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Nitrogen Fertility and Chip Processing Quality Comparison for Four Chipping Cultivars Under Irrigated and Non-Irrigated Production

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Abstract

Development of cultivar specific management profiles for new potato (*Solanum tuberosum* L.) releases is an ongoing goal for potato breeding programs in order to provide growers with research-based information that can be used to make well-informed production decisions. The objectives were to compare the influence of nitrogen (N) fertility on tuber yield and chipping quality for 'Dakota Crisp' and 'Dakota Diamond', two relatively recent releases from the North Dakota State University potato breeding program, with 'Dakota Pearl' and 'NorValley', two commonly grown chipping cultivars, under irrigated and non-irrigated field conditions. When irrigated, the highest total yield for all cultivars occurred with the highest N rate (224 Kg ha^{-1} N), whereas under non-irrigated conditions, the highest yield was with 112 Kg ha^{-1} or 168 Kg ha^{-1} N. Higher marketable yields of 'Dakota Crisp' under both field conditions indicated a better economic return compared to 'Dakota Diamond', 'Dakota Pearl', and 'NorValley'. Petiole nitrate-nitrogen testing, as a practical method to evaluate the nitrogen status in plants, indicated low nitrate-nitrogen levels from June through August at the irrigated site both years, suggesting that the N rate recommendation for each cultivar under irrigated production should have been higher than 224 kg ha^{-1} to maximize yield potential. 'Dakota Crisp' and 'Dakota Diamond' processed with acceptable chip color; the sucrose and glucose levels were lower than the industry standard maximum level under both production conditions. However, the glucose content, which has been used as a quantitative indicator of potato chip quality, was generally higher in non-irrigated tubers. Among the four cultivars examined, 'Dakota Crisp' tended to have lower sucrose and glucose under both production conditions, suggesting a greater potential for long-term storage.

***Keywords:** Solanum tuberosum; Potato Chip Quality; Nitrogen Requirements; Petiole Nitrate-Nitrogen*

Abbreviations

FW: Fresh Weight; N: Nitrogen; NO_3-N: Nitrate Nitrogen; NS: Not Significant; SR: Sucrose Rating

Introduction

Chipping potatoes are an important market for potato producers, with 21% of the harvested crop devoted to chips and shoestrings or approximately 2,700,000 Mg of potatoes per year [1]. Processors demand high quality chipping cultivars, especially "cold chippers" with the ability to be processed from cold storage temperatures (4 to 6°C). 'Dakota Crisp' and 'Dakota Diamond' are two cultivars released by the North Dakota State University potato breeding program in 2005. 'Dakota Crisp' resulted from the cross of 'Yankee Chipper' and 'Norchip' and produces round to oblong tubers with a high yield potential. 'Dakota Diamond' resulted from the cross of ND4103-2 and 'Dakota Pearl' and produces round tubers with exceptionally high yield.

Among the 16 essential plant nutrients, nitrogen (N) is a macronutrient and the main component impacting potato yield and quality [2]. Nitrogen demand in a potato crop depends primarily on the length of the growing season and the cultivar being grown [3]. Adequate nitrogen may also help suppress the development of some diseases such as early blight and its associated yield loss. However**,** heavy applications of N may stimulate excessive vegetative growth [4]. This kind of excessive vegetation, resulting from over application of N is not economical, may also delay tuber bulking, and subsequently may lower yields. Additionally, some tuber characteristics, such as low specific gravity and high tuber nitrate (NO_3-N) concentration are more prevalent when fertilization exceeds the N requirement for maximum tuber yield [5]. Specific management strategies with regard to nitrogen requirements and application timing are not clearly defined for 'Dakota Crisp' and 'Dakota Diamond'. In addition, potatoes produced under irrigated and non-irrigated production may have different N requirements. The N fertilization strategy of these new cultivars needs to be addressed in order to maximize yield and tuber quality.

Nutrient monitoring based on petiole NO_3-N analysis is a valuable tool to maximize N use efficiency and reduce NO_3-N leaching to groundwater [6]. Petiole testing for NO_3-N is also a very practical method to determine the nutrient status of plants and the critical nutrient range for specific cultivars [7]. Thus, monitoring petiole NO_3-N throughout the growing season can be used as an indirect measurement of soil N availability and other factors influencing plant N uptake, growth, and yield. The profile of petiole NO_3-N associated with different N rates is very helpful in understanding N demand of a new cultivar.

Nitrogen is a phloem-mobile nutrient that can move to tubers at harvest [8]. Thus, N management may also affect sugar and starch content of tubers. Chemical maturity monitoring, which was developed to measure the "chemical maturity" of potatoes in the field, is based on sugar concentrations [9]. Concentrations of sucrose and reducing sugars, more specifically glucose, have been used as quantitative indicators of potato acceptability for chipping [10-12]. Chip color should be acceptable if the glucose content is 0.40 mg/g fresh weight (FW) or less, accompanied with a sucrose rating (SR) of 1.5 mg/g FW or less [13]. This standard is also suggested to determine an optimal harvest time to minimize accumulation of reducing sugar in long-term storage. Besides high yield potential, 'Dakota Crisp' and 'Dakota Diamond' were selected for their potential to resist cold-sweetening in low (5.5 to 7.7°C) temperature storage. The determination of sucrose content at maturity may aid potato breeders in developing potentially superior storage potato cultivars for processing [14].

Objectives of the Study

The objectives of this study were to evaluate N fertilization, N status during the growing season and the influence of the nitrogen management strategy on the processing quality for 'Dakota Crisp' and 'Dakota Diamond' in comparison to the commercial standards of 'Dakota Pearl' and 'NorValley' under irrigated and non-irrigated conditions.

Materials and Methods

Field trials were conducted during 2004 and 2005 at the Northern Plains Potato Growers Association Irrigated Research site, near Tappen, ND, on an Arvilla sandy loam soil (sandy, mixed, frigid Calcic Hapludoll), and at the North Dakota Agricultural Experiment Station research site near Prosper, ND, on a Perella-Bearden silty clay loam (Perella: fine-silty, mixed, superactive Typic Endoaquoll; Bearden: fine-silty, mixed, superactive, frigid Aeric Calciaquoll) for the non-irrigated study.

At each site, the experimental design was as a randomized complete block with four replicates. Treatments included a factorial arrangement of three nitrogen rates (112, 168 and 224 Kg ha^{-1}) and four potato cultivars (Dakota Crisp, Dakota Diamond, Dakota Pearl, and NorValley) at both sites. Plots consisted of four rows, 0.9m wide and 15.24m in length the first year, reduced to 9.14m in length the second year. Seed pieces were planted on 8 May and 28 May, 2004, and on 3 May and 23 May, 2005, for the irrigated and non-irrigated sites, respectively.

Fertilizer treatments

For the irrigated site, liquid fertilizers (10-34-0) and (28-0-0) were applied at planting to all plots to supplement residual N from the soil test to achieve 78 Kg ha^{-1} N for all treatments. Additional N amounts of 34, 45, and 78 Kg ha^{-1} N were side dressed using liquid fertilizer (28-0-0) during cultivation on June 14 for the low, medium, and high N rate treatments, respectively. The remaining N was applied over the row using granular urea (46-0-0) at four timings (7, 14, 20, and 27 July) at rates of 0, 11, and 17 Kg ha^{-1} N for the low, medium, and high nitrogen rates, respectively. Irrigation water was applied immediately following each urea application in order to reduce volatilization losses.

For the non-irrigated site, the initial N application was 15.7 Kg ha^{-1} using liquid fertilizer (10-34-0). This plus the residual soil N resulted in 68 Kg ha^{-1} N available at planting. The remaining amounts for each of the three N rates (112, 168, and 224 Kg ha^{-1}) were side dressed using urea (46-0-0) during cultivation. Phosphorus (P) and potassium (K) were applied as liquid fertilizer at planting following North Dakota State University Extension recommendations based on soil test results for both years [15].

Petiole NO_3-N

Weekly petiole samples of the fourth leaf from the top of the main stem were randomly collected starting 60d after planting until tuber maturation. A total of 10 petioles were collected from each plot at each sampling date. Leaflets were removed from petioles prior to being placed into a cooler and transported to the laboratory at Fargo, ND. Petioles were dried at 60°C and ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ) to pass through a 20 mesh sieve. The trans-nitration by the salicylic acid method [16] was used to determine the petiole NO_3-N content of samples collected.

Yield assessment

The middle two rows of each plot were harvested approximately 21 days after the vine desiccant application of diquat dibromide at 1.06 Kg ai ha^{-1} (Reglone, Syngenta, Greensboro, NC). Total yield, tuber size, and tuber numbers per plot were determined from the plot harvested sample using a programmable electronic weight sizer located at the USDA Potato Storage Research site at East Grand Forks, MN. Tubers were graded according to the U.S. standards for grades of potatoes for chipping [17]. Tubers less than 113g are undesirable for chipping and often not paid for by processors because of their small size.

Chip color measurement

Samples from each plot were collected the same day of harvest at both sites to test for tuber sucrose and glucose levels, and chip color at harvest. Tubers from each sample were cut in half lengthwise (bud to stem end). One-half of each tuber was used for sugar extraction and the remaining half for processing into chips. Only the second and third full slices (1 - 2 mm thick) from the center of each tuber were used to make up the 16 chips used for visual color rating and instrumental measurements (Agtron Process Analyzer, Agtron Inc, Reno, NV). All tuber slices were rinsed in tap water and fried in corn oil at 185°C until bubbling ceased 2 - 3 minutes later. Each slice received a visible score for color using a scale of 1 - 10 (light to dark), at one unit intervals according to the Color Reference Standard for potato chips (courtesy of B.L. Thomas, B.L. Thomas and Associates, Cincinnati, OH, and Snack Food Association, Arlington, VA). For the second chip color assessment, reference reflectance disks were used to calibrate the Agtron instrument before measurement (Agtron value 0=black and Agtron value 90 = white). Each sample was crushed and placed in a cuvette for agtron value determination utilizing reflectance spectrophotometry. A visible rating score of 4 or less was considered an acceptable chip color value by industry standards [18]. An Agtron reading of 50 or greater was considered an acceptable chip color [9]. The Agtron value for chip color was divided into more detailed categories: excellent > 60, acceptable 56 to 60, marginal 50 to 55, and rejected < 50 [9,20].

Sugar level measurement

The remaining one-half of each tuber from the chip color measurement was used for sugar using a modified procedure developed by Sowokinos [21]. In this procedure, one-half of each tuber per sample was cored to remove approximately a 25-g piece from each tuber until a total sample weight of 200g (± 0.2g) was obtained. The 200 g sample was added to a juicer (Acme Model #6001) with 150 ml diluted phosphate buffer, pH 7.2 (pH value was adjusted with solid NaOH, 1:1 diluted buffer with super-Q water, and stored in a cooler at 4°C near the juicer). After solution extraction, diluted phosphate buffer was added in order to bring the final volume to 275 ml. Measurements of sucrose and glucose were made with the YSI Model 2700 Industrial Sugar Analyzer (Yellow Spring Instrument Co., Inc., Yellow-Springs, OH). Three consecutive readings were taken and averaged to determine the concentration of sucrose and glucose for each sample

Statistical analysis

Data from each location (non-irrigated and irrigated) were analyzed individually in order to provide cultivar specific management information for the potato producers in the different production systems. All data were subjected to analysis of variance, and treatment means were compared where appropriate using the Fisher's protected least significant difference test ($P \leq 0.05$) using SAS version 9.2 software (SAS Institute, Inc., Cary, NC).

Results and Discussion

Environmental conditions (temperature and precipitation) experienced at both the irrigated and non-irrigated locations were extremely different during 2004 and 2005 and contributed to varied potato production responses. Thus, data from each year were tested for homogeneity to determine whether to analyze separately under the variable environmental conditions.

Irrigated site

The F test for homogeneity indicated that yield data among years were not homogeneous, thus data were separately analyzed. The average total yield and marketable yield was lower in 2004 compared to 2005. Multiple storms with precipitation greater than 20 mm during May 2004 and lower average temperatures for May through August (19 to 21°C) compared to the 30 yr average [22] contributed to the lower total and marketable yield in 2004 compared to 2005 when more favorable growing conditions occurred.

In 2004, the interaction between cultivar and nitrogen rate was not significantly different for total and marketable yields. The main factors of cultivar and nitrogen rate had a significant influence on tuber total yield and marketable yield. Averaged over nitrogen rates, 'Dakota Diamond' had greater total yield than the other three cultivars (Table 1). However, 'Dakota Crisp' had the greatest marketable yield followed by 'NorValley'. 'Dakota Diamond' and 'Dakota Pearl' had the lowest marketable yields. The late maturity characteristic of 'Dakota Diamond' tubers may have contributed to the high portion of unmarketable tubers, especially under insufficient N supply. The highest marketable yield of 'Dakota Crisp' suggests higher economic return potential under similar input conditions. 'Dakota Pearl' had the lowest total and marketable yields (31.3 and 14.9 T ha^{-1}, respectively).

Cultivar	Total yield		Marketable yield	
	2004	2005	2004	2005
----------------------------------t/ha------------------------------				
Dakota Crisp	32.4 bc*	43.2	21.0 a	36.7 a
Dakota Diamond	36.1 a	42.3	14.5 c	34.4 a
Dakota Pearl	31.3 c	41.1	14.9 c	28.2 b
NorValley	33.7 b	42.7	18.0 b	34.3 a
P-Value	< 0.001	0.873	< 0.001	0.017
LSD	1.5	NS	1.7	5.2

Table 1: *Effect of cultivar on total and marketable yield averaged over nitrogen rates at the irrigated site for 2004 and 2005, Tappen, ND.*

**Means within a column followed by the same letter are not different at p = 0.05 for Fisher's Protected LSD test.*

In 2004, the total yield and marketable yield averaged over cultivar increased as N rate increased with the highest total and market yield at 36.4 and 20.2 T ha^{-1}, respectively (Table 2). The lack of a sigmoidal yield response to increasing N rates suggested that an optimum N rate was not reached. Under these growing conditions, the N rate recommendation for all four cultivars would have been above 224 kg ha^{-1} to maximize tuber yields.

N rate	Total yield		Marketable yield	
	2004	2005	2004	2005
Kg ha^{-1}	--------------------t/ha-----------------			
112	30.2 c*	38.0 b	13.0 c	27.7 b
168	33.6 b	41.3 b	18.1 b	32.1 b
224	36.4 a	47.7 a	20.2 a	40.2 a
P-Value	< 0.001	< 0.001	< 0.001	< 0.001
LSD	1.3	4.5	1.5	4.5

Table 2: *Effect of N rate on total yield and marketable yield averaged over cultivars, at the irrigated site for 2004 and 2005, Tappen, ND.*
**Means within a column followed by the same letter are not different at p = 0.05 for Fisher's Protected LSD test.*

In 2005, the interaction between cultivar and nitrogen rate was not significant for total and marketable yields. The main factor of cultivar also did not significantly influence tuber total yield, but cultivars did influence tuber marketable yields (Table 1). Cultivars Dakota Crisp, Dakota Diamond and NorValley had similar marketable yield (≥ 34.3 T ha^{-1}), while Dakota Pearl had a lower marketable yield. 'Dakota Pearl's' lowest marketable yield for both years under irrigated conditions suggested that it has a lower yield potential in comparison to 'Dakota Crisp', 'Dakota Diamond', or 'NorValley'.

The main factor of N rate had a significant effect on both total and marketable yields in 2005 (Table 2). Again the highest N rate had the highest total and marketable yield (47.7 and 40.2 T ha^{-1}, respectively) while the lower N rates of 112 and 164 kg ha^{-1} had similarly lower total and marketable yields. Therefore, even under the more favorable growing conditions in 2005, N rates higher than 224 kg ha^{-1} may have increased tuber yields for all four cultivars.

Specific gravity

The F test for homogeneity indicated that specific gravity data for 2004 and 2005 were homogeneous, thus data were combined across years. The main factor of cultivar had significant influence on tuber specific gravity with the highest specific gravity for 'Dakota Diamond' (Table 3). 'Dakota Pearl' and 'NorValley' had similar but lower specific gravity compared to 'Dakota Diamond', while 'Dakota Crisp' had the lowest specific gravity. However, all four cultivars had specific gravity higher than 1.080, the minimum industry standard for most northern production [23]. Nitrogen rate did not influence tuber specific gravity, with similar values for all N rates (data not shown). Belanger., *et al.* [5] reported that specific gravities decreased as nitrogen rate increased for 'Russet Burbank' and 'Shepody'. They concluded that the risk of low specific gravity is greater when fertilization exceeds the N requirement for tuber maximum yield. However, the highest N rate (224 kg ha^{-1}) in this study resulted in a yield increase, suggesting that the N requirement for each cultivar was not exceeded, thus greater tuber dry matter accumulation as N rate increased.

Cultivar	Specific Gravity	
	Irrigated	Non-irrigated
Dakota Crisp	1.083 c*	1.085 b
Dakota Diamond	1.097 a	1.094 a
Dakota Pearl	1.087 b	1.091 a
NorValley	1.088 b	1.086 b
P-Value	0.003	< 0.001
LSD	0.004	0.003

Table 3: *Effect of cultivar on specific gravity, averaged over nitrogen rates and across years, for the irrigated site, Tappen, ND and average-over nitrogen rates in 2005 at the non-irrigated site, Prosper, ND.*

**Means within a column followed by the same letter are not different at p = 0.05 for Fisher's Protected LSD test.*

Petiole nitrate-nitrogen level

Petiole testing for NO_3-N is a very practical method to determine the nutrient status of potato plants. Weekly petiole tests enable growers to supplement N when values drop below desired levels. However, with predetermined N inputs, petiole testing was monitored to help explain yield and chip quality results.

Petiole NO_3-N levels varied throughout both growing seasons, and were very low for all cultivars during 2004, while in 2005, the petiole NO_3-N levels were much higher, which was consistent with the yield performance (Figure 1 and 2). In both years, the trends of petiole nitrate-nitrogen levels were similar with a large decline at 67 days after planting for every cultivar. At each sampling time, there was no significant difference for petiole NO_3-N levels among cultivars. The similar petiole NO_3-N pattern among cultivars suggested that the same nitrogen management strategy could apply for these four cultivars in order to maximize yields. 'Dakota Diamond' had the lowest petiole nitrate nitrogen levels of in both years compared to other cultivars, which was attributed to its late maturity characteristics. The lower percentage of marketable yields of 'Dakota Diamond' also reinforced the N uptake pattern with less N uptake during the early season compared to other cultivars.

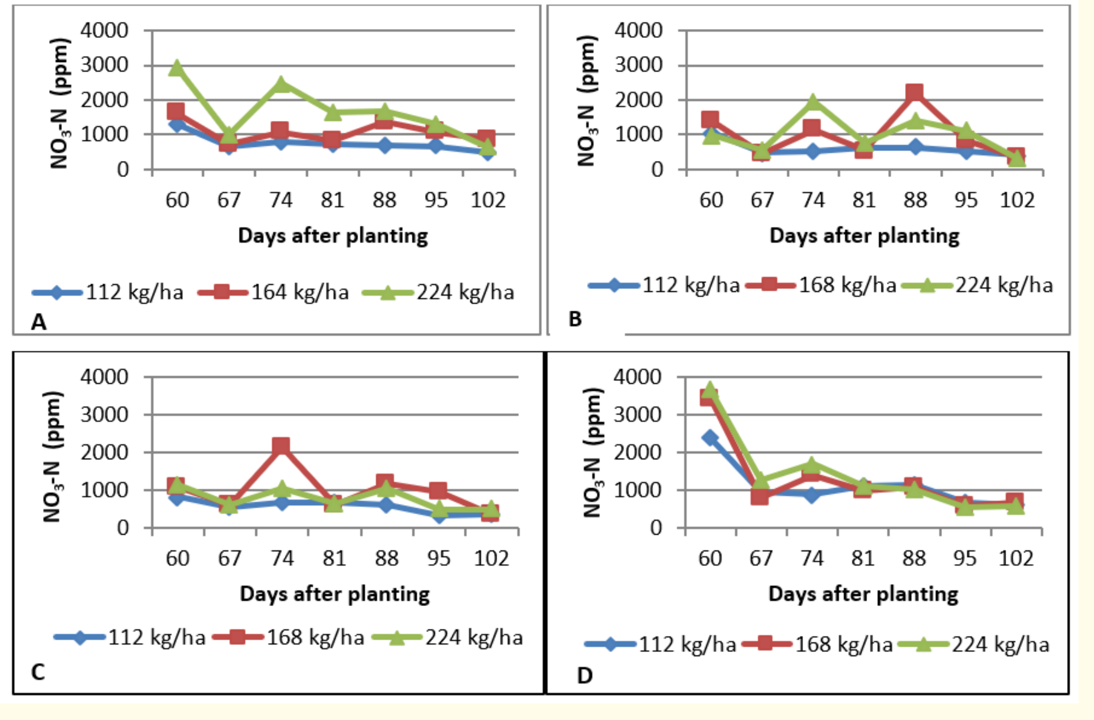

Figure 1: The petiole NO3-N levels during growth season of 'Dakota Crisp', 'Dakota Diamond', 'Dakota Pearl' and 'NorValley' (A, B, C, D, respectively) in 2004 for the irrigated site, Tappen, ND.

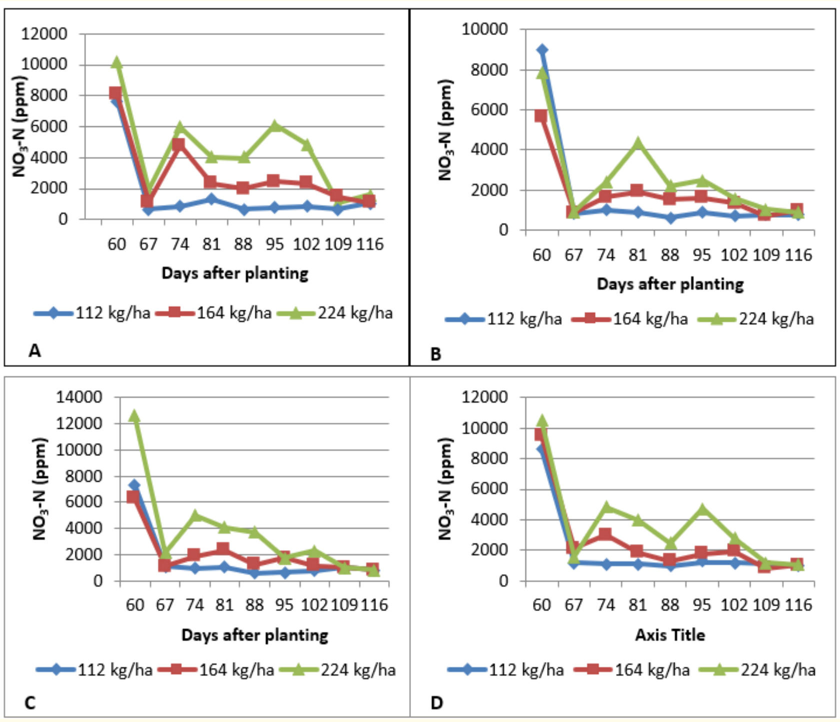

Figure 2: The petiole NO3-N levels during growth season of 'Dakota Crisp', 'Dakota Diamond', 'Dakota Pearl' and 'NorValley' (A, B, C, D, respectively) in 2005 for the irrigated site, Tappen, ND.

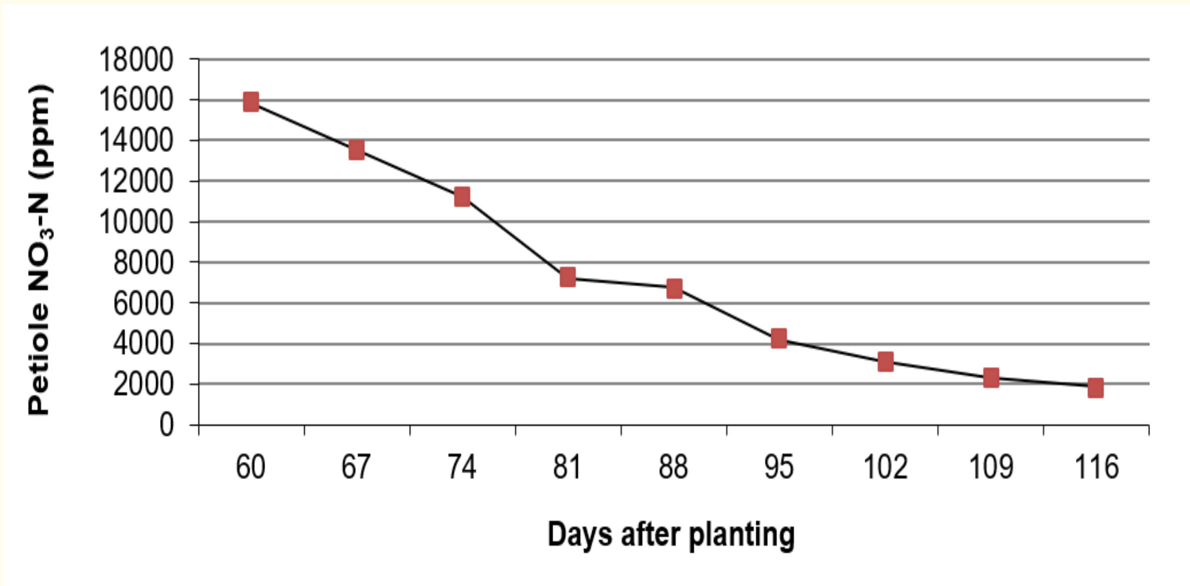

Figure 3: The petiole $NO_{3-}N$ levels average over cultivars, N rates, and years during growth season for the non-irrigated site, Prosper, ND.

Sugar content and chip color at harvest

In 2004, the interaction between cultivar and N rate was not significant for tuber sugar level and chip color. Cultivar influenced sucrose, and visible color, but not glucose level or Agtron value. As previously stated, chip color should be acceptable if the glucose content is 0.4 mg/g FW, accompanied with a SR of 1.5 mg/g FW or less [13]. All cultivars at harvest had a glucose level much lower than the minimum chemical maturity level 0.4 mg/g fresh weight (Table 4). However, 'Dakota Diamond' had a significantly higher sucrose level than other cultivars, which was also slightly higher than the SR of 1.5 mg/g FW, indicating a lower potential for long term storage with regard to chip color. 'Dakota Crisp' tubers had a significantly lower sucrose level than other cultivars, indicating long-term storage potential compared to other cultivars due to reduced risk of high sucrose concentrations converted into glucose in storage. 'Dakota Diamond' had better chip color, according to the color chart, than 'Dakota Crisp' or 'Dakota Pearl' chips. However, the chip color visible grades averaged over nitrogen rates were all ≤ 4.0. The maximum acceptable chip color value according to industry standards [13] is < 4.0, so 'Dakota Pearl' chips would be considered marginally acceptable. Agtron values for all cultivars were at least 60, which were above the minimum acceptable color value of 50, according to industry standards and were considered excellent chip color [13]. This indicated that these four cultivars can be processed into chips with excellent chip color when they are chemically mature and that N rate did not influence sugar content or chip color.

Cultivar	Sucrose Content	Glucose Content	Chip Color[1st]	Agtron Value[2nd]
	--mg/g--	--mg/g--	--1 to 10--	--1 to 100--
Dakota Crisp	0.81c*	0.01	3.8 a	61
Dakota Diamond	1.57 a	0.02	3.3 b	60
Dakota Pearl	1.25 b	0.02	4.0 a	60
NorValley	1.12 b	0.05	3.6 ab	61
P-Value	< 0.001	0.09	0.02	0.9
LSD	0.18	NS**	0.4	NS

Table 4: *Effect of cultivar on tuber sucrose and glucose levels, and chip color averaged over nitrogen rates at harvest, Tappen, ND, 2004.*

**Means within a column followed by the same letter are not different at p = 0.05 for Fisher's Protected LSD test.*

***NS means not significant.*

[1st] Acceptable < 4.0.

[2nd] Excellent > 60, acceptable = 56 to 60, marginal 50 to 55, and rejected < 50.

In 2005, cultivar had a significant influence on tuber sucrose and glucose levels. As in 2004, 'Dakota Diamond' had higher sucrose and glucose levels than the other cultivars, reinforcing its lower potential for long term storage when grown under similar conditions (Table 5). The higher sugar level of 'Dakota Diamond' may be attributed to its late maturity. With an extended growing period, the sugar level of 'Dakota Diamond' might be lower with the conversion of sugar into starch. 'Dakota Crisp' had similar sucrose and glucose content as 'Dakota Pearl' or 'NorValley'. The sugar levels of these three cultivars were lower than the maximum sugar level acceptable to process acceptable chip colors. Cultivar did not influence visible chip color or agtron values, even though the 'Dakota Diamond' chip color was just above the acceptable level of < 4.0.

Cultivar	Sucrose Content	Glucose Content	Chip Color[1st]	Agtron Value[2nd]
	--mg/g--	--mg/g--	--1 to 10--	--1 to 100--
Dakota Crisp	1.01 b*	0.08 b	3.5	60
Dakota Diamond	1.53 a	0.13 a	4.0	59
Dakota Pearl	1.03 b	0.06 b	3.5	61
NorValley	1.08 b	0.09 ab	3.6	60
P-Value	< 0.001	0.01	0.08	0.8
LSD	0.27	0.04	NS**	NS

Table 5: *Effect of cultivar on tuber sucrose and glucose levels, and chip color averaged over nitrogen rates at harvest, Tappen, ND, 2005.*

**Means within a column followed by the same letter are not different at p = 0.05 for Fisher's Protected LSD test.*

***NS means not significant.*

[1st] *Acceptable < 4.0.*

[2nd] *Excellent > 60, acceptable = 56 to 60, marginal 50 to 55, and rejected < 50.*

Non-irrigated site

The F test for homogeneity indicated that the two years were homogenous for total and marketable yield variables. Thus, combined yield analyses were conducted to compare cultivar, N rate, and their interaction effects. The combined analysis of the two-year study indicated that there was a significant two-way interaction between year and cultivar for tuber total yield and marketable yield. 'Dakota Crisp' and 'Dakota Diamond' had higher tuber total and marketable yields in 2004 (52.3 and 46.0; 51.6 and 45.1 T ha^{-1}, respectively) compared to the other two cultivars (Table 6). However, in 2005, 'Dakota Crisp' had the highest tuber total and marketable yield, while 'Dakota Diamond' had the lowest yields. The low yield with 'Dakota Diamond' was unexpected, but may have resulted from frequent rainfall after planting. 'Dakota Crisp' had the highest total and marketable yields in both years, suggesting that even under quite variable environmental conditions, 'Dakota Crisp' should provide better economic returns with the same input under the non-irrigated growing system.

Year	Cultivar	Total Yield	Marketable Yield
		-------------------t/ ha--------------	
2004	Dakota Crisp	52.3 a*	46.0 a
	Dakota Diamond	51.6 a	45.1 a
	Dakota Pearl	44.8 bc	40.3 b
	NorValley	42.3 c	35.0 c
2005	Dakota Crisp	47.7 ab	36.6 b
	Dakota Diamond	37.0 d	31.4 d
	Dakota Pearl	41.2 cd	33.9 cd
	NorValley	45.5 b	36.4 bc
P-Value		< 0.001	< 0.001
LSD		4.2	3.9

Table 6: *Mean yield performance for cultivar average nitrogen rates in 2004 and 2005 at the non-irrigated site, Prosper, ND.*

**Means within a column followed by the same letter are not different at p=0.05 based on Fisher's Protected LSD test.*

Nitrogen rate did not influence tuber total yield or marketable yield. The total and marketable yields under each nitrogen rate averaged over cultivars were higher than 44.2 and 36.8 T ha^{-1}, respectively. The lack of response to increasing N rates for yield was attributed to nutrient-holding capacity with the clay loam soil, which potentially reduced N leaching. The lowest N rate provided sufficient N for each cultivar to maximize their yield performance. Thus, in non-irrigated production with a clay loam soil, the N rate of 112 kg ha^{-1} would be recommended to growers as sufficient N to maximize yield and maintain high tuber quality.

Specific gravity

The F test for homogeneity indicated that the specific gravity data for these two years were not homogeneous, thus data were analyzed separately. In 2004, none of the variables tested influenced tuber specific gravity. In 2005, 'Dakota Diamond' and 'Dakota Pearl' had significantly higher specific gravity (1.094 and 1.090, respectively) than 'Dakota Crisp' or 'NorValley' (Table 3). Tubers from the low and medium N rates of 112 kg ha^{-1} and 168 Kg ha^{-1} had greater specific gravity compared to the highest nitrogen rate of 224 kg ha^{-1} (Table 7). This was consistent with previous research and reinforced conclusions that excess nitrogen reduces tuber specific gravity [5].

Nitrogen rate	Specific gravity
Kg ha^{-1}	
112	1.088 a*
168	1.088 a
224	1.085 b
P-Value	0.012
LSD	0.002

Table 7: *Effect of nitrogen rate on tuber specific gravity, averaged over cultivar at the non-irrigated site, Prosper, ND, 2005.*

**Means within a column followed by the same letter are not different at p = 0.05 based on Fisher's Protected LSD test.*

Petiole nitrate-nitrogen level

The F test for homogeneity indicated that the results were homogeneous, thus combined analyses across years were conducted. There were no significant differences for petiole NO_3-N level among the main factor cultivar or N rate, indicating the same N management strategy with a N rate at 112 kg ha^{-1} should be applied for these four cultivars to maximize yields.

In both years, petiole NO_3-N levels averaged over N rate and cultivar kept decreasing from 60 DAP with only a slight horizontal level at 81 to 88 DAP, which might be attributed to the active N uptake during the tuber bulking stage. The results showed that at 60 DAP, the petiole NO_3-N level was above 18,000 ppm in 2004 and approximately 13,000 ppm in 2005. The different petiole NO_3-N levels in the two years were attributed to the heavy rainfall after planting in 2005, which may have also lowered yields in 2005, compared with 2004. In both years, the petiole NO_3-N levels decreased to approximately 2000 ppm by the tuber maturation stage.

Sugar content and chip color at harvest

The F test for homogeneity indicated that the sugar content and chip color data for these two years were not homogeneous; therefore, data were analyzed separately.

In 2004, only cultivar influenced some of the chip quality variables measured. However, cultivar did not affect the tuber sucrose level at harvest (Table 8). The sucrose levels of all four cultivars were slightly higher than when grown under the irrigated production and above the SR of 1.5 mg/g FW, with the exception of 'Dakota Crisp'. Cultivar significantly influenced tuber glucose level, chip visible color, and Agtron value. As with irrigated production, 'Dakota Crisp' under non-irrigated production had the lowest glucose level (0.08 mg/g) with better chip color performance than other three cultivars. The glucose levels of the other three cultivars were higher, but with the exception of 'NorValley', still lower than 0.40 mg/g FW, the maximum level to produce acceptable chip color [13]. Chip color for the four cultivars were lower than 4.0 (industry maximum level acceptable chip color), and Agtron values were all acceptable except the 'NorValley' chip color Agtron value was 54, which is within the marginal range (50-55). This was not expected as Wang., *et al.* [19] showed how mild environmental stresses with chipping cultivars resulted in higher reducing sugar levels and darker chips.

Cultivar	Sucrose Content	Glucose Content	Chip Color[1st]	Agtron Value[2nd]
	--mg/g--	--mg/g--	--1 to 10--	--1 to 100--
Dakota Crisp	1.47	0.08 b**	3.4 b	57 a
Dakota Diamond	1.71	0.20 ab	3.9 a	56 ab
Dakota Pearl	1.83	0.34 a	3.9 a	56 a
NorValley	1.64	0.45 a	3.9 a	54 b
P-Value	0.404	0.043	0.046	0.019
LSD	NS*	0.26	0.4	1.3

Table 8: *Effect of cultivar on sucrose, glucose level, chip color, and agtron value at harvest for the non-irrigated site, Prosper, ND, 2004.*

**NS means not significant.*

***Means within a column followed by the same letter are not different at p = 0.05 for Fisher's Protected LSD test.*

[1st] Acceptable < 4.0.

[2nd] Excellent > 60, acceptable = 56 to 60, marginal 50 to 55, and rejected < 50.

In 2005, there was significant differences for sucrose and glucose levels among cultivars. 'Dakota Crisp' had significantly lower sucrose and glucose levels than 'Dakota Diamond', reinforcing its potential for long term storage under the same growing conditions (Table 9). 'Dakota Pearl' and 'NorValley' had similar glucose levels as 'Dakota Crisp', resulting in the similar chip color. The results reinforced that the higher sugar level of 'Dakota Diamond' may be attributed to its late maturity.

Cultivar	Sucrose Content	Glucose Content	Visual Chip Color[1st]	Agtron Value[2nd]
	mg/g	mg/g	1-10	1-100
Dakota Crisp	1.28 b*	0.29 b	3.5	57
Dakota Diamond	1.52 a	0.47 a	4.0	55
Dakota Pearl	1.34 b	0.25 b	3.6	56
NorValley	1.08 c	0.23 b	3.4	57
P-Value	0.006	0.006	0.06	0.056
LSD	0.17	0.15	NS**	NS

Table 9: *Effect of cultivar on sucrose, glucose level, visual chip color, and agtron value at harvest for the non-irrigated site, Prosper, ND, 2005.*

***NS means not significant.*

**Means within a column followed by the same letter are not different at p = 0.05 based on Fisher's Protected LSD test.*

[1st] Acceptable < 4.0.

[2nd] Excellent > 60, acceptable = 56 to 60, marginal 50 to 55, and rejected < 50.

Conclusion

The purpose of this research was to investigate the N management strategies for two recently introduced chipping potato cultivars (Dakota Crisp and Dakota Diamond) with two commercial standard cultivars (Dakota Pearl and NorValley) under irrigated and non-irrigated production conditions. The results indicated that the N rate 224 kg ha^{-1} or higher and N rate 112 kg ha^{-1} are recommended for these four cultivars grown under irrigated and non-irrigated production, respectively. Of these four cultivars, 'Dakota Crisp' can produce high marketable yields with high specific gravity. The higher marketable yields of 'Dakota Crisp' also indicated a better economic return compared to 'Dakota Diamond', 'Dakota Pearl', and 'NorValley'. Continued research should investigate N application timing and application method to increase the N use efficiency especially for the irrigated production system.

The sugar content of 'Dakota Crisp' was generally lower than other cultivars under both production systems, indicating the chipping potential of this cultivar under long-term storage. Further research should investigate the sugar development of each cultivar under cold temperatures during long-term storage to evaluate the storage profiles of these cultivars.

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Conflict of Interest

No conflict of interest occurred.

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