Am. J. Pot Res
DOI 10.1007/s12230-010-9185-9

Evaluation of In-Row Plant Spacing and Planting Configuration for Three Irrigated Potato Cultivars

David D. Tarkalson · Bradley A. King · Dave L. Bjorneberg · John P. Taberna Jr

Abstract Research studies have shown that planting potatoes (*Solanum tuberosum* L.) in a bed configuration can improve water movement into the potato root zone. However, plant spacing recommendations are needed for potatoes planted in a bed configuration. This study was conducted to evaluate the effect of in-row plant spacing and planting configuration on yield of Russet Burbank, Russet Norkotah, and Ranger Russet potatoes under sprinkler irrigation. For the three cultivars, the effect of in-row plant spacing (three spacing treatments) for each planting configuration (4 row conventional ridged-row [4RC], 5 row bed [5RB], and 7 row bed [7RB]), and the effect of planting configuration at a uniform population on total tuber yield, U.S. No. 1 tuber yield, tubers per ha, average size (by weight), and large tuber yield were investigated at the USDA-ARS Northwest Irrigation & Soils Research Lab in Kimberly, ID on a Portneuf silt loam (coarse-silty mixed mesic Durixerollic Calciorthid) in 2008 and 2009. The greatest influence of in-row plant spacing was on average size and tubers per ha. In general, as in-row plant spacing increased (plant population decreased) the average tuber size increased and tubers per ha decreased. There was little influence of in-row spacing on measured production variables under the bed planting configurations except for tubers per ha which generally increased with narrower plant spacing. For Russet Norkotah and Ranger Russet there were few differences in measured production variables between planting configuration treatments. For Russet Burbank, the 4RC planting configuration had 14.6% significantly greater total tuber yield than the 7RB planting configuration, 20.2% greater U.S. No. 1 tuber yield than both bed planting configurations, and 25.2 and 29.9% greater large tuber yield than the 5RB and 7RB planting configurations, in 2009. Optimum production of Russet Norkotah and Ranger Russet potatoes is possible under all the planting configurations and plant spacing range evaluated in this study, granting growers flexibility in their systems, however, evidence from this study suggests that production of Russet Burbank may be less suited to bed planting configurations.

Resumen Investigaciones han demostrado que plantar papa (*Solanum tuberosum* L.) en una configuración de cama puede mejorar el movimiento del agua hacia la zona de la raíz de la papa. No obstante, se necesitan las recomendaciones de espaciamiento de plantas de papa sembradas en la configuración de cama. Este estudio se condujo para evaluar el efecto del espaciamiento entre plantas en el surco y de configuración de plantación en el rendimiento de papa Russet Burbank, Russet Norkotah, y Ranger Russet bajo riego por aspersión. En 2008 y 2009, se les investigó a estas tres variedades el efecto en espaciamiento entre plantas en el surco (tres tratamientos de distancias) para cada configuración de plantación (4 surcos convencionales [4RC], cama de 5 hileras [5RB], y cama de 7 hileras [7RB]), y el efecto de la configuración de la plantación a una población uniforme, sobre rendimiento total de tubérculo, rendimiento de U.S. No. 1, tubérculos por ha, tamaño promedio (por peso), y rendimiento de tubérculo grande, en el Laboratorio de Investigación sobre Riego y Suelos del Noroeste del USDA-ARS en Kimberly, ID, en un suelo limoso Portneuf (mezcla de limo-grueso

D. D. Tarkalson (✉) · B. A. King · D. L. Bjorneberg
USDA ARS Northwest Irrigation and Soils Research Laboratory,
Kimberly, ID 83341-5076, USA
e-mail: david.tarkalson@ars.usda.gov

J. P. Taberna Jr
Western Ag Research, LLC,
Blackfoot, ID 83221, USA

Published online: 07 February 2011

con medio Durixerollico Calciortido). La mayor influencia del espaciamiento de las plantas dentro del surco fue en el promedio de tamaño y tubérculos por ha. En general, a medida que aumentó el espaciamiento entre plantas en el surco (disminución en la población de plantas) el tamaño promedio del tubérculo aumentó y los tubérculos por ha disminuyeron. Hubo poca influencia en los espaciamientos dentro del surco en las variables de producción medidas bajo las configuraciones de plantación en camas, excepto para tubérculos por ha, que generalmente se aumentaron con espaciamientos más cortos entre plantas. Para Russet Norkotah y Ranger Russet hubo pocas diferencias en las variables medidas de producción entre los tratamientos de configuración de plantación. Para Russet Burbank, la configuración 4RC tuvo 14.6% significativamente más rendimiento de tubérculo total que la de 7RB, 20.2% más rendimiento de tubérculo U.S. No. 1 que las dos configuraciones de cama, y 25.2 y29.9% más de rendimiento de tubérculo grande que las configuraciones 5RB y 7RB en el 2009. Es posible la producción óptima de papa de Russet Norkotah y Ranger Russet bajo todas las configuraciones y de los rangos de espaciamiento entre plantas evaluados en este estudio, garantizándole a los productores flexibilidad en sus sistemas. No obstante, la evidencia de este estudio sugiere que la producción de Russet Burbank pudiera ser menos deseable para las configuraciones de plantación en camas.

Keywords Russet Burbank · Russet Norkotah · Ranger Russet · Bed planting

Introduction

There may be advantages to planting potatoes (Solanum tuberosum L.) in bed configurations compared to conventional ridged-rows. Research has shown that potatoes planted in beds can have production output at least as comparable (Nelson 1967; Wayman 1969; Thompson et al. 1974; Alva et al. 2002), greater yields and net return (Prestt and Carr 1984; McKeown 1987; Fisher et al. 1993; King et al. 2010), increased rate of potato emergence (Prestt and Carr 1984), more uniform water distribution in the root zone (Prestt and Carr 1984), reduced runoff and erosion (Prestt and Carr 1984; Alva et al. 2002), and greater water use efficiency (Fisher et al. 1993; King et al. 2010) than conventional ridged-row planted potatoes. Essah and Honeycutt (2004) found that wide raised beds in potato systems increased the amount of water that was captured in the soil surface compared to ridged rows where more water was directed into furrows due to the steep slopes of the ridges leading to decreased water retention in the root zone.

In irrigated areas of the U.S., the conventional ridged-row planting system provided a convenient furrow between potato rows for surface irrigation. Over the past 60 years, advances in irrigation technology and irrigated potato production practices have substantially changed. Yet, the basic ridged-row planting configuration for commercial irrigated potato production remains unchanged. Currently, irrigated potato production in the Pacific Northwest, which produces over 50% of the U.S. fall potato production, is essentially all sprinkler irrigated (King et al. 2010). The traditional ridged-row planting configuration is no longer necessary for irrigation water distribution and may actually be antagonistic to efficient water management under high application rate (center pivot) sprinkler irrigation. Runoff from the sides of the ridged potato row leads to water ponding in the furrow and water infiltration below and to the side of a substantial percentage of the potato root zone (Saffigna et al. 1976; Curwen and Massie 1984; Robinson 1999; Essah and Honeycutt 2004) resulting in sub-optimal water application efficiency and nitrogen (N) leaching (Saffigna et al. 1976).

The potential benefits from planting potatoes in beds rather than ridged-rows has led to the development of two wide-bed potato planting configurations being tested in Idaho by Western Ag Research (Blackfoot, ID). The bed planting configurations are both 3.7 m wide with either: 1) 5 rows spaced 66 cm apart centered on the bed, or 2) 7 rows equally spaced 46 cm apart. The 3.7 m bed width was selected to be compatible with existing 4-row (0.91 m row spacing) conventional potato harvesting equipment. Potato planters for both wide-bed planting configurations are currently commercially available from Harriston Industries (Minto, ND) and Spudnik Equipment Company (Blackfoot, ID). Over the past 5 years of research and development, several thousand hectares of potatoes have been planted using the wide-bed configurations as a result of on-farm studies conducted by Western Ag Research. Overall, the results have been positive in regards to enhancing potato yield and quality, and increasing irrigation water use efficiency (King et al. 2010). Several producers have reported seasonal water application reductions of 10% to 15% relative to conventional ridged-row planted potato fields with equal or better potato tuber yield and/or quality (King et al. 2010).

Field studies investigating the effect of plant population on potato yield have been conducted in North America under both irrigated (Iritani et al. 1972; Lynch and Rowberry 1977; Davis and Groskopp 1979; Rykbost and Maxwell 1993; Love and Thompson-Johns 1999) and non-irrigated (Entz and LaCroix 1984; Rex 1990; Nelson 1967; White and Sanderson 1983; Rex et al. 1987; Rex 1991) conditions. Most of the studies investigated the effect of in-row spacing only, however, with the exception of Lynch and Rowberry (1977), which also included between row spacing as a population variable. In general, variations in plant populations less than 20% do not result in significant differences in

total or U.S. No. 1 yields when plant population is at or greater than the environmental optimum. In general, however, higher plant populations result in lowering average tuber size. Rykbost and Maxwell (1993) evaluated the effect of in-row spacing on seven potato cultivars in the Klamath Basin of Oregon under sprinkler irrigation. They found no significant difference in total or U.S. No. 1 yields with plant populations ranging from 41,152 to 72,621 plants ha^{-1} for Shepody, Russet Norkotah, Frontier Russet, Ranger Russet or Century Russet potatoes. Davis and Groskopp (1979) found no significant difference in total or U.S. No. 1 yields of Russet Burbank potatoes with plant populations ranging from 37,037 to 74,074 plants ha^{-1} in Idaho.

Optimum plant populations in bed planting configurations have not been determined for potato cultivars commonly grown in the Pacific Northwest. Plant population is important when planting in bed configurations due to the increased opportunity to manipulate plant population to target a specific tuber size market. The objectives of this study were to: 1) compare in-row plant spacings for the production of Russet Burbank, Russet Norkotah, and Ranger Russet potatoes planted in 4 row conventional ridged-row (4RC), 5 row bed (5RB), and 7 row bed (7RB) configurations under sprinkler irrigation and 2) compare total tuber yield, U.S. No. 1 tuber yield, tubers per ha, average size, and large tuber yield of Russet Burbank, Russet Norkotah, and Ranger Russet potatoes planted in the 4RC, 5RB, and 7RB planting configurations.

Materials and Methods

Experimental Design and Practices

The field study was conducted during 2008 and 2009 at the USDA-ARS Northwest Irrigation & Soils Research Lab in Kimberly, ID on a Portneuf silt loam (coarse-silty mixed mesic Durixerollic Calciorthid). The soil profile was well drained with a saturated hydraulic conductivity of 3.2 cm/h. Available water holding capacity was 0.2 cm cm^{-1} (USDA 2009). The site was under lateral-move sprinkler irrigation.

Treatments included three cultivars (Russet Burbank, Russet Norkotah, and Ranger Russet), three planting configurations (4RC, 5RB, and 7RB), and three in-row plant spacings for each planting configuration (Table 1). Plant spacings for the planting configurations were based on published recommendations (4RC) (Bohl et al. 2003) and best scientific judgment (5RB and 7RB) since no research has been conducted to determine the optimum in-row plant spacings in order to give a potential range around the optimal population for production. For the 4RC planting configuration, the middle plant spacing treatment for each cultivar was based on recommendations from Bohl et al. (2003) and the other two spacing treatments were approximately 10 cm greater and less than the recommended spacing. For the 5RB and 7RB planting configuration treatments, the widest in-row plant spacing was set to equal the plant population given by the middle in-row plant

Table 1 In-row plant spacing and plant populations of planting configurations for Russet Burbank, Russet Norkotah, and Ranger Russet potatoes

Cultivar	Planting configuration[a]	In-row plant spacing cm	Plant population plants ha^{-1}
Russet Burbank and Russet Norkotah	4RC	20	53,800
		30	35,900
		41	26,900
	5RB	29	46,600
		33	41,200
		38	35,900
	7RB	41	46,600
		46	41,200
		53	35,900
Ranger Russet	4RC	18	61,500
		28	39,100
		38	28,700
	5RB	27	50,900
		30	45,000
		35	39,100
	7RB	38	50,900
		43	45,000
		49	39,100

[a] *4RC* 4 row conventional ridged-row planting configuration, *5RB* 5 row bed planting configuration, *7RB* 7 row bed planting configuration

spacing treatment of the 4RC planting configuration for each cultivar. The middle and narrowest in-row plant spacings for the bed planting configurations were established by decreasing the widest in-row plant spacing by approximately 13 and 30%. For Russet Burbank and Russet Norkotah, the in-row plant spacing produced plant populations (plants ha^{-1}) ranging from 26,900 to 53,800 for the 4RC planting configuration and 35,900 to 46,600 for the 5RB and 7RB planting configurations (Table 1). For Ranger Russet the in-row plant spacing produced plant populations (plants ha^{-1}) ranging from 28,700 to 61,500 for the 4RC planting configuration and 39,100 to 50,900 for the 5RB and 7RB planting configurations (Table 1). A systemic insecticide treatment (imidacloprid) was added to the seed pieces prior to planting. Each treatment combination was replicated four times in a randomized complete block factorial design. Each plot was 3.7 m wide and 7.6 m long.

Prior to planting in 2008 and 2009, soil samples were collected at depths of 0 to 30 and 30 to 60 cm across the study locations to determine nutrient input requirements. Subsamples from each site and depth were composited, air dried, ground to pass through a 2 mm sieve, and analyzed for bicarbonate extractable P and K (Olsen et al. 1954), and NO_3-N and NH_4-N (Keeney and Nelson 1982). Based on the soil test results, nutrients were applied over the entire study area in fertilizer based on the University of Idaho recommendations for Russet Burbank potatoes and a yield goal of 49 Mg ha^{-1} (Stark et al. 2004). In 2008, N, P (as P_2O_5), and manganese (Mn) were applied at rates of 258, 202, 11 kg ha^{-1}, respectively. Nitrogen was split applied with 155 kg ha^{-1} (urea, 46% N) applied prior to planting and 56 kg N ha^{-1} (urea ammonium nitrate, 32% N) applied through irrigation water on July 11 and 28. In 2009, N, P (as P_2O_5), and manganese (Mn) were applied at rates of 134, 280, 8 kg ha^{-1}, respectively. Nitrogen was split applied with 44 kg ha^{-1} (urea, 46% N) applied preplant and 45 kg N ha^{-1} (urea ammonium nitrate, 32% N) applied through irrigation water on July 1 and 22. Phosphorus fertilizer consisted of ammonium polyphosphate (10-34-0). Plots were hand planted on May 6 and 11 in 2008 and 2009, respectively to ensure precise plant spacing. A toolbar with adjustable harrows was used to mark rows for the three planting configuration treatments. After marking rows a push harrow was used to make the seed furrow. Precise seed piece placement was accomplished using marked PVC pipes. The seeds were then covered with the soil to a depth of approximately 15 cm. For the 4RC configuration a toolbar with large furrow shovels was use to make the hills. The plots were irrigated to meet the estimated crop evapotranspiration (ETc) rate for potatoes. The crop ETc was calculated using the U.S Bureau of Reclamation AgriMet System (www.usbr.gov/pn/agrimet/) based on climatic conditions measured within 4 km of the study site. Average irrigation rate was 50 mm h^{-1} and peak rate was 100 mm h^{-1}. Total individual irrigation times were less than 30 min. University of Idaho recommended weed control practices were used in 2008 and 2009.

Prior to harvest, potato vines were killed with a desiccant spray (diquat dibromide) on September 15 and 11 in 2008 and 2009, respectively. Tubers from this study were harvested with a conventional 4-row potato windrower on September 25 and 23 in 2008 and 2009, respectively. An area 3.7 m wide by 4.9 m long was harvested from each plot, bagged by hand and stored until graded. Plot samples were graded (U.S. No. 1 and No. 2 tubers) and passed through an automated potato sizing machine that weighed and recorded the weight of each tuber on October 9 and 6 in 2008 and 2009, respectively. Total tuber yield was the sum of U.S. No. 1 and No. 2 tubers. Average tuber size was calculated as total tuber yield divided by the number of tubers harvested. large tuber yield was the U.S. No. 1 tubers ranging from 213 to 510 g in size.

Statistical Analysis

Plant spacing comparisons of production variables (total tuber yield, U.S. No. 1 tuber yield, tubers per ha, average tuber size, and large tuber yield) were conducted within each cultivar and planting configuration. Comparisons of planting configuration production variables were conducted within each cultivar at a plant spacing that produced the same plant population on an area basis (plant spacing treatments 30, 38, and 53 cm for the 4RC, 5RB, and 7RB planting configurations, respectively in Russet Burbank and Russet Norkotah, and 28, 35, and 49 cm for the 4RC, 5RB, and 7RB planting configurations, respectively in Ranger Russet (Table 1). All production variables were tested for homogeneity of variances using Hartley's F max test (Hartley 1950). All production variables variances were found to be homogeneous. Analysis of variance was conducted using the Completely Randomized Block Model from Statistix 8 (Analytical Software 2003). The least significant difference (LSD) method was used for mean separations. Significance was determined at the $p=0.05$ probability level for all statistical analysis.

Results

In-Row Spacing Production Comparisons

Data and statistics for the effects of plant spacing on total tuber yield, U.S. No. 1 tuber yield, tubers per ha, average tuber size, and large tuber yield within each planting configuration for Russet Burbank, Russet Norkotah, and Ranger Russet are summarized in Tables 2, 3, and 4, respectively.

Table 2 Russet Burbank total tuber yield, U.S. No. 1 tuber yield, tubers per ha, average tuber size, and carton tuber yield of in-row plant spacing treatments for planting configurations in 2008 and 2009

Planting configuration[a]	In-row plant spacing	2008[b]					2009[b]				
		Total tuber yield	U.S. no. 1 tuber yield	Tubers per ha	Average tuber size	Large tuber yield[c]	Total tuber yield	U.S. no. 1 tuber yield	Tubers per ha	Average tuber size	Large tuber yield
	cm	Mg ha^{-1}	Mg ha^{-1}	tubers ha^{-1} (×1000)	g	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}	Tubers ha^{-1} (×1000)	g	Mg ha^{-1}
4RC	20	40.4	28.2	123[a]	184.7[b]	12.5	59.0	38.1	182[a]	181.9[c]	15.6
	30	40.2	26.3	110[b]	205.4[ab]	13.1	57.4	34.2	157[b]	205.8[b]	17.4
	41	35.5	22.3	89[c]	224.6[a]	13.4	53.6	33.2	129[b]	234.1[a]	13.0
	Mean	**38.7**	**25.6**	**107**	**204.9**	**13.0**	**56.7**	**35.2**	**156**	**207.3**	**15.3**
	P Value	*0.0500*	*0.1636*	*0.0001*	*0.0203*	*0.9153*	*0.4275*	*0.5817*	*0.0110*	*0.0044*	*0.6335*
5RB	29	37.6	25.8	117	181.0	10.8	56.6	34.6	175[a]	181.7	9.8
	33	37.4	25.4	115	182.4	11.1	50.9	31.9	151[b]	189.8	14.4
	38	38.4	24.0	107	202.0	11.5	53.3	28.4	145[b]	206.5	13.9
	Mean	**37.8**	**25.1**	**113**	**188.5**	**11.1**	**53.6**	**31.6**	**157**	**192.7**	**12.7**
	P Value	*0.9034*	*0.8218*	*0.1362*	*0.1461*	*0.9456*	*0.1786*	*0.4650*	*0.0478*	*0.3073*	*0.2853*
7RB	41	39.0	25.2	130	170.1	9.3	51.0	32.1	163[ab]	175.6[b]	13.9
	46	35.9	22.6	115	174.6	9.3	58.4	38.8	178[a]	183.7[b]	16.4
	53	36.9	22.5	111	186.9	7.1	50.1	28.5	141[b]	199.8[a]	13.4
	Mean	**37.3**	**23.4**	**119**	**177.2**	**8.6**	**53.2**	**33.1**	**161**	**186.4**	**14.5**
	P Value	*0.4355*	*0.2133*	*0.1177*	*0.0993*	*0.5331*	*0.0545*	*0.0540*	*0.0282*	*0.0179*	*0.3768*

[a] *4RC* 4 row conventional ridged-row planting configuration, *5RB* 5 row bed planting configuration, *7RB* 7 row bed planting configuration

[b] Values in the same column within a planting configuration with same letter are not significantly different at $p=0.05$

[c] U.S. No. 1 yield potatoes between 240 and 510 g

Table 3 Russet Norkotah total tuber yield, U.S. No. 1 tuber yield, tubers per ha, average tuber size, and carton tuber yield of in-row plant spacing treatments for planting configurations in 2008 and 2009

Planting configuration[a]	In-row plant spacing	2008[b]					2009[b]				
		Total tuber yield	U.S. no. 1 tuber yield	Tubers per ha	Average tuber size	Large tuber yield[c]	Total tuber yield	U.S. no. 1 tuber yield	Tubers per ha	Average tuber size	Large tuber yield
	cm	Mg ha^{-1}	Mg ha^{-1}	tubers ha^{-1} (×1000)	g	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}	tubers ha^{-1} (×1000)	g	Mg ha^{-1}
4RC	20	46.8	39.5	124[a]	211.8[b]	20.7	54.9	43.5	153[a]	201.5	17.1
	30	47.6	37.8	108[ab]	248.6[a]	19.9	49.9	39.7	137[a]	204.1	20.8
	41	46.5	37.4	100[b]	261.2[a]	20.7	46.4	37.8	109[b]	239.2	16.2
	Mean	**47.0**	**38.2**	**111**	**240.5**	**20.4**	**50.4**	**40.3**	**133**	**214.9**	**18.0**
	P Value	*0.9380*	*0.8901*	*0.0471*	*0.0190*	*0.9512*	*0.0606*	*0.2396*	*0.0084*	*0.1208*	*0.7829*
5RB	29	48.3	40.5	131[a]	207.0	21.6	51.6	39.7	153	189.8	20.3
	33	48.5	39.6	124[a]	219.0	21.2	50.1	38.6	143	195.4	19.5
	38	45.0	36.2	109[b]	232.3	19.8	52.1	39.3	141	207.4	21.2
	Mean	**46.8**	**38.8**	**121**	**219.4**	**20.9**	**51.3**	**39.2**	**146**	**197.5**	**20.3**
	P Value	*0.1775*	*0.1833*	*0.0311*	*0.2702*	*0.7318*	*0.8595*	*0.9077*	*0.3757*	*0.1563*	*0.8228*
7RB	41	47.3	40.3	133[a]	198.9	21.1	52.2	39.8	142	206.1	22.0
	46	48.3	37.8	133[a]	204.3	19.8	54.6	41.5	147	208.2	22.6
	53	44.1	36.4	115[b]	214.3	20.0	50.9	37.9	133	213.9	19.9
	Mean	**46.6**	**38.2**	**127**	**205.8**	**20.3**	**52.6**	**39.7**	**141**	**209.4**	**21.5**
	P Value	*0.3097*	*0.4671*	*0.0312*	*0.0788*	*0.8517*	*0.5925*	*0.6348*	*0.2210*	*0.5289*	*0.5904*

[a] *4RC* 4 row conventional ridged-row planting configuration, *5RB* 5 row bed planting configuration, *7RB* 7 row bed planting configuration

[b] Values in the same column within a planting configuration with same letter are not significantly different at $p=0.05$

[c] U.S. No. 1 yield potatoes between 240 and 510 g

Table 4 Ranger Russet total tuber yield, U.S. No. 1 tuber yield, tubers per ha, average tuber size, and carton tuber yield of in-row plant spacing treatments for planting configurations in 2008 and 2009

Planting configuration[a]	In-row plant spacing	2008[b]					2009[b]				
		Total tuber yield	U.S. no. 1 tuber yield	Tubers per ha	Average tuber size	Large tuber yield[c]	Total tuber yield	U.S. no. 1 tuber yield	Tubers per ha	Average tuber size	Large tuber yield
	cm	Mg ha^{-1}	Mg ha^{-1}	tubers ha^{-1} (×1000)	g	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}	tubers ha^{-1} (×1000)	g	Mg ha^{-1}
4RC	18	40.1	26.9	104[a]	216.1[b]	14.1	56.6	41.9	179[a]	177.2[c]	17.4[b]
	28	41.1	27.2	87[b]	265.3[a]	13.6	56.9	42.6	157[b]	203.2[b]	20.5[ab]
	38	38.2	22.6	77[b]	277.4[a]	12.3	55.0	39.7	136[c]	226.3[a]	22.8[a]
	Mean	**39.8**	**25.6**	**89**	**252.9**	**13.3**	**56.2**	**41.4**	**158**	**202.2**	**20.2**
	P Value	*0.3846*	*0.3110*	*0.0021*	*0.0056*	*0.6959*	*0.4017*	*0.5035*	*0.0029*	*0.0001*	*0.0187*
5RB	27	41.9	27.8	104	226.2	15.8	56.4	40.6	176	179.8	16.1
	30	40.0	27.2	100	225.1	13.3	58.0	37.6	167	194.6	16.8
	35	40.4	27.0	94	241.9	14.0	56.9	36.9	159	200.5	17.4
	Mean	**40.8**	**27.3**	**99**	**231.1**	**14.3**	**57.1**	**38.4**	**167**	**191.6**	**16.8**
	P Value	*0.6910*	*0.8182*	*0.2802*	*0.3035*	*0.1033*	*0.8157*	*0.3949*	*0.1205*	*0.0655*	*0.6409*
7RB	38	41.9	29.7	117[a]	201.9[b]	14.5	54.7	38.8	175[a]	175.4[b]	16.4
	43	41.2	27.6	108[b]	213.0[b]	13.7	53.3	35.0	163[b]	183.2[ab]	14.5
	49	41.4	28.4	101[c]	231.2[a]	14.5	53.0	33.3	151[c]	197.0[a]	15.7
	Mean	**41.5**	**28.6**	**109**	**201.9**	**14.2**	**53.7**	**35.7**	**163**	**185.2**	**15.5**
	P Value	*0.7548*	*0.6850*	*0.0033*	*0.0080*	*0.8115*	*0.7716*	*0.1756*	*0.0006*	*0.0264*	*0.6056*

[a] *4RC* 4 row conventional ridged-row planting configuration, *5RB* 5 row bed planting configuration, *7RB* 7 row bed planting configuration

[b] Values in the same column within a planting configuration with same letter are not significantly different at $p=0.05$

[c] U.S. No. 1 yield potatoes between 240 and 510 g

Russet Burbank

In-row plant spacing affected average tuber size under the 4RC planting configuration in 2008 and 2009, and under the 7RB planting configuration in 2009 (Table 2). Average tuber size in the 4RC planting configuration in 2008 was increased by 21.6%, when in-row plant spacing increased (decreasing plant population) from 20 to 41 cm. Average tuber size in the 4RC planting configuration in 2009 was increased by 13.1 and 28.7%, when in-row plant spacing increased from 20 to 30 and 20 to 41 cm, respectively. Average tuber size in the 7RB planting configuration in 2009 increased by 13.8 and 8.8%, when in-row plant spacing increased from 41 to 53 cm and 46 to 53 cm. This difference in average tuber size did not result in differences in large tuber yield.

In-row plant spacing affected tubers per ha under the 4RC planting configuration in 2008 and 2009 and the 7RB in 2009 (Table 2). Tubers per ha in the 4RC planting configuration in 2008 was increased by 38.2, 11.8, and 23.6%, when in-row plant spacing decreased (increasing plant population) from 41 to 20, 30 to 20, and 41 to 30 cm, respectively. Tubers per ha in the 4RC planting configuration in 2009 was increased by 41.1 and 15.9%, when in-row plant spacing decreased from 41 to 20 and 30 to 20 cm, respectively. Tubers per ha in the 5RB planting configuration in 2009 was increased by 20.7 and 15.9%, when in-row plant spacing decreased from 38 to 29 and 33 to 29 cm, respectively. Tubers per ha in the 7RB planting configuration in 2009 was increased by 26.2%, when in-row plant spacing decreased from 53 to 46 cm.

Russet Norkotah

In-row plant spacing affected average tuber size under the 4RC planting configuration in 2008 (Table 3). Average tuber size in the 4RC planting configuration in 2008 was increased by 17.4 and 23.3%, when in-row plant spacing increased from 20 to 30 and 20 to 41 cm, respectively.

Decreasing in-row plant spacing (increasing plant population) increased tubers per ha under the 4RC planting configuration in 2008 and 2009 and the 5RB and 7RB in 2008 (Table 3). Tubers per ha in the 4RC planting configuration in 2008 was increased by 24.0%, when in-row plant spacing decreased from 41 to 20 cm. Tubers per ha in the 4RC planting configuration in 2009 was increased by 40.4 and 25.7%, when in-row plant spacing decreased from 41 to 20 and 41 to 30 cm, respectively. Tubers per ha in the 5RB planting configuration in 2008 was increased by 20.2 and 13.8%, when in-row plant spacing decreased from 38 to 29 and 38 to 33 cm, respectively. Tubers per ha in the 7RB planting configuration in 2008 was increased by 15.7%, when in-row plant spacing decreased from both 53 to 41 and 53 to 46 cm.

Ranger Russet

In-row plant spacing affected average tuber size under the 4RC and 7RB planting configurations in 2008 and 2009 (Table 4). Average tuber size in the 4RC planting configuration in 2008 was increased by 22.8 and 28.4%, when in-row plant spacing increased (decreasing plant population) from 18 to 28 and 18 to 38 cm, respectively. Average tuber size in the 4RC planting configuration in 2009 was increased by 14.7, 27.7, and 11.4%, when in-row plant spacing increased from 18 to 28, 18 to 38, and 28 to 38 cm, respectively. Average tuber size in the 7RB planting configuration in 2008 increased by 14.5 and 8.5%, when in-row plant spacing increased from 38 to 49 cm and 43 to 49 cm. Average tuber size in the 7RB planting in 2009 was increased by 12.3%, when in-row plant spacing increased from 38 to 49 cm. In-row plant spacing affected large tuber yield under the 4RC planting configuration in 2009. Large tuber yield in the 4RC planting configuration in 2009 was increased by 31.0%, when in-row plant spacing increased (decreasing plant population) from 18 to 38 cm.

Decreasing in-row plant spacing (increasing plant population) increased tubers per ha under the 4RC and 7RB planting configurations in 2008 and 2009 (Table 4). Tubers per ha in the 4RC planting configuration in 2008 was increased by 35.1 and 19.5%, when in-row plant spacing decreased from 38 to 18 and 28 to 18 cm, respectively. Tubers per ha in the 4RC planting configuration in 2009 was increased by 31.6, 14.0, and 15.4%, when in-row plant spacing decreased from 38 to 18, 28 to 18, and 38 to 28 cm, respectively. Tubers per ha in the 7RB planting configuration in 2008 was increased by 15.8, 8.3, and 6.9%, when in-row plant spacing decreased by 49 to 38, 43 to 38, and 49 to 43 cm, respectively. Tubers per ha in the 7RB planting configuration in 2009 was increased by 15.9, 7.4, and 7.9%, when in-row plant spacing decreased by 49 to 38, 43 to 38, and 49 to 43 cm, respectively.

Planting Configuration Production Comparisons

Data and statistics for the effects of planting configuration on total tuber yield, U.S. No. 1 tuber yield, tubers per ha, average tuber size, and large tuber yield at plant spacings that give an equal population for each cultivar are located in Table 5.

Planting configuration had no significant effect on any measured variable for Russet Norkotah or Ranger Russet. For Russet Burbank in 2009, row configuration affected total tuber yield, U.S. No. 1 tuber yield, and large tuber

Table 5 Total tuber yield, U.S. No. 1 tuber yield, tubers per ha, average tuber size, and carton tuber yield of planting configurations for Russet Burbank, Russet Norkotah, and Ranger Russet potatoes in 2008 and 2009

Cultivar	Planting configuration[b]	2008[c]					2009[c]				
		Total tuber yield Mg ha^{-1}	U.S. no. 1 tuber yield Mg ha^{-1}	Tubers per ha tubers ha^{-1} (×1000)	Average tuber size g	Large tuber yield[d] Mg ha^{-1}	Total tuber yield Mg ha^{-1}	U.S. no. 1 tuber yield Mg ha^{-1}	Tubers per ha tubers ha^{-1} (×1000)	Average tuber size g	Large tuber yield Mg ha^{-1}
Russet Burbank[a]	4RC	40.2	26.3	110	205.4	13.1	57.4[a]	34.2[a]	137	205.8	17.4[a]
	5RB	38.4	24.0	107	202.0	11.5	53.3[ab]	28.4[b]	141	206.5	13.9[b]
	7RB	36.9	22.5	111	186.9	7.1	50.1[b]	28.5[b]	133	199.8	13.4[b]
	Mean	**38.5**	**24.3**	**109**	**198.1**	**10.6**	**53.6**	**30.4**	**137**	**204.0**	**14.9**
	P Value	*0.2152*	*0.4259*	*0.8294*	*0.3128*	*0.1986*	*0.0426*	*0.0405*	*0.1402*	*0.7924*	*0.0445*
Russet Norkotah[a]	4RC	47.6	37.8	157	248.6	19.9	49.9	39.7	87	204.1	20.8
	5RB	45.0	36.2	145	232.3	19.8	52.1	39.3	94	207.4	21.2
	7RB	44.1	36.4	141	214.3	20.0	50.9	37.9	101	213.9	19.9
	Mean	**45.6**	**36.8**	**148**	**231.7**	**19.9**	**51.0**	**39.0**	**94**	**208.5**	**20.6**
	P Value	*0.1459*	*0.5649*	*0.3961*	*0.0661*	*0.9914*	*0.7179*	*0.7091*	*0.4607*	*0.4375*	*0.5661*
Ranger Russet[a]	4RC	41.1	27.2	108	265.3	13.6	56.9	42.6	157	203.2	20.5
	5RB	40.4	27.0	109	241.9	14.0	56.9	36.9	159	200.5	17.4
	7RB	41.4	28.4	115	231.2	14.5	53.0	33.3	151	197.0	15.7
	Mean	**41.0**	**27.5**	**111**	**246.2**	**14.0**	**55.6**	**37.6**	**157**	**200.2**	**17.9**
	P Value	*0.9274*	*0.9106*	*0.0800*	*0.0803*	*0.9020*	*0.5032*	*0.1413*	*0.6933*	*0.5731*	*0.1573*

[a] Russet Burbank and Russet Norkotah planting configuration comparisons were conducted at a plant population of 35,864 plants ha^{-1}. Ranger Russet planting configuration comparisons were conducted at a plant population of 39,125 plants ha^{-1}

[b] *4RC* 4 row conventional ridged-row planting configuration, *5RB* 5 row bed planting configuration, *7RB* 7 row bed planting configuration

[c] Values in the same column within a cultivar with same letter are not significantly different at $p=0.05$

[d] U.S. No. 1 yield potatoes between 240 and 510 g

yield. For Russet Burbank in 2009, the 4RC planting configuration had 14.6% greater total tuber yield than the 7RB planting configuration, and 20.4 and 20.0% greater U. S. No. 1 tuber yield than the 5RB and 7RB planting configurations, respectively (Table 5). For Russet Burbank in 2009, the 4RC planting configuration had 25.2 and 29.9% greater large tuber yield than the 5RB and 7RB planting configurations, respectively (Table 5).

Discussion

One objective of this study was to compare in-row plant spacings for the production of Russet Burbank, Russet Norkotah, and Ranger Russet potatoes planted in 4RC, 5RB, and 7RB planting configurations. The in-row plant spacing range used had little effect on total tuber yield, U.S. No. 1 yield, and large tuber yield for these cultivars. Love and Thompson-Johns (1999) found that total yield was greatest at narrow in-row spacing and decreased with increasing in-row spacing for Russet Burbank, Frontier Russet, and Ranger Russet grown under conventional ridged hills. However, the narrowest in-row plant spacing in the study by Love and Thompson-Johns (1999) was 8 cm which had the highest total yield, was much narrower than the narrowest in-row spacing found in our study for the 4RC treatments (20.3 cm for Russet Norkotah, and Russet Burbank, and 17.8 for Ranger Russet). The reason we did not see differences in U.S. No. 1 and large tuber yield may have been due to the relatively narrower range of in-row plant spacing used in our study. Love and Thompson-Johns (1999) reported that in-row plant spacing ranges of 23 to 46 cm and 15 to 46 cm maximized net returns in Russet Burbank and Ranger Russet, respectively. The in-row plant spacing range in our study may have fallen within a wide optimum range for optimum production. The data from our study and Love and Thompson-Johns (1999) indicate that a wide in-row plant space range can optimize potato production under conventional and bed planting configurations. Our and other cited data indicate that it is possible to adjust in-row plant spacing to manipulate tuber size distribution. Since no data existed evaluating in-row plant spacing in 5RB and 7RB configurations we had to make a best scientific judgments on in-row plant spacing ranges for comparison. Future research using wider in-row plant spacing ranges under bed planting configurations will help clarify optimum in-row plant spacing ranges.

Our research demonstrates the ability of potatoes to compensate as a result of changing populations and plant positioning. In our study, decreasing in-row plant spacing increased tubers per ha, the inverse of the relationship between in-row plant spacing and average tuber size. The results of this study are consistent with those of Rykbost and Maxwell (1993) who found no significant difference in total or U.S. No.1 tuber yield of Russet Norkotah or Ranger Russet potatoes over a plant population ranging from 41,152 to 72,621 plants ha^{-1}. The effects of plant population on average tuber size found in this study are consistent with the results of Lynch and Rowberry (1977) who found average tuber size to decrease with increasing plant population as a result of various in-row and between row plant spacings (planting architecture). The results of these cited studies, along with this study indicate that potato plants have the ability to compensate for planting architecture to produce nearly equivalent tuber mass per unit area when plant population is at or above the environmental optimum.

Another objective of this study was to compare production factors of Russet Burbank, Russet Norkotah, and Ranger Russet potatoes planted in the 4RC, 5RB, and 7RB planting configurations. In our study, Russet Norkotah and Ranger Russet had similar production factor comparisons between all the planting configurations, and data indicates that Russet Burbank performs better under the conventional configuration than in beds. It is possible that Russet Burbank is more sensitive to competition from adjacent plants than Russet Norkotah and Ranger Russet, but more research is needed to truly elucidate the factors contributing to this observation.

References

Analytical Software. 2003. Statistix 8. Analytical and Software, Tallahassee, FL.

Alva, A.K., T. Hodges, R.A. Boydston, and H.P. Collins. 2002. Effects of irrigation and tillage practices on yield of potato under high production conditions in the Pacific Northwest. *Communications in Soil Science and Plant Analysis* 33(9&10): 1451–1460.

Bohl, W.H., N. Olsen, S.L. Love, and P. Nolte. 2003. Chapter 7: Seed and planting management. In *Potato production systems*, ed. J.C. Stark and S.L. Love. Moscow: University of Idaho Cooperative Extension System.

Curwen, D., and L.R. Massie. 1984. Potato irrigation scheduling in Wisconsin. *American Potato Journal* 61: 235–241.

Davis, J.R., and M.D. Groskopp. 1979. Influences of the rhizoctonia disease on production of the Russet Burbank potato. *American Potato Journal* 56: 253–264.

Entz, M.H., and L.J. LaCroix. 1984. The effect of in-row spacing and seedtype on the yield and quality of a potato cultivar. *American Potato Journal* 61: 93–105.

Essah, S.Y.C., and C.W. Honeycutt. 2004. Tillage and seed-sprouting strategies to improve potato yield and quality in short season climates. *American Journal of Potato Research* 81: 177–186.

Fisher, A., R.J. Bailey, D.J. Williams. 1993. Growing potatoes using a bed-planting technique. Soil Management in Sustainable Agriculture; Proceedings of the Third International Conference on Sustainable Agriculture, Wye College University of London, 561–568.

Hartley, H.O. 1950. The use of range in analysis of variance. *Biometrika* 37: 271–280.

Iritani, W.M., R. Thornton, L. Weller, and G. O'Leary. 1972. Relationships of seed size, spacing, stem numbers to yield of Russet Burbank potatoes. *American Potato Journal* 49: 463–469.

Keeney, D.R., and D.W. Nelson. 1982. Nitrogen: Inorganic forms. In *Methods of soil analysis, Part 2, Chemical and microbiological properties*, 2nd ed, ed. A.L. Page, 643–698. Madison: American Society of Agronomy and Soil Science Society of America.

King, B.A., D.D. Tarkalson, D.L. Bjorneberg, J.P Taberna, Jr. 2010. Planting system effect on yield response of Russet Norkotah to irrigation and nitrogen under high intensity sprinkler irrigation. American Journal of Potato Research (In Press, Online First, 7 October 2010).

Love, S.L., and A. Thompson-Johns. 1999. Seed piece spacing influences on yield, tuber size distribution, stem and tuber density, and net returns of three processing potato cultivars. *HortScience* 34(4): 629–633.

Lynch, D.R., and R.G. Rowberry. 1977. Population density studies with Russet Burbank II. The effect of fertilization and plant density on growth, development and yield. *American Potato Journal* 54: 57–71.

McKeown, A.W. 1987. Increased yield of small seed tubers of Yukon Gold potatoes using multiple-row beds. *Canadian Journal of Plant Science* 67: 365–367.

Nelson, D.C. 1967. Effects of row spacing and plant populations on yields and tuber-size of Potatoes. *American Potato Journal* 44: 17–21.

Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. *Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA. Circ 939*. Washington, DC: U.S. Government Printing Office.

Prestt, A.J., and M.K.V. Carr. 1984. Soil management and planting techniques for potatoes. *Aspects of Applied Biology* 7: 187–204.

Rex, B.L. 1990. Effect of seed piece population on the yield and processing quality of Russet Burbank potatoes. *American Potato Journal* 67: 473–789.

Rex, B.L. 1991. The effect of in-row seed piece spacing and harvest date of the tuber yield and processing quality of Conestoga potatoes in southern Manitoba. *Canadian Journal of Plant Science* 71: 289–296.

Rex, B.L., W.A. Russell, and H.R. Wolfe. 1987. The effect of spacing of seed pieces on yield, quality and economic value for processing of Shepody potatoes in Manitoba. *American Potato Journal* 64: 177–189.

Robinson, D. 1999. A comparison of soil-water distribution under ridge and bed cultivated potatoes. *Agriculture Water Management* 42: 189–204.

Rykbost, K.A., and J. Maxwell. 1993. Effects of plant population on the performance of seven varieties in the Klamath Basin of Oregon. *American Potato Journal* 70: 463–474.

Saffigna, P.G., C.B. Tanner, and D.R. Keeney. 1976. Non-uniform infiltration under potato canopies caused by interception, stemflow and hilling. *Agronomy Journal* 68: 337–342.

Stark, J., D. Westermann, and B. Hopkins. 2004. *Nutrient management guidelines for Russet Burbank potatoes. Bul 840*. Moscow: University of Idaho Extension.

Thompson, R., D. Gray, and J.A. Pascal. 1974. Potatoes for canning—Design of growing systems. *Journal Agricultural Science Cambridge* 82: 233–243.

USDA. 2009. Web soil survey. http://websoilsurvey.nrcs.usda.gov/app/. Accessed 03 March 2009.

Wayman, J.A. 1969. Experiments to investigate some of the problems in mechanisation associated with the cultivation of potato beds. *European Potato Journal* 12: 200–214.

White, R.P., and J.B. Sanderson. 1983. Effect of planting date, nitrogen rate, and plant spacing on potatoes grown for processing in Prince Edward Island. *American Potato Journal* 60: 115–126.