American Journal of Potato Research (2024) 101:481–489
https://doi.org/10.1007/s12230-024-09974-2

Nitrogen and Spacing Requirements for Advanced Chipping Selections ND7799c-1 and ND7519-1

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Accepted: 24 October 2024 / Published online: 16 November 2024
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Abstract

Adoption of new cultivars is challenging for commercial growers. To understand the best nitrogen fertilization rate (90, 134, 179, and 224 kg N ha^{-1}) and within-row spacing (15, 23 and 31 cm) for two potential potato cultivar releases from North Dakota State University, a study was carried out in 2019 and 2020 in North Dakota. The advanced chipping selections ND7799c-1 and ND7519-1 were compared to a chip industry standard, Dakota Pearl. In 2019, ND7799c-1 grown at 23 cm within-row spacing had similar marketable yield to Dakota Pearl. In 2020, ND7519-1 at all within-row spacings, and ND7799c-1 at 15 and 23 cm within-row spacing, yielded similarly to Dakota Pearl. Nitrogen rate did not affect yield or chipping quality in 2019 or 2020. The advanced selections had lower sucrose and glucose levels one month after harvest compared to Dakota Pearl in 2020. ND7799c-1 stored for 8 months, and ND7519-1 for 6 months, before chip quality declined. This research demonstrates the potential for ND7799c-1 and ND7519-1 to be successful chip processing cultivars for the Northern Plains.

Keywords Non-irrigated · Agronomic production · Chip potato clone

Resumen

La adopción de nuevas variedades es un desafío para los productores comerciales. Para comprender la mejor tasa de fertilización nitrogenada (90, 134, 179 y 224 kg N ha-1) y el espacio dentro de los surcos (15, 23 y 31 cm) para dos posibles liberaciones de variedades de papa de la Universidad Estatal de Dakota del Norte, se llevó a cabo un estudio en 2019 y 2020 en Dakota del Norte. Las selecciones de líneas avanzadas para freído ND7799c-1 y ND7519-1 se compararon con un estándar de la industria de frituras, Dakota Pearl. En 2019, ND7799c-1 cultivado a 23 cm de distancia entre plantas dentro del surco tuvo un rendimiento comercializable similar al de Dakota Pearl. En 2020, ND7519-1 en todos los espaciamientos entre plantas dentro del surco, y ND7799c-1 en espaciamientos entre plantas de 15 y 23 cm, rindieron de manera similar a Dakota Pearl. La tasa de nitrógeno no afectó el rendimiento ni la calidad del freído en 2019 o 2020. Las selecciones avanzadas tuvieron niveles más bajos de sacarosa y glucosa un mes después de la cosecha en comparación con Dakota Pearl en 2020. ND7799c-1 se almacenó durante 8 meses y ND7519-1 durante 6 meses, antes de que la calidad del freído disminuyera. Esta investigación demuestra el potencial de ND7799c-1 y ND7519-1 para ser variedades exitosas de procesamiento de freído para las llanuras del norte.

Introduction

There is a continuous need to develop new potato cultivars because of climate change, shifting market demands, and rapid adaptability of pests such as insects, weeds, and pathogens. Potato breeders work to develop clones with increased nutrient and water use efficiency, disease resistance, and improved capacity for long-term storage (Armstrong et al. 2020; Fulladolsa et al. 2015). Improving nitrogen uptake efficiency (NUE) addresses concerns about high production

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costs and environmental damage that may come from using excessive nitrogen (N) or inappropriately timing the application (Tiwari et al. 2019). In addition to these traits, chipping potatoes are bred with specific traits including high dry matter content and low sugar accumulation, that affect chip color and processing quality (Wayumba et al. 2020).

When new cultivars are released with specific traits benefitting the potato industry, some habitual agricultural practices may not accommodate a new cultivar, such as nitrogen rates and timing, and it can be mistakenly labeled as a failure. One such example is Dakota Diamond, a cultivar released from the NDSU breeding program. This cultivar has a higher yield potential than other common chipping potatoes released at the time, in addition to having higher marketable yield under irrigated and non-irrigated field production (Thompson et al. 2008). However, this cultivar requires less nitrogen fertilizer than standard chipping potato cultivars, and standard nitrogen fertilization rates were too high, resulting in excessive vegetative growth, decreased specific gravity, reduced yield, and an increase in sugar content that had negative effects on processing quality, storage, and grower acceptance (A. Thompson, personal communication, March 6, 2020).

The purpose of this study was to assess the best agronomic practices for two advancing selections from the NDSU potato breeding program, ND7799c-1 and ND7519-1. These selections have "cold chipping" potential, thus they may be able to chip directly from cold storage without the need for reconditioning. They also can be chipped immediately after harvest without the need to pre-condition the tubers in storage. ND7799c-1 resulted from a cross between Dakota Pearl and NY115. It has high yield potential with a uniform tuber size profile, and high specific gravity (1.086+) across irrigated and non-irrigated field sites; it chips well from 5.5 °C storage. ND7519-1 resulted from a cross between ND3828-15 and W1353. It has excellent chipping qualities, medium-high yield potential, high specific gravity (1.090+) across irrigated and non-irrigated locations, and can chip from 5.5 °C storage.

The objective of this study was to determine the optimal nitrogen rate and within-row spacing for ND7799c-1 and ND7519-1 in non-irrigated field conditions to maximize tuber yield and chipping quality. It was hypothesized that these potential new cultivars would have similar yield and quality when compared to industry standard, Dakota Pearl (Thompson et al. 2005).

Materials and Methods

Trials were established in 2019 and 2020 near Hoople, ND (N 48° 32.0828', W 97° 38.0885'). Field soil types for 2019 and 2020 were classified as well drained Glydon silt loam soils with 2% organic matter content, 0 to 2% slope, a pH of 8.2 to 8.4 and a residual nitrogen content of 30 lb N ha^{-1}. In 2019, the advanced selection ND7799c-1 and industry standard Dakota Pearl were grown. In 2020, ND7799c-1, ND7519-1, and Dakota Pearl were grown. ND7519-1 was included in 2020 because this clone had many positive traits and there was sufficient seed available.

Experimental Design

The experiment utilized a randomized complete block design with factorial arrangement of treatments. Treatments included clone (ND7799c-1, ND7519-1 and Dakota Pearl), nitrogen fertilizer rate (90, 134, 179 and 224 kg N ha^{-1}), and within-row spacing of seed pieces (15, 23 and 31 cm) on 91 cm wide rows. Normal row spacing in the Northern Plains non-irrigated potato production is 23 cm with rows that are 91 cm apart. Trials were machine planted with a two-row planter on June 8 and 13, 2019 (a rainstorm caused a delay in planting), and on June 3, 2020. Each treatment was replicated four times. Within-row spacing treatments were based on a range of common spacings used in non-irrigated chipping potato production. Nitrogen treatments were determined as the best possible increments in a range of possible N rates from low to high. The nitrogen fertilizer urea (46% N) was broadcast prior to planting each year, at rates of 90, 134, 179, and 224 kg of N ha^{-1}. Plots measured 3.7 m wide by 7.6 m long. The two center rows were labeled A and B. Row A was used for measuring plant height and harvesting of the tubers, while row B was used in assessing nitrogen levels by sampling plants. Border rows were utilized to minimize edge effects. All other production practices were standard potato production practices for non-irrigated potato in ND and MN (Bissonnette et al. 1993). Growing Degree Days (GDD) were calculated with a base temperature of 7 °C using the formula (Sands et al. 1979):

$$Growing\ Degree\ Days\ (GDD) = [(minT + maxT)/2 - 7^\circ C]$$

In-Season Monitoring for Nitrogen Uptake Efficiency of Above Ground Biomass

In 2020, NUE was determined 5, 7, 9 and 11 weeks after emergence. The entire above-ground biomass from the area occupied by three plants was removed from row B and fresh weight was determined. A subsample of 0.9 kg was retained and dried at 40 °C in paper bags for 2 weeks. Dried tissue was processed by Agvise Laboratories (Northwood, ND) for percent total N determination using the Dumas combustion method in an Elementar rapid N analyzer (Jones and Case 1990). Nitrogen uptake efficiency was calculated by taking the percent N content of the dry plant tissues, multiplying it by the scaled weight of the plants in kilograms and the area they occupied in hectares, and dividing it by the total nitrogen applied in kg ha^{-1} for the plot.

$$Nitrogen\,Uptake\,Efficiency\ (NUE) = \frac{Percent\ N\ of\ plants \times Total\ N\ of\ sampled\ area\ \left(kg\ ha^{-1}\right)}{Total\ nitrogen\ applied\ \left(kg\ ha^{-1}\right)}$$

Tuber Yield

Approximately three weeks after vine-kill, desiccated potato vines were flailed prior to harvest. Tubers were harvested on September 4, 2019, and on September 8, 2020. Tubers were stored at 13 °C for four weeks for wound healing and suberization. After wound healing, tubers were graded on a Kerian Speed Sizer calibrated to sort potato tubers as oversized (greater than 8.9 cm diameter), marketable chip size (4.7 to 8.9 cm diameter), and small or undersized (less than 4.7 cm diameter). Grading was done according to the USA Snacking Nutrition and Convenience (SNAC) International Chip Trial grading standards for potatoes for chipping (Gould and Plimpton 1985).

Post-Harvest Tuber Quality

At the end of suberization (1 month after harvest) a sample of 10 tubers were evaluated for specific gravity, sucrose and glucose level, and Hunter L-value for processed potato chips. Seven samples of 10 marketable chip size tubers for each clone and nitrogen treatment at the 23 cm within-row spacing were arbitrarily selected after grading to evaluate tuber quality and storage capacity of each treatment. The remaining tubers were arbitrarily sampled and divided into two groups and stored at 7.2 and 9.9 °C. After 3, 6, and 8 months of storage, 10 tubers from each storage temperature were evaluated for specific gravity, sucrose and glucose content, and Hunter scores determined for processed chips.

Specific gravity was determined by the weight-in-air and weight-in-water method (Lulai and Orr 1979). Sucrose and glucose levels were determined by juicerating 200 g of potato tuber tissue with 150 ml of a sodium phosphate buffer in a Waring juicer. Distilled water was added to the sample bringing the volume to 275 ml; the sample was refrigerated for 30 min to allow for settling. The sample was injected into a YSI 2500 Biochemistry Analyzer (Yellow Springs Instrument) with a sucrose and glucose membrane. Sucrose content and glucose content were transformed from mg ml^{-1} to mg g^{-1} and compared to the target maximum sucrose and glucose content reported by Stark et al. (2020).

Thirty chips were peeled and cut per treatment to 1.27 mm thickness then fried for 2 min at 185 °C in canola oil. Hunter L value score was then used to assess chip quality color after frying following the methods of Hunter and Harold (1987). The Hunter L value was obtained using a Hunter D25-NC colorimeter (Hunter Instrument) to assess chip color after frying.

Statistics

Analyses were computed for yield, nitrogen content, and chip quality attributes. Because of the addition of ND7519-1 to the study in 2020 and differences in environmental conditions between the two years, separate statistical analyses were conducted for each year. All statistical analyses were computed using the statistical analysis software R version (v3.6.1 R Core Team 2021). Analysis of variance and a Tukey separation of means were computed using $\alpha = 0.05$ for all statistical models.

ND7799c-1 was compared to the industry check Dakota Pearl, in 2019. Using a linear model, the analyses of variance were analyzed using replicate, clone, nitrogen rate, and within-row spacing as fixed effects. Statistical analysis was performed for total and marketable yield. Four separate chip quality and post-harvest linear models were developed for sucrose content, glucose content, specific gravity, and Hunter score. Each post-harvest model was considered for statistical differences between clones at varying nitrogen rates and storage temperatures as a function of time.

ND7799c-1 and ND7519-1 were compared to Dakota Pearl in 2020. The results were analyzed using a linear model using clone, nitrogen rate and within-row spacing as fixed effects. Data analyses were conducted for yield attributes including total, marketable, undersized, and oversized yield. Four separate chip processing quality and post-harvest linear models were determined for sucrose content, glucose content, specific gravity, and Hunter L-value. Each post-harvest model was considered for statistical differences between clones at varying nitrogen rate and storage temperature as a function of duration in months of storage. Nitrogen uptake efficiencies (Weih et al. 2011) were evaluated by clone, nitrogen rate, and as a function of weeks after planting.

Table 1 Growing degree days (GDD) and rainfall in 2019 and 2020 and the 30-year normal from the NDAWN weather station at Crystal, ND

Month	Growing degree days accumulated		Rainfall (mm)		30-year normal weather at Crystal, ND[1]	
	Year		Year		GDD	Rainfall (mm)
	2019	2020	2019	2020		
June	399	361	106	68	329	97
July	418	369	51	23	407	90
August	244	250	19	40	380	66
Total	1061[2]	980	176	131	1,116	253

[1]Crystal NDAWN weather station is located approximately 13 km away from each field site. 30-year normal weather is calculated from 1991 to 2020 according to international standards

[2]Total growing degree days (base 7 °C) and rainfall were calculated using the day of planting as the start date and the day the vines were flailed as the last day

Table 2 Marketable yield (MT ha^{-1}), total yield, undersized tubers (< 4.8 cm), and oversized tubers (> 8.9 cm) for Dakota Pearl, ND7799c-1 and ND7519-1 at within-row spacings of 15, 23 and 31 cm grown near Hoople, ND, in 2019 and 2020

Spacing	2019				2020			
	US No. 1	Total yield	< 4.8 cm	> 8.9 cm	US No. 1	Total yield	< 4.8 cm	> 8.9 cm
Dakota Pearl								
15 cm	28.4 *a*	30.3 *ab*	1.8 *a*	1.4 *b*[1]	27.2 *a*	28.7 *a*	1.5 a*b*	1.9 *bcd*
23 cm	26.3 *b*	27.6 *bc*	1.2 *bc*	0.7 *b*	26.3 *a*	27.5 *a*	1.3 a*bc*	1.6 *bcd*
31 cm	26 *b*	27.3 *bc*	1.3 a*b*	0.1 *b*	24.4 *ab*	24.9 *ab*	0.5 *bc*	2.2 *bcd*
ND7799c-1								
15 cm	25.6 *b*	27.4 *bc*	1.7 *ab*	0.5 *b*	25.4 *ab*	26.1 *ab*	0.7 *bc*	5.5 *ab*
23 cm	30.9 *a*	31.5 *a*	0.6 *cd*	2.9 *a*	27.2 *a*	27.5 *a*	0.2 *c*	8.8 *a*
31 cm	25.9 *b*	26.1 *c*	0.2 *d*	3.0 *a*	17.8 *b*	18.0 b	0.1 *c*	4.8 *bc*
ND7519-1								
15 cm	-	-	-	-	20.7 *ab*	23.0 *ab*	2.3 *a*	0.4 *d*
23 cm	-	-	-	-	24.1 *ab*	26.3 *a*	2.2 *a*	0.1 *d*
31 cm	-	-	-	-	21.0 *ab*	21.8 a*b*	0.8 *bc*	0.1 *d*

[1]Data points followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at $P = 0.05$

Results and Discussion

Weather

Rainfall was considered numerically less than the average for the Crystal, North Dakota, Agriculture Weather Network (NDAWN) weather station located approximately 13 km from the field sites, in 2019 and 2020. There was 45 mm more precipitation throughout the growing season in 2019 compared to 2020 (Table 1). Precipitation, totaling 66 mm, occurred early in the 2019 growing season during tuber initiation and early tuber bulking 2019. A late season rainstorm in 2020 came before vine kill, thus it likely did not affect tuber yield. Overall, 2020 had fewer growing degree days (GDD) than 2019 by 81 GDD.

Total and marketable yield for Dakota Pearl and ND7799c-1 were numerically less in 2020 than 2019 (Table 2). The difference in total yield for all clones in 2020 may be because of water stress. However multiple biotic and abiotic factors can influence yield and clone as year-to-year variability in potato yield is common. Water stress, particularly during the tuber bulking phase, has been shown to have a negative effect on yield, a reduction in the formation of new leaves, and an increase in water loss through evapotranspiration (Aliche et al. 2019). Water stress appeared to have a much larger effect numerically across the two years on yield and quality of ND7799c-1 compared to Dakota Pearl, implying that ND7799c-1 may be less efficient at acquiring or using water. Further research is warranted to confirm this because of the difference of 81 GDD between the two growing seasons, which may denote a degree of differences in temperature or length of growing seasons.

ND7799c-1 produced numerically three times the number of oversized tubers in 2020 compared to 2019 (Table 2). This was similar to the findings of Levy (1983) who reported potato clones subjected to intentional water stress produced more oversized tubers. Glucose levels in our study were numerically higher at harvest in 2020 than in 2019, usually this is accompanied by lower Hunter L values. However, there were numerically higher Hunter L-values (lighter fry color) in 2020 compared to 2019. Specific gravity was also numerically lower for all lines at harvest. The results for 2020 can be examined considering potential water stress, which is more common under non-irrigated production conditions. Reduction in tuber yield and quality can be mitigated by proper water management during the growing

Table 3 Nitrogen uptake efficiency (NUE) of the above-ground biomass for Dakota Pearl, ND7519-1, and ND7799c-1 at 35, 50, 65, and 77 days after planting (DAP), near Hoople, ND in 2020

Clone	Nitrogen uptake efficiency (%)			
	35 DAP	50 DAP	65 DAP	77 DAP
Dakota Pearl	86 *a*[1]	49 *b*	57 *a*	37 *b*
ND7519-1	88 *a*	59 *a*	65 *a*	43 *a*
ND7799c-1	58 *b*	53 *b*	59 *a*	40 *ab*

[1]Data points followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at $P = 0.05$

Table 4 Nitrogen uptake efficiency (NUE) of the above-ground biomass analyzed by nitrogen rate combined across all clones, at 35, 50, 65, and 77 days after planting (DAP) near Hoople, ND, in 2020

Nitrogen Rate (kg ha^{-1})	Nitrogen uptake efficiency (%)			
	35 DAP	50 DAP	65 DAP	77 DAP
90	122 *a*[1]	82 *a*	96 *a*	60 *a*[1]
134	78 *b*	58 *b*	60 b	42 *b*
179	55 *b*	39 c	50 *bc*	32 *c*
224	52 *b*	35 *c*	37 *c*	26 *d*

[1]Data points followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at $P = 0.05$

season with proper management in irrigated potato production conditions (Levy et al. 2013).

Within-Row Spacing Effect on Yield

In 2019 and 2020, within-row spacing and clone were significant factors effecting marketable (US No. 1), total, undersized, and oversized yield (Table 2). In 2019, Dakota Pearl planted at a within-row spacing of 15, 23–31 cm had similar total yield. ND7799c-1 planted at the 23 cm within-row spacing had similar marketable and total yield to Dakota Pearl planted at 15 cm. These data show that ND7799c-1 can be planted at a lower density, reduce seed cost, and provide a greater economic return.

In 2020, Dakota Pearl and ND7519-1 total and marketable yield was similar across all within-row spacings (15, 23 and 31 cm). ND7799c-1 had lower marketable and total yield when planted at the 31 cm within-row spacing compared to the 15 and 23 cm spacing. These data indicated that planting ND7799c-1 at 23 cm spacing and ND7519-1 at 31 cm for non-irrigated potato production in the Northern Plains was optimum for highest total and marketable yield potential, while reducing seed.

Less rainfall was received during the 2020 growing season; however, the soil water capacity was not measured in this study, making it difficult to determine the exact timing or growth stage of the crop when it was at its' greatest water stress. In 2020, ND7799c-1 produced more oversized tubers at the 15 and 23 cm within-row spacings compared to the other clones and spacings. Walworth and Carling (2002) and Aliche et al. (2019) reported that when stressed during the season, certain clones differed in their propensity to reabsorb developing tubers in favor of reallocation of resources to foliage, resulting in fewer tuber sinks, leading to an increase in oversized tubers. Tuber numbers were not tracked during the growing season in this study; however, the higher percentage of oversized tuber may indicate a faster bulking rate and growers may need to monitor the tuber size profile earlier, or potentially decrease row spacing. The bulking rate of ND7799c-1 and effects of stress could be evaluated in future studies to further understand the development of tubers and effects of water and fertilizer on ND7799c-1.

Nitrogen Uptake Efficiency in the Above Ground Biomass

Nitrogen uptake efficiency was only analyzed in 2020, focusing exclusively on the above-ground portion of the plant. The effect of N was significant across all clones at each sampling time except for 65 days after planting (Table 3). ND7519-1 and ND7799c-1 had a similar or better NUE when compared to Dakota Pearl at each sampling date, except for ND7799c-1 at 35 DAP, where the NUE was lower than for Dakota Pearl. ND7519-1 had a higher NUE at 50 and 77 DAP when compared to Dakota Pearl. These similarities provide evidence that ND7519-1 and ND7799c-1 could be grown using a similar N fertilization regime as Dakota Pearl.

Nitrogen rate was a significant factor when determining NUE in 2020 (Table 4). When combined across clones, any amount of N applied greater than 90 kg N ha^{-1} reduced NUE. Plants were more efficient at N uptake at 90 kg N ha^{-1} at each sampling when compared to higher N rates. The lower NUE on the higher N treatments may be explained by a water deficit at the non-irrigated field site and the associated reduction in mass flow of N to roots (Saravia et al. 2016). Or it could indicate that the plant NUE improves with lower N. Irrigation or additional rainfall has the potential to provide more N mobility and could potentially improve the NUE for these clones when grown under non-irrigated conditions. Contrastingly, in some situations when soils receive excessive precipitation, NUE may be decreased because of leaching of N away from the root zone, or with the addition of excess N beyond a genetic line's requirements (Zotarelli et al. 2014). Further research should be conducted to determine the NUE for ND7519-1 and ND7799c-1 under irrigated production conditions.

Nitrogen Effect on Yield and Post-Harvest Quality

Across clones, N rate had no effect on marketable yield in 2019, while in 2020, N rate had a significant effect on marketable yield (Table 5). In 2020, yield at the lowest rate of N (90 kg ha^{-1}) was not different compared to the other rates,

Table 5 Marketable yield combined across clones by nitrogen rate near Hoople, ND, in 2020

Nitrogen rate (kg ha^{-1})	Marketable yield (MT ha^{-1})	
	2019	2020
90	27	26 *a*[1]
134	28	23 *ab*
179	26	23 a*b*
224	28	22 *b*

[1]Numbers followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at $P=0.05$. If no letters are present no statistical affect was found

Table 6 Post-harvest sucrose content at 1 month of suberization at 13 °C, combined across clones and analyzed by nitrogen rate, near Hoople, ND, in 2019

Nitrogen rate (kg ha^{-1})	Sucrose at harvest mg g^{-1}	
	2019	2020
90	0.81 *b*[1]	0.71
134	0.95 *ab*	0.70
179	0.96 *ab*	0.76
224	1.08 *a*	0.70

[1]Numbers followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at $P=0.05$. If no letters are present no statistical affect was found

except for the 224 kg ha^{-1}rate. In 2019 and 2020, across clones, there were no differences for total yield between N rates (data not shown), indicating that reducing N to the lowest rate (90 kg ha^{-1}) did not decrease total or marketable yield in both years, providing an economical and environmental benefit to growers. Rens et al. (2015) reported that chip processing cultivar FL1867 experienced no increase in yield with increasing N rate above the reported level of 168 kg ha^{-1} for three different treatment timings. Further research should be conducted to determine if splitting N application for ND7519 and ND7799c-1 could result in a yield response for N rates above 90 kg ha^{-1}.

Across clones, sucrose levels were affected by N rate in 2019, but not in 2020 (Table 6). At the 90 kg ha^{-1} N rate, sucrose levels were similar for the other N rates; however, in 2019 the 224 kg ha^{-1} rate produced tubers with higher sucrose levels. These data indicate that generally N rate had little effect on sucrose level. Across clones, in 2019 and 2020, N rate did not influence the quality parameters of specific gravity, glucose level, or Hunter L-value (Tables 7, 8, 9, and 10). Previous research with irrigated chip processing clones found similar results, with clone being the major contributor to post-harvest tuber quality characteristics, and clone was predominantly independent from in-season treatments, including N fertility (Long et al. 2004). However, Long et al. (2004) found differences in specific gravity as a result of the amount of N applied. Their results suggested that for non-irrigated chipping potato production the likelihood of having differences in chipping quality parameters because of N rate may be lower than for irrigated environments. Considering nitrogen had no effect on overall yield across clones, the 90 kg ha^{-1} of nitrogen applied was the most beneficial, during the two years. Further research needs to be conducted to determine optimal N rates for ND7799c-1 and ND7519-1 under irrigated potato production scenarios.

Post-Harvest Quality

Differences in specific gravity were found between clones each year, and storage temperature (Table 7). Although specific gravity may change in storage because of water loss, sprouting, or respiration, a consistent high specific gravity is desirable to processors because of the effect on processing quality (Stark et al. 2020). In 2019, following 1 month of suberization at 13 °C, ND7799c-1 had lower specific gravity compared to Dakota Pearl. However, specific gravity was similar to Dakota Pearl following 3, 6, and 8 months of storage at 7.2 and 9.9 °C. In 2020, ND7799c-1 had a lower

Table 7 Specific gravity for Dakota Pearl, ND7799c-1 and ND7519-1 after 1 month of suberization at 13 °C, and following 3, 6, and 8 months of storage at 7.2 and 9.9 °C for potatoes grown near Hoople, ND, in 2019 and 2020

Clone	Specific gravity							
	2019				2020			
	Time (months)				Time (months)			
	1[2]	3	6	8	1	3	6	8
	7.2 °C				7.2 °C			
Dakota Pearl	1.078 *a*[1]	1.080	1.081	1.080	1.075 *a*	1.073 *a*	1.073 *a*	1.076 *b*
ND7799c-1	1.074 *b*	1.079	1.080	1.080	1.065 *c*	1.063 *b*	1.059 *b*	1.067 *c*
ND7519-1	-	-	-	-	1.070 *b*	1.068 *b*	1.075 *a*	1.080 *a*
	9.9 °C				9.9 °C			
Dakota Pearl	1.078 *a*	1.082	1.078	1.081	1.075 *a*	1.073 *a*	1.066 *a*	1.070 *b*
ND7799c-1	1.074 *b*	1.080	1.081	1.080	1.065 *c*	1.062 *b*	1.058 *b*	1.064 *c*
ND7519-1	-	-	-	-	1.070 *b*	1.072 *a*	1.067 *a*	1.072 *a*

[1]Data points followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at $P=0.05$. Data points followed by no letters indicate no statistical differences

[2]Specific gravity determined after 1 month of storage at 13 °C to allow for wound healing and suberization post-harvest

Table 8 Sucrose content of Dakota Pearl, ND7799c-1 and ND7519-1 after 1 month of suberization at 13 °C, and following 3, 6, and 8 months of storage at 7.2 and 9.9 °C for potatoes grown near Hoople, ND, in 2019 and 2020

Clone	Sucrose levels[1] (mg g⁻¹)							
	2019				2020			
	Time (months)				Time (months)			
	1[3]	3	6	8	1	3	6	8
		7.2 °C				7.2 °C		
Dakota Pearl	1.08 *a*[2]	0.54 *a*	0.58 *a*	0.99 *a*	1.03 *a*	0.76[3]	1.30	1.92
ND7799c-1	0.82 *b*	0.38 *b*	0.39 *b*	0.73 *b*	0.51 *c*	0.57	1.28	2.39
ND7519-1	-	-	-	-	0.61 *b*	0.64	1.03	2.14
		9.9 °C				9.9 °C		
Dakota Pearl	1.08 *a*	0.37 *a*	0.48 *a*	0.92 *a*	1.03 *a*	0.52	1.79	1.51
ND7799c-1	0.82 *b*	0.24 *b*	0.29 *b*	0.75 *b*	0.51 *c*	0.39	1.18	1.46
ND7519-1	-	-	-	-	0.61 *b*	0.38	1.17	2.04

[1]Target maximum for sucrose content at harvest is 1.5 mg g^{-1} fresh weight (Stark et al. 2020). Target maximum for post-harvest is 1.0 mg g^{-1} fresh weight (Stark et al. 2020)

[2]Data points followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at $P = 0.05$. Data Points followed by no letters showed no statistical differences

[3]Sucrose levels taken at 1 month had been stored at 13 °C to allow for wound healing and suberization post-harvest

Table 9 Glucose content of Dakota Pearl, ND7799c-1, and ND7519-1 after 1 month of suberization at 13 °C, and following 3, 6, and 8 months of storage at 7.2 and 9.9 °C for potatoes grown near Hoople, ND, in 2019 and 2020

Clone	Glucose levels[1] (mg g⁻¹)							
	2019				2020			
	Time (months)				Time (months)			
	1[3]	3	6	8	1	3	6	8
		7.2°C[1]				7.2 °C		
Dakota Pearl	0.08[2]	0.06	0.01 *b*[2]	0.01 *b*	0.29 *a*	0.07	0.01 *b*	0.01 *c*
ND7799c-1	0.07	0.05	0.03 *a*	0.02 *a*	0.12 *b*	0.07	0.05 *a*	0.10 *b*
ND7519-1	-	-	-	-	0.35 *a*	0.10	0.00 a	0.19 *a*
		9.9 °C				9.9 °C		
Dakota Pearl	0.08	0.03	0.01	0.01	0.29 *a*	0.03	0.01 *b*	0.02 *c*
ND7799c-1	0.07	0.04	0.01	0.01	0.12 *b*	0.05	0.04 *a*	0.11 *b*
ND7519-1	-	-	-	-	0.35 *a*	0.01	0.01 *b*	0.58 *a*

[1]Target maximum for glucose levels at harvest and post-harvest is 0.35 mg g^{-1} FW (Stark et al. 2020)

[2]Data points followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at $P = 0.05$. Data points followed by no letters indicate no statistical differences

[3]Glucose levels taken at 1 month had been stored at 13 °C to allow for wound healing and suberization post-harvest

Table 10 Hunter-L value of Dakota Pearl, ND7519-1, and ND7799c-1 after 1 month of suberization at 13 °C and following 3, 6, and 8 months of storage at 7.2 and 9.9 °C for 2019 and 2020

Clone	Hunter L-value (1-100) [1]							
	2019				2020			
	Time (months)				Time (months)			
	1[2]	3	6	8	1	3	6	8
		7.2 °C				7.2 °C		
Dakota Pearl	68[3]	66 *b*	70	70	57 *b*	58	64	62 *a*
ND7799c-1	69	68 *a*	70	70	62 *a*	59	63	55 *b*
ND7519-1	-	-	-	-	57 *b*	56	63	57 *b*
		9.9 °C				9.9 °C		
Dakota Pearl	68	69 *b*	72	70	57 *b*	62	65	63 *a*
ND7799c-1	69	71 *a*	72	70	62 *a*	61	66	62 *a*
ND7519-1	-	-	-	-	57 *b*	61	63	54 *b*

[1]Data points followed by the same letter in a column are not significantly different according to Tukey pair-wise comparison at $P = 0.05$. Data points followed by no letters indicate no statistical differences

[2]Hunter-L values taken at 1 month had been stored at 13 °C to allow for wound healing and suberization post-harvest

specific gravity than Dakota Pearl at each time measured. Specific gravity for ND7519-1 was lower or similar to Dakota Pearl after 1, 3, and 6 months of storage. However, following 8 months storage, ND7519-1 had higher specific gravity than Dakota Pearl at 7.2 and 9.9 °C storage. This demonstrates the ability of ND7519-1 to maintain specific gravity during long-term storage in colder temperatures which may be an economic benefit to growers and processors (Stark et al. 2020).

Differences were found between sucrose levels of clones (Table 8). In 2019, sucrose levels were lower for ND7799c-1 compared to Dakota Pearl after suberization through 8 months of storage at 7.2 and 9.9 °C. In 2020, sucrose levels for ND7799c-1 and ND7519-1 were higher compared to Dakota Pearl at 1 month after suberization, but at longer storage times there were no significant differences in sucrose levels across clones. Results for ND7799c-1 are consistent with findings that tuber sucrose content may increase for some clones as a result of moderate drought or heat stress, with a more dramatic effect when the stress occurs during early tuber bulking (Bethke et al. 2009).

Glucose levels differed for year and storage temperature (Table 9). Glucose levels after wound healing in 2019 and 2020 for all clones were below target maximum levels of 0.35 mg g-1 FW (Stark et al. 2020). In 2019, glucose levels for ND7799c-1 were higher than for Dakota Pearl following 6- and 8- months storage at 7.2 °C. In 2020, ND7799c-1 had lower glucose levels when compared to Dakota Pearl after 1 month of suberization at 13 °C, and glucose levels for ND7799c-1 were similar to Dakota Pearl after 3 months of storage; however, thereafter, glucose levels rose following 6 and 8 months of storage at 7.2 and 9.9 °C. This increase was expected and conjecturally concluded to be because as tubers are stored for long periods of time starch can be converted to sucrose, which in turn breaks down into the reducing sugars of glucose and fructose resulting in undesirable chipping qualities (Stark et al. 2020). However, starch levels were only measured indirectly by specific gravity measurements, and therefore could be a point for future experimentation. In 2020, ND7519-1 had similar glucose levels compared to Dakota Pearl following 1, 3, and 6 months of storage (Table 9). After 8 months storage, glucose levels for ND7519-1 were greater than for Dakota Pearl at storage temperatures, 7.2 and 9.9 °C. Glucose levels for 2019 and 2020 samples after 8 months storage were at an acceptable level for chip processing for all clones, except ND7519-1 stored at 9.9 °C for 8 months, which is above the storage temperature of 5.5 °C for which the clone was selected.

Differences in Hunter L-values occurred in 2019 and 2020 at some storage timings (Table 10). In 2019, Hunter L-values were higher after 3 months of storage for ND7799c-1 at each storage temperature compared to Dakota Pearl, but similar at the other timings, indicating better chipping color out of short-term storage. In 2020, ND7519-1 had similar Hunter L-values compared to Dakota Pearl through 6 months of storage at both storage temperatures. However, following 8 months of storage, ND7519-1 had lower Hunter L-values compared to Dakota Pearl at 7.2 and 9.9 °C storage temperatures, indicating less desirable chip color from longer-term storage at these temperatures. In 2020 at 7.2 and 9.9 °C ND7799c-1 had a higher Hunter L-value compared to Dakota Pearl after 1 month of suberization and had similar Hunter L-values compared to Dakota Pearl after 3, 6, and 8 months of storage; however with the exception of a lower Hunter L-value after 8 months storage at 7.2 °C. Higher Hunter L-values indicate lighter chip color, which is desired for processing, with a Hunter L value > 60 as a chip processing standard of acceptability (Sahin 2000). Chip color is affected by sucrose and reducing sugar content that interact with amino acids in the Maillard reaction; higher levels of glucose cause darker processed product color and when evaluated with a Hunter Instrument result in lower Hunter L-values (Rodriguez-Saona and Wrolstad 1997).

Conclusion

The results of this experiment indicate the potential for growing ND7519-1 and ND7799c-1 in non-irrigated production areas for chip processing. By adjusting within-row spacing and N rate, growers have the potential to produce potatoes for chip production with similar yield, the potential for longer-term storage, and better chip processing quality. Reducing the nitrogen rate to 90 kg ha^{-1} did not affect yield or tuber quality, but instead improved overall chip processing quality, reduced the amount of potentially leachable nitrogen in the soil, and reduced overall fertilizer input costs under drought conditions. Future research is needed to evaluate ND7519-1 and ND7799c-1 under irrigated production conditions to determine the optimum nitrogen threshold, while maintaining comparable marketable yields and not impacting chip processing quality.

Funding for this project was made possible by the U.S. Department of Agriculture's (USDA) Agricultural Marketing Service through grant AM180100XXXXG018. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the USDA.

Data availability Data is available upon request.

Declarations

Conflict of interest Authors have no conflict of interest.

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