial or detrimental, depending on the length of the growing season. Areas that experience short growing seasons may not benefit from delayed maturity, or may even cause a loss of yield due to delayed bulking, while areas with a long growing season could benefit from an extended bulking period.

Tuber Initiation

Tuber initiation, the point at which new tubers are formed, is controlled by the balance of gibberillic and absisic acids. Multiple factors influence tuber initiation such as day length, temperature, and N fertilization (Haverkort and Struik, 2015). Although day length and temperature cannot be controlled in commercial production settings, N applications can be used to manipulate tuber initiation. Appropriate N applications allow the plant to initiate tuber growth at the optimal time for maximum production.

Kleinkopf et al. (1981) concluded that plant growth habit (determinate vs. indeterminate, terms that are materially synonymous with early and late maturing) influences nutrient demands, which in turn influences tuber initiation. Tuber initiation and N uptake tend to start earlier for determinate varieties in comparison to indeterminate varieties. Thus early N applications are especially important for determinate varieties. On the other hand, high available N levels should be avoided at planting when indeterminate varieties are grown, which tend to start tuber initiation later than determinate varieties. Adding excess N can delay tuber initiation to a greater degree (7 to 10 days) in indeterminate varieties (Kleinkopf et al., 1981; Kelling et al. 2015). This can be especially detrimental in climates with a short growing season due to the reduced length of the tuber bulking period. As a general guideline, research suggests pre-plant applications of N for indeterminate potato varieties should be between 70 to 110 kg per ha (Kelling et al. 2015).

Tuber Bulking

Ensuring adequate available soil N is extremely important during tuber bulking (Alva, 2004). Just as excessive N applications can delay tuber initiation, they can also delay tuber bulking (Hay and Walker, 1989). Increased N application rates can also increase the tuber bulking rate once it begins by increasing the photosynthetic leaf area up the optimal range. Once leaf area index has reached the sufficiency range (3 to 3.5), further increases in bulking rate will not occur. Therefore, increasing vine and leaf area above the sufficiency range can be detrimental to total tuber yield by diverting nutrient resources to the vines (Alva, 2004).

Maturation

Determinate varieties senesce earlier than the indeterminate varieties. Therefore, those varieties with an indeterminate growth habit maintain their canopy for a longer period, which allows them to generate more carbohydrate through photosynthesis (Millard and MacKerron, 1986). Harverkort and Struik (2015) explain that late varieties are able to intercept more light but early varieties tend to use their resources more efficiently. In an environment with a shorter growing season, the efficiency provided by a determinate variety would be more important than total light interception.

Insufficient N during the growing season often results in reduced leaf growth, less photosynthesis (Millard and Marshall, 1986), and earlier crop senescence, with the result being lower yields (Kleinkopf et al. 1981; Love et al. 2005). On the other hand, applying excessive N can also delay skin set and maturity resulting in reduced tuber quality and storability. (Kelling et al. 2015).

Nitrogen Rate and Yield

Multiple researchers have found that adding N to potato crops increases total and marketable yield (Arsenault et al., 2001; White et al., 1974; O'Beirne and Cassidy, 1990; Zebarth et al., 2004a). Other studies have found reductions in yield with excessive N rates, especially when late maturing varieties were grown in areas with shorter growing seasons (Porter and Sisson, 1991b; Lauer, 1986).

Due to the complex interactions between N fertilization and variety maturity, location can have a large impact on the relationship between N management and yield (Arsenault and Malone, 1999). For example, Lauer (1986) found that N fertilization rates of 300-400 kg/ha were necessary in the Columbia Basin to obtain economically optimum yields for Russet Burbank. In Klamath Falls, Oregon Rykbost et al. (1993) reported that Russet Burbank needed only 202 kg/ha of N to obtain optimal yields. Therefore, location and environment play large roles in determining optimal N rate and timing needs (Alva, 2004).

Disease pressure has also been found to influence potato N requirements. Mackenzie (1981) conducted a study to evaluate the effect of N rate on potato yields as influenced by the level of infection with early blight. They found that when the potatoes were blight free, 133kg N/ha was required to produce optimum yields; when the potatoes were blight infected 160kg N/ha was needed to produce the same result.

Nitrogen use efficiency (NUE) indicates how much applied N is actually used by the plant. In general, research has found that as N rate increases, N use efficiency decreases (Zebarth et .al. 2004a; Poljack et al., 2011; Ospina et al., 2014; Vos, 1999). One way that researchers have tried to increase NUE is by manipulating N application timing.

Nitrogen Application Timing and Yield

Historically, research results have been mixed with regard to split applications of N, some suggesting little or no effect on total or marketable processing yield (Kumar et al. 2013; Zebarth et al. 2004a), others suggesting a higher proportion of N applied early in the season reduced the yield of marketable tubers (Errebhi et al., 1998). Other research studies have provided evidence that some varieties will respond positively to adjustments in application timing. Love et al. (2005) found that the variety Summit Russet provided higher profitability when 2/3rds of the N was applied late (during tuber bulking), while Russet Burbank, Bannock Russet, and Gem Russet in the same study did not respond to N application timing. Stark et al. (1993) found that applying in-season N every two weeks resulted in maximum yield when growing Russet Burbank on a silt loam soil.

Depending on variety and growing conditions, evidence suggests split application of N does not always produce higher returns. However, split N applications have been found to improve potato NUE (Westermann et al., 1988; Vos, 1999). Splitting large N applications in to smaller amounts, applied frequently during tuber bulking, often provides the crop with necessary N when demand is highest (Goffart et al. 2008). One impact of higher NUE is reductions of N leaching losses (Zebarth et al. 2004b) especially in sandy soil conditions (Alva, 2004). Critical benefits in sustainability are associated with split N applications without down-side because split application typically produce yields that are similar to or greater than when only a single N application is made at planting (Roberts et al. 1982).

Petiole Nitrates

From year to year and from field to field, growing conditions and optimal fertility levels can be different. Because the potato crop is very sensitive to fluctuations in N concentrations it is important to monitor In-season N levels. Extreme deficiency symptoms can be visually identified, but slight deficiencies, sufficient to impact productivity, are not visible. Thus it is important to monitor petiole NO_3-N concentrations, as a tool to help maintain N availability within an optimum range (Stark et al., 2004). Research shows that the timing of N applications and rates are reflected in petiole sap NO_3 –N levels throughout the season (Gardner and Jones, 1975; Porter and Sisson, 1991a). Therefore, petiole NO_3-N concentrations can be used to make in-season N management decisions in areas where the practice has been shown to be effective and where adequate calibration data exist (Westermann and Kleinkopf, 1985). Differences have been noted in N concentrations throughout the year between varieties but all varieties follow similar trends (Waterer, 1997).

Nitrogen and Tuber Quality

There are many parameters that influence the total quality of a potato crop. Specific gravity is an important measurement that provides an estimate of the starch content and total solids of the potato (Laboski and Kelling, 2007). There are advantages to using potatoes with high SG, including: increased processed product yield per unit of raw product used, reduced fry time, and lighter fry color (Laboski and Kelling, 2007). Although a high SG is desired, there is a point where SG's are considered to be too high. Laboski and Kelling (2007) reported that potatoes with excessively high SG are more susceptible to bruising.

Most research results suggest that excessive N causes a reduction in SG, especially when unnecessary N applications are made late in the season (Kumar et al. 2013; Laboski and Kelling, 2007; White et al. 1974; Long et al. 2004; O'Bernie and Cassidy 1990; Belanger et al. 2002; Zebarth et al. 2004a; Sparrow and Chapman, 2003; Kelling et al. 2015; Porter and Sisson, 1991b). Conversely, other work gives evidence that SG was not reduced by N rates (Sandar and Nelson, 1968). The salt indices of the fertilizer being applied can have a greater impact on SG than the amount of N applied. Fertilizers with high salt indices will reduce SG more than a fertilizer with a low salt index (Laboski and Kelling, 2007; Davenport and Bentley, 2001).

Fry color is an aspect of fry quality, with dark fry color being considered unacceptable. Accumulation of reducing sugars (glucose and fructose) is the main cause of dark fry color (Kumar et al., 2004). Fry color can also be influenced by N fertility. Tubers grown with appropriate levels of N fertilizer have less reducing sugars at harvest and accumulate less reducing sugars in storage. Alternately, a crop grown with low N concentrations is more likely to have stress-related sugar accumulation at the stem end of the potato, which causes sugar ends (dark fry color at one end of the tuber).

Nitrogen and Tuber Size Distribution

Potato size distribution is an important aspect of crop quality because it impacts the amount of usable potatoes produced. A higher percentage of marketable potatoes leads to a higher economic return. Nitrogen appears to play a role in optimizing tuber size distribution. Some researchers have found that increasing N rates produce a higher percentage of marketable sized tubers (Zebarth et al., 2004a; White et al., 1974). Generally adding N reduces the percentage of small tubers (Poljak et al., 2011; Zebarth et al., 2004a) and increases the percentage of large tubers (Porter and Sisson, 1993; Zebarth et al., 2004a; Belanger et al., 2002).

Seed Piece Spacing

Seed piece spacing influences tuber size thereby impacting the yield and quality of the potato crop. Spacing is especially important because different potato markets have unique demands for tuber size. Some markets pay premiums for tubers of a certain size categories (Guenthner, 2003). Adjusting seed piece spacing is a practical way to manipulate tuber set and related size distribution (Blauer et al., 2013). Spacing can also influence total yield, marketable yield, and other quality traits. Thus spacing can be strongly correlated to total net returns. (Love and Thompson-Johns, 1999; Bussan et al., 2007; Blauer et al., 2013).

Plant and Stem Density

Bussan et al. (2007) found that increasing seed piece spacing decreases plant density. On the other hand he found that stem density increased with decreased seed piece spacing. He concluded that stem density was a better indicator of tuber set than plant density. Increased stem density correlates to higher tuber density, because when more tubers are set the average tuber size is correspondingly smaller (Bohl et al. 2011; Bussan et al., 2007). Love and Thompson-Johns (1999) found that for three russet type varieties (Russet Burbank, Frontier Russet and Ranger Russet) the best returns were obtained when stem density was between 10.5 and 12.1 stems per meter of row and when tuber densities were between 23.9 and 24.9 tubers per meter of row.

Spacing, Yield, and Quality

Yield and quality are two factors that greatly impact the total economic return of a potato crop. Because incentives are often given for tubers within a given size category, size is often viewed as a quality parameter. In many processing contracts incentives are given for larger tubers. Generally wider seed piece spacing decreases the number of tubers per unit area (Kumar et al. 2013), and increases average tuber weight (Arsenault et al., 2001; White et al., 1974; Zebarth et al., 2006; Poljak et al., 2011). In addition wider spacing typically produces lower total and marketable yields (Zebarth et al., 2006; Arsenault and Malone, 1999; Long et al., 2004; Polijak et al., 2011; Bohl et al., 2011). Others have observed an increase in percent marketable yield from increasing spacing (White et al., 1974; Arsenault et al., 2001). Love and Thompson-Johns (1999) found, the maximum yield was obtained at 8 cm spacing, but the spacing with the best return came when seed pieces were planted between15 and 46 cm for Ranger Russet and 23 to 46 cm for Russet Burbank. Size incentives can increase total economic return, and optimum spacing for yield is not always optimum for economic return. Therefore, it is imperative that a balance between yield and size distribution be identified for each new variety.

Nitrogen and Spacing Interaction

Interactions between spacing and N fertility can be quite complex, made more complicated by the fact that these interactions can be influenced by a wide array of environmental and cultural conditions. Long et al. (2004) reported conflicting results over years in a spacing/N-rate study. In the first year yield increased as a result of higher N rates at wider spacing (33cm), but not at narrow spacing (20cm). In the second year of the study, tuber yield was not increased by higher N rates even though petiole nitrate concentrations increased. Related studies have not shown significant interactions between N rate and spacing on tuber yield (Arsenault et al., 2001), but others have found that increased seed piece spacing decreased NUE (Poljak et al., 2011; Zebarth et al. 2006).

Summary

Nitrogen applications and seed piece spacing impact the growth and development of the potato crop. Excessive N can result in delayed tuber initiation, tuber bulking and reduced yield as well as delayed tuber maturity and poor skin set, which can reduce tuber quality and storability. The effects of N application timing vary depending on variety, soil type and local environmental conditions. Adjusting seed piece spacing appears to be a practical way to manage tuber size distribution. Often larger tubers are produced using a wider spacing and smaller tubers are produced using narrower spacing. Therefore spacing and N management have large impacts on yield and quality, but relatively little is known about the interactive effects of these management variables on potato yield and economic return.

The objective of this research is to identify how N rate, N application timing and seed piece spacing influence the development, yield, and net economic processing returns of the potato crop. Nitrogen and seed piece spacing have significant effects on the development of the canopy, tuber initiation, and the rate and duration of tuber bulking. Yield, quality, and net returns are also impacted. Varieties respond uniquely to N and spacing treatments, meaning there is economic value in identifying specific best management practices for new varieties such as Clearwater Russet.

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CHAPTER 2: YIELD, QUALITY, AND ECONOMICS

Abstract

Clearwater Russet is a new variety, released by Northwest Potato Variety Development Program, and has been accepted by producers and the processing industry. However, like all new varieties, research is needed to understand how to maximize its production potential. The objectives of this study were to identify the optimum combination of nitrogen (N) fertilizer rate, N application timing, and seed piece spacing required to produce maximum economic returns for Clearwater Russet. Investigated seed piece spacing's were 25 and 33 cm, combined with three N rates, 0, 202, and 269 kg N/ha, and two N application timings; consisting of either 2/3 of N applied prior to tuber initiation (early-loaded) and 1/3 after tuber initiation, or 1/3 of N applied prior to tuber initiation and 2/3 after tuber initiation (late-loaded). Post-harvest assessment of treatments included measurements of total yield, U.S. No 1 yield, tuber size distribution, and tuber specific gravity (SG). Economic returns based on fry contract parameters were calculated to determine the profitably of individual treatments. The 25 cm spacing treatment produced the highest total yield, but the economic return with the 33 cm spacing treatment was 11% higher due to increased yields of large (>397 g) tubers, and a higher percent of U.S. No. 1's. Nitrogen applications, especially when applied early, increased yield of tubers >397 g, reduced yield of small (114-170 g) and undersized tubers (<114 g). Nitrogen management treatment combinations that increased tuber size, contributed to greater economic returns. The early-loaded 202 kg/ha N treatment produced the highest economic return. Although the early-loaded 269 kg/ha N treatment produced a similar return. The results of this study indicate that N rates for Clearwater Russet should be about 25% less than recommended N rates used for Russet Burbank, with 2/3rds of N applied prior to tuber initiation. Seed piece spacing of 33 cm, in 91 cm-wide rows should produce higher economic fry returns than narrower spacing, when size incentives are offered for large tubers.

Introduction

Clearwater Russet has several characteristics that make it an excellent processing variety, including high U.S. No 1 yield, few external defects, low glucose concentrations, few sugar ends, and excellent cold sweetening resistance, which enables it to maintain light fry color over extended storage periods. Its cold sweetening resistance, allows it to be stored at 7.2°C for up to 250 days without the need for reconditioning (Novy et al. 2010). In full-season trials conducted over a three-year period in California, Colorado, Idaho, Oregon, and Washington, Clearwater Russet produced total yields slightly lower than Ranger Russet and Russet Burbank, but averaged 2% and 30% higher U.S. No. 1 yields, respectively, across all states. Average SG of Clearwater Russet is comparable to Ranger Russet and significantly higher than Russet Burbank. (Novy et al. 2010). The increased interest in production of Clearwater by the potato processing industry has created a need for additional agronomic research to assist growers in maximizing the potential of this new variety.

Nitrogen management is a critical production factor, due to its impact on yield and quality of potatoes. Researchers have historically found that adding N up to an optimal amount increases total and marketable potato yields (Arsenault et al., 2001; White et al., 1974; O'Beirne and Cassidy, 1990; Zebarth et al., 2004a), but excessive N rates have been shown to reduce yields, especially when late maturing varieties were grown (Porter and Sisson, 1991b; Lauer, 1986). Thus N must be managed carefully to produce maximum economic returns. Love et al. (2005) reported that potato varieties respond differently to N application timing and that adjustments in N timing can produce significant improvements in economic return.

Seed piece spacing is also an important agronomic factor that impacts the yield and quality of the potato crop, particularly since different potato markets have unique demands for tuber size distributions. Some buyers pay premiums for tubers within specific size categories (Guenthner, 2003). Adjusting seed piece spacing, therefore, is a practical way to manipulate tuber set and size distribution (Blauer et al., 2013), and therefore capture size incentives to increase economic returns.

Generally, wider seed piece spacing decreases the number of tubers per unit area (Kumar et al. 2013), and increases average tuber weight (Arsenault et al., 2001; White et al., 1974; Zebarth et al., 2006; Poljak et al., 2011). In addition wider spacing typically produces lower total and marketable yields (Zebarth et al., 2006; Arsenault and Malone, 1999; Long et al., 2004; Polijak et al., 2011; Bohl et al., 2011). However, others have observed an increase in percent marketable yield from increased seed piece spacing (White et al., 1974; Arsenault et al., 2001). Because spacing can influence total yield, marketable yield, and size distribution, it is strongly correlated to total net returns (Love and Thompson-Johns, 1999; Bussan et al., 2007; Blauer et al., 2013).

Each new variety has the potential to respond differently to N rates, N application timing, and seed piece spacing, and as a result, there is a need for variety specific research to identify optimum combinations of management practices. This study was conducted to identify the optimum combination of seed piece spacing, N rate, and N application timing to maximize yield and economic fry processing return for Clearwater Russet.

Materials and Methods

Field experiments were conducted on a Declo loam soil at the University of Idaho Research and Extension Center in Aberdeen, Idaho in 2015 and 2016. Treatments were established in a randomized complete block, split plot design, with combinations of N rate and timing as main plots and spacing treatments as sub-plots (Table 2.1). Spacing treatments included 25 cm and 33 cm in-row seed spacing. Total N rates included an untreated check (0 N), and two N application rates: 202 kg/ha, and 269 kg/ha, which were considered to be low to moderate N rates for the local production area. To investigate the role of N application timing, N applications were made pre-plant, at tuber initiation (when tubers swelled to twice the diameter of the stolons), and in-season. The in-season N application was divided into three applications starting two weeks after tuber initiation, with an application being made every two weeks. Early or late loaded N splits were produced by adjusting N rates for each N application (Table 2.1).

The early (E) loaded split treatment consisting of 2/3 of the total N applied between pre-plant and tuber initiation applications, with the remainder applied in-season (after the tuber initiation application), and a late (L) loaded split treatment consisting of 1/3 of the total N applied between pre-plant and tuber initiation applications, with the remainder applied in-season. Combinations of N rate and N application timing (N management) include 0 kg/ha (0), 202 kg/ha N applied early (202E), 202 kg/ha N applied late (202L), 269 kg/ha N applied early (269E), and 269 kg/ha N applied late (269L).

All N was applied using a hand-held broadcast applicator except for the pre-plant applications, which were made using a tractor-mounted drop spreader. The pre-plant applications were incorporated with a harrow operation, while the other N applications were incorporated with 1.5 to 2 cm of sprinkler irrigation. Phosphorus, zinc, and manganese were applied (pre-plant) to all plots according to University of Idaho recommendations (Stark et al., 2004).

Plots of Clearwater Russet potatoes were planted on April 30th in 2015 and May 9th in 2016 with a two-row planter. Plots were six rows wide (5.46 m) and 12 m long, with 91 cm spacing between rows. Each plot contained a designated petiole sampling row, a whole-plant sampling row, a harvest row, and three buffer rows designed to maintain the integrity of normal plant competition throughout the growing season. The plot sampling arrangement worked well in 2016; but in 2015, some plants needed to be removed due to PVY infection. Consequently, some rows that were intended to be harvest rows were not able to be used as such because of the removal of plants and a different row that had plant competition on each side was selected and used as the harvest row.

Weeds were controlled by applying Eptam 7-E (5.84 L/ha), TriCor 4F (1.17 L/ha), and Matrix (109 ml/ha). Admire (584 ml/ha) was applied to control insects. Late blight was a concern in 2015, and fungicides were applied on July 17th (Gavel 2.24 kg/ha), July 31st (Bravo 1.75 L/ha), August 14th (Gavel 2.24 kg/ha), and August 21st (Bravo 1.75 L/ha). All research plots were irrigated with a solid-set sprinkler system, scheduled to maintain available soil water content above 65% throughout tuber initiation and bulking.

The growing season was 16 days longer in 2015 with 151 days from planting to harvest, compared to 135 days in 2016. Growing degrees were calculated using the following formula: $GD= ((T_{MAX}+T_{MIN})/2) - T_{BASE}$. Where T is the maximum and minimum temperatures and the base temperature equals 10°C. Growing degrees differed between years, with 1,246 GDs accumulated from planting to harvest, while only 1,103 GDs accumulated in 2016. Temperature fluctuations in 2016 were also greater, with higher highs and lower lows than in 2015 (Table 2.2).

Differences between years with regard to residual soil N concentrations were evident when comparing pre-plant soil test results. In 2015, residual N consisted of 19 mg/kg nitrate-N and 2 mg/kg ammonium- N, compared to 13 mg/kg nitrate-N and 3 mg/kg ammonium- N in 2016, resulting in 22 kg N/ha more in 2015 than in 2016. Complete soil test results can be found in Table 2.3.

Vine kill occurred on September 3rd in 2015 and August 31st in 2016. Plots were harvested on September 28th in 2015 and September 21st in 2016, by harvesting 9.1 m of row from the middle of each plot.

After harvest the tubers were graded into the following categories: > 397 g, 284-397 g, 170-284 g, 114-170 g, <114 g, U.S. No. 2's, and culls (tubers >114 g that are malformed or green). From these measurements total yield and U.S. No. 1's (tubers > 114 g and free from malformations) were calculated. Specific gravity was measured by weighing a sample of potatoes in air and then weighing the same sample in water. Specific gravity was determined using the equation: SG= (weight in air) / [(weight in air) – (weight in water)].

Economic returns were calculated based on a fry processing model contract, similar to those used by Hutchinson (2003) and Love et al. (2005). The economic analysis was based on yield, size distribution, SG, N fertilizer and seed costs. The cost of fertilizer and seed were taken from the 2016 University Of Idaho Estimated Cost Of Potato Production Guide (Eborn, 2016).

The economic analysis used a base price of $132/Mg, adjusted by the percent of U.S. No.1 tubers that are >170g. An incentive adjustment of $0.66/Mg was added for each percent over 60% up to 71%. The maximum incentive ($7.27/Mg) was added between 71% and 80% U.S. No. 1's >170 g. For tubers >170 g deductions ($0.66/Mg) were taken for each percentage >80%. Specific gravity deductions ($1.10/Mg) were calculated for each thousandth point >1.090 or <1.079. Income was then calculated by multiplying the over 170 g tubers by the final incentive adjusted price/Mg. The income from washed processed grade tubers (tubers only good for dehydration processing) was then added to the total income. Finally treatment expenses for seed piece spacing and N fertilizer were subtracted from the income.

Seed costs varied based on seed piece spacing treatment, figuring that seed size remains constant (71 g). The 25 cm spacing required 3,049 kg/ha of seed, while, the 33 cm spacing required only 2,343 kg/ha of seed. Greater quantities of seed required per ha also resulted in increased seed cutting costs of $27 more per ha. Accounting for all associated variables, a cost difference of about $222/ ha existed between the two spacing treatments, the higher cost attached to the 25 cm spacing (Table 2.4).

The cost of N fertilizer was calculated using dry N fertilizer ($0.90/ kg) for pre-plant applications and liquid N ($1.05/kg) for tuber initiation and in-season applications. Subsequently applying N early (pre-plant) was more cost-efficient. Nitrogen fertilizer costs increased by about $70/ha (Table 2.5) when N rates increased from 202 to 269 (kg/ha).

Yield and quality data was analyzed with analysis of variance using the GLIMMIX procedure with a $P \leq 0.10$ criteria using SAS (Version 9.4, SAS institute Inc., 2002-2012, Cary, NC, USA). Means were separated by LSD (Least Significant Difference) test with $P \leq 0.10$.

Results and Discussion

Analysis of Variance

Analysis of variance (Table 2.6) revealed a statistically significant effect of year on every yield and quality parameter except for SG and culls. Higher yields, higher economic fry returns, and larger tubers were produced in 2015 than in 2016 (Table 2.7).

Seed piece spacing had significant effects on total yield, % U.S. No. 1 yield, economic fry returns, and on some tuber size categories, including > 397 g, 170-284 g, 114-170 g, and <114 g tubers. Nitrogen application treatments significantly affected SG, and some tuber size categories, including >397 g, 114-170 g, and 0-114 g tubers.

Year by N interactions were significant for the >397 g tuber size category and %U.S No.1's. Year by seed piece spacing interactions were significant for %U.S. No. 1 Yield, and the following tuber size categories: >397 g, 284-397 g, 170 -284 g, and <114 g.

Total Yield

Spacing had a significant impact on total yield with the 25 cm spacing out-yielding the 33 cm spacing by 3.03 Mg/ha (Figure 2.1). Previous research documented reduced yields with increased seed piece spacing (Zebarth et al., 2006; Arsenault and Malone, 1999; Long et al., 2004; Polijak et al., 2011; Bohl et al., 2011; love and Thompson-Johns, 1999).

Nitrogen management did not have a significant effect on total yield. Results reported by other researchers showed yield increases with the addition of N (Arsenault et al., 2001; White et al., 1974; O'Beirne and Cassidy, 1990; Zebarth et al., 2004a), and some have reported reductions in yield with excessive N (Porter and Sisson, 1991b; Lauer, 1986). Other researchers suggest an optimum N range with yields reduced if N levels were above or below the optimum (Alva, 2004; Porter and Sisson, 1991b; Arsenault et al., 2001; White et al., 1974; O'Beirne and Cassidy, 1990; Zebarth et al., 2004a). The highest N rate treatment in this study was designed to provide a total N supply that was similar to that required for Russet Burbank (269 kg N/ha) with the lower rate (202 kg N/ha) providing about 25% less. However, the relatively high residual soil N coupled with high mineralization rates, particularly during the warmer 2016 season, possibly reducing the effect of N treatments.

U.S. No 1 Yield

Neither N application nor spacing treatments had significant effects on U.S. No. 1 yield. However, seed piece spacing affected the percent of U.S. No. 1 tubers produced. The

33 cm spacing produced 86%, while the 25 cm spacing only produced 82% U.S. No 1's (Figure 2.2). Previous research shows similar results, where the percent marketable yield increases as seed spacing increases (White et al., 1974; Arsenault et al., 2001). Other studies have documented an opposite response, with marketable yields decreasing as seed piece spacing increases (Arsenault and Malone, 1999; Long et al., 2004; Bohl et al., 2011). The year of the study had a significant effect on percent U.S. No. 1's, with 2015 producing 85% while 2016 only produced 82% (Table 2.7).

Year by N interactions were significant for the % of U.S No.1's produced (Figure 2.3). In 2015 a slightly higher percentage of U.S. No. 1's were obtained with reduced N rates, while the %U.S.No.1's increased when N was applied in 2016. Year by seed piece spacing interactions were also significant for %U.S. No. 1 Yield (Figure 2.4). The 33 cm spacing maintained a higher percentage of U.S. No.1's in both years, but the 25 cm spacing produced a higher % in 2015 than in 2016 in relation to the 33 cm spacing.

Tuber Size Distribution

Nitrogen treatments had significant effects on tuber yields >397 g, 114-170 g, and 0-114 g (Table 2.8). Nitrogen applications (especially when applied early) increased yield of tubers > 397g. There were differences between the 0 and 269L N treatments for the 170-284 g size category; the 0 treatment produced the highest yield while 269L produced the lowest. The 0 and 202L treatments produced the highest yield of tubers between 114 and 170 g, while the other N treatments produced significantly lower yields in this size category. The 202E treatment produced the lowest yield of <114 g tubers, followed closely by the 269E treatment, while the late-loaded N treatments produced the highest yield in this size category. Overall lower N rates generally led to increased yield of small tubers, while early N applications led to higher yield of large tubers (>397g).

Seed piece spacing had a significant effect on tuber size distribution. The 33 cm seed piece spacing produced a higher yield of tubers >397 g, and the 25 cm spacing produced a higher yield of 170-284 g, 114-170 g, and <114 g tubers (Table 2.8). Thus, wider (33 cm) seed piece spacing produced larger tubers and narrower (25 cm) spacing produced smaller tubers. Figure 2.5 shows the difference between spacing treatments when comparing the percent of tubers >170 g. The 33 cm spacing produced 8% more tubers >170 g than the 25 cm spacing. The observation of increased tuber size with increased seed piece spacing is consistent with findings from other research (Arsenault et al., 2001; White et al., 1974; Zebarth et al., 2006; Poljak et al.., 2011).

Tuber size distribution plays a large part in determining final value of a potato crop for processing (Guenthner, 2003). Nitrogen treatments 202L and 0 received the maximum size incentive while the other N application treatments received slight deductions (between $1.98- $1.32/Mg) because their percentage of >170 g tubers is slightly over 80% (Figure 2.6). The trend of increased percentages of large tubers resulting from increased N applications is consistent with the results of other studies (Poljak et al., 2011; Zebarth et al., 2004a; Porter and Sisson, 1993; Belanger et al., 2002).

Larger tuber size was obtained with the 33 cm spacing which has 84 % of its tubers >170 g, which would result in this treatment receiving a slight deduction ($2.65/Mg). Processing contracts providing incentives for larger tubers, would find the 33cm spacing more appealing than the 25 cm spacing, which produced smaller tubers.

Year by N interactions were significant for the >397 g tuber size category (Figure 2.7). While year had significant effects on the differences in yield of large (>397 g) tubers among N management treatments, most of the difference was due to increases in yield above the untreated check. Otherwise the treatments ranked similarly in performance in both years. The treatments followed a similar trend for both years but the differences between early and late treatments were greater in 2015 than in 2016.

Year by spacing interactions had significant effects on the following tuber size categories: >397 g, 284-397 g, 170 -284 g, and <114 g (Figure 2.8). While year had significant effects on the differences in yield with in these tuber size categories, the treatments ranked similarly in performance in both years, except for the tuber size category 284-397 g. In this case slightly higher (but not statistically significant) yields were obtained in 2015 for the 25 cm spacing than the 33 cm spacing, while higher (significant) yields were obtained for the 33 cm spacing in 2016.

Tuber Specific Gravity

Nitrogen application treatment had a significant effect on SG. Specific gravity generally declined with increasing N application rates (Table 2.9). The 0 N treatment produced SG values of 1.095, but when N was applied the values dropped to a range of 1.090 to 1.088. This is consistent with other research that suggests that adding N fertilizer reduces SG (Kumar et al. 2013; Laboski and Kelling, 2007; White et al. 1974; Long et al. 2004; O'Bernie and Cassidy 1990; Belanger et al. 2002; Zebarth et al. 2004b; Sparrow and Chapman, 2003; Kelling et al. 2015).

Processers often give incentives or deductions based on SG (Guenthner, 2003). The processing contract used to analyze this data takes deductions for SG >1.090 and for SG <1.079 In this case low SG wasn't a concern, the 0 and 202L treatments received deductions because of high SG. Deductions ($1.10/Mg) were taken for each thousandth over 1.090. In this case slight reductions in SG from the application of N provided an economic incentive.

Economic Returns for French fry Processing

The final value for economic fry contract return was affected by seed piece spacing. The 33 cm spacing on average returned $433/ ha more than the 25 cm spacing (Figure 2.9). This difference is largely due to an increased % of U.S. No. 1 tubers >170 g associated with the 33 cm spacing treatment. Even though deductions are given for lots that have greater than 80% > 170 g, income was increased as a result of greater yield of this size category. Planting at 33 cm rather than 25 cm saved about $222/ha, by reducing seed costs. The 33 cm spacing, therefore, produced the greater value to the grower because of reduced seed costs and higher economic returns.

The 202E N treatment provided the best economic return based on the fry processing contract used in this study, while the 269E treatment provided a similar return (Figure 2.10). Although there is not a statistical difference between these two treatments, the difference in mean economic return is about $226 /ha. The difference between the

202E and the 0 treatment was significant (at P ≤0.1), with the 202E treatment providing \$675/ ha more than the 0 treatment. The 202E treatment had high total yield, high U.S. No. 1 yield, and low yield of <114 g tubers and it did not receive deductions because of SG. All of these factors contributed to the 202E treatment producing the highest economic return.

Summary and Conclusions

The 25 cm spacing produced the highest total yield, while the 33 cm spacing treatment produced a higher percentage of U.S. No. 1's. The 33 cm spacing produced an 11% greater economic return due to increased yields of large (>397 g) tubers combined with lower seed costs. By comparison, the 25 cm spacing produced a higher yield of small (170-284 g, 114-170 g, and <114 g) tubers. Based on the results from the fry processing contract used in this study, the 33 cm spacing provided the highest economic return for Clearwater Russet. Reduced seed cost, higher % U.S. No. 1's, and increased tuber size are significant contributors to the greater economic return of the 33 cm spacing.

Nitrogen applications (especially when applied "early") increased yield of large tubers (>397g), reduced yield of small (114-170 g) and undersized tubers (<114 g). The 202E and 269E treatments produced the lowest yield of <114 g tubers. Nitrogen management treatments that increased tuber size distribution contributed to greater economic returns. The 202E N treatment produced the highest economic return, which was statistically similar to the 269E N treatment. Suggesting that the lower N rate (202E) is sufficient for producing maximum economic returns.

In summary, the results of this study indicate that N rates for Clearwater Russet should be about 25% less than recommended N rates used for Russet Burbank, with 2/3rds of N applied prior to tuber initiation. Seed piece spacing of 33 cm, in 91 cm-wide rows should produce higher economic fry returns than narrower spacing, when size incentives are offered for large tubers.

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Tables

Table 2.1 Treatment combinations including seed piece spacing, total N applied, and timing of N applications. Spacing treatments included 25 cm and 33 cm in-row seed spacing. Two total N rates were used 202 kg/ha and 269 kg/ha. The early loaded split treatment consisting of 2/3 of the total N applied between pre-plant and tuber initiation applications, with the remainder applied in-season (after the tuber initiation application), and a late loaded split treatment consisting of 1/3 of the total N applied between pre-plant and tuber initiation applications, with the remainder applied in-season.

N Management Treatments		**N Applications (kg/ha)**			**Seed Piece Spacing**
Total N (kg/ha)	N Timing	Pre-Plant	Tuber Initiation	In-Season	cm
0	0	0	0	0	25
					33
202	Early Split	67	67	67	25
					33
202	Late Split	34	34	135	25
					33
269	Early Split	90	90	90	25
					33
269	Late Split	45	45	179	25
					33

Table 2.2 Average maximum and minimum temperatures (°C) by month for 2015 and 2016.

Maximum and Minimum Temperatures

	Year	April	May	June	July	August
Maximum	2015	15.2	19.0	28.3	27.6	29.2
	2016	16.7	19.2	27.3	29.7	29.6
Minimum	2015	-0.6	6.2	10.4	11.3	10.5
	2016	2.1	4.9	9.3	10.1	8.3

Table 2.3 Pre-plant soil test results for 2015 and 2016.

Soil Test Data	**2015**	**2016**
pH	8.1	8.3
Sodium (mg/kg)	3	3
Excess Lime (%)	6.7	9.4
Organic Matter (%)	1.58	1.25
Ammonium-N (mg/kg)	2.3	3.0
Nitrate-N (mg/kg)	19	13
Phosphorus (mg/kg)	22	22
Potassium (mg/kg)	340	255
Calcium (mg/kg)	105	113
Magnesium (mg/kg)	31	32
Sulfate-S (mg/kg)	17	20
Zinc (mg/kg)	1.1	0.9
Iron (mg/kg)	3.9	7.4
Manganese (mg/kg)	2.8	3.6
Copper (mg/kg)	1.0	0.7
Boron (mg/kg)	1.40	0.95

Table 2.4 Effect of seed piece spacing on seed costs ($/ha). The seed cost was $0.28 /kg. The price of seed cutting was $0.04/ kg. Figuring that seed size remains constant (71 g), seed requirements increase as planting density increases.

	Cost of Seed	
	25 cm	**33 cm**
Seed Rate (kg/ha)	3049	2343
Seed Cost ($/ha)	840.16	645.56
Seed Cutting Cost ($/ha)	117.62	90.38
Total Seed Cost ($/ ha)	957.78	735.94

Table 2.5 Cost of nitrogen fertilizer based on N treatment. The cost of pre-plant dry N was $0.90/ kg, the cost of tuber initiation and in-season applications were calculated using liquid N ($1.05/kg).

Cost of Nitrogen

	0	**202E**	**202L**	**269E**	**269L**
Pre-Plant N (kg/ha)	0	67	34	90	45
Tuber Initiation (kg/ha)	0	67	34	90	45
In-Season (kg/ha)	0	67	135	90	179
Total N (kg/ha)	0	202	202	269	269
Cost of N ($/ha)	0.00	203.10	208.48	270.80	277.97

Table 2.6 Fixed effect values from analysis of variance (type III tests) for yield parameters. Significant Pr>F values (at <0.10) denoted with bold faced font.

Parameters		**Year**	**N**	**Spacing**	**Year*N**	**N*SP**	**Year*SP**	**Year*N *SP**
Total Yield	Num DF	1	4	1	4	4	1	4
	F Value	30.89	1.02	6.77	0.56	0.10	0.89	0.19
	Pr > F	**0.0014**	0.4165	**0.0143**	0.6966	0.9820	0.3520	0.9398
U.S. No. 1 Yield	Num DF	1	4	1	4	4	1	4
	F Value	28.97	1.19	0.22	0.58	0.14	0.00	0.28
	Pr > F	**0.0017**	0.3398	0.6446	0.6782	0.9661	0.9905	0.8901
% U.S. No. 1 Yield	Num DF	1	4	1	4	4	1	4
	F Value	11.73	1.46	17.6	2.28	1.27	4.55	2.26
	Pr > F	**0.0141**	0.2468	**0.0002**	**0.0902**	0.4608	**0.0412**	0.5838
Economic French Fry Return	Num DF	1	4	1	4	4	1	4
	F Value	33.32	1.76	11.2	0.57	0.38	0	0.13
	Pr > F	**0.0012**	0.1709	**0.0022**	0.6888	0.8213	0.9543	0.9702
Specific Gravity	Num DF	1	4	1	4	4	1	4
	F Value	0.22	10.1	1.56	1.72	0.62	0.26	0.20
	Pr > F	0.6534	**<.0001**	0.2215	0.1795	0.6522	0.6165	0.9337
% U.S. No. 1's >170 g	Num DF	1	4	1	4	4	1	4
	F Value	37.64	6.46	60.02	0.77	1.13	0.38	0.52
	Pr > F	**0.0009**	**0.0011**	**<.0001**	0.5524	0.3605	0.5421	0.7211
Yield >397 g	Num DF	1	4	1	4	4	1	4
	F Value	39.3	4.53	34.4	1.08	1.74	20.13	1.38
	Pr > F	**0.0008**	**0.0072**	0.3906	**<.0001**	0.1680	**<.0001**	0.2643
Yield 284-397 g	Num DF	1	4	1	4	4	1	4
	F Value	18.97	0.75	2.81	0.73	1.30	6.60	0.29
	Pr > F	**0.0048**	0.5690	0.5813	0.1041	0.2919	**0.0154**	0.8803
Yield 170-284 g	Num DF	1	4	1	4	4	1	4
	F Value	6.39	0.89	12.21	1.92	0.25	5.29	1.08
	P Value	**0.0449**	0.4839	**0.0015**	0.1399	0.9084	**0.0286**	0.3847
Yield 114-170 g	Num DF	1	4	1	4	4	1	4
	F Value	23.29	6.05	53.19	0.51	0.78	0.02	0.75
	Pr > F	**0.0029**	**0.0016**	**<.0001**	0.7262	0.5448	0.8892	0.5653
Yield <114 g	Num DF	1	4	1	4	4	1	4
	F Value	18.31	3.23	53.86	1.73	1.27	3.11	0.81
	Pr > F	**0.0052**	**0.0295**	**<.0001**	0.1772	0.3020	**0.0879**	0.5263
U.S. No. 2 Yield	Num DF	1	4	1	4	4	1	4
	F Value	11.44	1.44	2.81	0.72	2.80	0.76	1.02
	Pr > F	**0.0148**	0.2508	0.1042	0.5892	**0.0435**	0.3911	0.4134
Cull Yield	Num DF	1	4	1	4	4	1	4
	F Value	0.01	1.98	0.82	0.78	0.20	1.79	0.42
	Pr > F	0.9404	0.1298	0.3717	0.552	0.9353	0.1905	0.7962

Table 2.7 Yield, economic fry return, and tuber size distribution as the result of production year.

	Total Yield	U.S. No. 1 Yield	% U.S. No.1's	Economic Fry Return	>397 g	284-397 g	170-284 g	114-170 g	<114 g
2015	483.7 A	414.8 A	85.7 B	1914.4 A	120.8 A	102.1 A	135.3 B	56.6 B	37.4 B
2016	414.7 B	339.9 B	82.7 B	1337.5 B	30.2 B	65.2 B	156.4 A	88.2 A	49.8 A

Yields with in a column followed by the same letter are not statistically significant at $P \leq 0.1$

Table 2.8 N management and seed piece spacing effect on tuber size distribution (Mg/ha).

Tuber Size Distribution

	TRT	**>397 g**	**284-397 g**	**170-284 g**	**114-170 g**	**<114 g**	**No. 2's**	**Culls**
N Management	**0**	5.5 C	8.3 A	17.4 A	10.0 A	5.2 AB	0.8 C	1.4 C
	202E	10.1 AB	10.1 A	16.4 AB	7.3 B	4.0 C	1.1 AB	2.6 A
	202L	7.9 B	9.6 A	16.7 AB	8.8 A	5.5 A	1.3 AB	1.7 BC
	269E	10.6 A	9.1 A	15.8 AB	7.4 B	4.4 BC	1.5 A	1.8 ABC
	269L	8.2 B	9.8 A	15.5 B	7.0 B	5.3 A	1.4 A	2.2 AB
Seed Spacing	**25**	6.3 B	8.9 A	17.6 A	9.8 A	6.1 A	1.4 A	1.8 A
	33	10.6 A	9.9 A	15.1 B	6.4 B	3.7 B	1.1 A	2.1 A

Yields with in a column followed by the same letter are not statistically significant at P ≤ 0.1

Table 2.9 Effect of N management treatments on specific gravity.

Treatment	Specific Gravity	
0	1.095	A
202L	1.090	B
269E	1.089	BC
202E	1.089	BC
269L	1.088	C

Yields with in a column followed by the same letter are not statistically significant at $P \leq 0.1$

Figures and Descriptions

Figure 2.1 Effect of seed piece spacing on total yield. Bars with the same letter are not statistically different at $P \leq 0.1$.

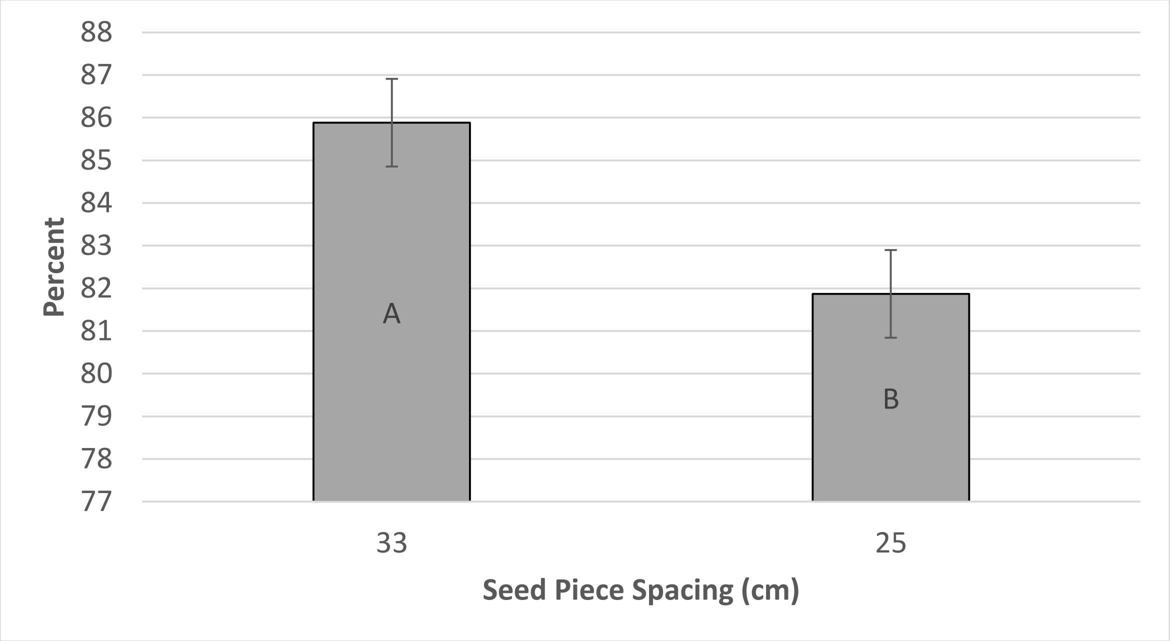

Figure 2.2 Effect of seed piece spacing on % U.S. No. 1 yield. Bars with the same letter are not statistically different at $P \leq 0.1$.

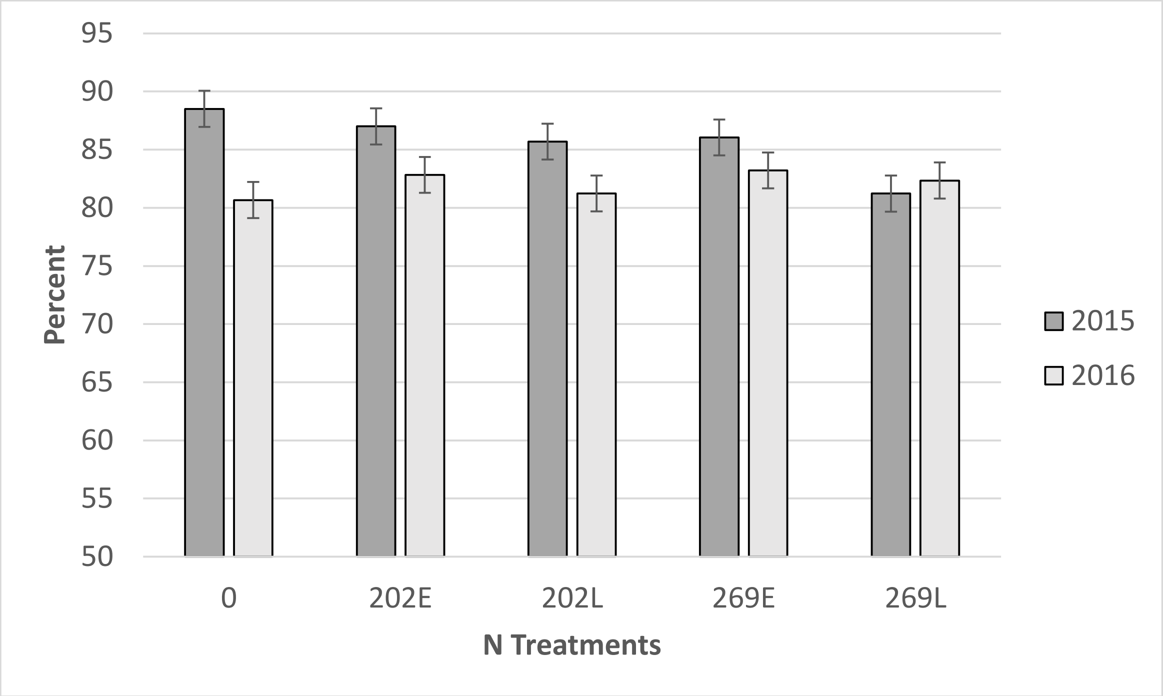

Figure 2.3 Effect N and year interaction on % U.S. No. 1 yield.

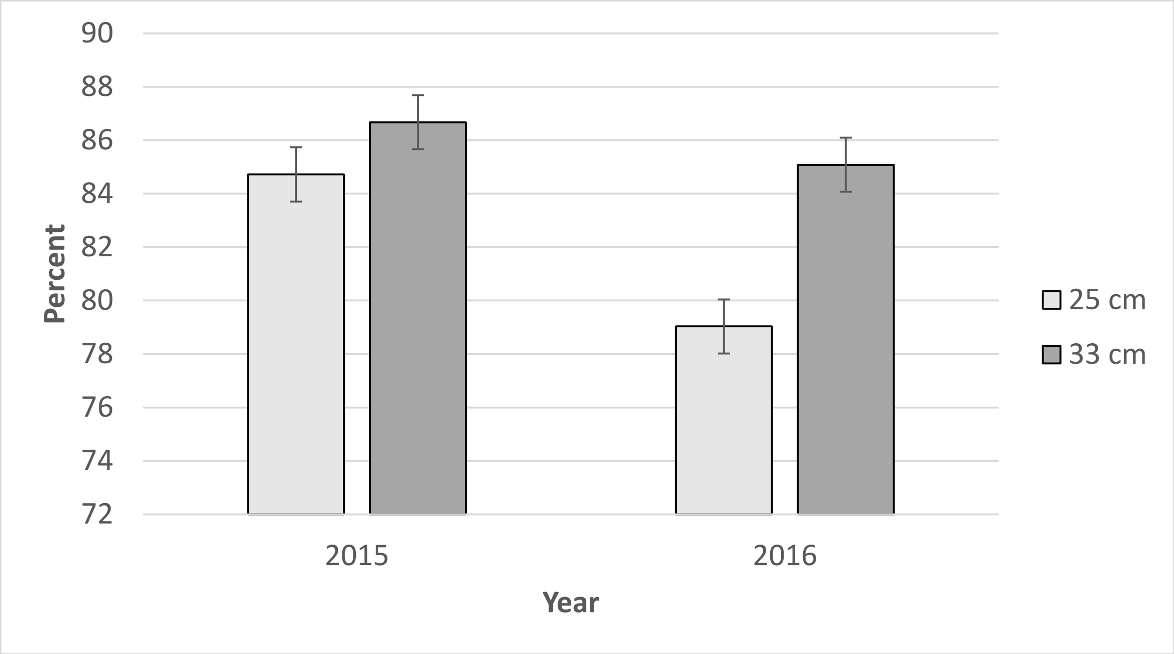

Figure 2.4 Effect of seed piece spacing and year interaction on % U.S. No. 1 yield.

Figure 2.5 Effect of seed piece spacing on % of U.S. No. 1 tubers > 170 g. Bars with the same letter are not statistically different at $P \leq 0.1$.

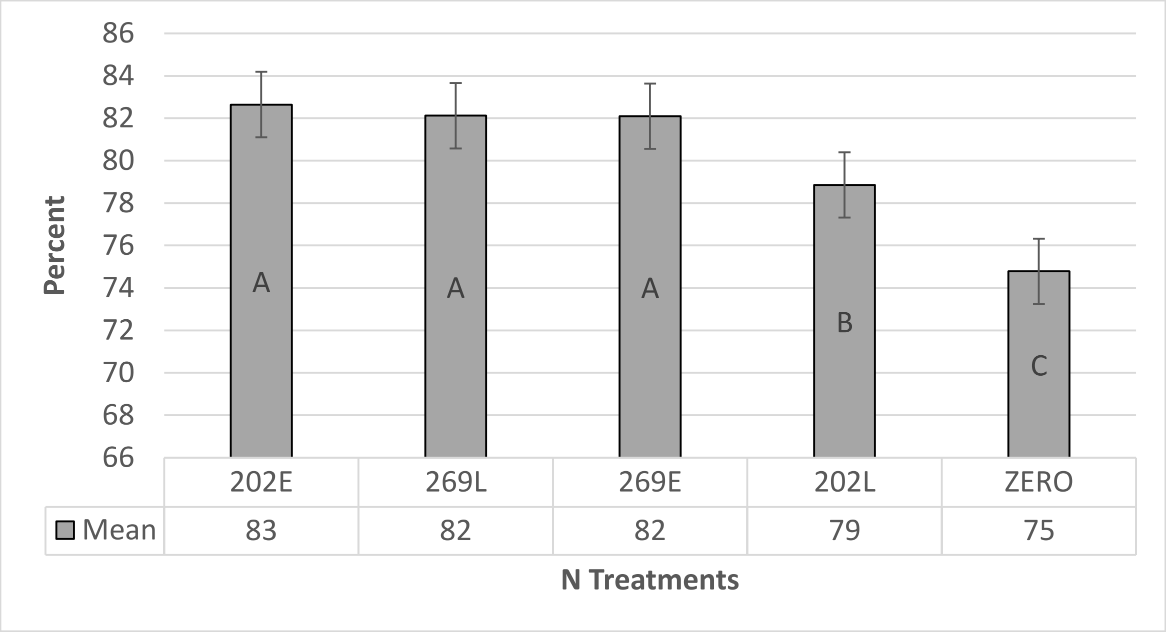

Figure 2.6 Effect of N management treatment on the % of U.S. No. 1 tubers > 170 g. Bars with the same letter are not statistically different at $P \leq 0.1$.

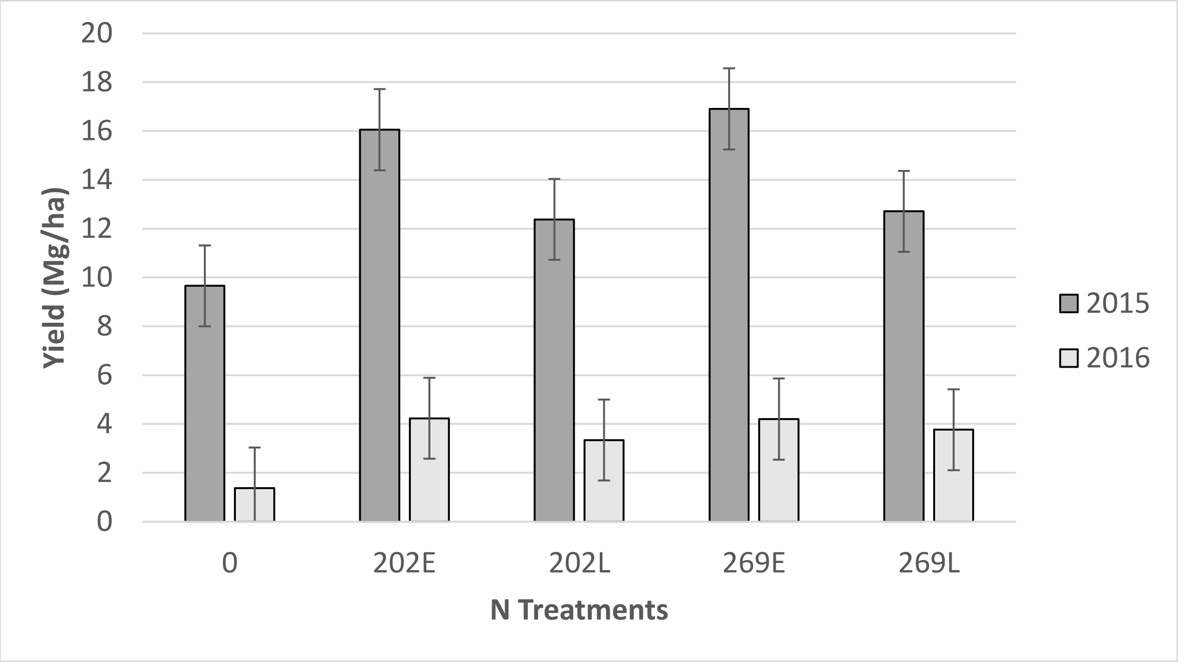

Figure 2.7 Effect of N and year interaction on yield of tubers >397 g.

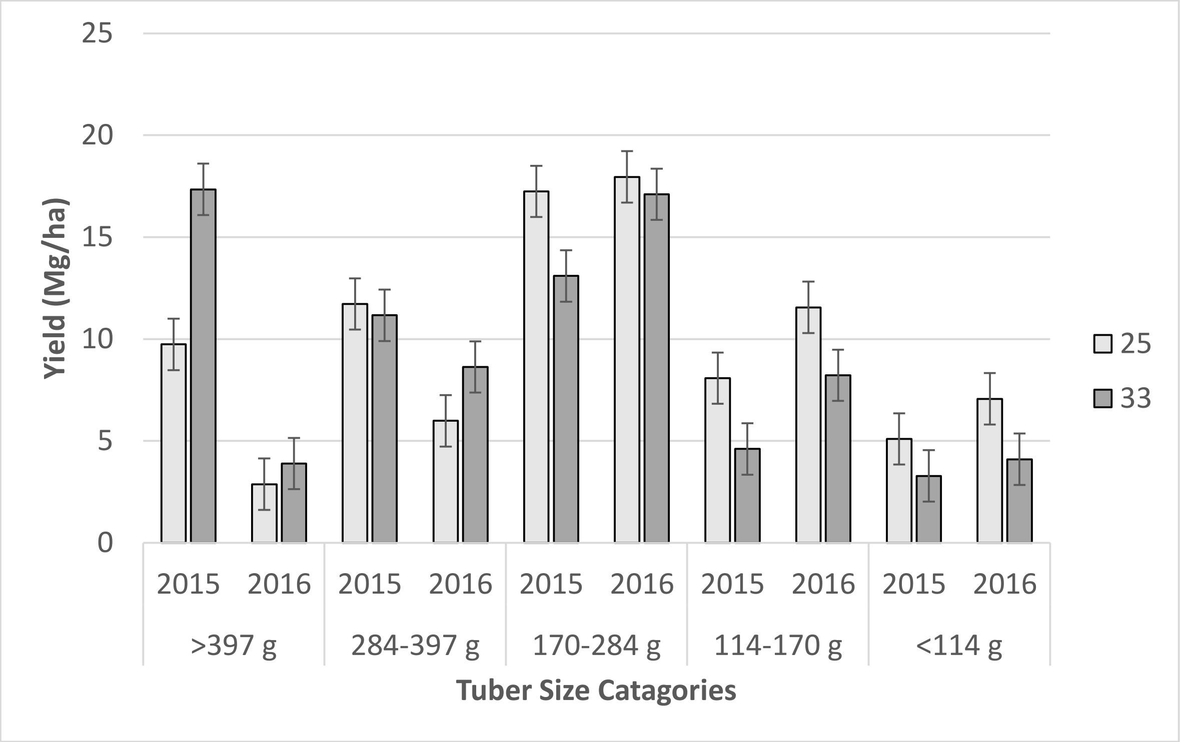

Figure 2.8 Effect of N and year interaction on tuber size distribution.

Figure 2.9 Effect of seed piece spacing on economic fry return. Bars with the same letter are not statistically different at P ≤ 0.1.

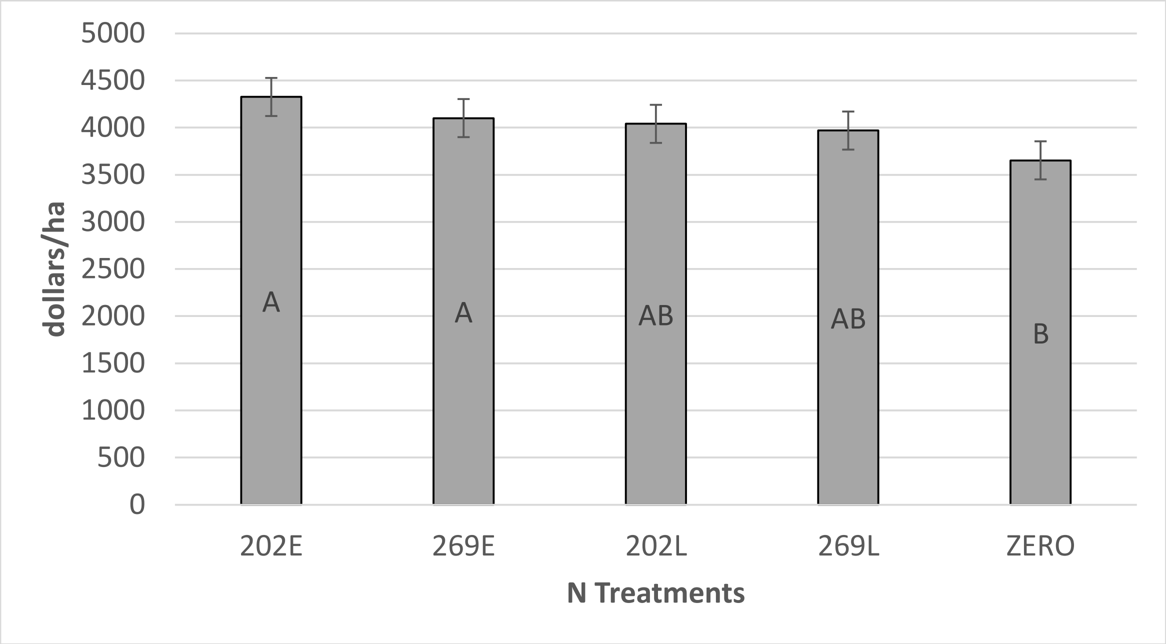

Figure 2.10 Effect of N management on economic fry return. Bars with the same letter are not statistically different at $P \leq 0.1$.

CHAPTER 3: DRY MATTER AND NITROGEN PARTITIONING

Abstract

Clearwater Russet is a new potato variety, released by Northwest Potato Variety Development Program. Clearwater Russet is rapidly being adopted by potato producers and the processing industry in the Pacific Northwest. The objective of this study was to determine how nitrogen (N) fertilizer rate, N application timing, and seed piece spacing influence tuber density, stem density, as well as plant N and dry matter (DM) partitioning. The experiment was arranged in a split plot, randomized complete block design with two seed piece spacing treatments (25 and 33 cm) as sub plots and N management treatments as main plots. Nitrogen management treatments consisted of three N rates, 0, 202, and 269 kg N/ha, factorially combined with two N split application timings (early or late). The "early" split treatment consisting of either 2/3 of N applied prior to tuber initiation (early-loaded) and 1/3 after tuber initiation, or 1/3 of N applied prior to tuber initiation and 2/3 after tuber initiation (late-loaded). Petioles were analyzed to assess effects of N management on plant NO_3 –N levels. In-season whole plant sampling was conducted to identify tuber density (tubers per unit area), N accumulation, and DM partitioning. The 25 cm seed piece spacing accumulated more DM and N in tubers. Nitrogen management significantly influenced DM and N partitioning between tubers and vines. High N rates applied early in the season significantly increased vine DM and N accumulation, but reduced tuber DM and N accumulation. Petiole NO_3- N correlated positively with rate and timing of N applications. The 33 cm spacing obtained higher petiole NO_3 –N levels at 72 and 101 days after planting (DAP). In-season specific gravity (SG) was reduced by N applications and the 33 cm seed piece spacing. Stems per unit area correlated positively with the number of tubers per unit area. The 33 cm spacing produced fewer tubers and stems per unit area, which resulted in larger tuber size and higher economic fry return. The results of this study show that low to moderate N rates applied with an "early" split (202E) appears to partition DM and N more effectively for Clearwater Russet grown for processing than when similar N rates or higher N rates are applied with "late" split treatments.

Introduction

Clearwater Russet has characteristics that make it an excellent processing variety, including high U.S. No 1 yield, few external defects, low glucose concentrations, few sugar ends and the ability to maintain light fry color and excellent texture over extended storage periods. Clearwater Russet is cold sweetening resistant, allowing it to be stored at a temperature of 7.2°C for up to 250 days without the need for reconditioning (Novy et al. 2010). In full-season trials conducted over a three-year period in California, Colorado, Idaho, Oregon, and Washington, Clearwater Russet produced total yields slightly lower than Ranger Russet and Russet Burbank, but averaged 2% and 30% higher U.S. No. 1 yields, respectively, across all states. Average SG of Clearwater Russet is comparable to Ranger Russet and significantly higher than Russet Burbank. (Novy et al. 2010). Increased interest in production of Clearwater Russet has created a need for agronomic research to assist growers in maximizing the potential of this new variety. This study seeks to explain how N rate, N application timing, and seed piece spacing influences the growth and N accumulations patterns of Clearwater Russet.

A number of studies have shown that N supply has a large effect on potato leaf area index (LAI), which is the leaf area produced per unit of ground area, with leaf area typically increasing as N application increases (Harris, 2012). In addition, the application of N often increases the size and number of leaves throughout the season (Hay and Walker, 1989; Jenkins and Mahmood, 2003). Conversely, reducing N supply has also been shown to reduce the magnitude of vine branching and growth (Jenkins and Mahmood, 2003). Applications of N also stimulate the growth of leaves, stems, and lateral branches for a longer duration of the season (Millard and MacKerron, 1986) by accelerating canopy development and delaying foliage senescence.

Nitrogen levels that influence canopy growth also effect the growth of tubers. A proper balance must be maintained between vine and tuber growth for optimal potato yields. Development of an oversized canopy is not beneficial, because plants cannot efficiently utilize all of the leaf area for production of carbohydrates. The LAI sufficiency range for maximum yield of potato is typically between 3 and 3.5 and an increase in LAI over 4 will usually not lead to increased DM production (Hay and Walker, 1989). The management goal, therefore, is to provide the crop with the amount of early season N that will enable it to maximize leaf area early and maintain it during season.

Tuber initiation, by definition, is the seasonal point at which new tubers are formed and generally lasts 10-14 days (Kleinkopf et al., 1981). There are multiple factors that influence tuber initiation such as day length and temperature (Haverkort and Struik, 2015). Tuber initiation is controlled by the balance of gibberillic and absissic acids, and other factors such as N fertilization. Although day length and temperature cannot be controlled in commercial production settings, N applications can be used to manipulate tuber initiation. Appropriate N applications allow the plant to initiate tuber growth at the optimum time.

Kleinkopf et al. (1981) concluded that plant growth habit (determinate vs. indeterminate) influences nutrient demands, which in turn influences tuber initiation. Tuber initiation and N uptake tend to start earlier for determinate varieties than indeterminate varieties. Thus early-season N applications are especially important for determinate varieties. On the other hand, high available N levels should be avoided at planting when indeterminate varieties are grown, since excess N can delay tuber initiation by 7 to 10 days (Kleinkopf et al., 1981; Kelling et al., 2015). This can be especially detrimental in areas with a short growing season due to a reduction in the length of the tuber bulking period. As a general guideline, research suggests pre-plant applications for indeterminate potato varieties be between 70 to 110 kg N per ha (Kelling et al. 2015).

Just as excessive N applications can delay tuber initiation, they can also delay tuber bulking (Hay and Walker, 1989). Once leaf area has reached the sufficiency range (3 to 3.5 LAI), further increases in bulking rate will not occur. Therefore, increasing vine and leaf area above the sufficiency range can be detrimental to total tuber yield (Alva, 2004).

Both dry matter and N accumulation follow similar developmental patterns in the potato plant (Alva et al., 2002) but DM accumulation lags behind N uptake. Kleinkopf et al. (1981) reported, that with the Russet Burbank variety, 60% of the total N required had been taken up by tuber initiation, but only 20% of the total DM had been produced.

Similarly at the end of tuber bulking plants had taken up 98% of total N, and only 80% of the final tuber weight had been produced. He concluded that N and carbohydrates from vines and roots must be translocated to the tubers during maturation in order to obtain maximum tuber yield.

Dry matter accumulation can be significantly impacted by N management. O'Berne and Cassidy (1990) found that DM production increased as N rates increased up to 50- 100 kg/ha, but applications of N over 150 kg/ha resulted in reduced DM in tubers. However, Sharifi et al., 2005 reported that applying N did not have an impact on tuber DM accumulation, but that vine DM increased as N rate increased.

Nitrogen application timing also impacts DM accumulation. Lower N application rates early in the growing season (within 50 days after emergence) results in lower vine dry weights (Vos, 1999). Conversely, applying high N rates early in the season tends to increase vine growth, which may or may not benefit tuber yield, depending on whether the resulting LAI is optimal for maximum yield. Because different potato varieties may have unique partitioning patterns (Sharifi et al., 2005), understanding how N and DM are partitioned within specific varieties should lead to improved management strategies.

Seed piece spacing impacts the density of stems and tubers, with wider seed spacing producing fewer stems and tubers per unit area (Bussan et al., 2007, Love and Thompson-Johns, 1999; Zebarth et al., 2006; Kumar et al., 2013). Lower tuber densities often lead to larger average tuber sizes (Arsenault et al., 2001; White et al., 1974; Zebarth et al., 2006; Poljak et al., 2011). Different potato markets have unique demands for tuber size distributions. Some buyers pay premiums for tubers within specific size categories (Guenthner, 2003). Adjusting seed piece spacing, therefore, is a practical way to manipulate tuber set and size distribution (Blauer et al., 2013), and therefore capture size incentives to increase economic returns. Love and Thompson-Johns (1999) reported that for three russet type varieties (Russet Burbank, Frontier Russet and Ranger Russet) the best economic returns were obtained when stem densities were between 10.5 and 12.1 stems per meter of row and when tuber densities were between 23.9 and 24.9 tubers per meter of row.

The objectives of this study were to determine the effects of N management, and seed piece spacing on DM and N accumulation with in vines and tubers. In addition tuber density, stem density, and in-season changes in SG were also documented to identify how treatments influenced potato growth.

Materials and Methods

Field experiments were conducted on a Declo loam soil at the University of Idaho Research and Extension Center in Aberdeen, Idaho in 2015 and 2016. Treatments were established in a randomized complete block, split plot design, with N management treatments (combinations of N rate and N timing) as main plots and spacing treatments as sub-plots (Table 2.1). Spacing treatments included 25 cm and 33 cm in-row seed spacing in 91 cm-wide rows. Total N rates included an untreated check (0 N), and two N application rates: 202 kg/ha, and 269 kg/ha. To investigate the role of N application timing, N applications were made pre-plant, at tuber initiation (when tubers swelled to twice the diameter of the stolons), and in-season. The in-season N treatments were divided into three applications starting two weeks after tuber initiation, with an application being made every two weeks. Early or late loaded N splits were obtained by adjusting N rates for each N application (Table 2.1). The early (E) loaded split N treatment consisted of 2/3 of the total N applied between pre-plant and tuber initiation applications, with the remainder applied in-season (after the tuber initiation application). The late (L) loaded split treatment consisted of 1/3 of the total N applied between pre-plant and tuber initiation applications, with the remainder applied in-season. Resulting combinations of N rate and N application timing included 0 kg/ha (0), 202 kg/ha N applied early (202E), 202 kg/ha N applied late (202L), 269 kg/ha N applied early (269E), and 269 kg/ha N applied late (269L).

All N was applied using a hand-held broadcast applicator except for the pre-plant applications which were made using a tractor-mounted drop spreader. The pre-plant applications were incorporated with a harrow operation, while the other N applications were incorporated with 1.5 to 2 cm of sprinkler irrigation. Phosphorus, zinc, and manganese were applied (pre-plant) to all plots according to University of Idaho recommendations (Stark et al., 2004).

Plots of Clearwater Russet potatoes were planted on April 30th in 2015 and May 9th in 2016 with a two-row planter. Weeds were controlled by applying Eptam 7-E (5.84 L/ha), TriCor 4F (1.17 L/ha), and Matrix (109 ml/ha). Admire (584 ml/ha) was applied to control insects. Late blight was a concern in 2015, fungicides were applied on July 17th (Gavel 2.24 kg/ha), July 31st (Bravo 1.75 L/ha), August 14th (Gavel 2.24 kg/ha), and August 21st (Bravo 1.75 L/ha). All research plots were irrigated with a solid-set sprinkler system, scheduled to maintain available soil water content above 65% throughout tuber initiation and bulking.

The growing season was 16 days longer in 2015 with 151 days from planting to harvest, compared to 135 days in 2016. Growing degrees (GDs) were calculated using the following formula: GDs= $((T_{MAX}+T_{MIN})/2) - T_{BASE}$ (10°C). Growing degrees differed between years, with 1,246 GDs accumulated from planting to harvest, while only 1,103 GDs accumulated in 2016. Temperature fluctuations were greater in 2016, with higher highs and lower lows than in 2015 (Table 2.2).

Differences between years with regard to residual soil N concentrations were evident when comparing pre-plant soil test results. In 2015, residual N consisted of 19 mg/kg nitrate-N and 2 mg/kg ammonium- N, compared to 13 mg/kg nitrate-N and 3 mg/kg ammonium- N in 2016, resulting in 22 kg N/ha more in 2015 than in 2016. Complete soil test results can be found in Table 2.3.

Plots were six rows wide (5.46 m) and 12 m long, with 91 cm spacing between rows. Each plot contained a designated row for petiole sampling, a row for whole-plant sampling, a row for final harvest, and three buffer rows designed to maintain the integrity of normal plant competition throughout the growing season. The plot sampling arrangement worked well in 2016; but in 2015, some plants needed to be removed due to PVY infection. Consequently, some rows intended to be used for plant sampling were not able to be used as such because of the removal of plants. In that case, a different row that had plant competition on each side was selected and used as the sampling row.

Petioles were collected five times during each growing season. Beginning just prior to tuber initiation, petioles were taken every two weeks, ending two weeks after the last in-season N application. Petioles were sampled according to University of Idaho recommendations (Stark et al., 2004). Petiole NO_3-N values were determined using the Cataldo (1975) procedure. Stand and stem counts were recorded in 2016 just prior to tuber initiation to document the effect of spacing on plant and stem density.

Whole plant samples were collected at 57, 70, 84, 98, and 112 days after planting (DAP). One meter of row was harvested from each plot on each sampling date. Fresh vine and tuber weights were recorded, tuber SG was assessed (SG= (weight in air) / [(weight in air) – (weight in water)]), vines and tubers were dried, dry weights were recorded, and DM was calculated. Total vine and tuber N concentrations were measured using high-temperature combustion (VarioMax CN Alalyzer, Elementar Americas Inc.)

Data was analyzed with analysis of variance using the GLIMMIX procedure with a $P \leq 0.10$ criteria using SAS (Version 9.4, SAS institute Inc., 2002-2012, Cary, NC, USA). Means were separated by LSD (Least Significant Difference) test with $P \leq 0.10$.

Results and Discussion

Analysis of Variance

Analysis of variance (Table 3.1) revealed a statistically significant effect for year on all growth parameters. Nitrogen management significantly impacted vine DM, tuber DM, vine N accumulation, whole plant N accumulation and in-season SG. Seed piece spacing significantly affected vine DM, tuber DM, tuber N accumulation, whole plant N accumulation, in-season SG, petiole NO_3 –N, tuber density, and stem density. Sampling date significantly affected each growth parameter. Interactions between sampling date and N management occurred for many growth parameters (vine DM, tuber DM, tuber nitrate, vine nitrate, vine fresh weight, In-season SG, and petiole NO_3 –N). Interactions between seed piece spacing and sampling date were significant for tuber DM, vine N, and in-season SG. There were no significant interactions between seed piece spacing and N management for any of the growth parameters. There were no interactions between year and N treatments or between year and spacing treatments.

Dry Matter Accumulation

The 25 cm seed piece spacing treatment produced 15% more DM in tubers and 5% more in vines than the 33 cm spacing (Figure 3.1), which is consistent with higher total yields produced by the 25 cm spacing (Chapter 2). The 25 cm seed piece spacing produced significantly greater tuber DM at every sampling date beginning at 84 DAP (Figure 3.2). Differences in vine DM accumulation between spacing treatments were significant only at 70 DAP (Figure 3.3). Although not statistically significant, the 25 cm seed piece spacing tended to maintain higher mean vine DM values throughout the sampling season except at 98 DAP, where the 33 cm spacing appeared to have higher mean vine DM accumulation.

Nitrogen management treatments significantly influenced DM accumulation within vines and tubers (Table 3.2). Interestingly, the 0 N treatment produced the highest tuber DM, while the 202E, 269E, and 269L treatments produced significantly less. O'Berne and Cassidy (1990) reported that applications of N over 150 kg/ha resulted in reduced DM in tubers. In our study, vine DM showed the opposite response in that the 202L and 0 treatments had significantly lower vine DM yield than other higher N management treatments. This is in agreement with other research that indicates that higher N treatments cause the plant to accumulate more DM in the vines (Sharifi et al., 2005). Vos (1999) reported that applying less N during the early phase of the growing season (within 50 days after emergence) resulted in lower vine dry weights as opposed to large applications of N early in the season, showing that early N applications have a greater effect on the growth of vines. In our study, applying large N rates early in the season resulted in increased vine growth.

The 202E treatment produced medium amounts of vine and tuber DM, suggesting that the 202E treatment partitions DM intermediately between the two extreme treatments. Extrapolating these results suggests that lower N rates may have higher tuber DM yields in season, but higher N treatments would prolong the canopy duration (Millard and MacKerron, 1986) and in turn increase final yields, if the tuber bulking period was sufficiently long. The 202E treatment produced the highest economic returns (Chapter 2), signifying that of N treatments imposed in this study, this treatment partitioned DM in the most economically efficient manner.

High N rates (269 kg/ha) began accumulating more vine DM at 84 days after planting in comparison with the lower rates (Figure 3.4). By 98 DAP the 269L treatment had accumulated significantly more vine DM than all other treatments except the 202E treatment. Vine DM began to fall after 98 DAP, and by 112 DAP the 0 treatment had significantly less vine DM than the other treatments, which is to be expected given the lack of N available for new vine production.

Differences in tuber DM accumulation over time were observed at 84 DAP, where the 269E, 269L, and the 202E treatments exhibited lower tuber DM accumulation than the 0 treatment (Figure 3.5), showing that higher N rates early in the season delayed tuber bulking. Others have observed delayed tuber initiation and tuber bulking with additions of N (Hay and Walker, 1989). At 98 DAP the 0 N treatment had significantly higher tuber DM than all other treatments. By 112 DAP the 0 and 202L treatments had similar high tuber DM accumulation, while the other N treatments produced significantly less.

Nitrogen Accumulation

There were significant seed piece spacing effects on plant N accumulation. Tubers grown using the 25 cm spacing accumulated 15% more N (g/m^2) than tubers grown with the 33 cm spacing (Table 3.3). Although not significant at every sampling date the 25 cm spacing maintained higher mean tuber N levels throughout most of the sampling period (70-112 DAP) (Figure 3.6). There were no significant differences in vine N accumulation (g/m^2) between seed piece spacing treatments. Zebarth et al. (2006), also reported that seed piece spacing did not have an effect on vine N accumulation.

Differences in tuber N accumulation between N treatments (Figure 3.7) were not prominent until the last sampling date (112 DAP). At this point treatment 202L had accumulated significantly more N than all other treatments. The 269L, 269E, and 202E treatments accumulated more vine N than the 202L and 0 treatments. Overall, whole plant N (vines and tubers) accumulation increased with increased N rates. Several other research studies also showed that increased N application leads to higher whole plant N accumulation (Biemond and Vos, 1992; Sharifi et al., 2005; Zebarth et al., 2006).

Significant effects of N and sampling date on vine N accumulation were observed (Figure 3.8). Significant differences in vine N accumulation among N treatments developed by 70 DAP. The 269E and 202E treatments accumulated more N than the 0 treatment, while the 202 E had also accumulated more N than the 202L treatment. These results show that “early loaded” N applications result in higher N accumulation early in the season for Clearwater Russet. All treatments accumulated more N than the 0 treatment by 84 DAP, with the 269E treatment having the highest N accumulation. At 98 DAP the 269L, 269E, and 202E treatments had accumulated the most N, while the 202L had accumulated significantly less. On the last sampling date (112 DAP) the 269L treatment had higher N accumulation than all other treatments except 269E treatment. In addition N accumulation for the 202E treatment decreased at the end of the sampling period, and exhibited similar N accumulation to the 202L treatment.

Petiole NO_3 –N

Petiole NO_3-N concentrations were significantly affected by N application rate, generally increasing with increasing N rates (Figure 3.9). Predictably, “early” N applications produced higher NO_3 –N levels early in the season, while late N applications maintained higher NO_3 –N levels late in the season. The 0 N treatment had significantly lower NO_3 –N levels early in the season than the fertilized treatments, and values declined throughout the tuber bulking period.

Previous research that included monitoring of potato sap NO_3-N concentrations during the growing season showed that N application rate and timing are typically reflected in the trends observed for petiole N levels (Gardner and Jones, 1975; Porter and Sisson, 1991a). In our study, trends for “early loaded” N treatments (especially 202E) were as expected, with high petiole values early in the season and then a slow decline over time.

The same trends were observed by Millard and MacKerron, 1986 and Porter and Sisson, 1991a.

Spacing also significantly influenced petiole NO_3 –N levels, in that the 33 cm spacing showed significantly higher NO_3 –N levels at 72 and 101 DAP (Figure 3.10). Conversely White et al. (1974), reported that seed piece spacing had no effect on tissue nutrient levels.

Tuber and Stem Densities

The 25 cm spacing treatment produced 12.5 stems/ meter, while the 33 cm spacing treatment only produced 9.2 stems/meter (Figure 3.11). Stem and tuber densities tend to increase with decreased seed piece spacing (Bussan et al., 2007, Love and Thompson-Johns, 1999; Zebarth et al., 2006). Nitrogen management did not have an effect on tuber numbers or stem density in this study. In contrast Zebarth et al. (2006) reported that the number of stems per unit area was increased by N fertilization, when all N was applied at planting. This discrepancy may be explained by the design of our experiment, wherein N was applied throughout the season.

Seed piece spacing significantly influenced the number of tubers produced per meter of row. The 25 cm spacing produced 24.1 tubers/meter of row while the 33 cm spacing produced 19.2 (Figure 3.11). Other researchers have also found that wider seed piece spacing produces lower tuber densities (Kumar et al., 2013), and that lower tuber densities, often lead to larger average tuber size (Arsenault et al., 2001; White et al., 1974; Zebarth et al., 2006; Poljak et al., 2011). This response is consistent with the results of this study, which show that the 33 cm spacing had the larger tuber size distribution (Chapter 2).

As concluded in other studies, there was a relationship between the number of stems per unit area and the number of tubers per unit area and that increased stem density is directly correlated with higher tuber density (Bussan et al., 2007, Love and Thompson-Johns, 1999). Love and Thompson-Johns (1999) reported that for three russet type varieties (Russet Burbank, Frontier Russet and Ranger Russet) the best economic returns were obtained when stem densities were between 10.5 and 12.1 stems per meter of row and when tuber densities were between 23.9 and 24.9 tubers per meter of row.

From this data it appears that Clearwater Russet requires fewer tubers and stems per meter to obtain maximum economic returns than these three other russet varieties.

In-Season Tuber Specific Gravity

Adding N significantly reduced SG, which is an estimation of tuber DM density (Figure 3.12). These results are consistent with other research that shows reductions in SG with the addition of N (Kumar et al. 2013; Laboski and Kelling, 2007; White et al. 1974; Long et al. 2004; O'Bernie and Cassidy 1990; Belanger et al. 2002; Zebarth et al. 2004a; Sparrow and Chapman, 2003; Kelling et al. 2015; Porter and Sisson, 1991b). Interestingly, seed piece spacing also had a significant impact on in-season SG. The 25 cm spacing had a higher SG than the 33 cm spacing, 1.0771 compared to 1.0746. However, specific gravity measurements taken at harvest suggest that spacing does not have a significant effect on final SG (Chapter 2).

Summary and Conclusions

The results of this study show that Clearwater Russet grown at a 25 cm seed piece spacing accumulated more DM and N in tubers compared with a 33 cm spacing, which correlated to increased yields (Chapter 2). However, because tuber size distribution determines, in part, final economic fry returns, tuber density is important and stem density is correlated to tuber density. Even though the highest DM and tuber N occurred at the 25 cm seed spacing, the 33 cm spacing produced fewer tubers and stems per unit area, which translated to larger tuber size and higher economic fry return.

Petiole NO_3- N concentrations were positively correlated with rate and timing of N applications, with early N applications resulting in increased early petiole NO_3- N levels and late applications maintaining high NO_3- N levels later in the season. In-season SG was reduced by N applications and by the wider 33 cm seed piece spacing treatment.

Dry matter and N partitioning were significantly influenced by N application treatments. High N rates applied early in the season (202E, 269E, and 269L) significantly increased vine DM and N accumulation, but reduced tuber DM and N accumulation. We can conclude from these observations that N application rate and timing significantly influence DM and N partitioning between tubers and vines. However, the resulting effects on tuber size distribution also have a significant effect of economic return from processed potatoes.

Based on the results from this study, when growing Clearwater Russet for processing, low to moderate N rates applied with an “early-loaded” split (202E) appears to partition DM and N more effectively than similar or higher N rates applied with a “late-loaded” split.

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Tables

Table 3.1 Fixed effect values from analysis of variance (type III tests) for growth parameters. Significant Pr>F values denoted with bold faced font.

Parameters		year	N	Year*N	sp	N*sp	Year* sp	year*N* sp	time	N*time	sp* time	N*sp* time	year* time	year*N * time	year* sp* time	year*N* sp* time
Vine DM	Num DF	1	4	1	1	4	1	4	4	16	4	16	4	16	4	16
	F Value	34.24	5.98	0.78	4.38	1.15	0.01	1.84	264.98	1.76	1.34	0.49	31.08	0.58	1.20	0.76
	Pr > F	**0.0011**	**0.0017**	0.5493	**0.0450**	0.3538	0.9138	0.1478	**<.0001**	**0.0371**	0.2566	0.9522	**<.0001**	0.8966	0.3116	0.7297
Tuber DM	Num DF	1	4	1	1	4	1	4	3	12	3	12	3	12	3	12
	F Value	51.14	3.66	0.56	32.83	1.38	1.87	2.49	880.09	1.95	2.70	0.37	7.44	3.80	0.11	0.78
	Pr > F	**0.0004**	**0.0183**	0.6914	**<.0001**	0.2643	0.1818	**0.0646**	**<.0001**	**0.0313**	**0.0469**	0.9711	**0.0001**	**<.0001**	0.9569	0.6714
Vine N	Num DF	1	4	1	1	4	1	4	4	16	4	16	4	16	4	16
	F Value	33.93	27.65	1.00	0.91	1.16	0.00	0.93	178.55	6.01	2.48	0.41	26.45	1.02	2.04	0.54
	Pr > F	**0.0011**	**<.0001**	0.4261	0.3474	0.3477	0.9554	0.4596	**<.0001**	**<.0001**	**0.0448**	0.9793	**<.0001**	0.4390	**0.0895**	0.9248
Tuber N	Num DF	1	4	1	1	4	1	4	3	12	3	12	3	12	3	12
	F Value	35.87	1.66	3.24	20.31	1.49	0.04	1.10	711.87	3.09	2.10	0.89	5.11	3.68	1.20	1.10
	Pr > F	**0.0010**	0.1920	**0.0292**	**<.0001**	0.2300	0.8391	0.3754	**<.0001**	**0.0005**	0.1014	0.5574	**0.0020**	**<.0001**	0.3110	0.3664
Whole Plant N	Num DF	1	4	1	1	4	1	4	4	16	4	16	4	16	4	16
	F Value	7.35	15.99	1.69	2.17	1.31	0.00	0.97	436.55	5.57	2.17	0.73	10.17	1.08	2.60	0.54
	Pr > F	**0.0350**	**<.0001**	0.1842	**0.0308**	0.2900	0.9935	0.4376	**<.0001**	**<.0001**	**0.0729**	0.7628	**<.0001**	0.3717	**0.0367**	0.9258
In-season SG	Num DF	1	4	1	1	4	1	4	3	8	3	8	3	8	3	8
	F Value	256.75	12.87	1.42	17.25	0.96	0.38	3.89	366.90	1.83	3.19	1.14	14.42	0.96	0.19	1.95
	P Value	**<.0001**	**<.0001**	0.2581	**0.0003**	0.4418	0.5415	**0.0116**	**<.0001**	**0.0790**	**0.0450**	0.3431	**<.0001**	0.4726	0.8265	**0.0593**
Tuber Density	Num DF	1	4	1	1	4	1	4	3	12	3	12	3	12	3	12
	F Value	20.46	0.77	0.37	41.61	1.21	0.11	0.89	17.44	1.80	1.40	0.60	6.78	1.04	1.77	0.79
	Pr > F	**0.0040**	0.5528	0.8291	**<.0001**	0.3253	0.7431	0.4806	**<.0001**	0.0513	0.2453	0.8387	**0.0002**	0.4119	0.1548	0.6636
Stem Density	Num DF	-	4	-	1	4	-	-	-	-	-	-	-	-	-	-
	F Value	-	0.89	-	105.48	0.89	-	-	-	-	-	-	-	-	-	-
	Pr > F	-	0.5063	-	**<.0001**	0.5034	-	-	-	-	-	-	-	-	-	-
Petioles	Num DF	1	4	1	1	4	1	4	4	16	4	16	4	16	4	16
	F Value	8.59	100.48	1.27	3.13	0.15	1.52	0.53	151.85	13.19	0.63	0.54	82.45	0.80	0.67	0.39
	Pr > F	**0.0263**	**<.0001**	0.3088	**0.0869**	0.9599	0.2276	0.7111	**<.0001**	**<.0001**	0.6390	0.9238	**<.0001**	0.6836	0.6137	0.9842

Table 3.2 Effect of N management on dry matter accumulation (Mg/ha) within vines and tubers.

	Dry Matter Accumulation (Mg/ha)			
N Treatment	**Tuber**		**Vine**	
0	53.3	A	28.6	B
202L	48.5	AB	30.1	B
202E	44.6	B	32.6	A
269L	43.9	B	34.5	A
269E	43.7	B	33.1	A

Yields with in a column followed by the same letter are not statistically significant at $P \leq 0.1$

Table 3.3 Effect of seed piece spacing on nitrogen accumulation within tubers

	N Accumulation (g N/m^2)
Spacing Treatment	**Tuber**
25 cm	7.8 A
33 cm	6.7 B

Yields with in a column followed by the same letter are not statistically significant at $P \leq 0.1$

Figures and Descriptions

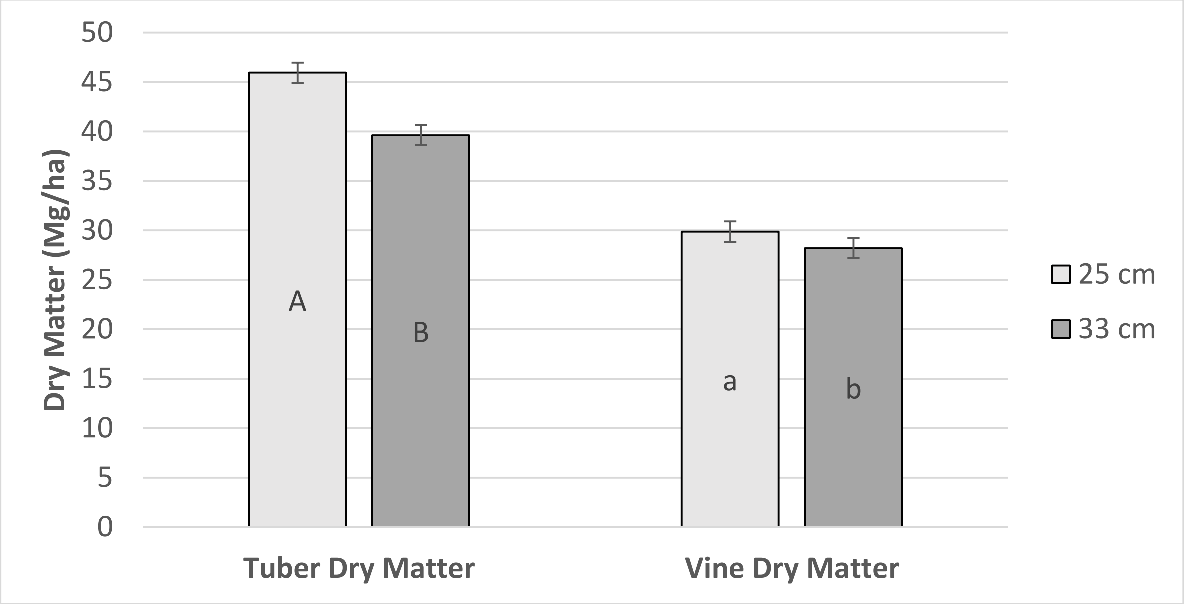

Figure 3.1 Effect of seed piece spacing on dry matter accumulation within vines and tubers. Bars with the same letter (and same growth parameter) are not statistically different at P ≤0.1

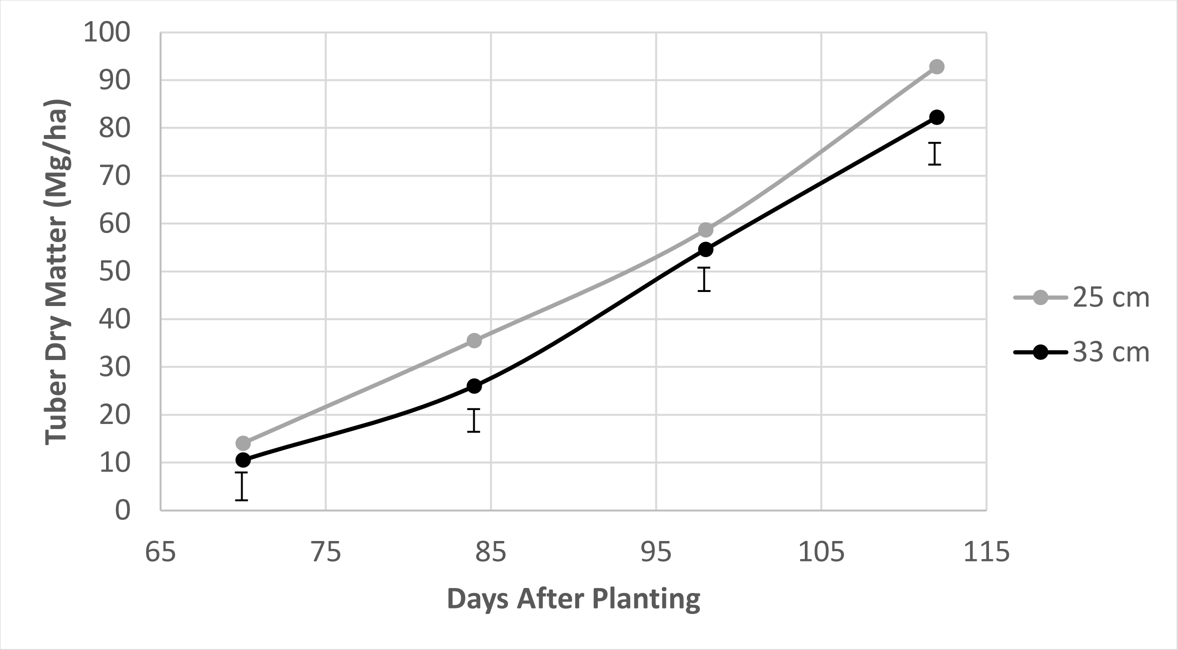

Figure 3.2 Effect of seed piece spacing on tuber dry matter accumulation across sampling dates. Error bars show least significant difference at P ≤0.1, for mean comparisons at each sampling date.

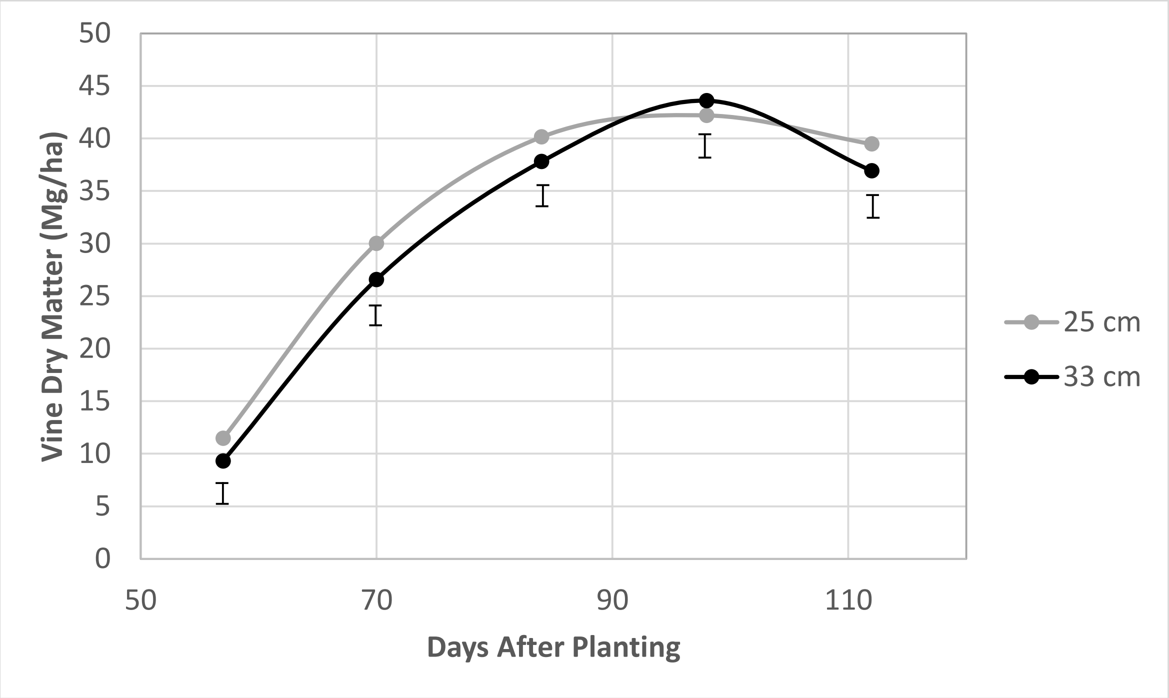

Figure 3.3 Effect of seed piece spacing on vine dry matter accumulation across sampling dates. Error bars show least significant difference at P ≤0.1, for mean comparisons at each sampling date.

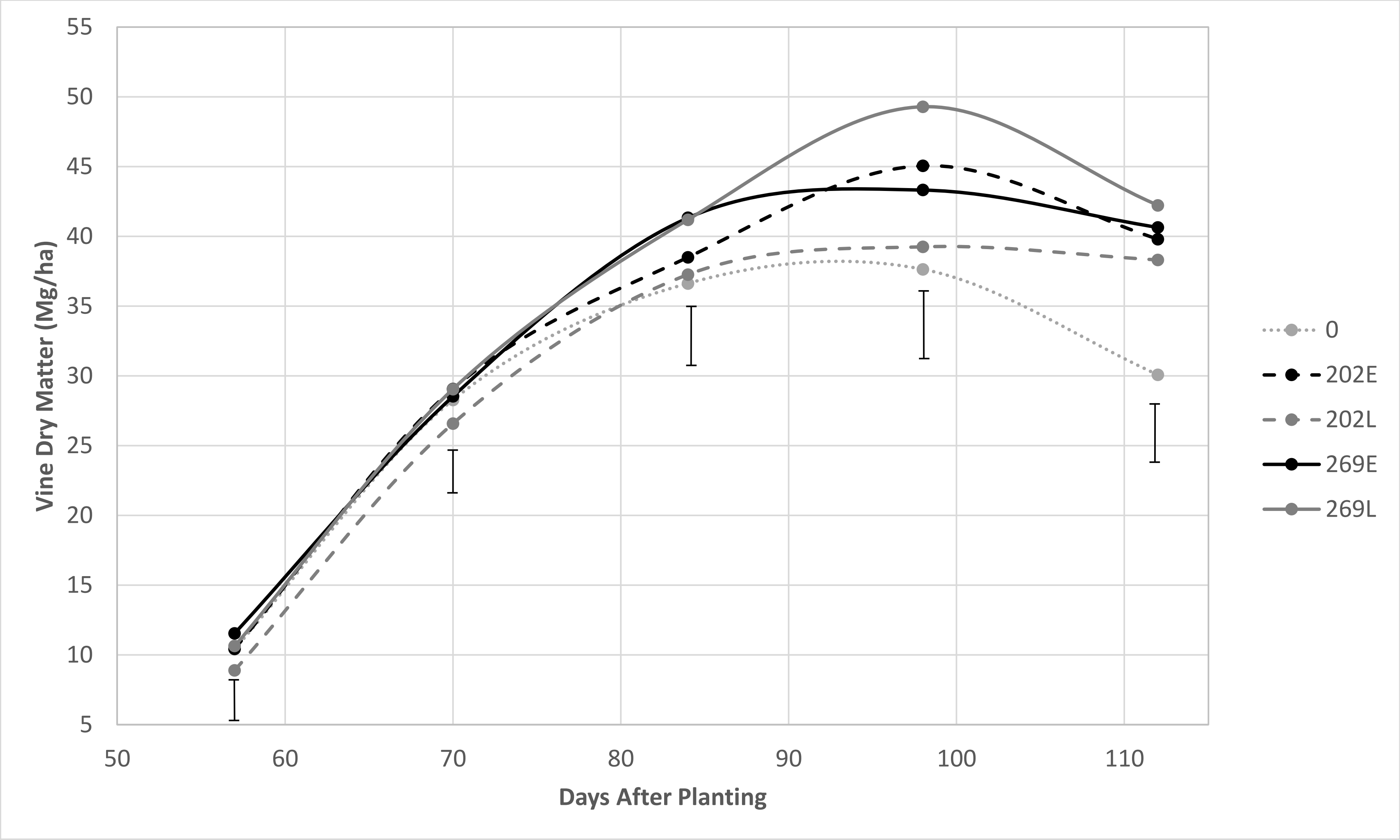

Figure 3.4 Effect of N management on vine dry matter accumulation across sampling dates. Error bars show least significant difference at P ≤0.1, for mean comparisons at each sampling date.

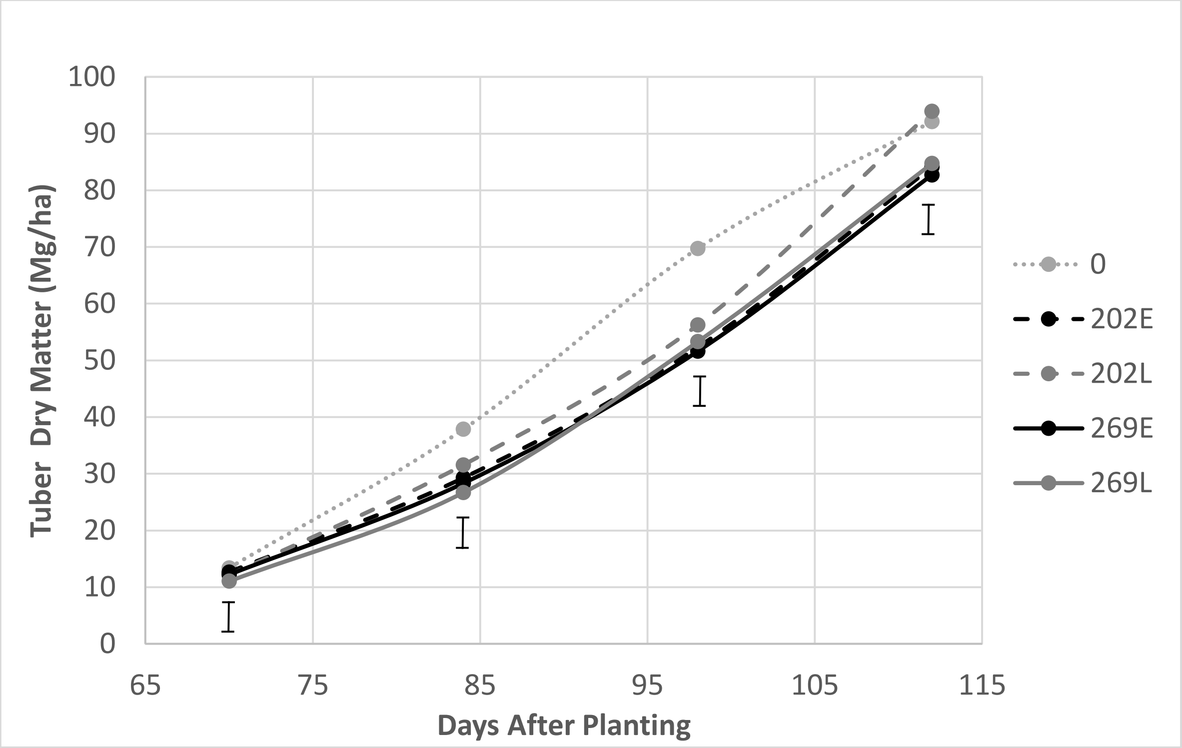

Figure 3.5 Effect of N management on tuber dry matter accumulation across sampling dates. Error bars show least significant difference at P ≤0.1, for mean comparisons at each sampling date.

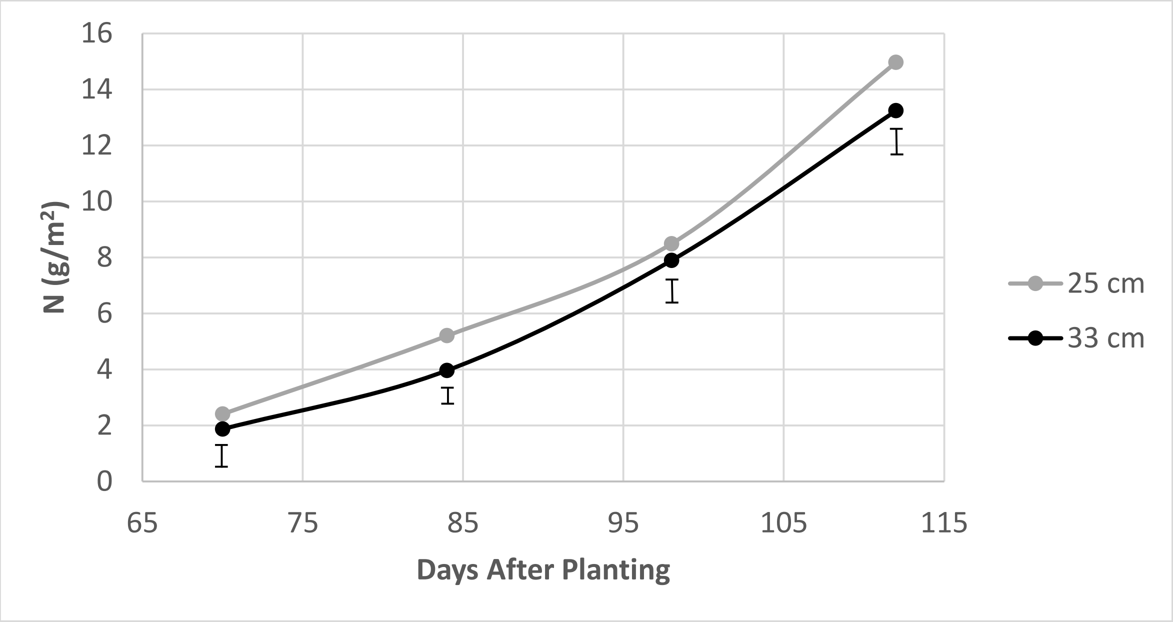

Figure 3.6 Effect of seed piece spacing on tuber N accumulation across sampling dates. Error bars show least significant difference at P ≤0.1, for mean comparisons at each sampling date.

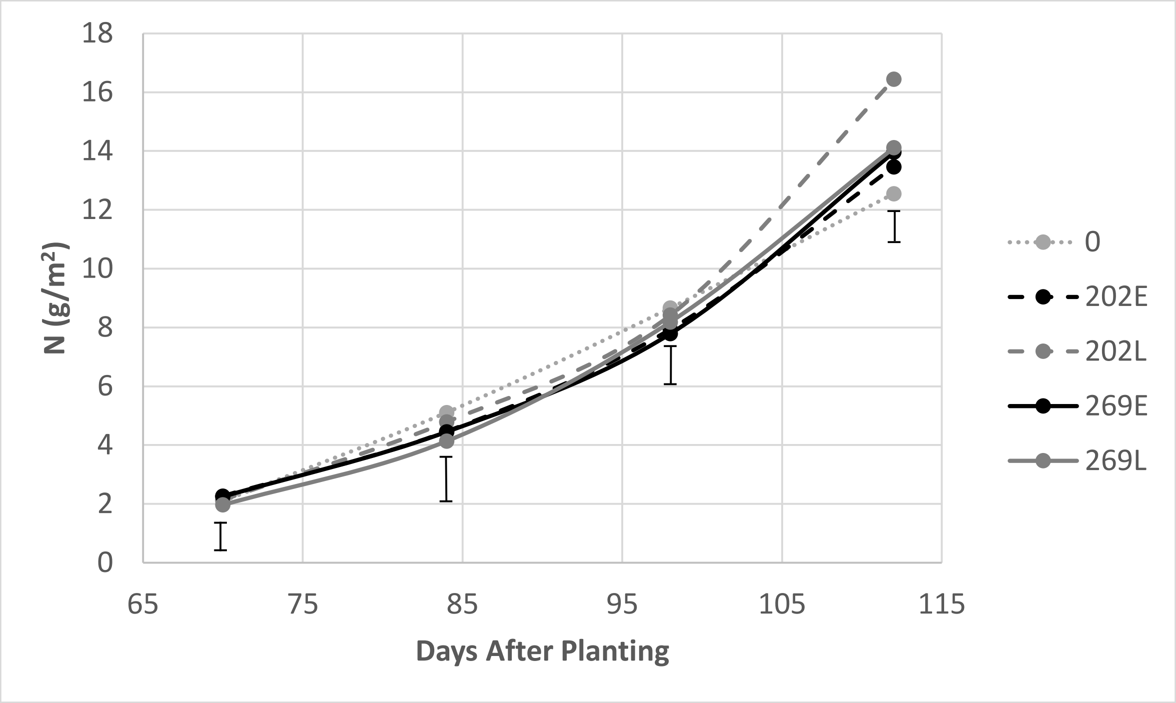

Figure 3.7 Effect of N management on tuber N accumulation across sampling dates. Error bars show least significant difference at P ≤0.1, for mean comparisons at each sampling date.

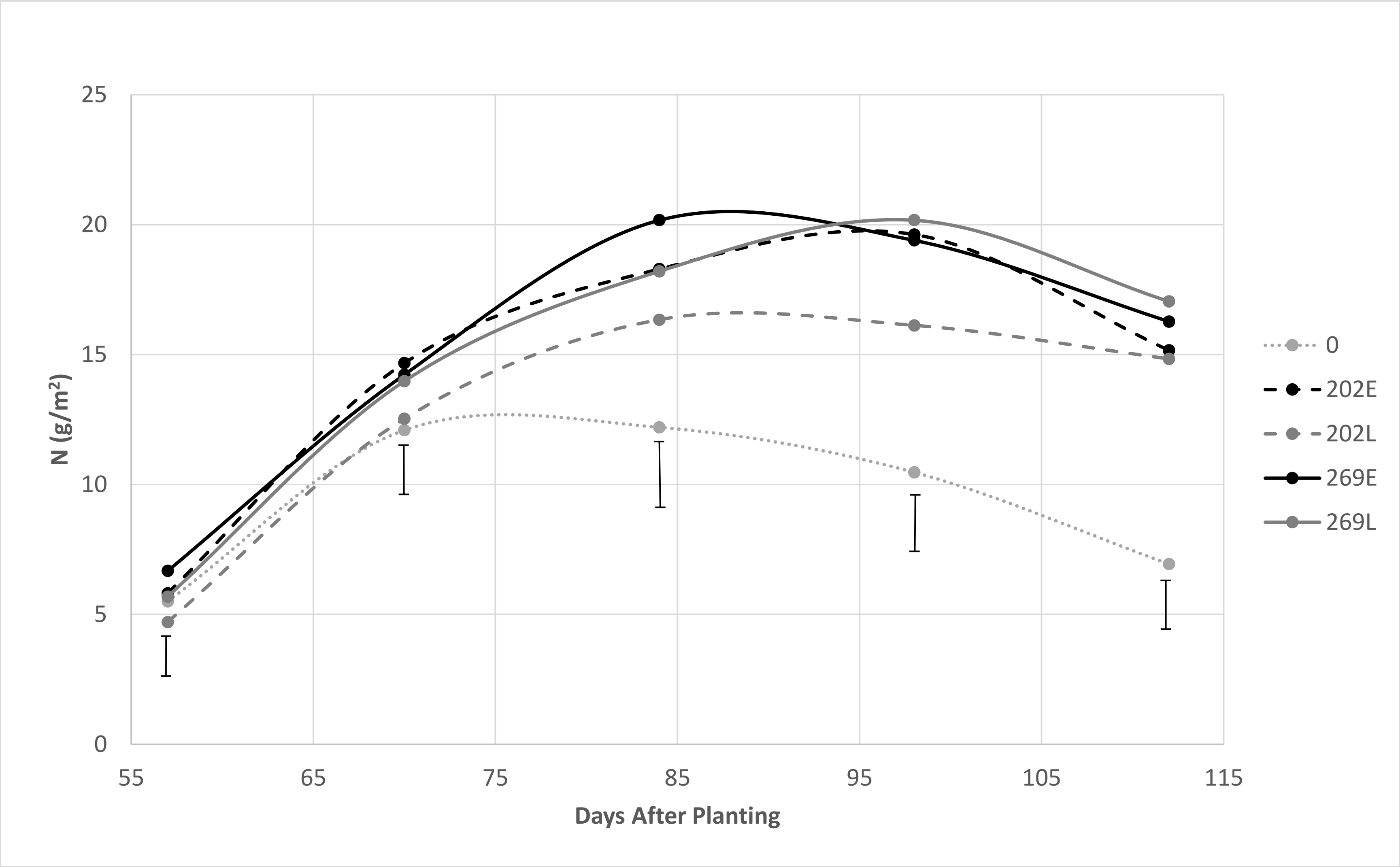

Figure 3.8 Effect of N management on vine N accumulation across sampling dates. Error bars show least significant difference at P ≤0.1, for mean comparisons at each sampling date.

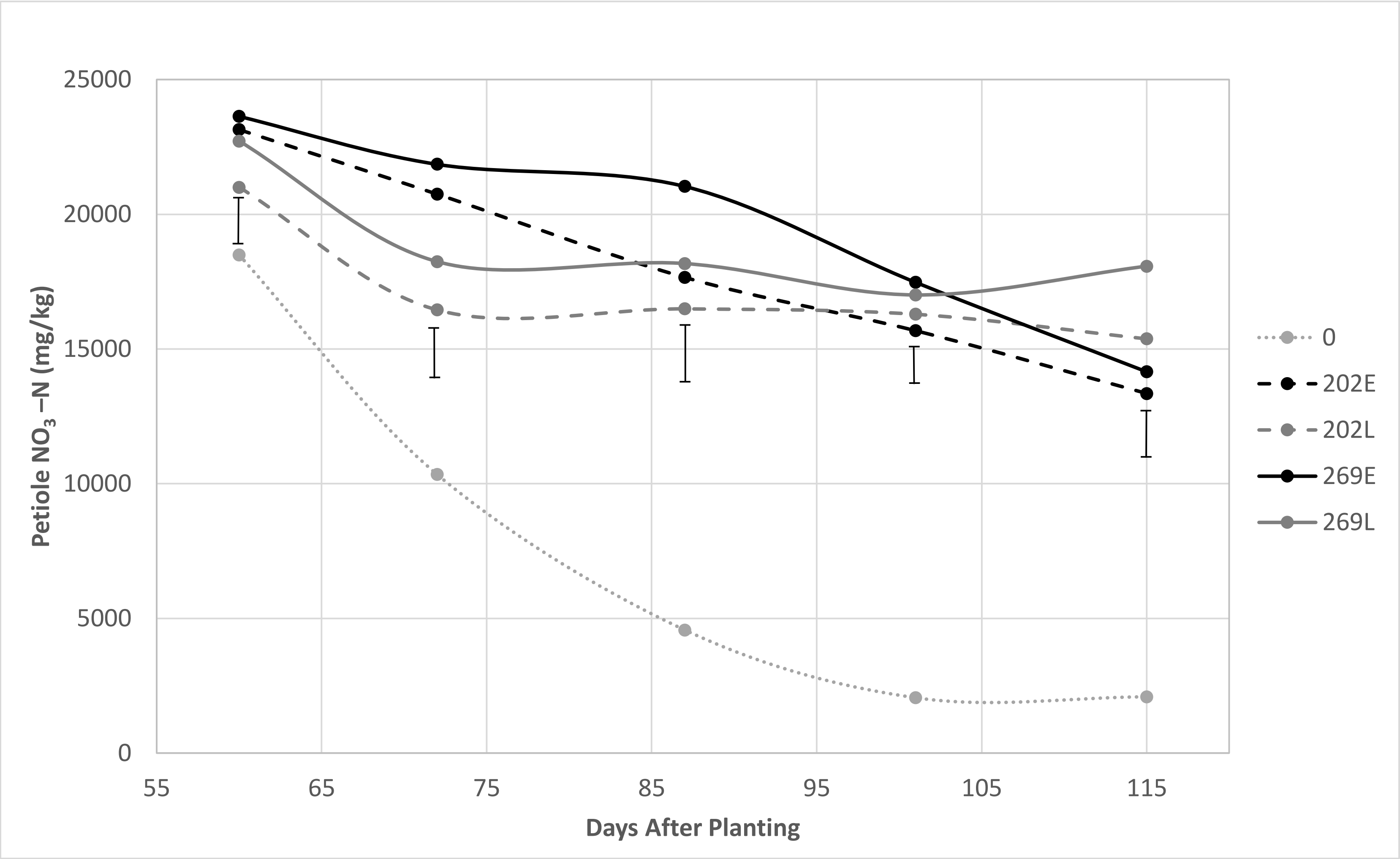

Figure 3.9 Effect of N management on petiole NO$_3$ –N across sampling dates. Error bars show least significant difference at P ≤0.1, for mean comparisons at each sampling date.

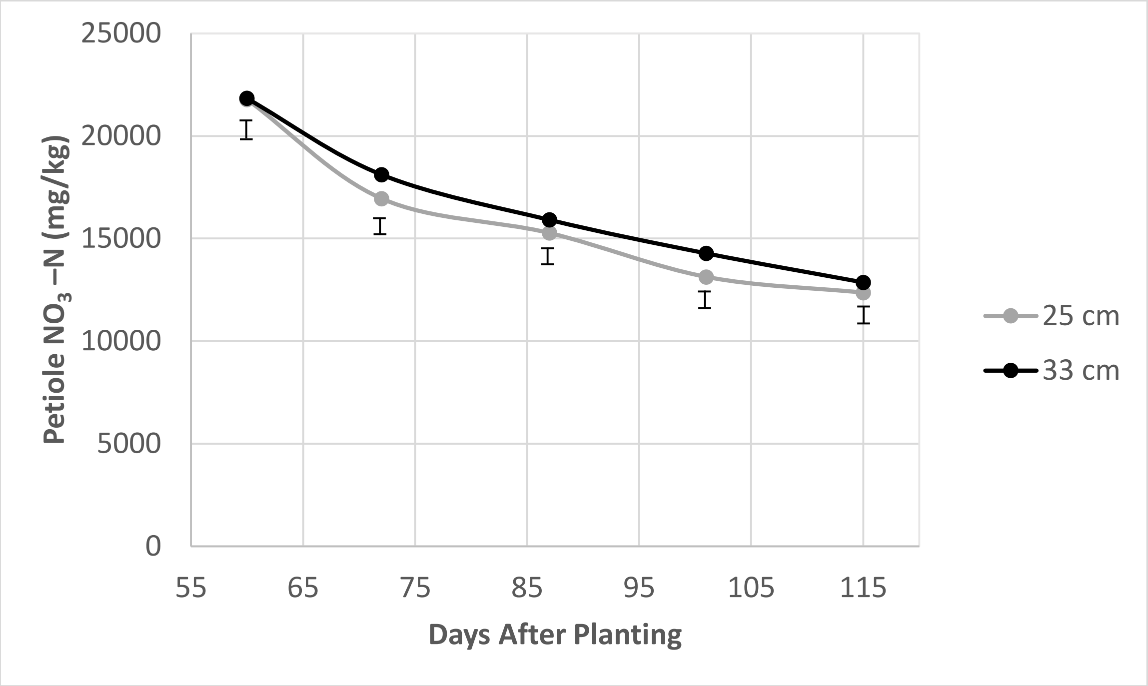

Figure 3.10 Effect of seed piece spacing on petiole NO_3 –N across sampling dates. Error bars show least significant difference at $P \leq 0.1$, for mean comparisons at each sampling date.

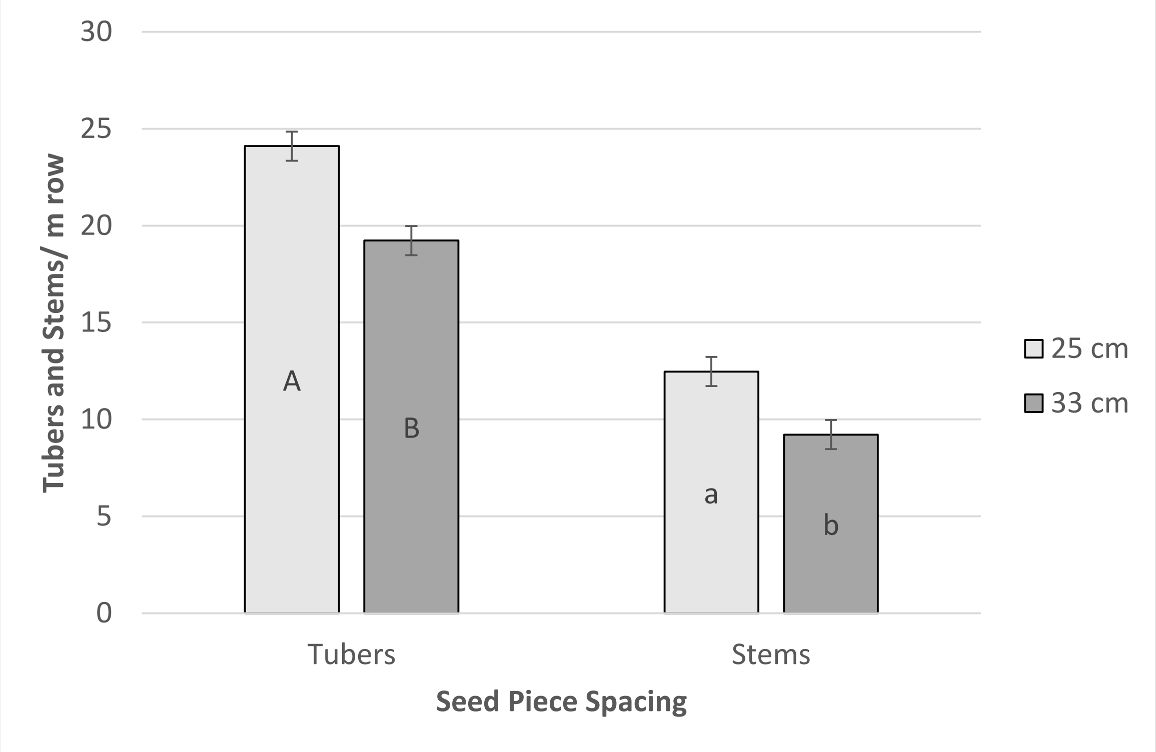

Figure 3.11 Effect of seed piece spacing on tuber and stem density. Bars with the same letter for the same category are not statistically different at P ≤0.1.

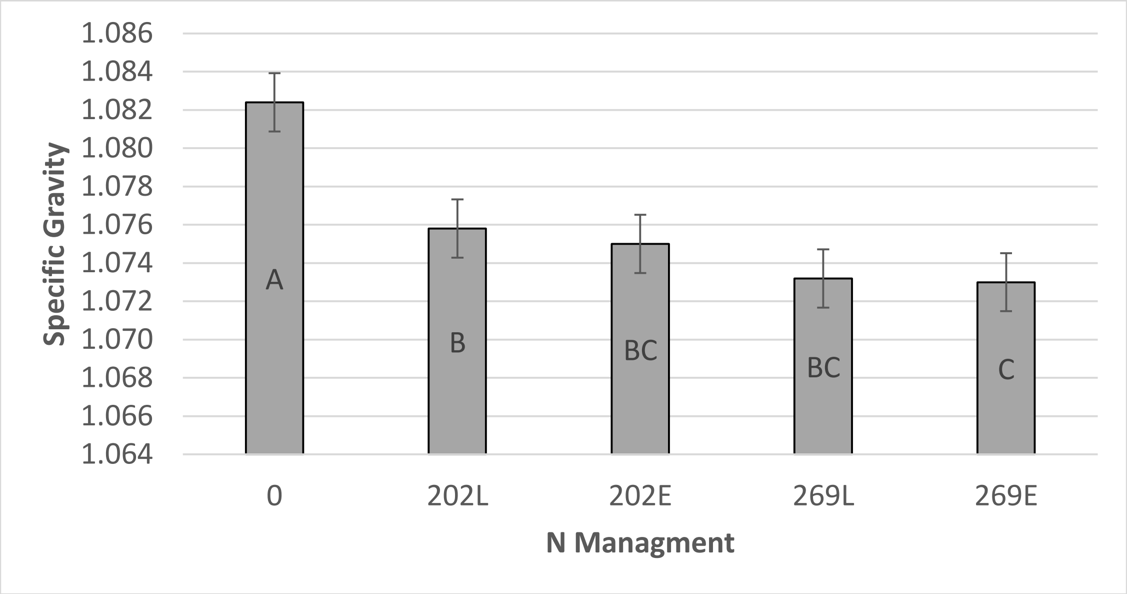

Figure 3.12 Effect of N management on in-season tuber specific gravity. Bars with the same letter are not statistically different at P ≤0.1.