Water Use and Water Productivity of Sugarbeet, Malt Barley and Potato Affected by Irrigation Frequency

J.D. Jabro, W.M. Iversen, R.G. Evans, W.B. Stevens and B.L. Allen
USDA, Agricultural Research Service, Northern Agricultural Research Laboratory, Sidney, MT 59270

US Department of Agriculture
Agricultural Research Service

Introduction

Crop water use efficiency (CWUE) originates in the economic concept of crop productivity and therefore is now known as crop water productivity (CWP). Water is an important factor in barley (Hordeum vulgare L.), sugarbeet (Beta vulgaris L.) and potato (Solanum tuberosum L.) production. The seasonal water requirements for barley range between 390 - 430 mm for optimum yield depending on variety, and crop and water management. The water use efficiency per unit harvested grain yield for barley is approximately 11.5 kg ha^{-1} mm^{-1} (Hills et al., 1990). Sugarbeet requires a considerable amount of water during the growing season, about 6.5 mm per day; actual crop evapotranspiration ranges between 900 and 1200 mm of water in a growing season depending on location, time of year, time and method of water application, and climatic conditions (Hills et al. 1990, Fabeiro et al. 2003). Research over the last several decades has shown that crop water use efficiency of sugarbeet ranges between of 9.60 and 17.5 kg m^{-3} or 96 and175 kg ha^{-1} mm^{-1} (Howell et al. ,1987; Hills et al. ,1990; Topak et al. , 2011). Wright and Stark (1990) reported seasonal water use efficiencies of 54 to 120 kg ha^{-1} mm^{-1} for total potato tuber grown in several climatic locations on sandy to sandy loam soils.

Objective

To evaluate and compare the effect of irrigation frequency on crop water use and crop water productivity of barley, sugarbeet and potato on a sandy loam soil.

Table 1. *Distribution of PCAP[1] fluxmeters used to collect drainage water by year, crop, and tillage and irrigation frequency.*

Year	Crop	Tillage	Irrigation frequency	Number of PCAPs
2007	Sugarbeet	Strip	High	3
2007	Sugarbeet	Strip	Low	3
2007	Malt barley	Conventional	High	3
2007	Malt barley	Conventional	Low	3
2008	Potato	Conventional	High	6
2008	Potato	Conventional	Low	6
2009	Sugarbeet	Conventional	High	3
2009	Sugarbeet	Conventional	Low	3
2009	Malt barley	Conventional	High	3
2009	Malt barley	Conventional	Low	3
2010	Sugarbeet	Strip	High	3
2010	Sugarbeet	Strip	Low	3
2010	Malt barley	Conventional	High	3
2010	Malt barley	Conventional	Low	3
2011	Potato	Conventional	High	6
2011	Potato	Conventional	Low	6

[1]PCAP is a passive capillary water fluxmeter.

Table 2. *Dates of planting and harvest of sugarbeet, malt barley and potato.*

Year	Sugarbeet		Malt Barley		Potato	
	Planting	Harvest	Planting	Harvest	Planting	Harvest
2007	4/24	9/24	4/27	8/1		
2008					5/5	9/12
2009	5/6	9/22-23	5/6	8/5		
2010	5/7	9/22-23	4/29	8/4		
2011					5/14	9/20

Methods

Location: The semiarid northern Great Plains at the USDA-ARS irrigated research farm (48.1640 N, 103.0986 W).

Soil: A Lihen sandy loam.

Rotation: Two cycles of a three-year rotation of sugarbeet, malt barley and potatoes under a linear-move self-propelled sprinkler irrigation system.

Irrigation: The high frequency (HF) irrigation involved applying small irrigation quantities at high frequency (approximately twice a week) while low frequency (LF) irrigation (conventional) involved applying large irrigation quantities at low frequency (approximately once a week).

Design: A stripped-randomized complete block experimental design consisting of two crop sequences with two irrigation frequencies and six replications with all components of each sequence present every year for a total of 72 plots.

Soil water contents: Monitored in-situ weekly at 23, 46, 61, 76 and 91 cm depths in every plot by a neutron probe. Soil moisture variations incorporated in the water balance equation were calculated weekly.

Drainage: Measured weekly using twelve automated passive capillary fiberglass wick (PCAP) fluxmeters (30 cm X 90 cm X 84 cm) placed 90 cm below the soil surface Jabro et al. (2012). The distribution of PCAP fluxmeters within each year crop rotation is given in ***Table 1***.

The CWU, also known as seasonal evapotranspiration (ET), is the sum of evaporation (E); transpiration (T), and water loss (mm) and was calculated as:

$$CWU \text{ or } ET = R + I - (\theta_v f - \theta_v i) - D \qquad [1]$$

where R is the amount of seasonal precipitation (mm), I is the amount of weekly or seasonal irrigation (mm), $\theta_v f$ is final volumetric soil water content, $\theta_v i$ is initial volumetric soil water content or the change in water storage in 0.91 m soil profile over the season measured by a neutron probe (mm), and D is soil drainage water percolated below the bottom of 0.91 m (mm). Calculations of CWU are based on the assumption that runoff from the plots was negligible and did not occur at any time due to well drained sandy soil conditions. Dates of planting and harvest (length of growing season) of sugarbeet, malt barley and potato for 2007, 2008, 2009, 2010 and 2011 are given in ***Table 2***.

The CWP (kg ha^{-1} mm^{-1} or kg m^{-3}) is defined as:

$$CWP = \frac{Y}{CWU} \qquad [2]$$

where Y is the yield of the irrigated crop (sugarbeet root, potato tuber and malt barley total grain yield) expressed in kg ha^{-1}.

Results and Discussion

Seasonal water balance equation components and CWU amounts for sugarbeet, malt barley and potato are presented in ***Tables 3, 4, and 5***, respectively. The results of statistical analyses for total yield (Y), CWU and CWP of sugarbeet, malt barley and potato of both HF and LF irrigations are presented in ***Tables 6, 7, and 8***, respectively. No significant differences due to irrigation frequency were found for yield, CWU, and CWP of sugarbeet, malt barley and potato ***(Tables 6, 7, and 8***).

A. Sugarbeet root and sucrose

Sugarbeet root yield and sucrose production were not significantly affected by irrigation frequency in 2007, 2009 and 2010. Averaged across three years, sugarbeet root and sucrose yields were only 5.5 and 2.9% greater in HF irrigation than in LF irrigation, respectively (***Table 6***).

Seasonal CWU and CWP of sugarbeet root yield and sucrose production under both HF and LF irrigations for 2007, 2009, 2010 and the average of these three years are presented in ***Table 6***.

B. Malt barley grain

Malt barley total grain yield was not significantly influenced by irrigation frequency in 2007, 2009 and 2010. Averaged across three years, malt barley grain yield was 2.9% greater (not significant at 0.05 level) in LF irrigation than in HF irrigation (***Table 7***).

Seasonal CWU and CWP of malt barley under both HF and LF irrigations for 2007, 2009, 2010 and the average of these three years are presented in ***Table 7***.

C. Total potato tuber

Statistical analysis showed that no significant differences due to irrigation frequency were found for total tuber yield in 2008 and 2011. Across two years, the mean potato tuber yield was approximately 1.5% greater in LF irrigation than in HF irrigation (***Table 8***). Seasonal CWU and CWP of potato tuber yield under both HF and LF irrigations for 2008, 2011 and the average of two years are given in ***Table 8***.

Table 3. *Seasonal water balance equation components of sugarbeet for high frequency (HF) and low frequency (LF) irrigations at the 0 - 91 cm soil depth.*

Component (mm)	2007		2009		2010	
	HF	LF	HF	LF	HF	LF
Rainfall	233	233	267	267	310	310
Irrigation	537	537	304	304	292	292
Change in soil moisture	-40	-18	-9	-41	-17	-5
Drainage	3	2	14	29	48	7
Water use[1]	807	786	566	583	571	600

[1] No significant differences between irrigation treatments at the 0.05 level.

Table 4. *Seasonal water balance equation components of malt barley for high frequency (HF) and low frequency (LF) irrigations at the 0 - 91 cm soil depth.*

Component (mm)	2007		2009		2010	
	HF	LF	HF	LF	HF	LF
Rainfall	193	193	204	204	218	218
Irrigation	64	64	81	81	81	81
Change in soil moisture	-66	-68	-5	-18	-6	-22
Drainage	1	2	21	8	22	13
Water use[1]	322	323	269	295	283	308

[1] No significant differences between irrigation treatments at the 0.05 level.

Table 5. *Seasonal water balance equation components of potato for high frequency (HF) and low frequency (LF) irrigations at the 0 - 91 cm soil depth.*

Component	2008		2011	
(mm)	HF	LF	HF	LF
Rainfall	172	172	393	393
Irrigation	440	440	267	267
Change in soil moisture	-27.5	-31.7	-36	-36
Drainage	2	15	76	53
Water use[1]	638	629	620	643

[1] No significant differences between irrigation treatments at the 0.05 level.

Table 6. *Crop water use (CWU) and crop water productivity (CWP) for root yield and sucrose yield of sugarbeet under two irrigation frequencies (high frequency, HF and low frequency, LF) for 2007, 2009, 2010, mean of three years combined.*

Year	Irrigation	Yield[3] (kg ha^{-1})		CWU[3] (mm)	CWP[3] (kg ha^{-1} mm^{-1})	
		Root	Sucrose		Root	Sucrose
2007[1]	HF	59203	10680	797	74.3	13.4
	LF	60840	11082	776	78.4	14.3
2009[2]	HF	69329	12846	565	122.7	22.7
	LF	66191	12275	582	113.7	21.1
2010[1]	HF	72878	12430	571	127.6	21.8
	LF	67408	11565	600	112.4	19.3
Mean	HF	67137	11985	644	108.2	19.3
	LF	64813	11641	653	101.5	18.2

[1]Sugarbeet was grown under strip tillage.
[2]Sugarbeet was grown under conventional tillage.
[3] No significant differences between irrigation treatments at the 0.05 level.

Table 7. *Crop water use (CWU) and crop water productivity (CWP) for grain yield of malt barley under two irrigation frequencies (high frequency, HF and low frequency, LF) for 2007, 2009, 2010 and mean of three years combined.*

Year	Irrigation	Crop	Grain yield[1] (kg ha^{-1})	CWU[1] (mm)	CWP[1] (kg ha^{-1} mm^{-1})
2007	HF	Barley	5429	322	16.9
	LF	Barley	5891	323	18.2
2009	HF	Barley	5927	269	22.0
	LF	Barley	5992	295	20.3
2010	HF	Barley	4664	284	16.5
	LF	Barley	4624	309	15.0
Mean					
	HF	Barley	5340	292	18.5
	LF	Barley	5502	309	17.8

[1] No significant differences between irrigation treatments at the 0.05 level.

Table 8. *Crop water use (CWU) and crop water productivity (CWP) of potato tuber under two irrigation frequencies (high frequency, HF and low frequency, LF) for 2008, 2011 and mean of two years combined.*

Year	Irrigation	Crop	Tuber yield[1] (kg ha^{-1})	CWU[1] (mm)	CWP[1] (kg ha^{-1} mm^{-1})
2008	HF	Potato	51491	638	80.7
	LF	Potato	54786	629	87.1
2011	HF	Potato	43302	620	69.8
	LF	Potato	41401	642	64.5
Mean					
	HF	Potato	47397	629	75.3
	LF	Potato	48094	635	75.8

[1] No significant differences between irrigation treatments at the 0.05 level.

Conclusions

No significant differences due to irrigation frequency were found for yield, CWU, and CWP of sugarbeet (root and sucrose), malt barley and potato.

The LF irrigation used 0.0061and 0.0021 m^3 more water than HF irrigation to produce one kilogram of sugarbeet root and malt barley grain, respectively, over the growing season on a sandy loam soil.

An equivalent amount of irrigation water was used to produce 1 one kilogram of potato tuber under both LF and HF irrigation.

Conventional LF irrigation thus can sustain yield, improve water use and reduce net economic input as feasibly as HF irrigation practices when a self-propelled automated sprinkler system is used on a sandy loam soil.

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