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Water savings in irrigated potato production by varying hill–furrow or bed–furrow configuration

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ABSTRACT

Current agronomic practices for potato production in the irrigated areas of southern Alberta involve a hill/furrow configuration that was adopted from elsewhere, and designed to shed rainfall away from the hill and into the furrow. However, the principal intent of supplemental irrigation is to capture as much of the applied water into the hill, where the potato tubers and roots are located, and minimize water accumulating in the furrow. A three-year project began in 2006 to quantify the potential irrigation water savings of altered hill shapes for potato production. The three treatments (standard hill, flat-topped hill, and double-planted wide-bed) were arranged in a randomized strip plot design replicated four times. Soil water in each treatment was generally kept between 60 and 90% of available. A fourth treatment, triple-planted wide bed, was added to the project in 2008. The irrigation requirements to maintain the treatments were 487, 442, and 449 mm for the standard hill, flat-topped hill, and double-planted bed, respectively, in 2006 and 442, 408 and 411 mm for the same treatments in 2007. This translates into approximately 10% less irrigation water required for the flat-topped hill shape compared to the standard hill shape. The flat-topped hill shape required 5.0% more irrigation than the standard hill in 2008, but the double and triple-planted wide beds required 8.0 and 9.9%, respectively, less irrigation water than the standard. Although not always statistically significant, water use efficiency was greater in all years for the altered bed shapes compared to the standard hill geometry. Greater water use efficiency can be interpreted as more of the applied water infiltrated into the hill, where the potato plant could use it for transpiration and tuber development. Total yield was greater in 2006 for both the flat-topped hill (72.3 Mg ha^{-1}) and wide-bed hill (69.2 Mg ha^{-1}) compared to the standard hill (61.4 Mg ha^{-1}); however, the treatments were not significantly different. Significantly greater marketable yield was realized from the flat-topped hill treatment in 2006. This treatment also had a significantly greater number of marketable size tubers. In 2007, there were no significant differences in total yield; however, the standard and flat-topped treatments had a significantly greater number and yield of tubers in the 113–170 g size category. Significant differences in total yield were found in 2008. The triple-planted wide bed had significantly greater yield in the smaller size categories compared to the standard treatment and significantly greater total tuber numbers than the other treatments, but the increase was in the smaller size categories, less than 170 g. There were no significant differences among the treatments in yield or total number of tubers in the size categories greater than 171 g in 2008.

1. Introduction

In southern Alberta, potatoes are always hilled after planting and covered with sufficient soil to prevent tuber greening, to ensure drainage in the area of tuber formation, and to facilitate mechanical harvest. Final hill shape is often determined by the type and make of the hilling implement. Traditional final hill shape has been one with a fairly peaked top and side slopes ending at the furrow position. This hill shape probably evolved as a practical solution to divert excess rainfall away from the potato tubers and maintain adequate aeration within the potato hill. Chow and Rees (1994) reported that the initiation of runoff from the furrow position was sooner for hilled potatoes rather than un-hilled ones. Cooley et al. (2007) also reported that traditional hill geometry reduces infiltration into the center of the hill and promotes water drainage into the furrow position. These studies indicate that the traditional final hill shape is effective at diverting applied water into the furrow position.

However, in the irrigated areas of semi-arid southern Alberta, excess rainfall is not usually an issue. Rather than diverting excess

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Fig. 1. Final hill shape of the flat-topped treatment.

Fig. 2. Power hiller set to form a 1.8 m wide bed.

rainfall into the furrow position, the goal for final hill shape in irrigated potato production should be a hill shape that maximizes the amount of applied irrigation water infiltrated into the center of the potato hill.

The infiltration of irrigation and rainfall into a potato hill is often assumed to be uniform. However, due to the topographic relief of hill-furrow tillage systems, it has been reported that the actual infiltration and subsequent redistribution of irrigation water is quite variable. Starr et al. (2005), Robinson (1999), and Saffigna et al. (1976) reported that more water enters the soil through the furrow than through the ridge or hill. It was believed that between precipitation events, increased soil matric forces due to declining soil water levels within the potato hill, act to redistribute some of the water into the hill position where it can be used by the plant. However, Starr et al. (2005) reported that uptake of soil water from the furrow position or toe of the hill was undetectable and the lowest soil water storage was in the center position of the potato hill.

Improved irrigation efficiency may be realized by altering the standard hill shape to one with a wider profile or a flattened top, so more of the applied irrigation water has time to infiltrate into the hill/bed before ponding in the furrow position. Starr et al. (2005) reported that infiltration of applied water did not reach the center of the hill under sprinkler irrigation. Irrigations to ensure sufficient soil water in the center of a standard hill shape translate into excessive runoff and ponding of the applied water in the furrow position. Deep percolation of applied water and minimal or no uptake of soil water by the potato plant from the furrow position results in a loss of irrigation water applied.

Mundy et al. (1999) planted three rows of potatoes in a 1.9 m wide bed to evaluate the effect on yield and quality. Although there were not always statistically significant differences, they reported the wider bed retained more water compared to the standard hill. Steele et al. (2006) compared yield and quality of potatoes planted within the furrow position of a modified ridge/furrow system to conventional standard hill-planted potatoes. They found significantly greater yields and a greater yield of larger size potatoes were harvested from the furrow-planted treatments compared to the hill-planted treatments. On two sampling dates for soil water, they found significantly greater soil water in the furrow position than in the hill. Starr et al. (2005) concluded that management practices targeted at wetting the hill center under the sprinkler would likely improve water use efficiency.

Water use efficiency (WUE) has been used in many studies on irrigated crops to describe yield per unit water consumed or applied (kg/ha mm) (Howell, 2006; Hatfield et al., 2001). Improvement in WUE has typically been interpreted as increased beneficial use of diverted water for irrigated agriculture or the "More crop per drop; same crop less drop" concept. The whole concept of, and proper interpretation of, WUE has been criticized lately (Bessembinder et al., 2005). Some of the criticism with the interpretation of WUE is the high variability from year to year, even with the same regimen of agronomic practices (Tow, 1993; Musick et al., 1994; Shae et al., 1999). The WUE is also influenced by other factors such as soil texture (Hatfield et al., 2001), and there are no consistent formulations for calculating WUE so comparisons between studies are difficult at best (Howell, 2006). However, improved WUE among treatments in the same year, the same crop, and the same variety is generally interpreted as better utilization of soil water (Kang et al., 2004).

The objective of this study was to quantify the water savings in altered hill/bed forms compared with the standard hill and to identify the influence altered bed shapes have on tuber yield, quality, and water use efficiency.

2. Methods

Three treatments consisting of a standard hill, flat-topped hill, and double-planted wide bed hill were arranged in a randomized strip plot design, replicated four times at the Crop Diversification Center (CDC) South in Brooks, Alberta, in 2006 and 2007. A fourth replicated treatment, consisting of a triple-planted, wide-bed hill, was added to the trial in 2008. Plot sizes were 6.1 m × 6.1 m with a 4 m buffer between plots. Hill forms were prepared using a Netagco power hiller/bedder. Standard and flat-topped hill treatments consisted of six rows, 0.91 m apart. The wide-bed treatments consisted of three, 1.8 m beds. Flat-topped hill preparation involved maintaining the same rotor configuration as for a standard power hiller but setting the rear shaper blade to flatten or "drag off" the peak of the standard hill (Fig. 1). The double and triple-planted beds were prepared by setting a firm tension on the rear shaper blade (Fig. 2). Plots were established in different portions of CDC South each year.

Soils at the site are Orthic Brown Chernozem (Chin Soil Series) (Agriculture and Agri-Food Canada, 1998) or Aridic Haploboroll (Soil Management Support Services, 1992), with soil textures ranging from loam to silt loam. Average available soil water (between field capacity and wilting point) in a 0.8 m soil depth was 164 mm.

The plots were prepared and planted with treated Russet Burbank potato pieces spaced 30 cm within the row at a depth of 15 cm on May 12, 2006; May 9, 2007; and May 8, 2008. A hand-move irrigation system, equipped with Nelson directional impact sprinklers with 4.76 mm nozzles and individual shut-off valves,

Table 1
Monthly precipitation during growing season at Brooks in 2006, 2007 and 2008 compared with 30-year (long-term) average precipitation.

Year	Precipitation (mm)					
	May	June	July	August	September	Totals
2006	58.4	73.6	14.7	19	65.5	231.2
2007	59.5	42.9	5.1	41.5	31.4	180.4
2008	65.8	68.1	61.5	15.7	34.5	245.6
LTA^z	42.6	58.8	41.7	39.3	38.9	221.3

LTA^z = 30-year (long-term) average precipitation (Canadian Climate Normals 1971–2000, Environment Canada).

was used for applying irrigation water in 2006. In 2007, Senninger mini-wobblers with 2.38 mm nozzles were used for applying the irrigation water and Hunter MP 3000 180° directional rotators were used in 2008. The mini-wobbler was rated with an application rate of 6.2 mm h^{-1}, the impact sprinkler was rated at 10.3 mm h^{-1} and the Hunter MP 3000 rotator was rated at 9.9 mm h^{-1}.

Aluminum access tubes (1.2 m in length) were installed in the hill position near the center of each plot for soil water determinations with a CPN® 503 (Campbell Pacific Nuclear Inc., Martinez, CA) soil moisture meter, previously calibrated for a loam textured soil. Soil water was measured twice each week from planting until harvest. Each treatment was irrigated once average soil water in the top 60 cm of soil profile for the four replicates reached 60% of available. Irrigation amounts were based on the difference between available water holding capacity and average soil water depletion. Tru-check cumulating rain gauges were placed adjacent to the access tube for determining irrigation and rainfall amounts.

Evapotranspiration values for all plots were calculated using the soil water balance method based on the difference between weekly soil water readings (Eq. (1)).

$$ET = P + I - R \pm \Delta M - D \quad (1)$$

where ET is evapotranspiration (mm), P is rainfall (mm), I is irrigation (mm), R is runoff (mm), ΔM is water changes in soil profile between two sampling dates, and D is deep drainage (mm). Runoff was assumed to be negligible and deep percolation was calculated as irrigation or rainfall in excess of the soil water holding capacity for a 0.6-m soil depth.

Individual soil temperature probes (Watchdog, B series button logger) were installed in each plot. They were positioned near the seed piece within the hill or bed and were buried 0.14 m below the soil surface. The loggers were set to record hourly temperatures throughout the growing season.

2.1. Agronomic operations

2.1.1. 2006

Fertilizer was broadcast on April 26 at a rate of 168 kg ha^{-1} of N and 84 kg ha^{-1} of P. Insecticides (Admire and Decis) were sprayed twice (July 5 and August 22) to control Colorado potato beetle. Dithane, Pencozeb and Ridomil Gold/Bravo were sprayed on July 16, August 3, and August 22, for early and late blight control. Plots

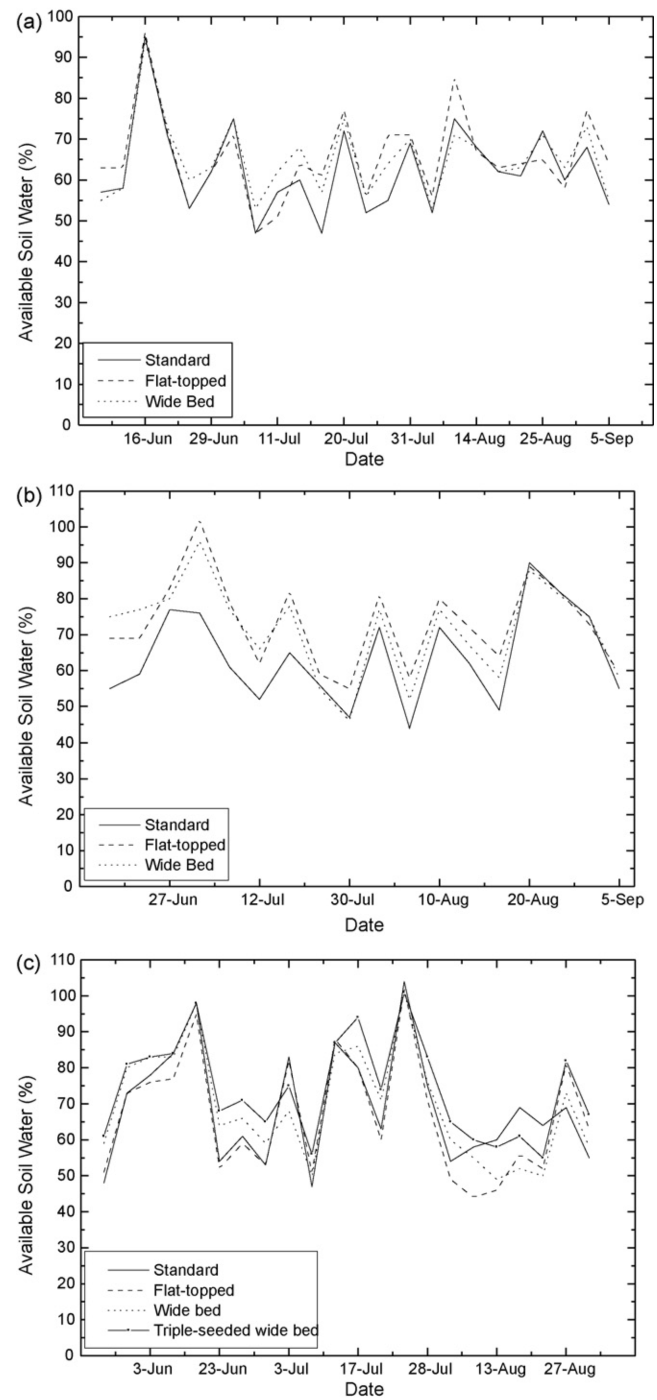

Fig. 3. Available soil water percentages in a 0.6 m soil depth for the seasons 2006 (a), 2007 (b) and 2008 (c).

Table 2
Irrigation demand and evapotranspiration for the hill-shape treatments.

Treatment	Irrigation (mm)			Evapotranspiration (mm)			Water use efficiency (kg/ha mm)		
	2006	2007	2008	2006	2007	2008	2006	2007	2008
Standard	487	442	374	500	462	533	122.8	136.6	165.4a
Flat topped	442	408	393	499	445	542	144.9	138.4	196.9b
Wide bed	449	411	344	488	441	511	141.8	139.9	186.7b
Triple bed			337			513			192.8b

Column means followed by the same letter are not significantly different at $p < 0.05$.

were sprayed with the dessicant, Reglone, on September 5 and were harvested on September 13.

2.1.2. 2007

Fertilizer was broadcast on May 5 at a rate of 150 kg ha^{-1} of N and 50 kg ha^{-1} of P. Admire was applied on July 5 to control Colorado potato beetle. Dithane, Bravo 500 and Ridomil Gold were applied on July 13, July 26 and August 20, for blight control. Reglone was applied on September 5 and the plots were harvested on September 17.

2.1.3. 2008

Fertilizer was broadcast on May 7 at a rate of 156 kg ha^{-1} of N and 56 kg ha^{-1} of P. The insecticide Thionex EC was sprayed on July 7 to control Colorado potato beetle. Quadris, Dithane, and Ridomil Gold/Bravo were sprayed on July 7, July 23, and August 20, for early and late blight control. Plots were sprayed with Reglone on September 12 and were harvested on September 29.

All tubers from the two center rows of the standard and flat-topped treatments and the entire center bed of the wide-bed treatment were harvested and evaluated for yield, size, quality, and specific gravity.

2.2. Statistical analysis

Statistical analyses of yield, evapotranspiration, water use efficiency and temperature data included analysis of variance (ANOVA) and separation of means by the Tukey multiple mean comparison test were conducted using Sigma Stat statistical software (SPSS, Chicago, IL).

3. Results

3.1. Meteorology

Monthly and seasonal precipitation values for 2006, 2007 and 2008 are shown in Table 1. Notable is the month of July in both 2006 and 2007 with monthly precipitation values being much below average.

3.2. Water use and evapotranspiration

There were no statistically significant differences in evapotranspiration between treatments in any year. Although not always statistically significant, the trend was for improved water use efficiency (kg/ha mm) in all years for the altered hill treatments compared to the standard hill treatment (Table 2). The standard hill treatments required 7.8 and 9.2% greater irrigation amounts in 2006 and 9.9 and 10.3% in 2007 than the double-planted wide-bed and flat-topped treatments, respectively. In 2008, the wide-bed treatments, double and triple planted, required 8.0 and 9.9% less irrigation than the standard treatment; however, unlike the two previous years, the flat-topped hill treatments required 5.0% more water than the standard hill treatments.

Seasonal available soil water, for the 3 years of the study, in a 0.6 m root zone is shown in Fig. 3(a–c). The modified bed shapes, either flat-topped or wide-bed treatments, sustained soil water at a higher level than the standard hillshape throughout most of the season in 2006 and 2007. In 2008, the wide-bed treatments sustained higher soil water but the flat-topped treatment was similar to the standard treatment for water requirements.

3.3. Soil temperature

Differences between daily maximum and minimum soil temperatures were greater for the wide-bed hill-shape treatments, than they were for the flat-topped and standard hill-shaped treatments (Table 3).

Table 3
Differences between maximum and minimum daily soil temperatures for May and August 2008.

Treatment	Difference between maximum and minimum temperatures (°C)	
	May	August
Standard	11.8a	4.0a
Flat topped	12.8a	3.0a
Wide bed	18.5b	5.5b
Triple bed	19.5b	5.0b

Column means followed by the same letter are not significantly different at $p < 0.05$.

Examples of the diurnal amplitude of soil temperature early in the season, May 7, 2008 and at row closure, July 6, 2008 are shown in Fig. 4(a and b).

3.4. Tuber yield and quality

Marketable yield (171–284 g) was significantly greater in the flat-topped hill compared with the standard hill treatments in 2006 (Table 4), and the number of tubers was higher for the flat-topped treatment compared to the standard or the wide-bed treatments. In 2007, there were no significant differences in total yield; however, the standard and flat-topped treatments had a significantly greater number and yield of tubers in the 113–170 g size category. In 2008, the flat-topped treatment had significantly greater total yield compared to the standard treatment. The triple-planted,

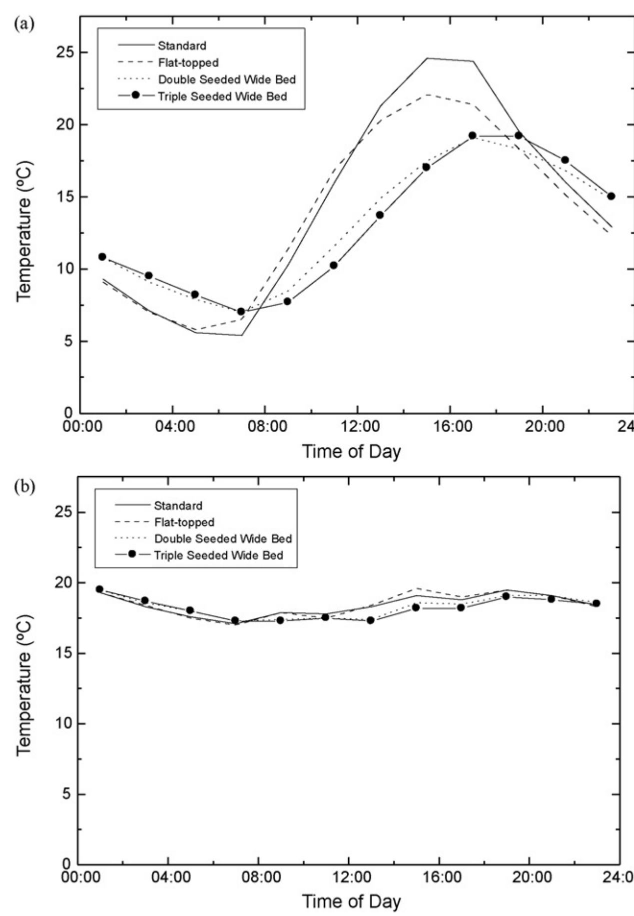

Fig. 4. Average soil temperatures for the four hill-shape treatments on (a) May 27, 2008 (at emergence) and (b) July 6, 2008 (row closure).

Table 4
Yield comparisons for the hill-shape treatments.

Yield (Mg ha^{-1})						Number of tubers (count)				
		Size categories (g)					Size categories (g)			
Treatment	Total	<113	113–170	171–284	>284	Total	<113	113–170	171–284	>284
2006										
Flat-top	72.3	15.8	19.3	22.8a	11.9	267a	118	75a	57	17
Wide-bed	69.2	16.6	18.2	20.2ab	12.2	255b	115	71ab	52	17
Standard	61.4	13.1	15.5	17.3b	13.0	216b	94	57b	45	20
Percentage of total tuber count in the various size categories										
Flat-top							44.2	27.9	21.5	6.5
Wide-bed							45.2	27.7	20.3	6.8
Standard							43.4	26.4	20.9	9.4
2007										
Flat-top	61.6	15.0	15.1b	18.1	8.9	246	119	59ab	46	13
Wide-bed	61.7	15.6	11.6a	18.5	11.1	259	142	46a	48	16
Standard	63.1	15.4	15.1b	19.9	9.1	249	118	60b	50	13
Percentage of total tuber count in the various size categories										
Flat-top							48.4	24.0	18.7	5.3
Wide-bed							54.8	17.8	18.5	6.2
Standard							47.4	24.1	20.1	5.2
2008										
Flat-top	106.7a	12.1a	15.9ab	29.2	44.2	282ac	91a	62ab	71	58
Wide-bed	95.4ab	12.1a	14.4ab	25.7	40.1	258ab	86a	57ab	63	51
Standard	88.2b	10.7a	13.3b	25.9	36.0	238b	77a	51b	63	47
Triple bed	98.9ab	16.4b	17.8a	26.3	35.3	304c	127b	67a	65	45
Percentage of total tuber count in the various size categories										
Flat-top							32.2	22.1	25.2	20.5
Wide-bed							33.3	22.3	24.5	19.9
Standard							32.5	21.2	26.6	19.7
Triple bed							41.7	22.1	21.5	14.8

Column means followed by the same letter are not significantly different at $p < 0.05$.

wide-bed treatment had significantly greater yield in the smaller size categories compared to the standard treatment and significantly higher total tuber numbers than the other three treatments, but the increase was in the lower size categories, less than 170 g. There were no significant differences among the treatments in yield or total number of tubers in the size categories greater than 171 g in 2008.

4. Discussion

The approximately 10% reduction in irrigation water applied between the standard hill and wide-bed treatments was consistent in all 3 years. However, the lower irrigation applications in 2006 and 2007 for the flat-topped hill were not observed in 2008. The significantly greater yield in the flat-topped treatment compared to the standard treatment likely contributed to the need for increased irrigation water in 2008.

The trend for greater water use efficiencies with the altered hill shapes in all 3 years indicated better conversion of the water used for transpiration to tuber yield. Greater marketable yield, increased number of marketable tubers, and reduced tuber deformities resulted with the altered hill shapes. Greater and sustained soil water content with the wide-bed hill shapes reduced the frequency of irrigation applications. These yield results are consistent with the findings of Kang et al. (2004), who found that more frequent watering with drip irrigation, and not allowing the soil profile to dry prior to wetting, resulted in the greatest yield of potatoes. Similarly, Steele et al. (2006) reported that the increase in tuber quantity and size for furrow-planted potatoes was most likely due to consistent seasonal soil water conditions.

The trial seeding 3 rows (triple-planted) on the 1.8 m wide bed was a modest success. Greater tuber numbers, even though the increase was in the smaller (less than 170 g) size category, resulted in more production per unit area. However, the expectation that an increase in total tuber weight compared to the other treatments was not realized. A possible explanation could be that extra nitrogen and phosphorus fertilizer, which would be needed for proper growth of an additional row of potatoes, was not applied. If the increased tuber numbers for the triple-seeded, wide-bed treatment had sufficient fertility for proper bulking, then a significant increase in total tuber yield for this treatment may have been realized.

Warmer daytime soil temperatures after planting for the standard or flat-topped hill should help to lessen tuber diseases. Wharton et al. (2007) identified a greater incidence of rhizoctonia the longer the seed tuber remained in wet, cold soil prior to emergence. Although wet, cold soils are not typically a problem in the semi-arid region of southern Alberta, the flat-topped or standard hill have more surface area exposed, intercept more incoming solar radiation, are elevated from the surrounding soil, and thus warm faster.

5. Conclusions

A 10% water savings for irrigated potato production is possible in southern Alberta by modifying the standard hill shape to either a flat-topped or wide-bed hill shape. Standard hill-shape geometry adopted from other potato growing areas was not as effective at retaining irrigation and precipitation. Altering the standard hill to a flat-topped or wide-bed shape allowed more irrigation and precipitation to infiltrate. In areas where irrigation is essential for sustained potato production, an altered hill shape may improve water use efficiency and increase potato yield and quality. When pre-emergent soil water content is high and soil temperatures are low, and irrigation is practiced, a flat-topped hill rather than a wide-bed hill would ensure improved water use efficiency and enable maximum soil warming prior to row closure.

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References

Agriculture and Agri-Food Canada 1998. The Canadian System of Soil Classification Third Edition. NRC Research Press, Ottawa.
Bessembinder, J.J.E., Leffelaar, P.A., Dhindwal, A.S., Ponsioen, T.C., 2005. Which crop and which drop, and the scope for improvement of water productivity. Agric. Water Manage. 73, 113–130.
Chow, T.L., Rees, H.W., 1994. Effects of potato hilling on water runoff and soil erosion under simulated rainfall. Can. J. Soil Sci. 74, 453–460.
Cooley, E.T., Lowery, B., Kelling, K.A., Wilner, S., 2007. Water dynamics in drip and overhead sprinkler irrigated potato hills and development of dry zones. Hydrol. Process. 21, 2390–2399.
Environment Canada, 2001. Canadian Climate Averages or Normals 1971–2000. http://climate.weatheroffice.gc.ca/climate_normals/index_e.html.
Hatfield, J.L., Sauer, T.J., Prueger, J.H., 2001. Managing soils to achieve greater water use efficiency: a review. Agron. J. 93, 271–280.
Howell, T.A., 2006. Challenges in increasing water use efficiency in irrigated agriculture. In: International Symposium on Water and Land Management for Sustainable Irrigated Agriculture, April 4–8, Adana, Turkey, p. 11.
Kang, Y., Wang, F.X., Liu, H.J., Yuan, B.Z., 2004. Potato evapotranspiration and yield under different drip irrigation regimes. Irrig. Sci. 23, 133–143.
Mundy, C., Creamer, N.G., Crozier, C.R., Wilson, L.G., 1999. Potato production on wide beds: impact on yield and selected soil physical characteristics. Am. J. Potato Res. 76, 323–330.
Musick, J.T., Jones, O.R., Stewart, B.A., Dusek, D.A., 1994. Water–yield relationships for irrigated and dryland wheat in the U.S. Southern Plains. Agron. J. 86, 980–986.
Robinson, D., 1999. A comparison of soil–water distribution under ridge and bed cultivated potatoes. Agric. Water Manage. 42, 189–204.
Saffigna, P.G., Tanner, C.B., Keeney, D.R., 1976. Non-uniform infiltration under potato canopies caused by interception, stemflow, and hilling. Agron. J. 68, 337–342.
Shae, J.B., Steele, D.D., Gregor, B.L., 1999. Irrigation scheduling methods for potatoes in the northern Great Plains. Trans. ASAE 42 (2), 351–360.
Soil Management Support Services 1992. Keys to Soil Taxonomy. SMSS Technical Monograph No. 19. Pocahontas Press Inc., Blacksburg, VA.
Starr, G.C., Cooley, E.T., Lowery, B., Kelling, K., 2005. Soil water fluctuation in a loamy sand under irrigated potato. Soil Sci. 170 (2), 77–89.
Steele, D.D., Greenland, R.G., Hatterman-Valenti, H.M., 2006. Furrow vs hill planting of sprinkler-irrigated Russet Burbank potatoes on coarse-textured soils. Am. J. Potato Res. 83, 249–257.
Tow, P.G., 1993. Persistence and water use efficiency of a tropical grass and lucerne on a solodic soil on the far North-West slopes of New South Wales. Aust. J. Exp. Agric. 33, 245–252.
Wharton, P., Kirk, W, Berry, D., Snapp, S., 2007. Rhizoctonia stem canker and black scurf of potato, Michigan Extension Bulletin E2994. May 2007.