Distribution of Soil Water in a Field Prepared for Potatoes by Varying the Hill-Furrow or Bed-Furrow Configuration

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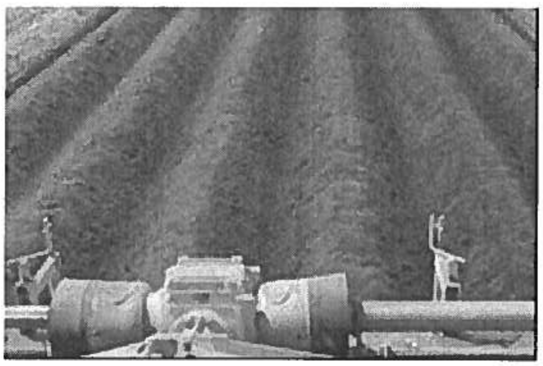
Executive Summary

In southern Alberta, potatoes are always hilled immediately after planting and covered with sufficient soil to prevent greening of the tubers, ensure drainage in the area of tuber formation and to facilitate mechanical harvest. The ideal shape for the potato hill, according the Manitoba Department of Agriculture (MDA), is one with fairly peaked top and gradual slope to the furrow position (ES Figure 1).



ES Figure 1. Ideal profile for a potato hill. (Courtesy of Gaia Consulting Ltd)

However with a profile described as ideal, much of the precipitation (either irrigation or rainfall) moves by gravity into the furrow position. Water ponds in the furrow position and if dammer dyked, gradually infiltrates with time. Water is believed to move from the furrow position into the hill position via soil matrix forces. Much of the precipitation accumulated in the furrow position likely percolates through the soil, below the root zone and is effectively lost to the plant.

A research project commenced in 2004 to identify the fate of precipitation (irrigation and rainfall) that infiltrates the soil in both the "ideal profile" hill and furrow position. The project continued in 2005, to determine the fate of infiltrated precipitation with altered hill shapes. The treatments included the standard or "ideal" hill profile, a modified flat-topped hill and a raised, double-row bed. Analysis included infiltration, redistribution, deep-percolation, evapotranspiration, yield and quality.

Infiltration of precipitation or increase in soil moisture after a rainfall/irrigation event was generally greatest for the double-row bed and the flat-topped hill. However, since the field was irrigated based on the standard hill shape and differential irrigation was not possible, the flat-topped hill and double row bed often lost the most amount of water

through deep percolation since they were often at or above field capacity for most of the growing season.

Evapotranspiration was similar between all treatments but soil moisture levels decreased the fastest in the standard hill profile, primarily a consequence of lower infiltration amounts for that treatment.

Modified hill profiles retain more of the applied irrigation water, thus increasing water savings within irrigated potato fields. Since it was not possible to quantify those water savings (all treatments were irrigated the same), a follow up study should be conducted to quantify water savings and to compare yield and quality data among treatments.

1. Introduction

Relative to other crops grown in southern Alberta, potato requires a very intensive irrigation management program to maximize economic returns. Potatoes have a relatively low tolerance to water stress, develop a shallow rooting system, and are typically grown on coarse-textured soils with inherently low water holding capabilities. Accordingly, growers must have an advanced knowledge of soil moisture status to maintain soil moisture at prescribed levels.

The infiltration of irrigation and rainfall into a potato hill is often assumed to be uniform. However, due to the implied topographic relief of hill-furrow tillage systems it is likely that the actual infiltration and subsequent redistribution of irrigation water is quite variable. This is supported by Saffigna et al. (1976); Stieber and Shock (1995); Bargar et al. (1999) and Robinson (1999) who all noticed that more water enters the soil through the furrow than through the ridge or hill. It is believed that between precipitation events, suction exerted by the plant's root system acts to redistribute some of the water into the hill position where it can be used by the plant. However, there is sufficient reason to believe that some of the water that collects in the furrow position will move to positions below the root zone, effectively lost for crop use.

Reservoir tillage (dammer-dyking) is commonly used in commercial potato production. In many instances it has been shown to effectively reduce runoff (Mickelsen and Schweizer, 1987; Kincaid et al., 1990). However, this practice may lead to increased movement of water beneath the furrow due to localized zones of increased infiltration. The ripping effect of the dammer-dyker's tillage shank, acts to shatter the soil, effectively increasing the ability of water to move into and through the soil. If rainfall or irrigation water ponds in the depression created by the dammer-dyker paddle, most of this water will infiltrate below the furrow position. Root density beneath the furrow is minimal and much of this water may be lost to deep percolation.

The development of the canopy of a potato crop also has a marked effect on the distribution of irrigation water. Results presented by Saffigna et al. (1976) suggest that early in the season, prior to row closure, water redistribution into the furrow was higher than after row closure. After row closure, approximately 40% of the irrigation water applied was directed toward the plant stem by the canopy. These results suggests that irrigation efficiency may actually improve throughout the growing season.

Improved irrigation efficiency may also be realized by altering standard hill shape so more of the applied irrigation water has time to infiltrate into the hill/bed before ponding in the furrow position. It is important to gain a detailed understanding of the fate of the irrigation water applied under various hill/bed configurations so the opportunity to improve irrigation efficiency is identified.

The objectives of this study are to:

1. Quantify the distribution of water within a standard hill/furrow prepared potato crop.
2. Quantify the distribution of water in altered hill/bed forms and compare with standard.
3. Quantify irrigation efficiency and identify opportunities for improvement.

2. Methodology

Year 1

The study was conducted at the Canada-Alberta Crop Development Initiative Demonstration Farm near Lethbridge, Alberta. An area of approximately 1.8 m wide x 2.0 m long, (an equivalent width of two beds and three furrow locations, extending for a distance of 2.0 m) was delineated within a field prepared and seeded to potatoes. Soil moisture was measured using 3 prong TDR sensors (Figure 1) and soil tension was measured using the granular matrix block (Watermark) sensors (Figure 2).

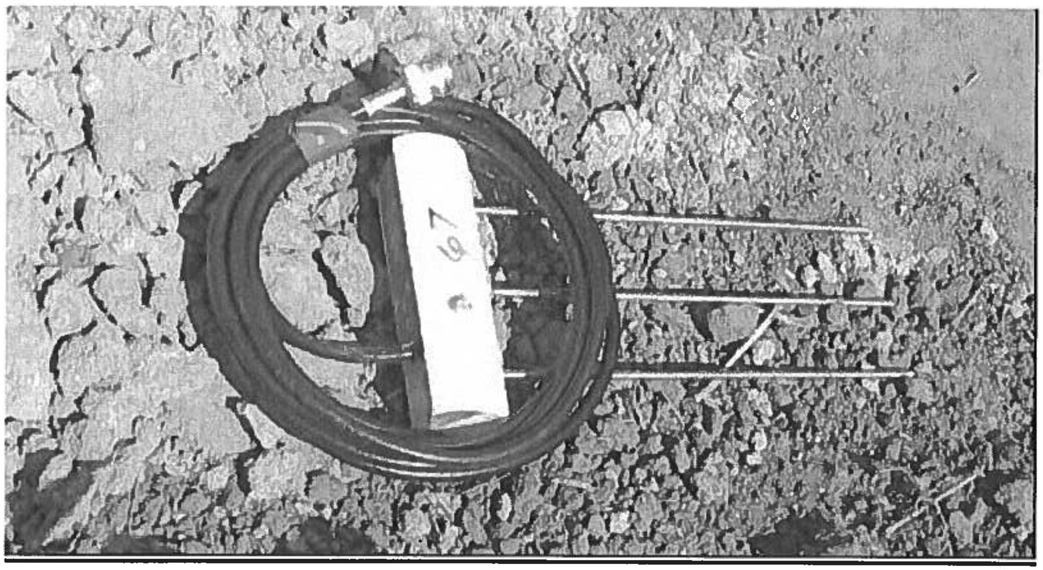


Figure 1. 3-prong TDR soil moisture probe.

Figure 2. Watermark granular matrix block soil tension probe.

A 2.1 by 0.8 m grid with 10 cm grid nodes was designed and the distribution of TDR and Watermark sensors within the soil profile for the hill-furrow configuration was determined. The TDR sensors were placed 10 cm below the surface within the hill position and 20 cm below the surface within the furrow position. Maximum vertical or horizontal distance between the probes was 10 cm within the hill position and 20 cm within the furrow (Figure 3).

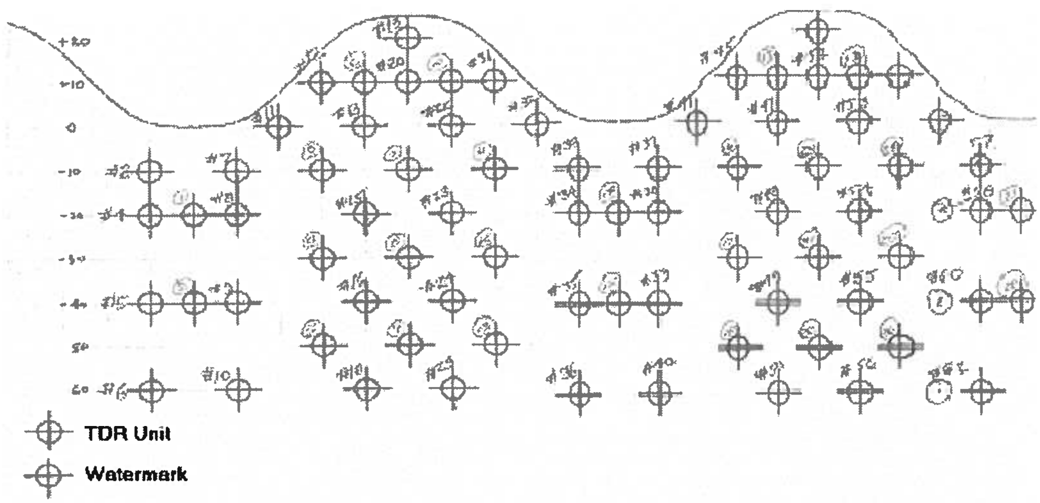


Figure 3. Schematic of soil moisture (TDR) and soil tension (Watermark) array.

A trench was excavated at one end of the plot to facilitate installation of the soil moisture and soil tension instrument array (Figure 4). A total of 50 TDR probes and 27 Watermark sensors were installed.

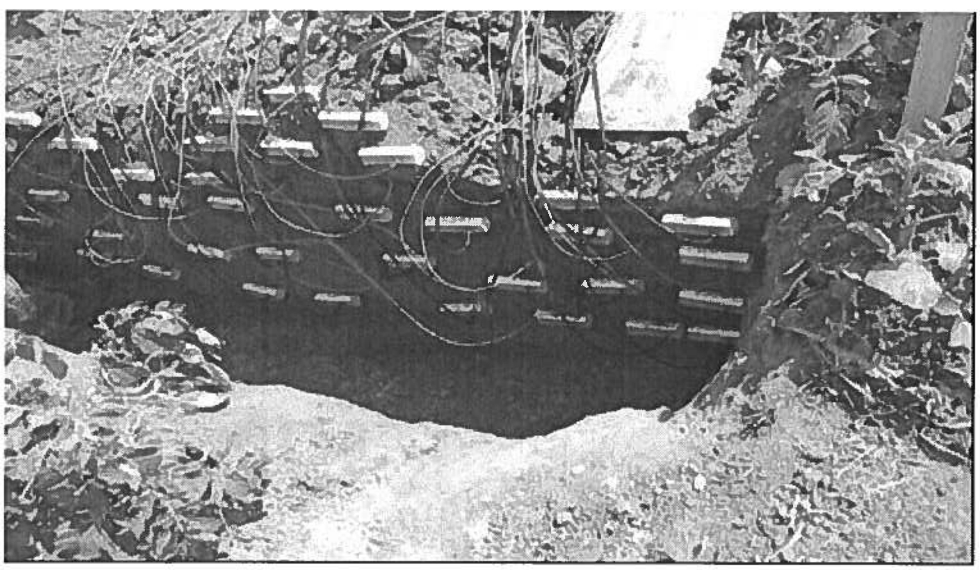


Figure 4. TDR and Watermark sensors installed in soil face.

The excavated area was hydrologically isolated from the out of plot area by installation of a 1.2 m wide by 2.4 m long by 0.23 m thick preserved wood plywood. The trench was backfilled using the excavated soil and the soil was packed in an attempt to minimize preferential infiltration into the disturbed soil (Figure 5).

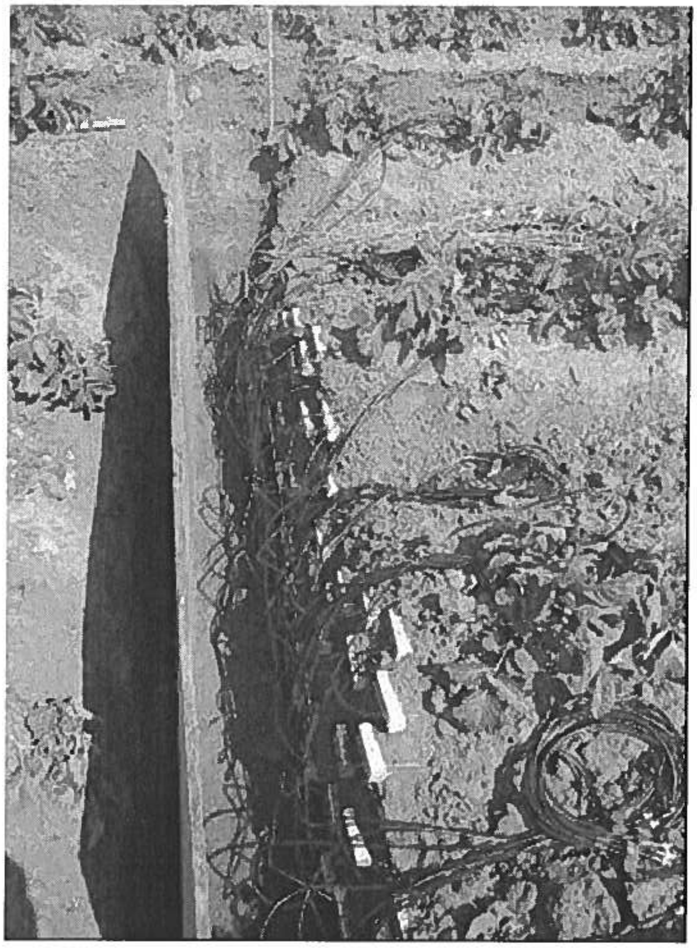


Figure 5. Plywood installed and backfill commenced.

The Watermark sensors were connected to a Campbell Scientific CR10X datalogger via a Campbell Scientific AM16/32 multiplexer (Figure 6). The TDR soil moisture probes were routed via a series of SDMX50 coax multiplexers (Figure 7) to a Tektronix 1502B TDR cable tester that was then connected to the data logger (Figure 8). Datalogger was programmed to output hourly values for soil moisture and soil tension for all the sensors.

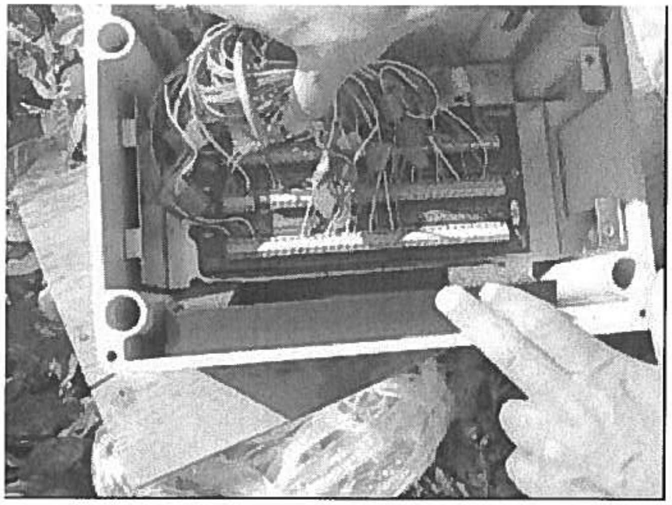


Figure 6. Watermark sensors to multiplexer.

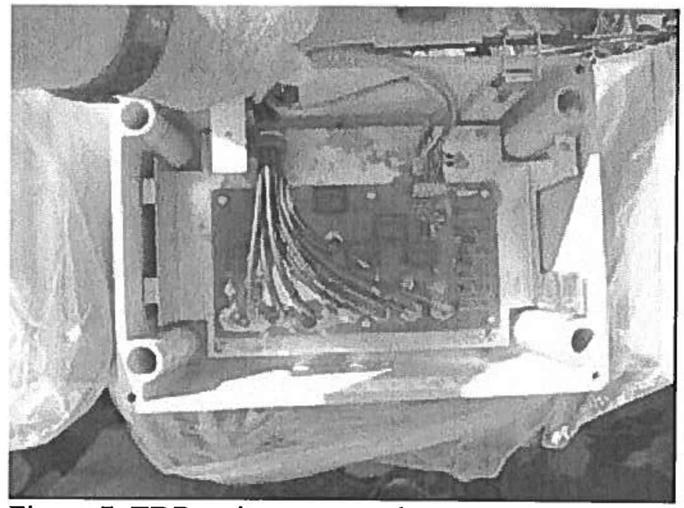


Figure 7. TDR units connected to coax multiplexer.

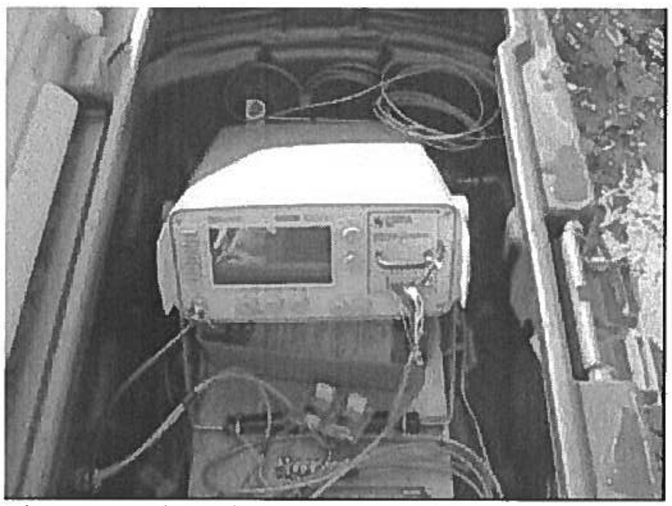


Figure 8. Tektronix 1502B cable tester.

A vadose zone fluxmeter (Figure 9) was placed 70 cm below the soil surface directly below the furrow position to record the quantity of either irrigation or rainfall that percolated below the root zone of the potato plant. The fluxmeter was also connected to the datalogger.

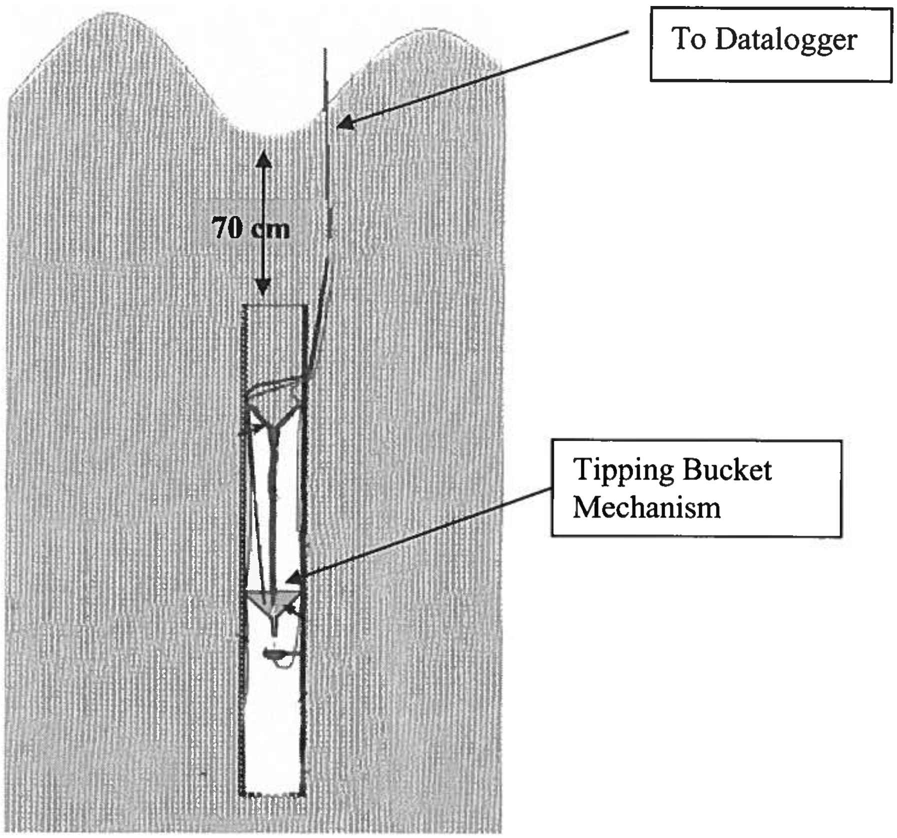


Figure 9. Flux meter installed below furrow position.

To complete the instrumentation, a tipping bucket rain gauge was installed to record rainfall or irrigation timing and amounts and two Delta T Devices, PR1-6 soil moisture probes were installed to record hourly soil moisture values within the plot. These instruments were connected to a separate datalogger.

The agronomic management practices followed were assumed to represent the majority of potato crops grown in southern Alberta and were:
- Seed Variety: Russet Burbank
-Seeded into beds spaced 0.9 m apart
-Beds constructed with power-hiller (immediately after planting operation)
-Reservoir tillage technique – ripping shank w/ dammer-dyker attachment (conducted soon after hilling)
-Irrigation method – medium pressure center pivot
-Water application – equivalent depth of 20-25 mm per application

Year 2

A total of 3 hill/bed furrow combinations were constructed on April 26, 2005, in a 12 m by 20 m area in a larger potato field irrigated with center pivot irrigation. The hill shapes were constructed with a bed former. The treatments included standard power hilled, flat topped hilled and 2 row, double cropped bed (Figure 10). The beds were seeded on April 26, 2005, with the Russet Burbank variety using a plot seeder.

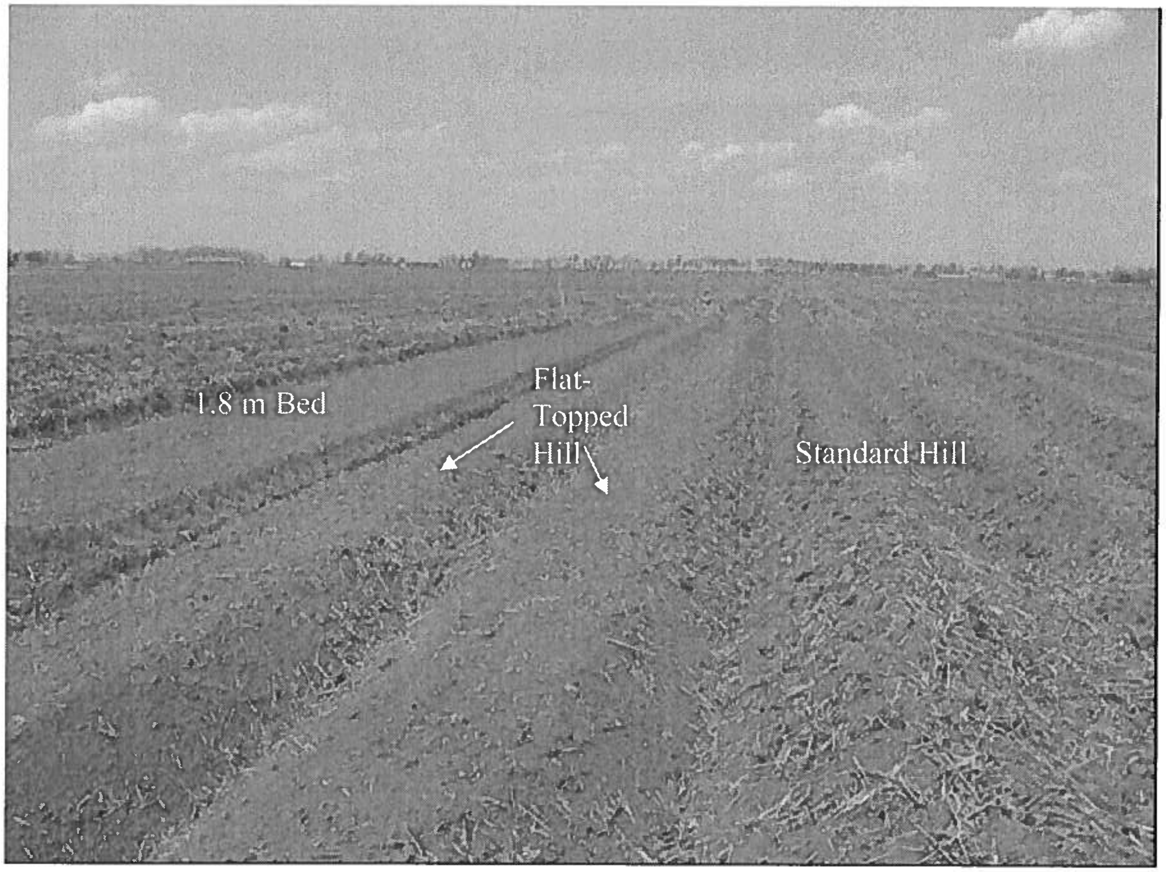


Figure 10. Bed and Hill Shape after Seeding.

Similar to Year 1, a 0.7 m deep by 0.6 m wide trench was excavated across the face of the three prepared hill shapes and an array of 32 Watermark sensors at a spacing of no greater than 20 cm either horizontally or vertically from each other were installed. All sensors were multiplexed through a Campbell Scientific AM 16/32 multiplexer and connected to a Campbell Scientific CR 10X datalogger for hourly soil tension readings. A vadose zone flux meter was installed below the furrow position near the middle of the plot at a depth of 70 cm below the soil surface.

The plot was hydrologically isolated from the upslope position with a wooden barrier. Initial rill meter readings were taken to quantify the final hill/bed shape.

Additional instrumentation included a tipping bucket rain gauge to monitor irrigation/ rainfall amount and timing, as well as an adjacent Bowen Ratio Energy Balance system to estimate potato evapotranspiration.

Analysis included infiltration into, water loss from and evapotranspiration for the various prepared bed shapes including the furrow position. Three furrows were monitored and the results were presented as an average of the three furrows.

Yield samples were taken from each plot on September 8, 2005. A three-meter section from each treatment was hand dug, the tubers were collected and analysis for potato yield and quality for the different prepared seed beds was performed.

3. Results and Discussion

Year 1
There were delays in obtaining and constructing some of the instrumentation that resulted in delays in data collection. Additional problems were experienced with programming the logger so data collection only started in early August. The soil matrix potential for August 10, 2004, is shown in Figure 11.

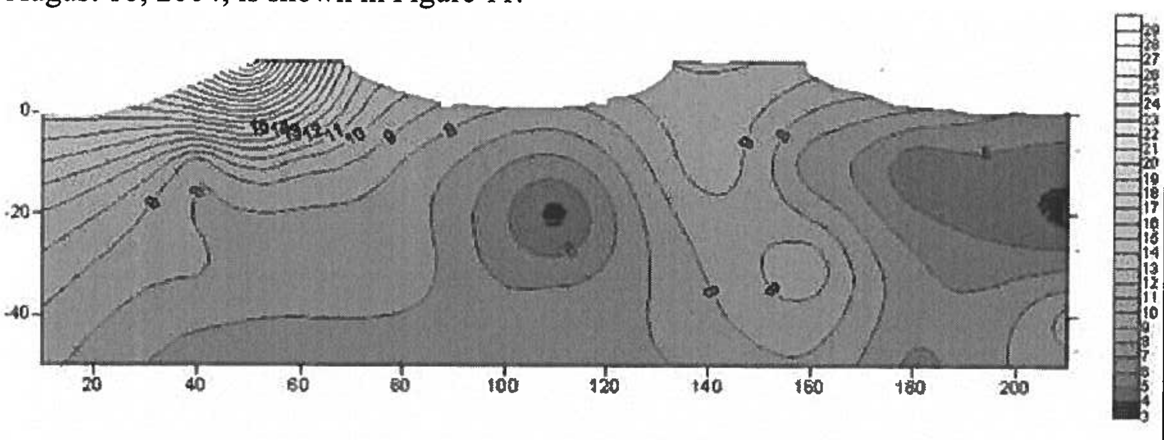


Figure 11. Soil tension profile for August 10, 2004.

Lower soil moisture content was expected in the hill versus the furrow but we found drier soil moisture conditions remained in the hill where the potato plants were actively growing, even though there was high soil moisture in the furrows. At soil moisture levels below field capacity, there appeared to be limited movement of soil moisture from the furrow into the hill. Similar soil moisture values near surface in the furrows were found at a 40 cm depth and greater in the hills.

Vadose Zone Flux Meter
There was no recorded flow through the vadose zone flux meter during the time of monitoring in August. Total rainfall and irrigation during August were 24 mm; insufficient to initiate deep percolation.

Year 2

Results were fairly consistent for infiltration of irrigation and rainfall events in that the 1.8 m bed generally gained the most moisture (an exception was when it was at or near saturation), the flat topped prepared hill gained the second most and the standard hill infiltrated the least amount of water. For many rainfall events, but not all, the furrow position had the greatest gain of soil moisture (Table 1). Since the furrow position was the average of three furrows and less water accumulated in the furrow position from the bed or the flat topped hill shape, thereby often lowering the average.

Table 1. Gain in soil moisture (mm) during rainfall/irrigation events (mm).

	June 17	June 23	June 26	June 29	July 9	July 23	July 26	August 11
Rainfall	8.6	0.0	3.6	16.4	7.0	0.6	0.0	9.2
Irrigation		14.2				28	18.2	
Bed	5.2	11.6	1.7	8.4	5.9	12.0	15.1	4.3
Flat	3.0	8.1	2.3	12.1	5.1	21.1	6.6	6.9
Standard	1.2	3.1	0.4	2.5	2.3	18.3	3.4	1.5
Furrow	7.3	17.6	7.4	2.8	15.5	14.0	9.1	2.7

However, even though the furrow position or flat-topped gained the most water during a precipitation event, since they both had consistently higher water content throughout the growing season, they also would lose, primarily through deep percolation, much of their infiltrated water. For example, a 23.0 mm rainfall event on June 17, 2005, resulted in an initial higher gain in soil moisture for both the bed and flat topped but subsequently, they lost the most to deep percolation. (Table 2). Similar results occurred for a June 27-28 rainfall of 28.2 mm.

Table 2. Infiltration and subsequent deep percolation for the various treatments.

Rainfall		Initial Gain in Soil Moisture	Subsequent Loss to Deep Percolation and Evapotranspiration
17-Jun		18-Jun	19-Jun
23.0	Bed	14.6	17.8
	Flat	6.1	8.6
	Standard	9.9	3.2
	Furrow	4.8	10.2
28-Jun		29-Jun	30-Jun
28.2	Bed	18.6	19.9
	Flat	20.8	13.0
	Standard	24.3	12.3
	Furrow	10.4	17.2

Figure 12 highlights the consistently higher soil moisture for both the bed and flat-topped hill shape compared to the standard.

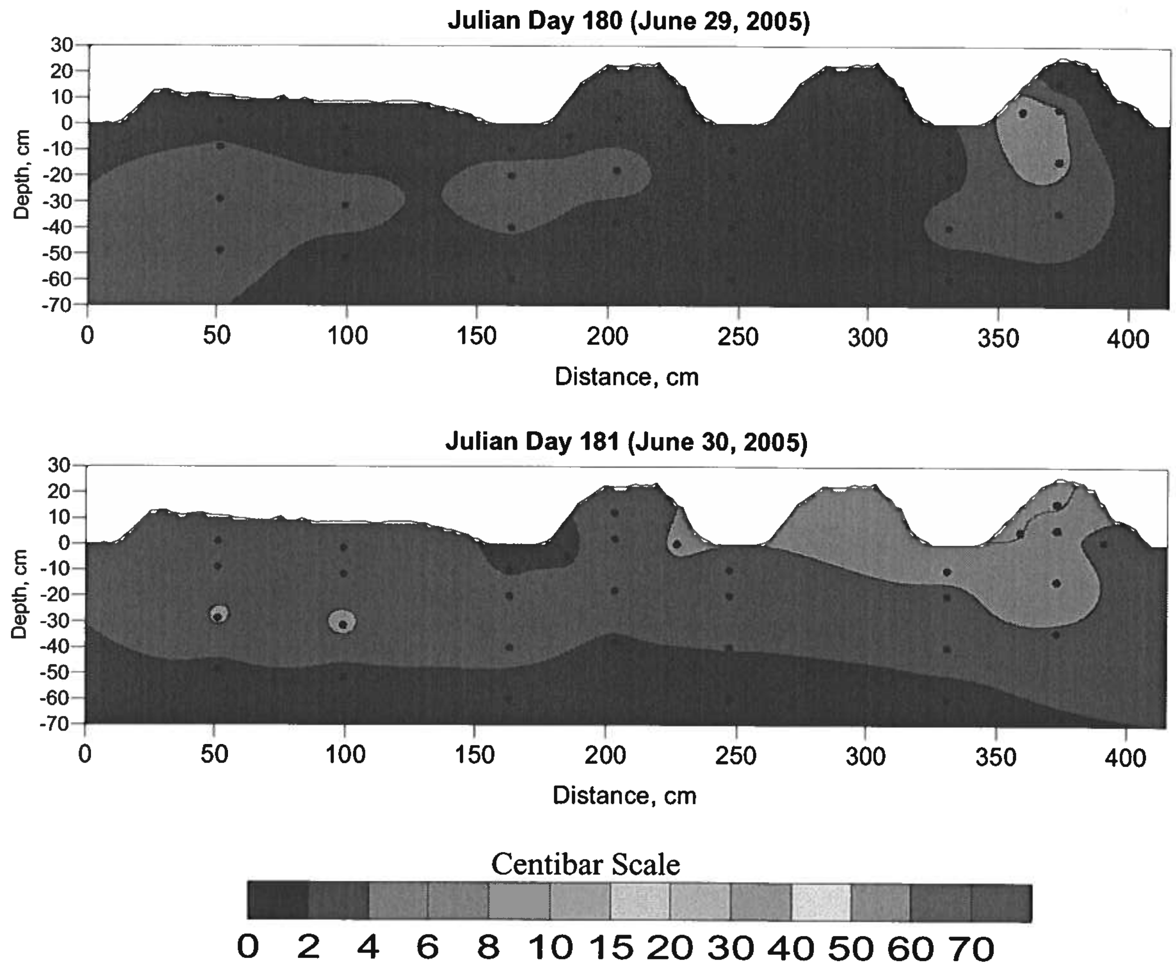


Figure 12. Drainage of profiles after saturation.

The standard-prepared hills infiltrated the least amount of water and soil moisture was depleted most rapidly within them. Figures 13 thru to 15 highlight the drying nature of the standard-prepared potato beds compared with the bed and flat-topped hill for selected times throughout the growing season. For interpretation, a soil tension reading of approximately 40-50 centibars would be the lower limit before an irrigation application.

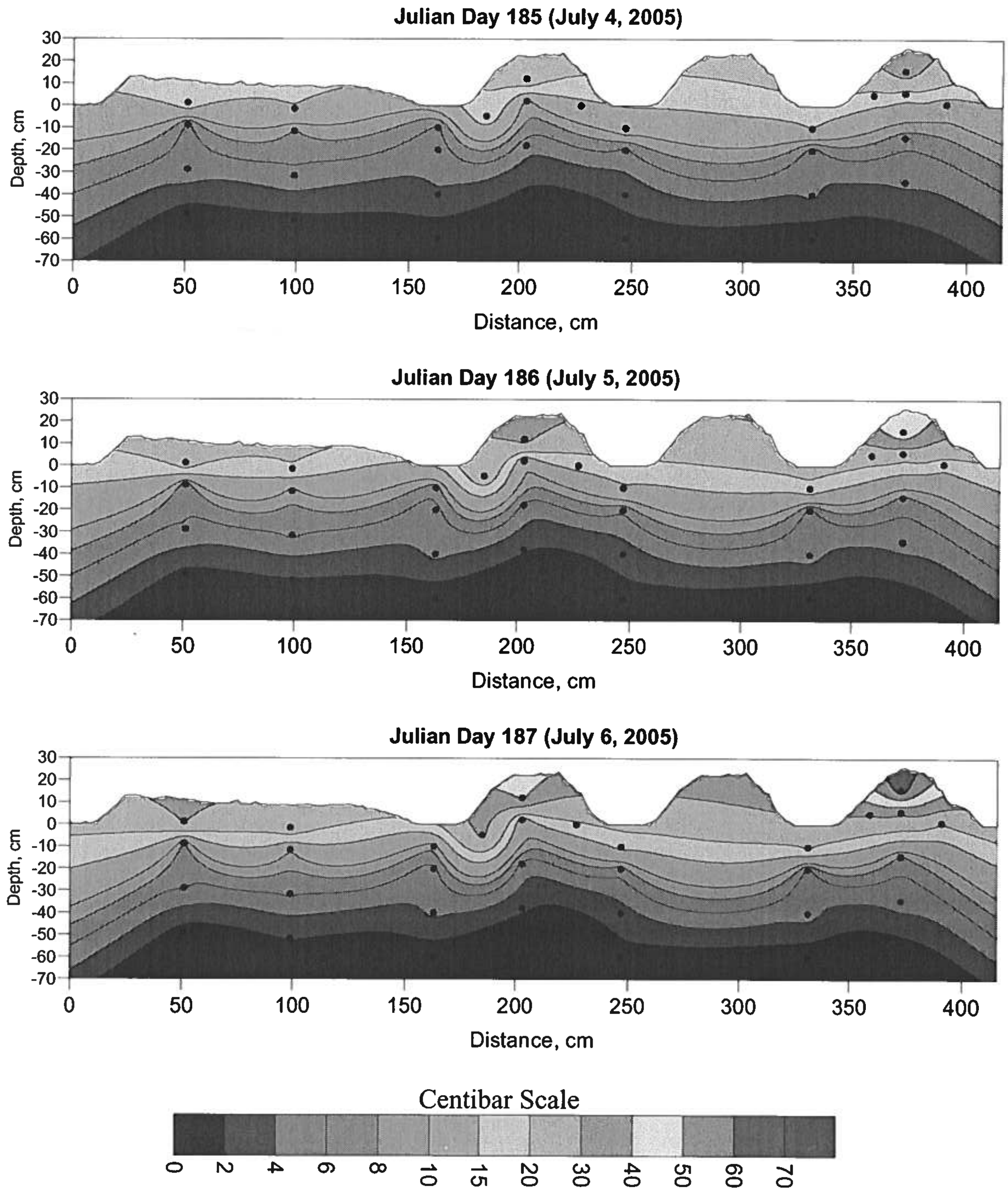


Figure 13. Soil tension readings (centibars) from July 4-6, 2005

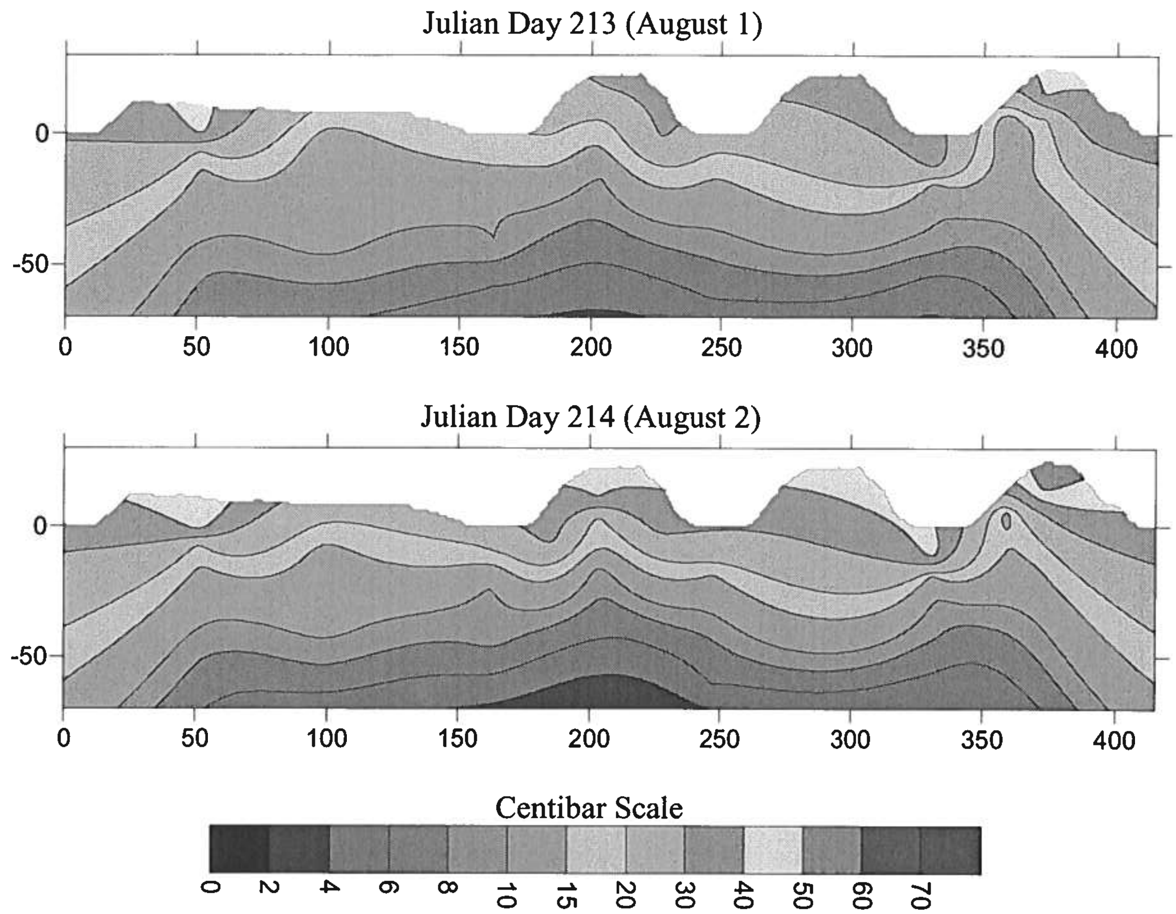


Figure 14. Soil tension readings (centibars) from August 1-2, 2005.

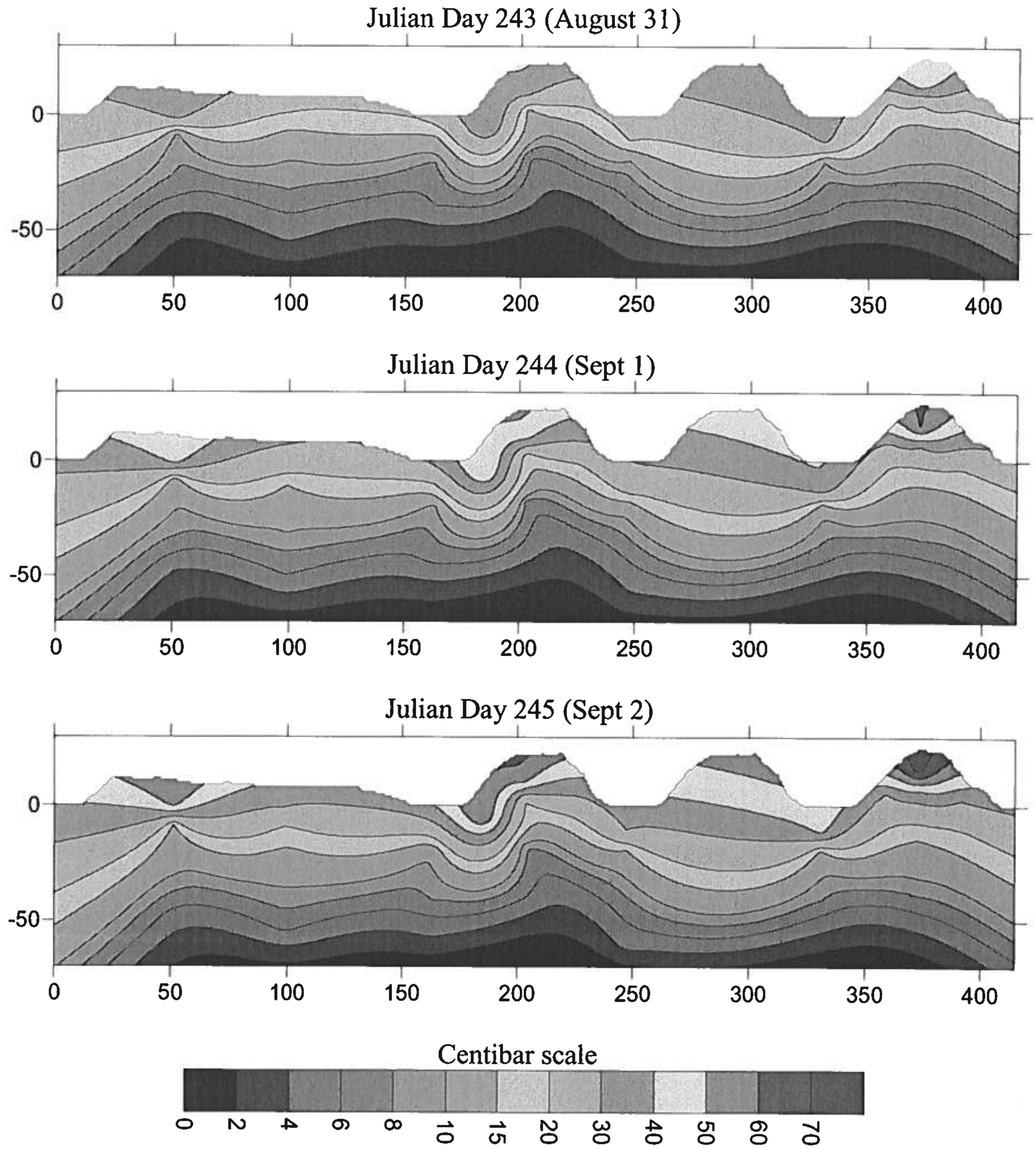


Figure 15. Soil tension readings (centibars) from August 31-Sept 2, 2005.

Evapotranspiration or potato water use was similar for all treatments throughout the growing season (Table 3) therefore differences in rate of depletion of soil moisture was primarily a result of less water infiltrating the standard-prepared hill.

Table 3. Daily evapotranspiration for the various bed/hill configurations, furrow position and theoretical potato evapotranspiration.

	21-Jun	24-Jun	1-Jul	5-Jul	11-Jul	15-Jul	22-Jul	20-Aug	22-Aug	30-Aug	31-Aug	1-Sep	2-Sep	6-Sep
Bed	4.9	2.9	5.2	5.5	3.0	2.5	1.8	7.1	7.2	3.4	7.6	1.0	2.2	3.8
Flat	4.9	2.2	6.2	4.5	2.3	2.5	5.2	8.4	6.3	2.7	6.6	0.1	1.7	3.9
Standard	4.6	3.2	5.2	3.5	1.6	3.5	4.8	7.8	5.4	2.0	5.7	0.0	2.2	5.3
Furrow	5.6	1.7	4.8	4.8	1.6	2.4	2.5	7.5	11.4	1.3	7.1	0.6	3.0	5.6
PM ET	4.8	3.5	5.5	4.9	4.6	2.7	4.8	7.5	7.1	4.3	6.7	5.0	4.5	3.6

Note: PM ET is calculated based on the FAO 56 Penman Monteith evapotranspiration equation using a locally calibrated potato crop coefficient curve.

Yield and Quality

No statistics were performed on the yield and quality data since the experiment was not a replicated trial. However, the standard and flat-topped hills were similar in number and in size categories. The double-row bed had a higher number of tubers but they were in the smaller size category. McKenzie (1998) also found that where soil moisture was consistently higher in the low-lying areas of the field, a greater number of tubers were collected but those tubers were of the smaller size category.

Table 4. Yield and quality for the three treatments.

Treatment	Graded Yield (tons/acre)	Total number of tubers	Tuber number in size categories				
			< 4 oz	< 4-6 oz	6-10 oz	>10 oz	Deformed
Double row bed	10.4	93	41 44.1%	35 37.6%	14 15.1%	1 1.1%	2
Flat Topped	9.3	63	12 19.1%	14 22.2%	25 39.7%	11 17.5%	1
Standard	10.3	73	21 28.8%	13 17.8%	29 39.7%	8 11.0%	2

4. Conclusions and Suggestions

The first year of the study identified that soil moisture/tension in the furrow position in a standard hill/furrow prepared field remained consistently wetter than the hill and that there was limited movement of soil moisture from the furrow position into the hill. Similar soil tension readings at near-surface position in the furrow occurred at a depth greater than 40 cm under the hill.

The second year of the study identified that by altering hill shape to either a 1.8 m double row bed or a flat-topped hill, more precipitation (either through irrigation applications or rainfall) infiltrated and soil moisture consistently remained higher. The design of the field plots for Year 2 did not allow differential irrigation of the various treatments. The field was irrigated for the standard-prepared hill since the plots were established within a larger field of potatoes and the entire field was irrigated using a center pivot system. This often resulted in the bed and flat-topped hill receiving an irrigation when the soil moisture was at or above field capacity. Therefore, quantifying the reduction of irrigation water required for the bed or flat-topped hill was not possible, however the qualitative data were evident.

A continuation or a follow-up study should be initiated with a replicated plot design where the arrangement of the irrigation equipment is such that each plot or group of plots could be irrigated separately from the other plots or groups of plots. Irrigation water savings could then be quantified and meaningful yield and quality comparisons may be realized.

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