PERFORMANCE OF RUSSET NORKOTAH LINE SELECTIONS AT DIFFERENT RATES OF NITROGEN

Submitted by
Kent P. Sather
Department of Horticulture and
Landscape Architecture

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY KENT P. SATHER ENTITLED **PERFORMANCE OF RUSSET NORKOTAH LINE SELECTIONS AT DIFFERENT RATES OF NITROGEN** BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate Work

Adviser: Dr. Asunta L. Thompson

Co-Adviser: Dr. David G. Holm

Committee Member: Dr. Scott J. Nissen

Department Head: Dr. Stephen J. Wallner

ABSTRACT OF THESIS

PERFORMANCE OF RUSSET NORKOTAH LINE SELECTIONS AT DIFFERENT RATES OF NITROGEN

Russet Norkotah line selections may be utilized to increase yields and profitability while reducing nitrogen applications normally required when producing Russet Norkotah. The *Solanum tuberosum* L. cultivar, Russet Norkotah, has increased in acreage since its release in 1987. Since the early 1990's, several breeding programs have made line selections that possess superior production potential under lower nitrogen rates. Five line selections and Russet Norkotah, were grown for two years at three rates of nitrogen in the San Luis Valley, Colorado. Selections included were Colorado 3 (CO3), Colorado 8 (CO8), Texas 112 (TXNS112), Texas 223 (TXNS223), and Texas 278 (TXNS278). The low, medium and high rates of nitrogen applied were approximately 100, 148 and 192 kilograms per hectare, respectively.

Total and marketable yields generally increased as nitrogen rates increased. Yields were fairly consistent between years, except for standard Russet Norkotah. In 1998, selections at the low rate out yielded Russet Norkotah under higher rates. In 1999, selections grown under the low rate yielded similarly to Russet Norkotah at the high rate. Selections grown at the medium and high rate yielded significantly more. CO3 was the best producer overall. As vine fresh weight increased, tuber yield also increased. These results indicate acceptable tuber yields may be attained with Russet Norkotah line selections grown at lower nitrogen rates than currently used for standard Russet Norkotah production. Using Russet Norkotah line selections may result in increased profitability by increasing yields and reducing input costs, and may also minimize nitrogen loss due to leaching and run-off.

Kent P. Sather
Horticulture and Landscape Architecture Department
Colorado State University
Fort Collins, CO 80523
Spring 2003

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INTRODUCTION

Nitrogen (N) management in agricultural crops has been the focus of research projects for many years (Gardner *et al.* 1985). The importance of N as an essential element in plant nutrition was established in the nineteenth century (Follet *et al.* 1981). Generalized fertilizer management, however, is no longer accurate or appropriate. Soil type and variability, residual nutrients, utilization by different crops and even growth of specific cultivars affect crop yield and quality (Kunkle and Thorton 1986). These factors are important in planning fertility programs. Results generated from research encourage new management practices for the grower. Modern-day N management continues to develop and change as new issues arise.

Managing N fertility is of particular importance in raising a potato (*Solanum tuberosum* L.) crop (Westermann and Kleinkopf 1985; Ojala *et al.* 1990; Vos 1997). Over 561,319 hectares of potatoes were planted in the United States in 2000 (National Potato Council 2001). As new cultivars are developed and released and as yield potentials change, N management practices must be reevaluated and modified to ensure economical application by the grower for efficient use of the crop (Shimshi and Susnoschi 1985). Insufficient N may restrict growth of plants and reduce yields (Ojala *et al.* 1990; Reeve *et al.* 1971; Reeve *et al.* 1973). Over fertilizing a crop may cause immaturity and reduce tuber quality (Iritani 1984; Timm and Flocker, 1966; Kleinkopf *et al.* 1981). Surplus N may also impact the environment since it is very mobile in the soil, has the potential to leach into ground water and can move with surface water (Plissey 1999; Delgado *et al.* 2001).

The fertility program used for potato production depends greatly on the cultivar that is grown. Cultivars that effectively take up and efficiently utilize N may require less than cultivars that are inefficient users (Tyler *et al.* 1983). More than seventy-two cultivars were grown in certified seed programs across the United States in 2000 (National Potato Council 2001). More are introduced annually through new releases (Chase and Davidson 2001) and importation. Managing fertility programs for optimal production of diverse cultivars under varying environmental conditions continues to be an ongoing challenge.

The North Dakota release, Russet Norkotah (Johansen *et al.* 1988), has been widely accepted by the potato industry. While the original cultivar continues to have popularity after fourteen years of commercial production, other cultivar development programs have succeeded in identifying line selections that have better agronomic characteristics than the mother clone (Holm 1998; Miller *et al.* 1999). Indications are that these selections require less N, produce better yields and maintain quality, when compared to standard Russet Norkotah. While certified seed acreage of Russet Norkotah selections has increased dramatically in the past several years in Colorado (Colorado Certified Seed Potatoes Directory 1995, 1996, 1997, 1998, 1999), detailed management information comparing N levels and production characteristics of the selections remains incomplete. The selections may have different N requirements than standard Russet Norkotah.

The objective of this project was to investigate and compare growth, yield and quality characteristics of several Russet Norkotah selections to standard Russet Norkotah, using three different N application rates. This information will contribute to the development of updated cultivar specific management profiles, providing optimum N management information for each selection. This information will maximize yield, tuber quality, and reduce production costs for the selections. Lower N requirements should also minimize the potential for nitrate leaching or movement with surface water.

LITERATURE REVIEW

Nitrogen

N is a necessary element for the growth and development of plants (Salisbury and Ross 1978). It is a constituent of many plant physiological elements including amino acids, amides, amines, proteins, nucleotides and nucleic acids, which contribute to the actual basis of life function. For example, amino acids are the building blocks of proteins, and proteins are used in the process of transferring genetic information from generation to generation (Follett *et al.* 1981; Salisbury and Ross 1978; Thompson-Johns 1999).

N can be taken up by plants as nitrate (NO_3^-) or ammonium (NH_4^+) (Gardner *et al.* 1985). Davis *et al.* (1986) found that NH_4^+ is detrimental to potato growth when it is the sole supply of N available. Plants mostly take up the NO_3^- form, due to rapid conversion of NH_4^+ to NO_3^- in the soil (Gardner *et al.* 1985). Nitrification depends on factors including microbial populations, the presence of inhibitors, moisture, temperature, soil pH, aeration, nutrient supply and organic matter (Barber 1995). Nitrate nitrogen (NO_3^-N)

moves with soil water to plant roots, where uptake can occur (Soil Improvement Committee and California Fertilizer Association 1985; Thompson-Johns 1999).

Once roots have taken up NO_3^-, nitrate reductase reduces NO_3^- to nitrite, and, in turn, nitrite eventually is reduced to ammonium (Follett *et al.* 1981; Salisbury and Ross 1978). This reduction is the first step in the formation of proteins. The supply of N is an environmental factor that affects the rate of conversion of NO_3^- to ammonium (Follett *et al.* 1981; Salisbury and Ross 1978). NO_3^- reductase activity in the plant increases as additional NO_3^-N is supplied. This increases the plant's ability to reduce NO_3^- to ammonium (Follett *et al.* 1981; Salisbury and Ross 1978).

Several forms of N exist in the environment. Physical and biological processes continually convert these forms, creating the nitrogen cycle (Barber 1995). The atmosphere contains 78% of N in the form of N_2, but it is difficult for organisms to obtain this form. Even so, this is the ultimate source of N. Fixation or reduction of N_2 needs to take place before it is available to plants (Soil Improvement Committee and California Fertilizer Association 1985). This is done biologically by microorganisms and commercially by industrial fixation. Commercial fertilizer forms include gas, liquid or dry. All are equally effective for plant uptake, if managed properly. Nitrous oxide and ammonium are formed by internal combustion engines, electrical storms, forest fires and industrial burning and can be washed to earth with rain (Salisbury and Ross 1978). Decaying organic matter is another important source of returning N to the soil. Once in NO_3^- form, N is available for plant uptake, and, due to its mobility, is also subject to leaching (Barbarick 1981).

Despite natural forms of N in the environment, many factors contribute to widespread low soil N levels. They include NO_3^- leaching, denitrification, volatization, crop N uptake and low soil organic matter content (required for N mineralization) (Stevenson 1982). As a result, additional N is necessary to produce high yielding potato crops in most soils.

N needs of a potato crop depend primarily on the length of the growing season and the cultivar being grown (Westermann 1993). Proper rates and timing can produce maximum yields and reduce losses due to leaching (Ojala *et al.* 1990). Late season applications may delay crop maturity (Timm and Flocker 1966), increase susceptibility to certain pathogens (Westermann and Davis 1992), interfere with the process of tuber maturity and skin set and increase difficulty in vine-killing operations (Thorton and Timm 1990). Demands for nutrients may exceed uptake rates during periods of high tuber growth rates (Moorby 1968). This may cause depletion of mobile nutrients in the vines, resulting in premature canopy senescence and a reduction of final yield (Ojala *et al.* 1990).

Many studies have been performed to determine yield and quality responses to varying amounts of N. Iritani (1984) showed fertility imbalance may cause overly mature tubers. These tubers tend to build up more sugars and do not store well compared to properly fertilized, mature tubers. Storage problems include shrink, higher bruise and rot susceptibility and premature sprouting.

Tuber malformations are another physiological disorder that may result from inadequate or over-fertilization during tuber initiation and bulking. Malformations may include knobby tubers, where lateral growth of buds has occurred, and growth cracks or splits in the outer flesh and skin of the tuber (Ojala 1988).

Specific gravity often is indicative of tuber maturity. Tubers able to complete the growth cycle without periods of stress generally will have a normal specific gravity (Westermann 1993). N supply can have an effect on this characteristic. High N rates may delay the tuber-bulking period and reduce potential yield and specific gravity (Kleinkopf *et al.*, 1981). Conversely, low N rates may cause stress and early vine death resulting in yield loss, which may increase specific gravity (Kleinschmidt 1984; Ojala *et al.* 1990; O'Beirne and Cassidy 1990; Herrman *et al.* 1995).

Arsenault and Malone (1999) found there was no effect on US No. 1 yields of NorWis and AC Novachip with increasing fertilizer rates. Increased N fertilization may have a negative effect on dry matter, while increasing the yield and the NO_3^- content of Spunta tubers (Cleomeis and Dogras 1990). Inconsistent results with Russet Norkotah and Spartan Pearl were found over a two year study (Chase *et al.* 1990). A significant yield increase in response to increased N application happened only one of two years. Santerre *et al.* (1986) determined that higher N levels actually reduced the total yield for early harvests of cultivars they studied, but had no significant effect upon later harvests.

Gardner and Jones (1975) found 160 kg/ha of N adequate for maximum tuber yield of Russet Burbank grown in Idaho. Lauer (1986) recommended rates of 300 – 400 kg/ha of N to raise maximum yields of Russet Burbank potatoes grown in Washington state. This contrast may be due to the longer growing season in Washington. O'Beirne and Cassidy (1990) reported an increase of total yield of five cultivars with increased N rates only to a point. N rates in excess of 150 kg ha^{-1} produced no significant yield increase.

Jefferies *et al.* (1991) concluded that the goal of high yield and quality tubers can only be realized by good agronomic practice, including proper application of agrochemicals.

Results of Iritani and Weller (1987) found that increased rates of N from 140 to 280 kg/ha did not produce an increase in total yield for Russet Burbank grown in Washington. Westermann *et al.* (1994) examined Russet Burbank tubers for yield and specific gravity at different N application rates of 0, 112, 224, and 336 kg/ha in Utah. Yield decreased at the highest N rate. They also showed that the two highest rates decreased specific gravity.

In another experiment, Westermann *et al.* (1994) evaluated Russet Burbank tubers for sugar and starch content based on plots grown with different treatments of N and potassium fertilizer rates. As N rates increased, tuber dry matter content in both the apical and stem end was reduced, with the highest reduction in the apical end. Excess N increased sugars in the apical end and decreased sugars in the stem end. This research concluded that for production of a high quality crop, growers should avoid using more N than the crop requires.

Higher tuber yields have been obtained with 35% less N using proper application management and irrigation scheduling (Saffigna *et al.* 1977). NO_3^- leaching was also reduced by 50% in this study. Roberts *et al.* (1982) found yields of potatoes under pivot irrigation did not significantly increase as N applications at planting increased. Higher N rates decreased yields of US No.1 potatoes compared to lower N rates which produced fewer second growth and misshapen potatoes.

Joren and Vitosh (1995a) evaluated the effects of two levels (112 and 168 kg/ha) of applied N on tuber yield and quality, dry matter production and N uptake of the Russet Burbank cultivar grown on irrigated sandy soils. While specific gravity was not affected, acceptable total yields and US No.1 tuber yields can be obtained from the lower N rate as compared to the higher N rate. Additional data from the same experiment showed the lower N rate reduced the net loss of N from the soil.

High applications of N can also cause physiological differences in tubers. Physiological traits, including leaf permeability, leaf water potential, photosynthesis rates and tuber dry matter, and tuber quality of several cultivars were compared when grown under different amounts of irrigation water and top dressings of N (Shimshi and Susnoschi 1985). As amounts of irrigated N decreased, dry matter content of the cultivars increased.

Adequate N rates may be a deterrent to diseases causing yield loss. Decreased crop yields can be associated with increased foliar early blight severity (Davis *et al.* 1990). Infection rates of potato early blight caused by *Alternaria solani* were shown to be reduced by applying increased rates of N fertilizer (MacKenzie 1981). The association of N fertilizer rates, tuber yields and early blight severity needs to be economically evaluated to establish current N fertilizer recommendations (Soultanpour and Harrison 1974). Westerman and Davis (1992) note that extensive foliar canopy may be caused by excessive applications of N. The moist microclimate created may promote foliar diseases such as blackleg or *Sclerotinia* stalk rot. Tuber diseases related to high humidity and moisture like pink rot or leak may also proliferate (Powelson *et al.* 1993). Late blight is another tuber disease that may develop with high humidity (Stevenson 1993).

Leaf area duration can be a determinant of potato yield (Dyson and Watson 1971). Plant leaf growth and branching determine leaf area index at different stages of growth. Potato production can be explained by quantitative evaluation of these dynamics in response to environmental variables. N availability is one variable that might affect leaf growth and branching. Vos (1995) compared the interaction between stem densities on leaf attributes and branching with N supply finding that variable stem density in a crop may modify crop response to N. He also found N availability per stem in dense populations is lower than in more open stands. In this study, the specific leaf area was not affected by N, but did increase with stem density. Previous research (Iritani *et al.* 1983) showed a decreased yield of U.S. No. 1 tubers as stem numbers increased.

Excessive application of N at the wrong time may reduce the quality of surface and ground water (Dahnke *et al.* 1993). Over fertilizing permits N to leach beneath the root zone, potentially causing groundwater contamination. Errebhi *et al.* (1998) found lower NO_3^-N leaching when reduced amounts of N were applied at planting. They also found plants had higher N recovery and improved marketable yields. Costa *et al.* (1997) suggested a moderate water shortage would improve N use efficiency without compromising yield, reducing the possible N losses through a higher recovery of the amount applied.

Shallow rooting of potato permits more movement of NO_3^-N below the root zone. Potatoes are commonly grown on course-textured soils (Thorton and Sieczka 1980).

Root systems tend to be shallow, limiting the efficiency of nutrient uptake (DeRoo and Waggoner 1961; Lesczynski and Tanner 1976). Depending on the cultivar and soil type, depth of potato root systems can range between 0.5 (Ovaa and de Smet 1984) and 1.0 m (Vos and Groenwold 1986) with about 85% of the length being concentrated in the upper 0.3 m (Lesczynski and Tanner 1976). A plant's capacity for N uptake directly affects the amount of N left in the soil after harvest. Delgado *et al.* (2001) found significantly greater levels of NO_3^-N below shallower root zones of potatoes compared to deeper root systems of barley. Post harvest soil N recovery provides an indication of N uptake efficiency of the plant, as well as NO_3^- leaching potential. Several studies have shown soil N recovery levels ranging between 25 and 33% (Gerwing *et al.* 1979; Tyler *et al.* 1983; Joren and Vitosh 1995b). This raises several questions. Can post harvest soil N recovery be reduced? Would lower recovery levels lessen the potential for groundwater contamination? Can decreasing overall N application reduce soil N recovery? Can this also be done by identifying cultivars that efficiently 'mine' N?

While discussing potato nutritional challenges into the future, Westermann and Davies (1992) concluded that it is necessary for research to focus on providing accurate information to aid in management decisions. Topics include understanding the nutritional characteristics and requirements of each cultivar, as well as, fertilization and tillage effects on N use efficiency. Understanding responses to nutrient availability can maximize plant growth and nutrient use efficiency.

Cultivar Selection

Traditional potato breeding programs have produced many successful potato cultivars (Chase and Davidson 2001). Selection and development of successful cultivars has resulted in benefits for the potato producer and targeted markets that are supplied (Dean 1994). Different end markets of the potato industry have played important roles in the acceptance of experimental and newly released cultivars.

The entrenchment of a cultivar in normal production does not necessarily signal the end of its development. Opportunities may still exist to improve the cultivar; one tool is line selection within that cultivar for improved characteristics. New selections may result from somatic mutations. Improvements may include higher yields, better skin color and increased vine vigor, among others. An example of this type of cultivar improvement is reported by Holm (1988). He was able to select strains of Sangre (Twomey *et al.* 1982) that demonstrated superior characteristics including plant size, maturity, total yield and marketable yield. Earlier examples of successful line selections include Russet Burbank, Irish Cobbler, Red Triumph, Russet Sebago and Red LaSoda (Miller 1954). More recent examples include Sangre Selections 10, 11, and 14 (Holm 1988), Norgold Russet Strains M, 35, and 19, Red LaSoda Strains 5 and 10, and Superior Strain 'New' (Leever *et al.* 1994).

Not all selections, however, demonstrate improved characteristics. Love *et al.* (1992) compared Russet Burbank clones from various geographical locations across North America. One objective of this study was to determine if the selected clones were unique, by demonstrating superior qualities. They found this was the case, but only to a slight degree. Subtle differences were detected including total yield, emergence, stem numbers and *Verticillium* susceptibility. However, the clones were very similar, when comparing traits like specific gravity, blackspot bruise potential and fry scores. Despite geographical selection and sufficient time since Russet Burbank had been in production, they concluded that no serious selection pressure had been applied to improve the easily recognizable traits of this cultivar.

Fresh market suppliers watched with interest the development and eventual release of a new cultivar in 1987. Russet Norkotah, a long, smooth, shallow-eyed, russet-skinned potato with wide adaptation, was released by Dr. Robert Johansen *et al.* (1988) of North Dakota State University. Tubers of Russet Norkotah set early, however, this cultivar was classified as having a medium late maturity under North Dakota growing conditions. It was an excellent candidate for the count carton market due to its high production of US No.1 tubers. The fresh market industry began to demand Russet Norkotah from its producers. Seed and commercial acreage quickly increased over the past decade and Russet Norkotah currently ranks second of all cultivars being grown in North America (NPC 2001). Seed acreage approved in 2001 was 7042 hectares, second only after Russet Burbank (NPC 2001). This translates into an estimated 64,752 hectares planted in the United States, or about ten percent of the total crop.

Despite the popularity of Russet Norkotah, it has limitations. One example is a limited root system (Miller *et al.* 1999). Tyler *et al.* (1983) demonstrated higher post-harvest soil N levels under smaller plants with a limited root system. The diminutive rooting characteristic of Russet Norkotah creates inefficiency in nutrient uptake, resulting in high fertilizer requirements and the potential for higher residual soil N. Russet Norkotah also has a weak vine and is susceptible to *Verticillium* wilt and PVY (Johansen *et al.* 1988). Coupled with these limitations and its commercial acceptance, line selection of Russet Norkotah was initiated.

In 1989, Dr. Creighton Miller, Jr. of Texas A&M University identified selections from Russet Norkotah through the Texas Potato Variety Development Program. That year, Dr. Miller and his staff made a total of 375 selections from Russet Norkotah fields planted in Colorado and Texas. Selection pressure was for tuber yield and type. Thirteen selections were entered into replicated trials running from 1992 to 1997 (Miller *et al.* 1999). In Western Regional Trials, these selections often out yield standard Russet Norkotah by 20 to 30% (Pavek *et al.* 1997). Three promising selections advanced by Dr. Miller are Texas Norkotah Strain (TXNS) 112, TXNS223 and TXNS278. All of these selections exhibit greater yields, stronger vines and more extensive root systems compared to standard Russet Norkotah.

Dr. David G. Holm of Colorado State University began research in 1990 to identify superior Russet Norkotah selections. In 1990 and 1991, he made fifty selections. He continued these selections in field evaluations and grower trials from 1991 to 1994. He and his staff identified two Colorado (CO) selections, CO3 and CO8, as performing better than standard Russet Norkotah. Significant differences included greater total yield, larger tuber size, increased vine vigor, increased plant height and later vine maturity (Holm 1998). These selections also demonstrated increased total yield and US #1 yield compared to Russet Norkotah in the Western Regional Trials (Pavek *et al.* 1997).

MATERIALS AND METHODS

Field evaluations were conducted on Dunal cobbly sandy loam (sandy-skeletal, mixed, frigid Typic Torriorthent) and Norte gravelly sandy loam (Loamy-skeletal, mixed, calcareous, frigid Aquic Ustorthent) (Soil Survey 1980) in 1998 and 1999, respectively, at the Colorado State University, San Luis Valley Research Center at Center, CO to evaluate growth characteristics of potato clones grown under different rates of N.

Russet Norkotah and five selections, CO3, CO8, TXNS112, TXNS223, and TXNS278, were grown in a factorial split plot design, replicated three times in 1998 and four times in 1999. N rates of approximately 100, 148 and 192 kg/ha (low, medium, and high, respectively) were main plot treatments and potato clones were subplots. The previous crop in the plot area for each year was barley.

A soil analysis to determine residual N was taken prior to planting each year. Plots in 1998 had residuals of 48 kg/ha. Plots in 1999 had residuals of 45 kg/ha.

Certified seed was hand cut with disinfected knives and allowed to suberize prior to planting. Planting dates were May 12, 1998 and May 25, 1999. Single row plots were 30 meters long, with 30 centimeter within-row spacing, and 86 centimeter between-row spacing. Guard rows were not used between experimental units. Previous studies demonstrate that no significant cross feeding occurs when inner rows were compared with guard rows of potatoes (Maier *et al.* 1991; Timm *et al.* 1983).

Except for N applications, cultural practices typical of the growing area were utilized. Appropriate crop pesticides were applied as needed. Plots received approximately 6 cm of precipitation and 34.5 cm of irrigation in 1998 for a total of 40.5 cm. In 1999 they received 10 cm of rain and 27.5 cm of irrigation for a total of 37.5 cm. NO_3^- residues in the irrigation water tested at 0.8 kg N per ha cm, totaling about 28 kg/ha in 1998. Irrigation in 1999 from a different well added only 0.16 kg N per ha cm totaling approximately 4.4 kg/ha. Slight hail damage occurred 60 days after planting (dap) in 1999. Growing degree days (daily high temperature + daily low temperature/2 - 7°C) (Appendix A) and soil/air temperatures (Appendix B, C) were similar, with only slight differences, for each year.

Split applications of N were made during the growing season to attain desired levels for plots for each year (Table 1, Table 2). Final low N rates were 22 units less in 1998 than 1999. Medium and high N rates were equivalent, respectively, both years.

Table 1. N credits and applications (t/h) for 1998 factorial split plot design.

	Low	**Medium**	**High**
Residual NO_3^- Credit	48	48	48
Pre-Plant	0	0	0
63 dap	6[b]	22[a] 6[b]	22[a] 6[b]
66 dap		22[b]	22[b]
85 dap			22[b]
94 dap			22[a]
97 dap		22[b]	22[b]
Irrigation NO_3^- Credit	28	28	28
TOTAL	82	148	192

[a] granular fertilizer 46-0-0
[b] liquid fertilizer 28-0-0-5S

Table 2. N credits and applications (t/h) for 1999 factorial split plot design.

	Low	Medium	High
Residual NO_3^- Credit	45	45	45
PrePlant, Liquid	56	56	56
34 dap		22 [a]	22 [a]
59 dap		22 [b]	22 [b]
72 dap			22 [b]
86 dap			22 [b]
Irrigation NO_3^- Credit	4	4	4
TOTAL	104	148	192

[a] granular fertilizer 46-0-0
[b] liquid fertilizer 28-0-0-5S

Weekly destructive harvests took place after plants emerged. This was initiated 30 dap in 1998 totaling twelve harvests, and 29 dap for eleven harvests in 1999. Five plants per plot were sampled each week. Data collected included plant height, number of stems per plot, fresh weight of vines, roots (including stolons) and tubers. After desiccation, dry weight of vines and dry weight of roots were recorded. Tubers were separated into four weight (size) categories, <114g, 114-170g, 170-342g, and >342g, with weight and number of tubers in each category recorded. Total weight and number of harvested tubers were recorded. Petiole samples were taken 79, 86, 93, and 100 dap in 1998 to monitor N status. Ten petioles, the fourth leaf from the growing tip, were sampled from each plot. After drying and grinding, petiole tissue was analyzed for NO_3-N by a specific-ion electrode (Milham *et al.* 1970). Statistical analyses of destructive harvest data were made with the SAS mixed procedure (SAS 1987) with repetition within years being a random variable. Significance of fixed effects was determined using the appropriate F-tests as determined by the SATTERTH option in the mixed procedure.

Vines of remaining hills were chemically desiccated with sulfuric acid 108 dap (August 28) in 1998 and 99 dap (September 1) in 1999. Tubers were harvested 124 dap (September 13) for 1998, and 112 dap (September 14) for 1999. Yield data were collected for 3 meters of harvested plot row in 1998 and 7.6 meters in 1999. Data collected included yield and grade components, internal defects and specific gravity. Grade and internal defects were determined according to the United States Department of Agriculture (USDA, 1991) grading standards. Ten tubers >342g per plot were sliced lengthwise and examined for internal defects, including hollow heart, internal purpling, and vascular discoloration of stem ends. Specific gravity was determined by the weight in air/weight in water method (Kleinkopf *et al.* 1987).

Statistical analyses of final yield data were made with the SAS mixed procedure (SAS 1987) with repetition within year being a random variable. Significance of fixed effects was determined using the appropriate F-tests as determined by the SATTERTH option in the mixed procedure.

RESULTS AND DISCUSSION

Destructive Harvest

A combined analysis of destructive harvest results for several growth characteristics was performed. A mixed procedure (SAS 1987) was used to process data. The focus of these results and discussion is on the trend of growth over years for each selection and Russet Norkotah. For this reason, a variable with significant year effect is not considered for these results and discussion.

Root Fresh Weight

Year, clone, nitrogen, year x clone, and clone x nitrogen were effects that showed significant differences of root fresh weight of selections and Russet Norkotah when destructive harvest data were analyzed (Table 3). Russet Norkotah produced the least weight of root mass as the summer progressed (Figure 1). The selections were all similar in weight throughout the summer. Greater root weight would indicate more extensive root growth. Plants with deeper, more extensive root systems would have greater capability for N uptake (Lesczynski and Tanner 1976), allowing for increased production, and reducing N leeching (Delgado *et al.* 2001). This data suggests Russet Norkotah selections have greater yield potential than Russet Norkotah.

Table 3. Analysis of variance for root fresh weight for Russet Norkotah and selections.

Effect	d. f.	F. Value	Pr > F
year	1	45.85	0.0011**
clone	5	50.29	<0.0001**
nitrogen	2	8.41	0.0072**
year x clone	5	27.31	<0.0001**
year x nitrogen	2	2.38	0.1425
clone x nitrogen	10	2.07	0.0448*
year x clone x nitrogen	10	1.74	0.0984
total	35		

*, ** Significant at ∝ = 0.05 and ∝ = 0.01, respectively.

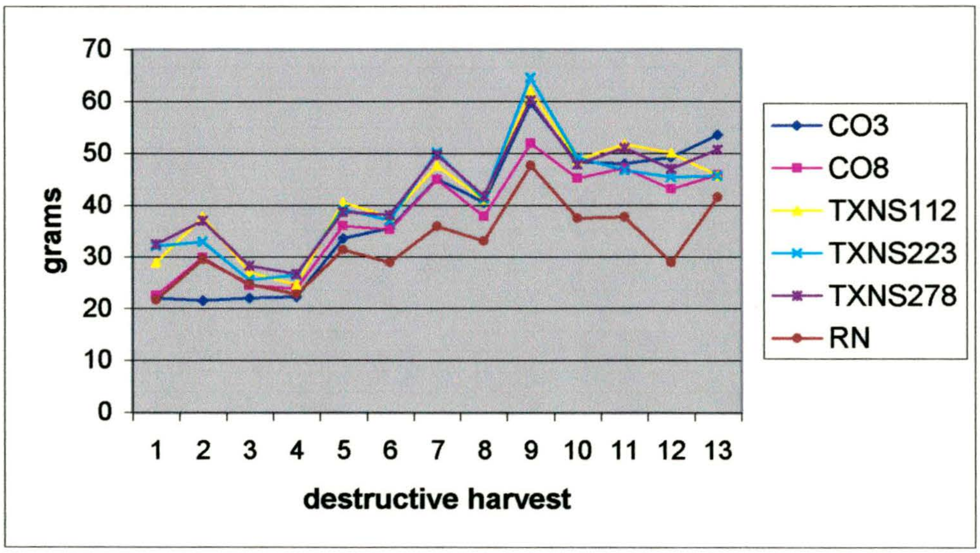


Figure 1. Root fresh weight per plant over two years.

Once roots were fully established (58 – 72 dap), N rates made no difference on root mass. At this point, continued N uptake may have been partitioned for development of other plant growth such as tuber bulking. Spikes in Figure 1 represent wet soil conditions during the destructive harvest as more soil adhered to roots when they were harvested.

Inconsistent root weight effects of N rates on root fresh weight were observed throughout destructive harvest dates. When comparing overall means, root weight with medium or high N was greater than weight with low N (Table 4). All selections at any rate of N had significantly greater root mass than Russet Norkotah grown at the low, medium or high rate of N (Table 5).

Table 4. Mean root fresh weight (g) for Russet Norkotah and selections over two years.

N rate	**Two Year Mean**
Low	36.7
Med	39.2
High	38.3
LSD (0.05)	1.0

Table 5. Mean root weight (g) for Russet Norkotah and selections by N rate over two years.

	Low	**Medium**	**High**
RN	32.1	33.4	32.7
3	35.9	37.9	37.2
8	36.2	37.4	37.2
112	39.3	43.0	39.7
223	36.8	41.9	43.0
278	40.6	42.4	40.8
LSD (0.05)		1.8	

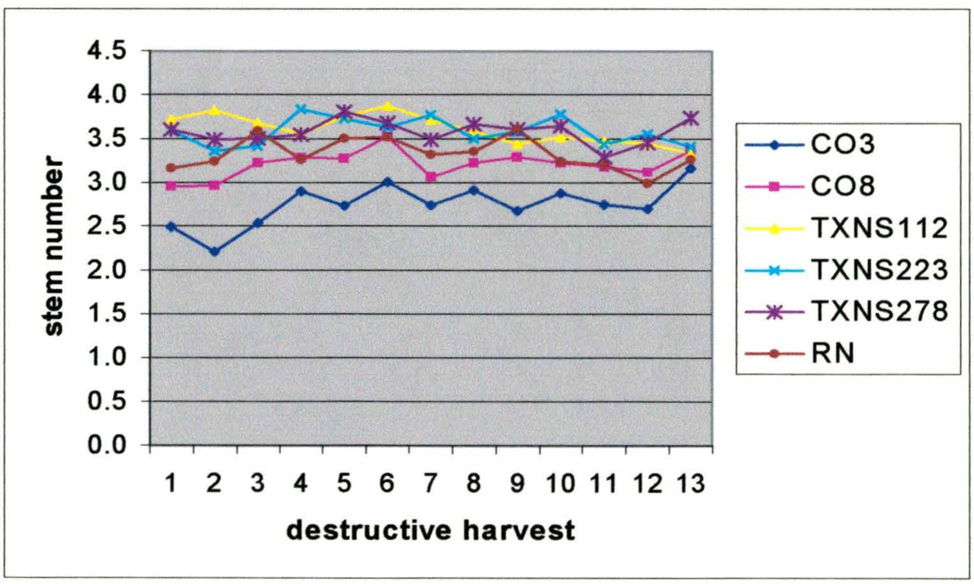
Stems per Plant

A combined analysis of stems per plant was performed (Table 6). Significant effects include year, clone, and the year x clone interaction. The number of stems per plant was established during the early growing season. Neither the amount of N applied nor the time of application seems to have an effect on stems per plant. For combined years (Figure 2), CO3 had the least number of stems compared to other selections and Russet Norkotah. Iritani *et al* (1972) showed a positive linear relationship between size of seed piece per stem and yield, with cut and whole seed of Russet Burbank at different spacing, inferring fewer numbers of stems per seed piece would produce greater yields. This would indicate production potential of larger tubers for CO3 compared to Russet Norkotah and the other selections.

Table 6. Analysis of variance for stem number for Russet Norkotah and selections.

Effect	d.f.	F Value	Pr > F
year	1	199.86	<0.0001**
clone	5	69.77	<0.0001**
nitrogen	2	3.58	0.0673
Year x clone	5	19.03	<0.0001**
Year x nitrogen	2	1.46	0.2779
Clone x nitrogen	10	1.52	0.1608
Year x clone x nitrogen	10	1.68	0.1115
Total	35		

** Significant at $\propto = 0.01$.



LSD (0.05) = 0.54

Figure 2. Stems per plant over two years.

Vine Height

Effects that had significant differences for vine height were year, clone, and nitrogen (Table 7). The year x clone interaction was also significant. Figure 3 shows vine height for combined years. All selections and Russet Norkotah grew at a similar rate until 58 days after planting (dap). Russet Norkotah growth rate slowed, becoming the shortest vine, while the selections continued to increase in height. CO3 continued to gain height at a faster rate than the other selections, becoming the tallest vine. All selections peaked in vine height at 79 dap. Height was maintained until vines were destroyed.

Vine height has been used as criteria in selection programs (Leever *et al.* 1994). Taller vines indicate larger, healthier vines, capable of later maturity and greater yields.

Table 7. Analysis of variance for vine height for Russet Norkotah and selections.

Effect	d. f.	F. Value	Pr > F
year	1	669.95	<0.0001**
clone	5	89.36	<0.0001**
nitrogen	2	15.97	0.0008**
Year x clone	5	12.81	<0.0001**
Year x nitrogen	2	0.85	0.4569
Clone x nitrogen	10	1.26	0.2772
Year x clone x nitrogen	10	1.82	0.0814
Total	35		

** Significant at $\propto = 0.01$.

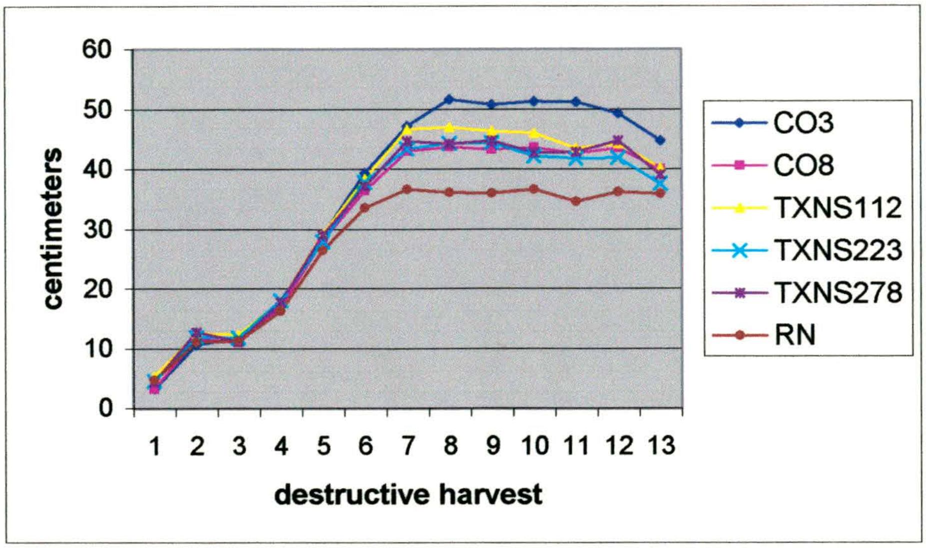


Figure 3. Height per plant over two years.

Plants responded positively as N rates increased from low to medium or high. There was no response in vine height when N rates were increased from medium to high (Table 8).

Table 8. Mean vine height (cm) for Russet Norkotah and selections over two years.

N Rate	Two Year Mean
Low	27.4
Medium	29.0
High	28.9
LSD (0.05)	0.5

Vine Fresh Weight

When vine fresh weight was analyzed for combined years, all effects and interactions were significantly different (Table 9).

Table 9. Analysis of variance for vine fresh weight for Russet Norkotah and selections.

Effect	d. f.	F. Value	Pr > F
year	1	95.07	0.0002**
clone	5	98.10	<0.0001**
nitrogen	2	99.49	<0.0001**
year x clone	5	22.12	<0.0001**
year x nitrogen	2	4.20	0.0474*
clone x nitrogen	10	2.74	0.0090**
year x clone x nitrogen	10	2.73	0.0092**
total	35		

*, ** Significant at $\propto = 0.05$ and $\propto = 0.01$, respectively.

All selections and Russet Norkotah increased in vine weight at a similar rate (Figure 4) early in the season. At 58 dap, Russet Norkotah continued to increase vine weight, but at a slower rate than the selections. All selections and Russet Norkotah increased vine weight until 79 dap. CO3 had the most weight per plant at this point. CO8 and the Texas selections were similar in weight, and Russet Norkotah had the least. Vine weight began to decrease as senescence was initiated and plants began to mature. More vine weight towards the end of the growing season indicates a later maturing vine (Dyson and Watson 1971). As with vine height, this would indicate selections with higher yield potential due to longer bulking periods. Based on results of this experiment, CO3 maintained the most fresh vine weight, indicating the greatest yield potential. Russet Norkotah had the least, indicating the lowest yield potential. CO8, TXNS112, TXNS223, and TXNS278 were similar in vine weight throughout the growing season, indicating greater yield potential than Russet Norkotah, but not as high as CO3.

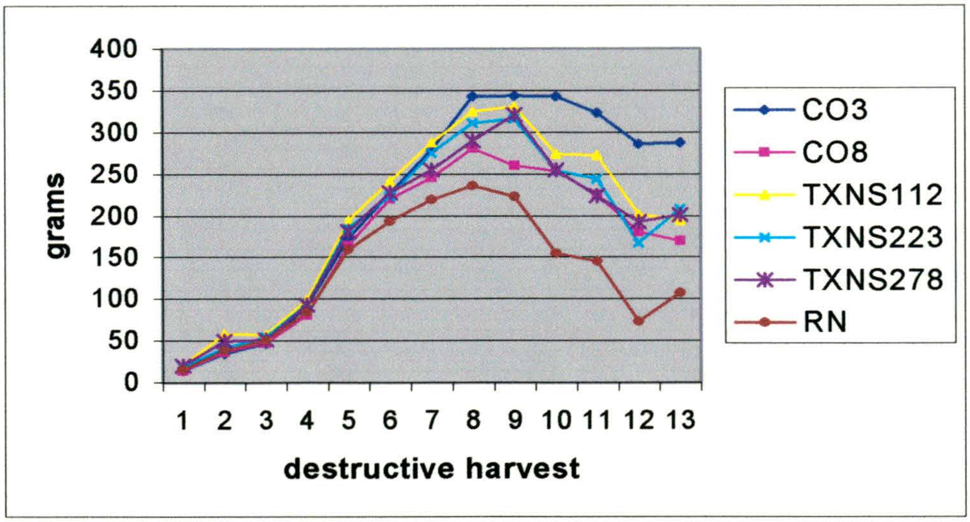


Figure 4. Vine fresh weight per plant over two years.

There were also significant differences in vine fresh weight production when N rates were compared (Table 10). Low N rates produced less vine fresh weight than medium or high rates. Medium rates produced more vine weight than either low or high early in the season. Later, however, there was no significant difference between medium and high N rates.

Table 10. Mean vine fresh weight (g) for Russet Norkotah and selections over two years.

N Rate	Two Year Mean
Low	131.0
Medium	172.9
High	168.0
LSD (0.05)	6.0

All selections grown at medium or high N rates produced more vine fresh weight than Russet Norkotah grown with any N rate (Table 11). These results are similar to vine height data discussed previously. Russet Norkotah produced the least weight of vine compared to selections, regardless of N rates applied.

Table 11. Mean vine fresh weight (g) for Russet Norkotah and selections by N rate over two years.

	Low	Medium	High
RN	107.9	134.6	132.4
3	145.2	194.0	183.5
8	125.3	166.9	148.2
112	147.7	196.9	187.0
223	129.3	181.2	186.2
278	134.7	171.8	179.3
LSD (0.05)		8.7	

Tuber Production

Tuber bulking was also analyzed with a mixed procedure (SAS 1987) combining destructive harvest data collected during both years. Size categories were tubers less than (<) 113 grams (g), 113 – 170 g, 170 – 340 g, and greater than (>) 340 g. Tubers <113 g are undesirable because of their small size. Plants producing tubers >113 g may provide the grower with greatest amount of marketable yield and best economic return. Total number and overall weight of tubers per plot were also recorded.

Year, clone, and year x clone interaction were the only significant effects for undersized tubers (<113) g per plant (Table 12). Those selections with fewest undersized tubers at the end of the growing season may have less undesirable production, based on size, for marketable yields. Figure 5 shows the comparisons of selections and Russet Norkotah during the growing season. All selections and Russet Norkotah began tuber initiation about the same time (44 dap). Because of this similar timetable, fertility applications for each selection and Russet Norkotah may be congruent. Timing and rates of N after this point may depend on differences between Russet Norkotah and selections, including vine growth, vine maturity and extent of tuber bulking. N requirements for the plant are elevated during this stage since both vine and tubers continue to increase in mass (Westermann and Kleinkopf 1985). At 72 dap, tuber size for all clones increased into the next weight category of 113 – 170 g, reducing the average weight per plant of undersized tubers. CO3 and TXNS278 ended the seasons with less weight of undersized tubers than Russet Norkotah and other selections. CO3 and TXNS278 production may result in fewer small potatoes, increasing the percentage of marketable yields after harvest.

Table 12. Analysis of variance for tubers <113 g for Russet Norkotah and selections.

Effect	d. f.	F. Value	Pr > F
year	1	95.07	<0.0001**
clone	5	98.10	<0.0001**
nitrogen	2	99.49	<0.0526
year x clone	5	22.12	<0.0001**
year x nitrogen	2	4.20	0.5643
clone x nitrogen	10	2.74	0.0984
year x clone x nitrogen	10	2.73	0.5031
total	35		

** Significant at $\alpha = 0.01$.

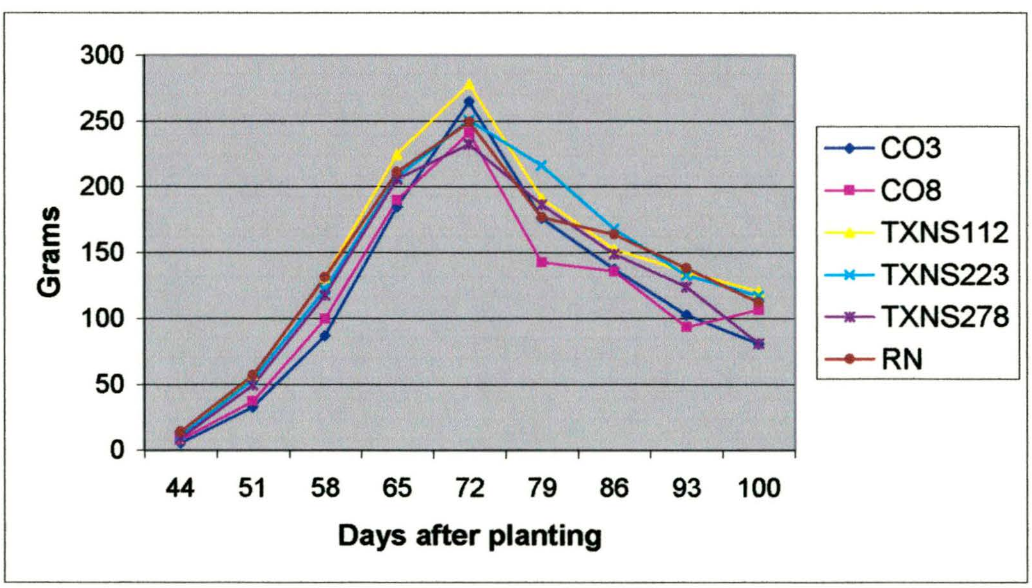


Figure 5. Tuber production per plant over two years: <113 g per plant.

There were no significant differences for combined years when tubers 113 – 170 g per plant were compared. All selections and Russet Norkotah produced similar bulking rates of this size range. Other studies have shown that increasing N will increase tuber size (Porter and Sisson 1991, Bélanger *et al.* 2002). All N rates used in this experiment were sufficient to size tubers to 113 - 170 g.

Significant differences were shown for clone, nitrogen and year x clone when comparing production of tubers weighing 170 – 340 g per plant (Table 13). All selections and Russet Norkotah began producing this size of tubers at the same time (72 dap), and initially, at the same rate (Figure 6). TXNS278 produced the most by the end of the season, projecting the best marketable yield. Russet Norkotah produced the least, indicating the least marketable yield. The other selections produced similar yields at the end of the season.

Table 13. Analysis of variance for tubers 170 – 340 g for Russet Norkotah and selections.

Effect	d. f.	F. Value	Pr > F
year	1	95.07	0.9925
clone	5	98.10	0.0109*
nitrogen	2	99.49	<0.0001**
year x clone	5	22.12	0.0035**
year x nitrogen	2	4.20	0.8505
clone x nitrogen	10	2.74	0.0781
year x clone x nitrogen	10	2.73	0.2850
total	35		

*, ** Significant at $\alpha = 0.05$ and $\alpha = 0.01$, respectively.

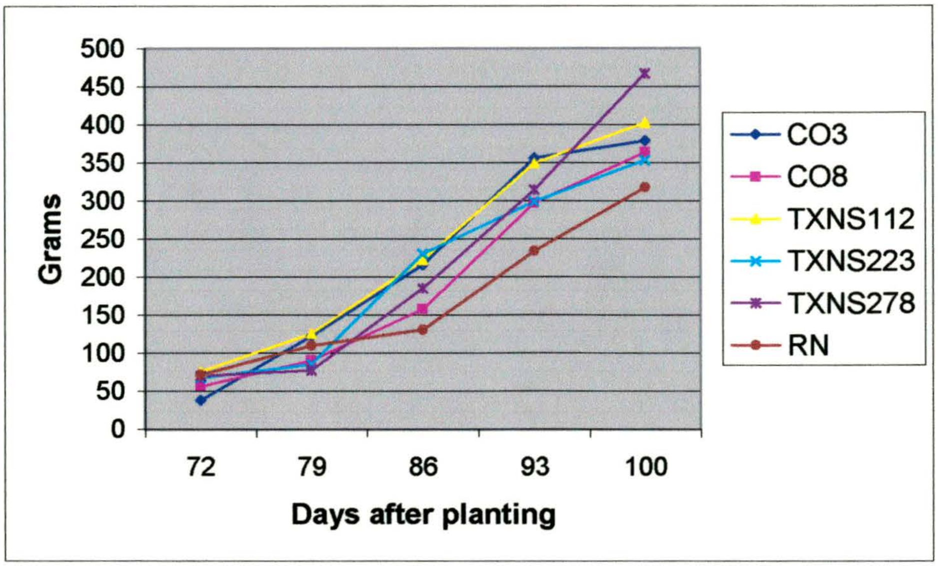


Figure 6. Tuber production over two years: 170 – 340 g per plant.

There were no significant differences for combined years when tubers greater than 340 g were compared for destructive harvest.

Significant effects for overall tuber weight per plant were year, clone, nitrogen, year x clone, and clone x nitrogen interaction (Table 14). Production of tubers was similar across selections and Russet Norkotah until 86 dap (Figure 7). Most selections continued to add tuber weight at a greater pace than Russet Norkotah and CO8. TXNS278 had the greatest tuber weight per plant at the end of the destructive harvests, indicating a greater overall yield. Russet Norkotah had the least indicating the least overall yield. Total tuber weight correlates with fresh vine weight. Fresh vine weight for all selections and Russet Norkotah peaks at 79 dap. Tuber weight for all plants increases at a consistent rate until 79 dap as well. Selections with higher fresh vine weight (CO3) continue to bulk at higher rates than others with lower fresh vine weight (Russet Norkotah). This data suggests plants with larger vines have potential for greater yields.

Table 14. Analysis of variance for tuber weight/plant for Russet Norkotah and selections.

Effect	d. f.	F. Value	Pr > F
year	1	95.07	<0.0001**
clone	5	98.10	<0.0001**
nitrogen	2	99.49	<0.0003**
year x clone	5	22.12	<0.0001**
year x nitrogen	2	4.20	0.4491
clone x nitrogen	10	2.74	0.0013**
year x clone x nitrogen	10	2.73	0.1545
total	35		

** Significant at $\propto = 0.01$.

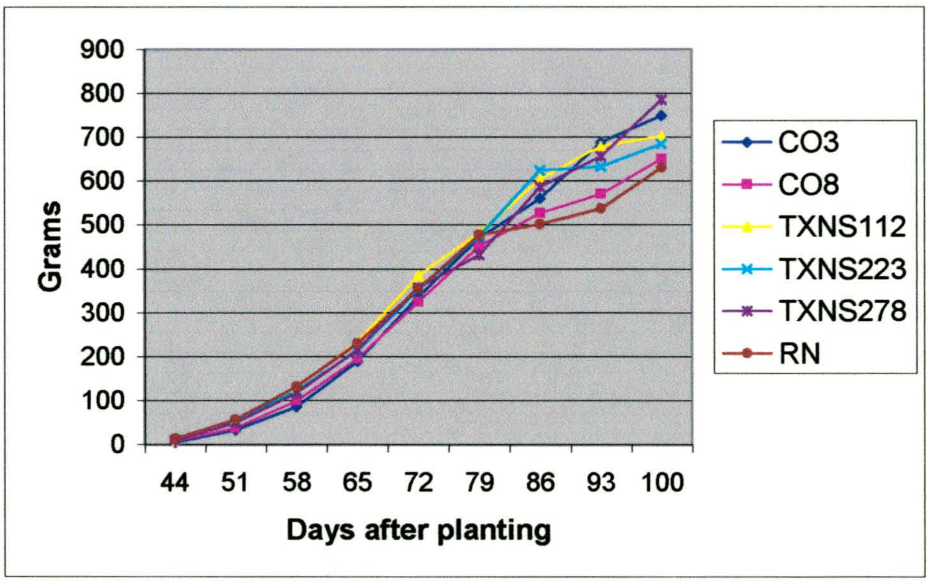


Figure 7. Overall tuber weight per plant over two years.

Nutritional requirements of the plant during the tuber bulking stage demanded higher rates of N to produce larger tubers. Medium and high rates of N increased overall tuber weight when compared to low rates (Table 15). Russet Norkotah and most selections responded in a like manner also. All increased tuber weight as N rates were increased from low to medium or high. In some cases, medium rates yielded significantly greater tuber weight than either high or low rates (Table 16).

Table 15. Overall tuber weight (g) for Russet Norkotah and selections over two years.

N Rate	**Two Year Mean**
Low	179.8
Medium	209.8
High	197.1
LSD (0.05)	8.1

Table 16. Overall tuber weight (g) per plant for Russet Norkotah and selections by N rate over two years.

	Low	**Medium**	**High**
RN	198.6	211.8	212.2
3	162.7	173.1	180.9
8	164.4	197.8	168.6
112	184.0	250.6	205.1
223	189.4	221.0	210.0
278	182.6	212.3	210.4
LSD (0.05)		13.0	

Significant effects when tuber number was compared was year, clone, year x clone, and year x clone x nitrogen (Table 17). All selections and Russet Norkotah produced between 4 and 7 tubers per plant (Figure 8), with some variance at different destructive harvest dates. Neither Russet Norkotah nor any selections stood out as consistently producing more tubers per plant. N rates did not appear to have an effect on tuber set. Sufficient N at all levels may have been available in early growth stages to produce similar tuber numbers per plant.

Table 17. Analysis of variance for tuber number/plant for Russet Norkotah and selections.

Effect	d. f.	F. Value	Pr > F
year	1	95.07	<0.0001**
clone	5	98.10	0.0006**
nitrogen	2	99.49	0.1638
year x clone	5	22.12	0.0255*
year x nitrogen	2	4.20	0.8805
clone x nitrogen	10	2.74	0.0882
year x clone x nitrogen	10	2.73	0.0092**
total	35		

*, ** Significant at $\alpha = 0.05$ and $\alpha = 0.01$, respectively.

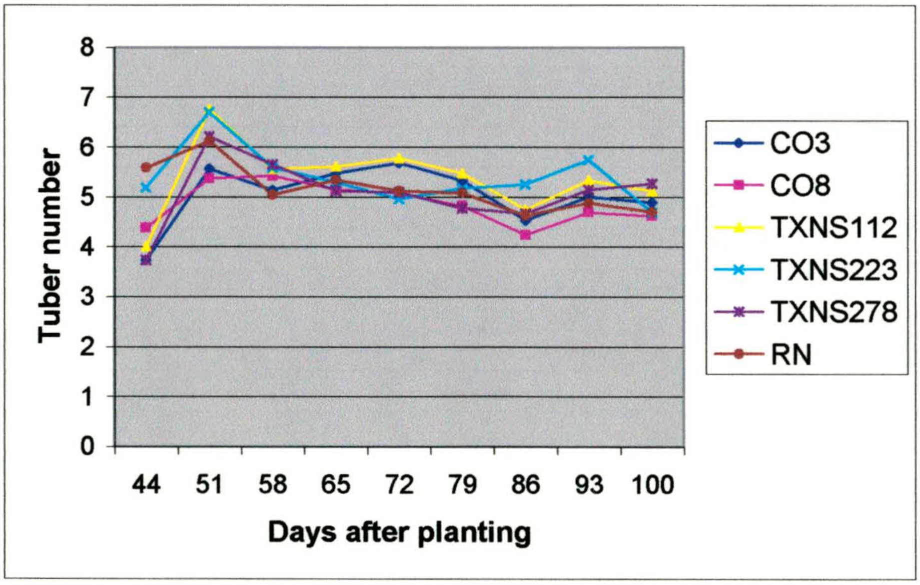


Figure 8. Tuber number per plant over two years.

Destructive harvest data gave some idea of growth patterns for the selections and Russet Norkotah used in this research. CO3 eventually produced the tallest and most vine fresh weight of all the selections and Russet Norkotah, even though its roots were not significantly larger than other selections. Nitrogen rates had little effect on root mass, but increasing rates did provide for more vine growth. Greater vine mass could result in more photosynthesis, which in turn, may have greater potential for tuber yield. Russet

Norkotah consistently grew less vine and root, which most likely limited its tuber production compared to selections. Tuber number per plant were similar between Russet Norkotah and selections, but Russet Norkotah had less yield of tubers weighing 170 – 340 g, and less overall tuber weight than all the selections. This indicates that average tuber size of Russet Norkotah tends to be smaller than average tubers of selections. CO3 produced least weight of tubers <113 g, increasing its tuber average weight. No distinct pattern of significance was detected for larger tubers near the end of the growing season. Medium and high rates of N did encourage larger vine and tuber growth. As vines matured and began senescence, however, tuber bulking was reduced. It is important to note that those selections with more vine fresh weight near the end of the season had greater potential to continue tuber sizing until actual vine kill. CO3 was the most prevalent in this category, followed by the rest of the selections.

Final Harvest

Total Yield

A combined analysis of total yield results for 1998 and 1999 was performed (Table 18) using a mixed procedure (SAS 1987). There was a significant difference for total yield for year, clone, and nitrogen. The year x clone interaction was also significant. While clone x nitrogen was not significant at the 5% level, it was significant at the 10% level. A third year of data may have stabilized this interaction. However, despite this lack of significance, the interaction may impact the potato producer economically.

Table 18. Analysis of variance for total yield for Russet Norkotah and selections.

Effect	d.f.	F Value	Pr > F
year	1	21.72	0.0055**
clone	5	25.34	<0.0001**
nitrogen	2	54.35	<0.0001**
year x clone	5	4.26	0.0017**
year x nitrogen	2	1.19	0.3105
clone x nitrogen	10	1.68	0.0997
year x clone x nitrogen	10	1.52	0.1467
Total	35		

** Significant at $\propto = 0.01$.

Overall mean yield in 1998 was 33.2 tons/hectare (t/h) compared to 37.2 t/h in 1999, a significant increase of 12%, or 4 t/h (Table 19). For years combined, mean yields ranged from 28.5 t/h for Russet Norkotah to 39.3 t/h for CO3, a 10.9 t/h or 38% difference. In 1998, Russet Norkotah mean yield was the least (23.5 t/h) and CO3 mean yield was the most (38.7 t/h). CO3 was the highest mean producer in 1999 (40.1 t/h), while Russet Norkotah again yielded the least (33.3 t/h).

Total yields from each year of production are also listed in Table 19. Russet Norkotah yielded the least for each level of N for both years. In 1998, CO3 and TXNS112 yielded 34.2 t/h with the low N rate. This was 11.4 t/h, or 50%, more than Russet Norkotah. Higher rates of N only slightly increased yields of Russet Norkotah to 23.9 t/h. Yields of CO3 and TXNS112 at the low N rate surpassed this by 43%. High N applications for Russet Norkotah in 1998 did not provide yield advantages or reduce N input since low applications for all other selections yielded more than Russet Norkotah.

Table 19. Total tuber yield (t/h) for Russet Norkotah and selections by N rate and years.

Clone	N Rate	1998	1999	Two Yr Mean
Russet Norkotah	Lo	22.8	29.9	26.3
	Med	23.9	35.8	29.8
	High	23.9	34.4	29.1
Mean		23.5	33.3	28.5
CO3	Lo	34.2	33.8	34.1
	Med	38.3	43.2	40.8
	High	43.6	43.3	43.5
Mean		38.7	40.1	39.3
CO8	Lo	27.9	30.4	29.1
	Med	30.9	38.3	34.6
	High	38.3	39.7	39.0
Mean		32.4	36.1	34.3
TXNS112	Lo	34.2	35.4	34.9
	Med	40.8	38.9	39.9
	High	37.4	41.6	39.6
Mean		37.4	38.7	38.1
TXNS223	Lo	27.0	34.1	30.6
	Med	36.9	39.2	38.1
	High	37.3	41.2	39.3
Mean		33.7	38.2	36.0
TXNS278	Lo	26.9	32.2	29.6
	Med	31.3	38.9	35.1
	High	40.6	39.3	40.0
Mean		33.0	36.8	34.9
Overall Mean		33.2	37.2	
LSD = 0.05		Year:	2.1	
		Clone:	2.2	
		Year x Clone:	3.3	

When comparing 1999 total yield results, lower N applications for selections may result in yield equal to or higher than Russet Norkotah grown with high N. Economic benefits in this case could be two-fold: a grower might have lower input costs for N units applied to the crop, and secondly, greater yield may potentially provide for more income as the crop is sold.

Across genotypes, increase in N rate provided a significant increase in total production for combined years (Table 20). Low rates yielded a mean of 30.7 t/h. Medium rates increased production by 5.6 t/h, or 18%, to 36.3 t/h. The high N rate two year mean was 38.4 t/h, 2.1 t/h (6%) more than medium N yields and 7.7 t/h (25%) more than low N production. This agrees with other studies that show increased yields with higher N rates (Chase *et al.* 1990; Cleomeis and Dogras 1990). Other results, however, (Arsenault and Malone 1999; Chase *et al.* 1990; Santerre *et al.* 1986; Westermann *et al.* 1994) indicate that greater rates of N do not always benefit production.

Table 20. Mean total yield (t/h) for Russet Norkotah and selections.

N rate	1998	1999	Combined Years
Low	28.8	32.6	30.7
Med	33.7	39.0	36.3
High	36.9	39.9	38.4
LSD (0.05)	2.0	1.7	1.6

In 1999, each selection at each N level generally produced yields equal to or greater than in 1998 (Table 21). Russet Norkotah yield increased 7.1 t/h, 11.9 t/h, and 10.5 t/h for low, medium and high N rates, respectively, when comparing years. This represents significant yield increases of 31, 50 and 44%. In contrast, there was no significant change for CO3 or TXNS112. Significant differences at only one rate of N were found for CO8, TXNS223 and TXNS278.

Table 21. Difference in total yield (t/h) within clones between years.

	Low N			Medium N			High N		
	1998	**1999**	**change**	**1998**	**1999**	**change**	**1998**	**1999**	**change**
RN	22.8	29.9	+7.1*	23.9	35.8	+11.9*	23.9	34.4	+10.5*
3	34.2	33.8	-0.4	38.3	43.2	+4.9	43.6	43.3	-0.3
8	27.9	30.4	+2.5	30.9	38.3	+7.4*	38.3	39.7	+1.4
112	34.2	35.4	+1.2	40.8	38.9	-1.9	37.4	41.6	+4.2
223	27.0	34.1	+7.1*	36.9	39.2	+2.3	37.3	41.2	+3.9
278	26.9	32.2	+5.3	31.3	38.9	+7.6*	40.6	39.3	-1.3

* Significant at $\propto = 0.05$. (LSD = 5.4)

There was a considerable increase in yield of Russet Norkotah between years, while the yields of selections were mostly similar. This difference may be the main cause of the significant year x clone interaction. In addition, selections at low N rates out-yielded Russet Norkotah at high rates in 1998. But in 1999, this was not the case. These comparisons suggest that environmental conditions between years affected growth and production of Russet Norkotah more than they did the selections. While growing degree days (Appendix A) and air temperatures (Appendix B) seemed similar, there were differences in soil temperature patterns (Appendix C). On approximately July 1, or 40 dap, soil temperatures for 1998 decreased considerably while 1999 soil temperatures increased considerably. This temperature range coincided with tuber initiation and early bulking for both years. Thus, intimating that yield of Russet Norkotah is more sensitive to environmental conditions than the yield of the selections. Also, adverse conditions unique to each growing season may significantly reduce the total yield of Russet Norkotah. Biotic and abiotic factors may contribute to this production contrast between years. The selections respond more consistently, suggesting they are better able to withstand the environmental variation and still yield reliably even under low N applications. They may have unique physiological or morphological differences that allow more adaptability to environmental stress. As discussed previously, vine size, root size and canopy endurance could be contributing factors to these differences. When choosing a cultivar for production, the ability to withstand environmental variation should be a factor for grower consideration. While Russet Norkotah may produce yields equal to, or greater than, the selections in some years, adverse production conditions may limit Russet Norkotah performance, making one of the selections a better choice.

For each year, yields of selections at different rates of N were compared to Russet Norkotah (Table 22). For example, in 1998, CO3 grown at the low N level yielded 10.3 t/h more than Russet Norkotah at high N. In more general terms, in 1998, all selections at all levels of N produced significantly greater yields than Russet Norkotah at high N with the exception of CO8, TXNS223 and TXNS278 at low N. While these increases were not significantly greater, they may be economically beneficial to a potato producer since less N was applied.

Total yield comparisons changed somewhat in 1999. When compared to Russet Norkotah at high N, selections at low N generally produced the same. Selections at medium and high N did yield more than Russet Norkotah, but not always by a significant amount. This contrast might be attributed to a significant difference in Russet Norkotah yield from 1998 to 1999 (Table 21), while yield of selections generally were consistent across years.

Table 22. Difference of selections' total yields (t/h) compared to Russet Norkotah at high N (base reference: 1998-23.9; 1999-34.4).

Selection	N Level	1998	1999
CO3	Low	10.3*	-0.6
	Medium	14.5*	8.6*
	High	19.7*	8.9*
CO8	Low	4.0	-4.0
	Medium	7.1*	3.9
	High	14.5*	5.3*
TXNS112	Low	10.3*	1.0
	Medium	16.9*	4.5
	High	13.4*	7.2*
TXNS223	Low	3.1	-0.3
	Medium	13.0*	4.8
	High	13.4*	6.8*
TXNS278	Low	3.0	-2.2
	Medium	7.4*	4.4
	High	16.7*	4.9*
LSD (0.05)		5.6	4.8

US No. 1 Tuber Production

An analysis for production of US No. 1 tubers from these plots was performed using SAS (1987) mixed procedure (Table 23). Results are similar to that of total yield. Year, clone and N effects were highly significant, as was the year x clone interaction.

Table 23. Analysis of variance for US No. 1 yield for Russet Norkotah and selections.

Effect	d.f.	F Value	Pr > F
year	1	112.33	0.0001**
clone	5	33.42	<0.0001**
nitrogen	2	7.98	<0.0001**
year x clone	5	58.62	<0.0001**
year x nitrogen	2	0.47	0.6282
clone x nitrogen	10	1.19	0.3120
year x clone x nitrogen	10	1.07	0.3980
Total	35		

** Significant at $\propto = 0.01$.

US No. 1 yield per hectare and the percentage of total yield is presented in Table 24. Under low N, Russet Norkotah produced only 7.7 t/h (34%) of US No. 1 potatoes in 1998. Under medium and high N, it produced 11.4 t/h (48%) and 9.8 t/h (40%) US No. 1 tubers, respectively. In the same year, CO3 produced 23.9 t/h (70%) under low N, 16.1 t/h more than Russet Norkotah. This was the greatest production for all clones under low N in 1998. US No. 1 tubers from other selections under low N ranged from 13.7 to 18.2 t/h. Even under low N, CO3 produced more than two times that of Russet Norkotah under medium or high N rates. All selections at low N produced more US No. 1 tubers than Russet Norkotah at any level of N. Medium and high rates of N resulted in greater yields of US No. 1 potatoes, and also generally increased the US No. 1 tuber percentage of total yield for 1998. CO3 produced the most overall, with 34.9 t/h (80%), under high N.

In 1999, Russet Norkotah again produced the least US No. 1 tubers (23.0 t/h, 77%) under low N. It yielded 29.7 t/h (83% and 86% respectively) under medium and high N levels. All selections produced more than standard Russet Norkotah grown with the low rate of N. At low N rates, CO3, TXNS112, TXNS223 and TXNS278 produced similar US No. 1 yields to Russet Norkotah at medium and high rates. The medium N rate increased production of US No. 1 yields significantly, compared to low N rates. However, there were no significant differences in US No. 1 yields when high applications of N were compared to medium rates in 1999, agreeing with Arsenault and Malone (1999). CO3 yielded the most under high N, 38.6 t/h (89%). This also agrees with the concept of Sharma and Arora (1987) that an increase in N and potassium significantly

Table 24. Yield of US No. 1 tubers in t/h (with % of total yield) for Russet Norkotah and selections.

Clone	N Rate	1998	1999	2 Yr Mean
Russet Norkotah	Lo	7.7 (34)	23.0 (77)	15.4 (58)
	Med	11.4 (48)	29.7 (83)	20.6 (69)
	High	9.8 (40)	29.7 (86)	19.7 (68)
Mean		9.6 (41)	27.5 (82)	18.6 (65)
CO3	Lo	23.9 (70)	27.3 (81)	25.7 (75)
	Med	32.5 (85)	38.4 (89)	35.5 (87)
	High	34.9 (80)	38.6 (89)	36.8 (84)
Mean		30.4 (78)	34.9 (86)	32.6 (83)
CO8	Lo	16.0 (57)	24.3 (80)	20.2 (69)
	Med	20.3 (66)	33.4 (87)	26.9 (78)
	High	25.4 (66)	34.3 (86)	29.9 (77)
Mean		20.6 (63)	30.7 (84)	25.7 (75)
TXNS112	Lo	16.8 (49)	28.9 (81)	22.9 (66)
	Med	25.6 (63)	32.7 (84)	29.1 (73)
	High	23.4 (63)	35.3 (85)	29.4 (74)
Mean		22.0 (58)	32.3 (83)	27.1 (71)
TXNS223	Lo	13.7 (48)	26.2 (77)	20.0 (65)
	Med	23.8 (64)	33.1 (84)	28.5 (76)
	High	18.0 (48)	35.5 (86)	26.8 (68)
Mean		18.5 (53)	31.6 (82)	25.1 (70)
TXNS278	Lo	18.2 (68)	27.1 (85)	22.6 (77)
	Med	21.7 (70)	33.5 (86)	27.7 (79)
	High	26.3 (65)	34.2 (87)	30.3 (76)
Mean		22.1 (98)	31.6 (86)	26.9 (77)
Overall Mean		20.5 (62)	31.4 (84)	
LSD = 0.05		Year: 2.7 Clone: 2.2 Year x Clone: 3.6		

Note: statistical analysis was done only on t/h, not for percentages.

decreased the number of tubers <25 g and increased tubers 25 – 75 g and >75 g. Based on minimum size requirements of 47.6 mm for US No. 1 (USDA 1991), a decrease of small potatoes and increase of larger potatoes will increase the yield of US No. 1 tubers.

Overall mean production of US No. 1 tubers in 1998 was 20.5 t/h. This represents 62% of the overall mean of total yield for this grade. In 1999, the US No. 1 production increased by 10.9 t/h (53%) to 31.4 t/h. This represents 84% of the total yield mean.

For combined years within clones, CO3 produced the most US No. 1 tubers with a mean of 32.6 t/h. This is 14.0 t/h (75%) more than the Russet Norkotah mean of 18.6 t/h. The other selections ranged from 25.1 to 27.1 t/h of US No. 1 tuber production.

The mean US No. 1 yield of all clones for both years under low N applications was 21.1 t/h (Table 25). Medium and high N applications yielded significantly higher at 28.0 t/h and 28.8 t/h, respectively. Because low N yielded significantly less than medium and high rates, there may be an economical justification for applying medium N levels instead of low N levels for most clones included in this experiment, depending upon the value of N units. It is difficult to justify high rates over medium rates, since the means are not significantly different, agreeing with Joren and Vitosh (1995a).

Table 25. Mean US No. 1 production in t/h (with % of total yield) across clones.

N rates	**1998**	**1999**	**Combined Years**
Low	16.0 (57)	26.2 (80)	21.1 (67)
Med	22.5 (68)	33.5 (86)	28.0 (77)
High	23.0 (62)	34.6 (87)	28.8 (75)
LSD (0.05)	2.2	1.9	1.5

Note: statistical analysis was done only on t/h, not for percentages.

US No. 1 tuber production within clones increased overall between the two years' crop (Table 26). Russet Norkotah had the most dramatic increase for each level of N. Low N yields increased by 15.2 t/h, a 197% difference from the previous year. Medium N yields increased by 18.3 t/h (160%) and high N increased by 20.0 t/h (205%). CO3 had the least amount of increase, 3.5 (15%), 5.9 (18%), and 3.7 t/h (11%) for low, medium and high N rates, respectively. While there may be some economical value in each increase, only the difference for medium N was significant. CO3 was the most stable across years, as all other selections produced significantly greater amounts of US No. 1 tubers for each level of N in 1999.

Table 26. Difference in US No. 1 tuber production (t/h) within genotypes between years.

	Low N			Medium N			High N		
	1998	1999	change	1998	1999	change	1998	1999	change
RN	7.7	23.0	+15.3*	11.4	29.7	+18.3*	9.8	29.7	+19.9*
3	23.9	27.3	+3.4	32.5	38.4	+5.9*	34.9	38.6	+3.7
8	16.0	24.3	+8.3*	20.3	33.4	+13.1*	25.4	34.3	+8.9*
112	16.8	28.9	+12.1*	25.6	32.7	+7.1*	23.4	35.3	+11.9*
223	13.7	26.2	+12.5*	23.8	33.1	+9.3*	18.0	35.5	+17.5*
278	18.2	27.1	+8.9*	21.7	33.5	+11.8*	26.3	34.2	+7.9*

* Significant at $\propto = 0.05$ (LSD = 5.6)

Significant differences were prevalent when each selection at each N level was compared to Russet Norkotah base production at high N level for the same year (Table 27). In 1998, all selections produced more US No. 1 tubers when compared to Russet Norkotah. All selections under low N produced more than Russet Norkotah. There was a significant increase in nearly every case.

Table 27. Difference of selections' US No. 1 yields (t/h) compared to Russet Norkotah at high N (base reference: 1998-9.8; 1999-29.7).

Selection	N Level	1998	1999
CO3	Low	14.1*	-2.4
	Medium	22.8*	8.9*
	High	25.1*	8.9*
CO8	Low	6.3*	-5.4
	Medium	10.5*	3.7
	High	15.6*	4.7
TXNS112	Low	7.1*	-0.8
	Medium	15.7*	3.0
	High	13.7*	5.6*
TXNS223	Low	3.9	-3.5
	Medium	14.0*	3.5
	High	8.3*	5.8*
TXNS278	Low	8.4*	-2.6
	Medium	12.0*	3.8
	High	16.6*	4.5
LSD (0.05)		5.7	5.0

In 1999, at low N, TXNS112 was the only selection to produce significantly more US No. 1 tubers than Russet Norkotah at low N. Russet Norkotah grown at high N rates out-produced all selections under low N, but not significantly. Selections produced under medium and high N rates yielded more US No. 1 tubers than Russet Norkotah at the medium and high rates, though not all differences were significant. CO3, at medium and high N rates, produced the greatest amount of all selections and 8.9 t/h more than Russet Norkotah. In summary, the selections, at low N, produced similar or significantly greater US No. 1 yields than Russet Norkotah at high rates. This should be a consideration when producers look for the greatest amount of saleable crop with the least amount of input.

Other Tuber Classes

In order to look deeper into the differences between total yield and US No. 1 production, undersized tubers (<113 g), yields of culls and US No. 2 tubers from each selection need to be considered.

Undersized Tubers

A US No. 1 potato grade has a minimum size requirement of 38 mm (USDA 1991). Russet Norkotah is described as a long potato (Johansen *et al. 1988*). All of the Russet Norkotah selections have this same characteristic. Generally, tubers of a long cultivar <113 g do not make the minimum size requirements for a US No. 1 grade. Therefore, cultivars that produce a high percentage of tubers <113 g will reduce the amount of marketable US No. 1 grade potatoes.

The two year combined analysis for production of undersized tubers is shown in Table 28. There are significant differences for the clone x nitrogen interaction. The year x clone and year x nitrogen interactions are highly significant, as are the individual effects of year, clone and nitrogen. The year x clone x nitrogen is not significant at a 5% level, however, it would have been at a 10% level. This interaction may have an economic impact on the producer.

Table 28. Analysis of variance for undersized tubers for Russet Norkotah and selections.

Effect	d.f.	F Value	Pr > F
year	1	85.15	0.0003**
clone	5	19.24	< 0.0001**
nitro	2	10.95	< 0.0001**
year x clone	5	10.98	< 0.0001**
year x nitro	2	5.98	0.0037**
clone x nitro	10	2.24	0.0228*
year x clone x nitro	10	1.72	0.0889
Total	38		

*, ** Significant at $\propto = 0.05$ and $\propto = 0.01$, respectively.

Overall production of undersized tubers in 1998 was 11.1 t/h, 33% of total yield (Table 29). This production decreased by 60% to 4.5 t/h (12%) in 1999. For the year x clone interaction, TXNS278 produced the fewest undersized tubers in 1999 with 3.6 t/h, 10% of total yield. Russet Norkotah produced the most in 1998 with 13.3 t/h, 57% of total yield.

In the clone x nitrogen interaction the least production of undersized tubers was CO3 under medium N and the highest was TXNS112 under low N, 3.7 t/h and 11.2 t/h, respectively. As was the case previously, Russet Norkotah had the highest percentage of undersized tuber production. This was 43% of the total yield when it was grown under low N. CO3 and CO8 produced the least amount of small tubers at medium N rates for both years. Russet Norkotah, TXNS223 and TXNS278 produced the least amount of small tubers at medium N rates for one year. Two year means of low N rates caused the greatest production of undersized tubers within a genotype for Russet Norkotah, CO3, CO8 and TXNS112.

The clone effect had highly significant differences in undersized tuber production. The two year mean for CO3 was the least with 5.5 t/h (14%). TXNS112 produced the most overall with 9.6 t/h (25%). The other selections ranged between 6.4 t/h (18%) and 9.1 t/h (32%).

Percentage-wise, CO3 was still least at 14% of total yield, but Russet Norkotah was highest with 32%. While Russet Norkotah did not produce as many small tubers as TXNS112, its percentage of total yield was greater because its total yield was less than that of TXNS112.

Table 29. Yield of undersized tubers in t/h (with % of total yield) for Russet Norkotah and selections.

Clone	N Rate	1998	1999	2 Yr Mean
Russet Norkotah	Lo	15.0 (66)	6.1 (20)	10.5 (43)
	Med	11.7 (49)	5.0 (14)	8.3 (32)
	High	13.2 (55)	3.4 (10)	8.3 (33)
Mean		13.3 (57)	4.8 (14)	9.1 (32)
CO3	Lo	8.9 (26)	5.7 (17)	7.3 (22)
	Med	4.0 (11)	3.4 (8)	3.7 (10)
	High	7.4 (17)	3.5 (8)	5.4 (13)
Mean		6.7 (17)	4.1 (10)	5.5 (14)
CO8	Lo	11.7 (42)	5.4 (18)	8.5 (30)
	Med	8.3 (27)	4.1 (11)	6.2 (19)
	High	11.1 (29)	4.3 (11)	7.6 (20)
Mean		10.3 (32)	4.6 (13)	7.4 (22)
TXNS112	Lo	17.1 (50)	5.3 (15)	11.2 (32)
	Med	14.0 (34)	4.8 (12)	9.4 (23)
	High	12.2 (33)	4.6 (11)	8.4 (22)
Mean		14.5 (39)	4.9 (13)	9.6 (25)
TXNS223	Lo	12.7 (47)	6.3 (18)	9.4 (33)
	Med	10.8 (29)	4.8 (12)	7.7 (21)
	High	15.1 (41)	4.0 (10)	9.6 (26)
Mean		12.9 (38)	5.0 (13)	9.0 (25)
TXNS278	Lo	7.5 (28)	3.7 (11)	5.6 (20)
	Med	8.7 (28)	3.8 (10)	6.3 (19)
	High	11.2 (28)	3.1 (8)	7.2 (18)
Mean		9.2 (28)	3.6 (10)	6.4 (18)
Overall Mean		11.1 (33)	4.5 (12)	
LSD = 0.05		Year: 1.8 Clone: 1.1 Year x Clone: 2.1 Clone x Nitrogen: 1.8		

Note: statistical analysis was done only on t/h, not for percentages.

Growing conditions in 1999 generally resulted in larger tubers being produced. All N levels reduced production of undersized tubers from 1998 to 1999 for all genotypes. This, coupled with an increase in total yield, resulted in greater amounts of US No. 1 tubers. The N effect alone shows that higher rates of N tend to decrease the amount of smaller tubers in both t/h and in percentage of total yield. However, Russet Norkotah, overall, produced the highest percentage of small tubers when grown under low N. This level still seemed to be insufficient to allow tubers to size during either growing season.

Table 30 shows that yields across genotypes of undersized tubers under high N decreased the most, by 69% from 11.8 t/h to 3.8 t/h. Yields under low N decreased by 56% and under medium N by 54%.

Table 30. Production of undersized tubers in t/h (with % of total yield).

N Level	1998 Mean	1999 Mean	Combined Years
Low	12.1 (41)	5.4 (16)	8.7 (28)
Medium	9.5 (28)	4.4 (11)	6.9 (19)
High	11.8 (32)	3.8 (10)	7.7 (20)
LSD (0.05)	1.1	1.0	0.9

Note: statistical analysis was done only on t/h, not for percentages.

The two year mean shows a decrease between low and medium N, 8.7 t/h to 6.9 t/h, respectively, which was a 21% decrease. There was also a 12% decrease comparing low N to high N. A slight increase, however, occurred between medium and high N, 6.9 t/h and 7.7 t/h, respectively, which was a 10% increase. Higher N levels may delay tuber set and slow tuber bulking, resulting in slightly more undersized tubers compared to medium N rates.

Table 31 shows the relation of production of undersized tubers within a selection and N level across two years. While all clones had a reduction of small tubers from 1998 to 1999, CO3 fluctuated the least. This suggests that CO3 may be a more consistent producer under varying levels of N.

Table 31. Difference in production (t/h) of undersized tubers within clones between years.

	Low N			Medium N			High N		
	1998	**1999**	**change**	**1998**	**1999**	**change**	**1998**	**1999**	**change**
RN	15.0	6.1	-8.9*	11.7	5.0	-6.7*	13.2	3.4	-9.8*
3	8.9	5.7	-3.2*	4.0	3.4	-0.6	7.4	3.5	-3.9*
8	11.7	5.4	-6.3*	8.3	4.1	-4.2*	11.1	4.3	-6.8*
112	17.1	5.3	-11.8*	14.0	4.8	-9.2*	12.2	4.6	-7.6*
223	12.7	6.3	-6.4*	10.8	4.8	-6.0*	15.1	4.0	-11.1*
278	7.5	3.7	-3.8*	8.7	3.8	-4.9*	11.2	3.1	-8.1*

* Significant at $\propto = 0.05$ (LSD = 2.9)

In a comparative analysis (Table 32) between selections and Russet Norkotah for undersized tubers, nearly all selections in 1998 had significantly fewer small tubers. The exception to this generalization is TXNS112. It tended to have greater production of small tubers in 1998, with some comparisons being significant. The 1999 comparisons show that selections produced a similar quantity of undersized tubers. Exceptions include CO3 at medium and high N produced significantly less than Russet Norkotah at low N, TXNS223 at low N produced significantly more than Russet Norkotah at high N and TXNS278 at high N produced significantly more than Russet Norkotah at low N.

Table 32. Difference of selections' undersized tubers (t/h) compared to Russet Norkotah at high N (base reference: 1998-13.2; 1999-3.4).

Selection	N Level	1998	1999
CO3	Low	-4.5*	2.4
	Medium	-9.3*	0
	High	-5.9*	0.1
CO8	Low	-1.7	1.9
	Medium	-5.0*	0.8
	High	-2.1*	0.9
TXNS112	Low	3.9*	1.9
	Medium	0.8*	1.5
	High	-1.1	1.2
TXNS223	Low	-0.7	2.8*
	Medium	-2.5	1.3
	High	1.9	0.7
TXNS278	Low	-5.8*	0.3
	Medium	-4.5*	0.4
	High	-2.0	0.2
LSD (0.05)		2.8	2.5

Culls and US No. 2 Tuber Production

Finally, amounts of culls combined with US No. 2 yields (other than undersized tubers) of final harvest were compared. Table 33 shows this analysis of variance. Individual clones produced significantly different amounts of culls and US No. 2 potatoes. There was also a highly significant difference among N levels.

Table 34 compares yield differences of culls and US No. 2 potatoes of selections contrasted to Russet Norkotah production of culls and US No. 2 potatoes. In 1998, TXNS223 had significantly higher production of culls and US No. 2 potatoes under medium N when compared to Russet Norkotah at low N. TXNS223 also was significantly greater under high N when compared to Russet Norkotah at all levels of N. Additionally, TXNS278 produced significantly more culls and US No. 2 potatoes under high N when compared to Russet Norkotah at all levels of N. There were no significant differences in 1999.

Table 33. Analysis of variance for yield of culls and US No. 2's for Russet Norkotah and selections.

Effect	d.f.	F Value	Pr > F
year	1	0.25	0.6356
clone	5	2.51	0.0360*
nitrogen	2	6.73	0.0019**
year x clone	5	1.11	0.3594
year x nitrogen	2	2.34	0.1028
clone x nitrogen	10	0.74	0.6814
year x clone x nitrogen	10	0.81	0.6210
Total	38		

*, ** Significant at ∝ = 0.05 and ∝ = 0.01, respectively.

Table 34. Difference of selections' culls and US No. 2's (t/h) compared to Russet Norkotah at high N (base reference: 1998-0.9; 1999-1.3).

Selection	N Level	1998	1999
CO3	Low	0.8	-0.6
	Medium	0.9	-0.1
	High	0.6	-0.2
CO8	Low	-0.6	-0.7
	Medium	1.0	-0.6
	High	1.0	-0.2
TXNS112	Low	-0.7	-0.1
	Medium	0.4	0
	High	0.9	0.2
TXNS223	Low	-0.1	0.2
	Medium	1.5	0
	High	3.3*	0.3
TXNS278	Low	0.4	0
	Medium	0	0.2
	High	2.1*	0.8
LSD (0.05)		1.9	1.7

The relatively minor amount of culls and US No. 2's generated by this trial are evidence that Russet Norkotah, and now the line selections, typically produce a high percentage of marketable tubers as described in its release (Johansen *et al.* 1988). As previously discussed, the largest grade-out factor is undersized tubers.

Summary

Russet Norkotah is a well established potato cultivar in the United States industry. Results of this experiment demonstrate advantages Russet Norkotah selections have compared to Russet Norkotah.

As N rates increased, mean total yield, mean US No.1 yield, and yield of culls and US No. 2's increased, while production of undersized tubers decreased. While culls and US No. 2's increased slightly, it was not enough to offset the increase of US No. 1 yield. Selections performed very well when production at low N was compared to Russet Norkotah grown with any rate of N. CO3 and TXNS112 produced the most overall yield at low N. CO3 also produced the most US No. 1 yield at low N. Independently, most selections and Russet Norkotah increased production as nitrogen rates increased. However, results of this experiment show lower N applications to selections may result in yields equal to or greater than Russet Norkotah grown at a high rate of N. This was especially prevalent in the first year of trials. In the second year, Russet Norkotah increased overall yields at high N. Even so, all selections equaled that when grown at low N, and surpassed it when grown at medium or high N. CO3 had the most consistent production of total yield and US No. 1 yield over two years. Russet Norkotah production varied the most.

Russet Norkotah produced lower yields, as predicted when discussing destructive harvest. Its lesser fresh vine weight and fresh root weight and reduced vine duration may have limited its production compared to line selections. This was most obvious during the first year of trials. As root and vine growth slowed, the vegetative growth stage of the potato plant phased into the tuber bulking stage. Results of this experiment support that sequential growth, while differences among selections and Russet Norkotah were pronounced. Russet Norkotah most often showed the least vegetative growth regardless of N rate. All selections grew greater mass of vine and root at low N compared to Russet Norkotah. Even though CO3 had less root weight than other selections, it had the tallest vine, and its fresh vine weight was greatest. This did translate into the best yield of all selections and Russet Norkotah. More detailed research may be necessary to determine phenotype differences of the selections.

Based on these results, Russet Norkotah line selections offer the grower a possibility of increased production with lower N application.

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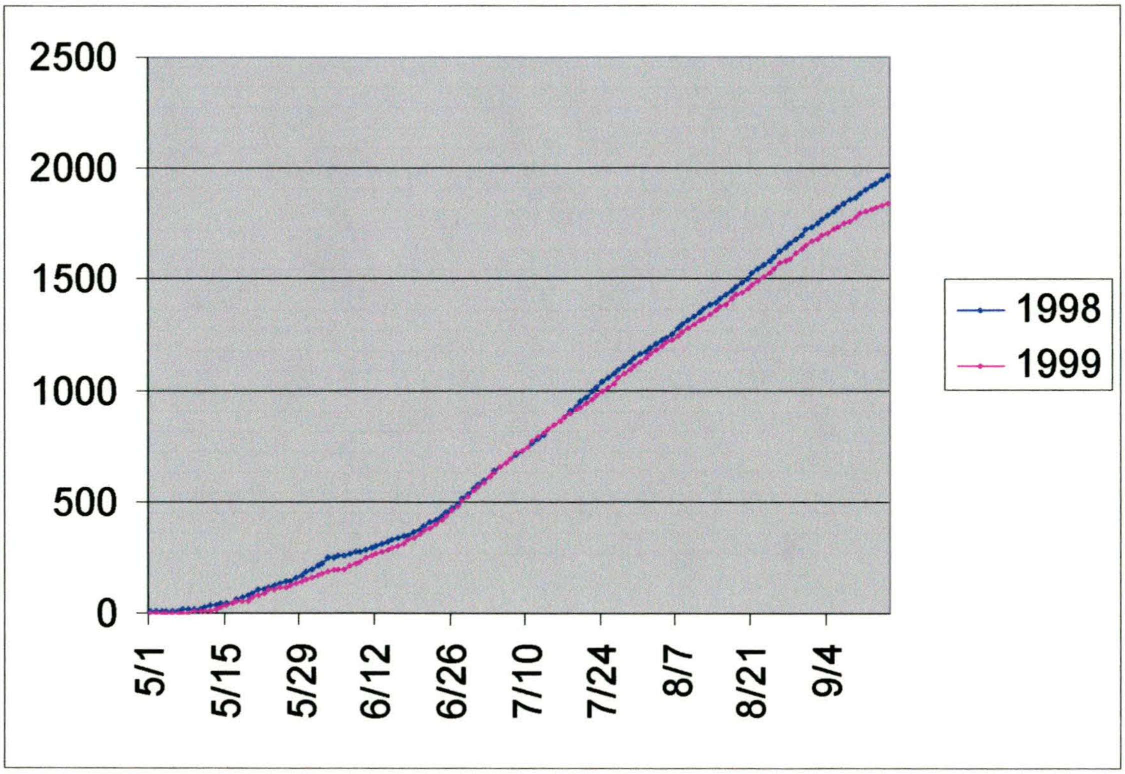
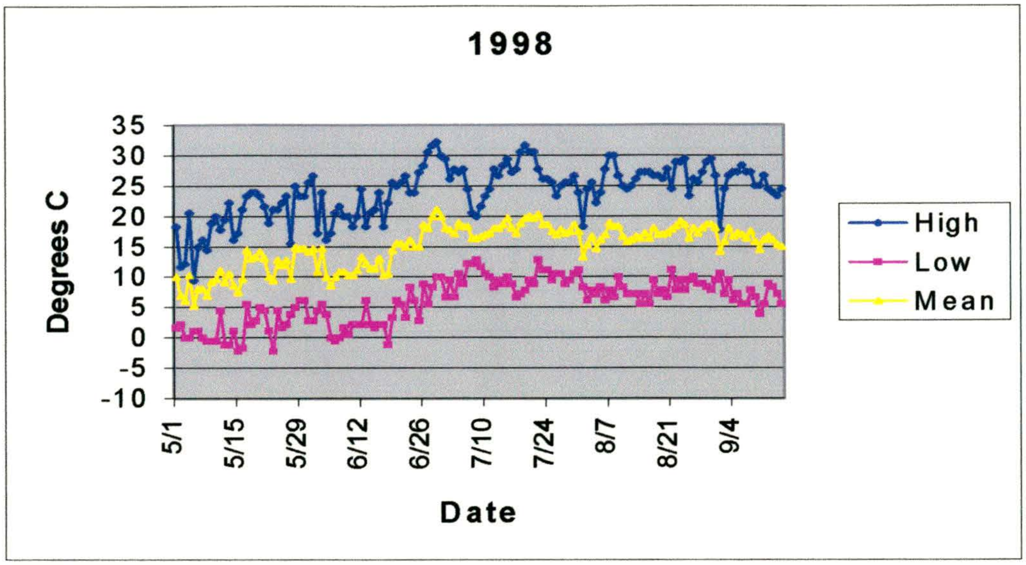
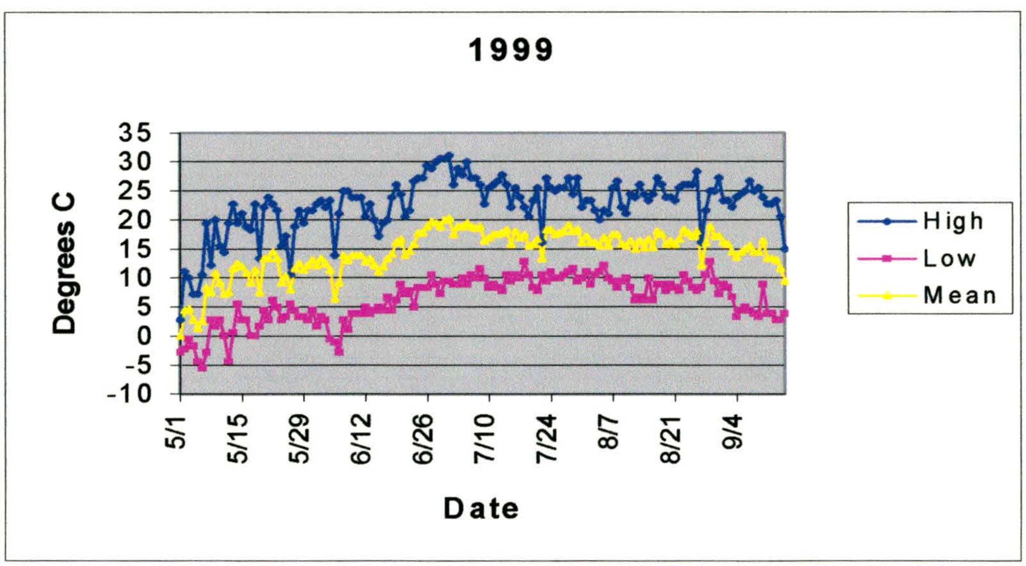
APPENDIX

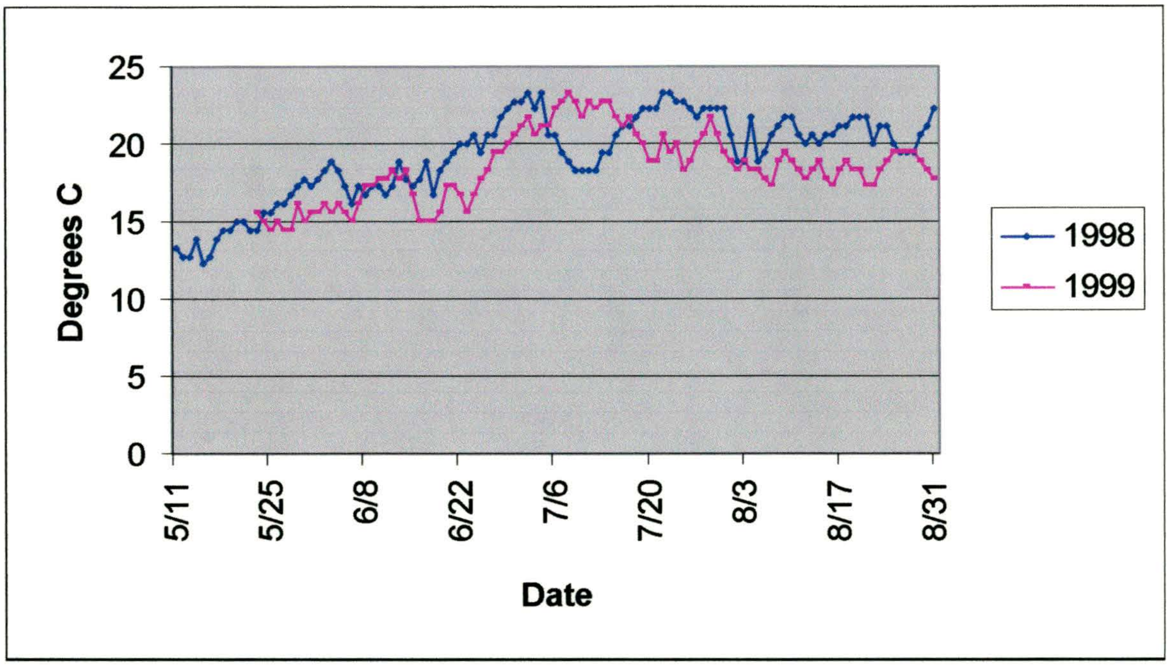


Appendix A. Growing degree days, San Luis Valley Research Center, Center, CO.





Appendix B. Daily air temperatures, San Luis Valley Research Center, Center, CO.



Appendix C. Daily minimum soil temperatures at 15 cm depth. San Luis Valley Research Center, Center, CO.