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Subirrigation with brackish water for vegetable production in arid regions

R.M. Patel[a], S.O. Prasher[a,*], D. Donnelly[b], R.B. Bonnell[a], R.S. Broughton[a]

[a] *Department of Agricultural and Biosystems Engineering, McGill University, MacDonald Campus, Box 950/21, 111 Lakeshore Rd., Ste-Anne de Bellevue, Quebec, Canada H9X 3V9*

[b] *Department of Plant Science, McGill University, Macdonald Campus, Ste-Anne de Bellevue, Quebec, Canada H9X 3V9*

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Abstract

Brackish water is the principal source of irrigation water in many arid regions. Surface irrigation with brackish waters is limited to salt tolerant crops or is used alternately with scarce freshwater resources. However, subirrigation may help overcome some of the limitations associated with the use of brackish water in arid agricultural regions. Use of this technique to produce potatoes (*Solanum tuberosum* L.), one of the world's major food crops, is investigated in this study. The yield and tuber grade of 'Atlantic' and 'Russet Burbank' potatoes were evaluated in field lysimeters packed with a sandy soil, salinized to 3.5 dS/m, and then subirrigated with water having salinity levels (EC_i) of 1, 5 or 9 dS/m, beginning 13 days after planting. Preventing rainwater entry by using plastic mulch simulated arid conditions. Water tables were maintained at 40 or 80 cm below the soil surface. At harvest, soil solution salinity (EC_w) in the lysimeters ranged from 3.5 to 7.6 dS/m. Water table depths or subirrigation water salinity levels had no significant effect on the total tuber weight of either cultivar. However, yield of grade A Russet Burbank tubers was greater when the water table was maintained at 40 cm. This trend was similar but not significant for Atlantic tubers. Productivity of Atlantic was lower than that of Russet Burbank. Subirrigation with brackish water in the saline soil resulted in yield that was 59% above the global average, thus demonstrating its utility for agriculture in dry regions.

Keywords: Subirrigation; Brackish water; Water table; Subirrigation water salinity; Soil solution salinity; Atlantic; Russet Burbank; Tuber size

1. Introduction

Irrigation has been practised all over the world for many centuries. There was a rapid expansion of irrigated areas from 1950 to 1990 (Umali, 1993), which resulted in the exploitation of most favourable land and water resources (FAO, 1992). It is estimated that the annual rate of land expansion under irrigation must be 2.25% to meet the increasing global demand for food (FAO, 1992). Today, net expansion of irrigated land areas is practically nil; while more land areas are being put under irrigation, about 6 million ha of cultivable land per year becomes unproductive due to increased salinity (Umali, 1993; FAO, 1995a). Globally, much of the undeveloped land area is in arid regions where freshwater supplies are limited. It is essential to develop crop production methods depending, at least partly, on the utilisation of brackish water (Thorne, 1970; Gupta and Abrol, 1990; FAO, 1995a).

Numerous problems are encountered in arid areas while using surface irrigation, particularly with brackish water (Gupta and Abrol, 1990). The intolerance of young plants to saline water and rapid salt build-up in the root zone during growing seasons are the most fundamental problems. This has limited the use of brackish water mainly to salt tolerant species. However, it may be possible to produce a wider variety of food crops, including relatively salt-sensitive types, by using subirrigation systems to apply brackish waters (von Hoyningen Huene, 1994). This irrigation technique eliminates surface contact of brackish water with young plant tissues. Any fresh water present in the unsaturated or saturated zone of soil above the drain is pushed up into the root zone by brackish water used with subirrigation. Drains can intercept saline percolating water thus preventing salinization of underground aquifers. This method has been successful in humid areas (Workman et al., 1990; Broughton, 1995). However, its

* Corresponding author. Tel.: 001-514-398-7773; fax: 001-514-398-8387.

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applicability in arid conditions must be investigated (Criddle and Kalisvaart, 1967; von Hoyningen Huene, 1994).

Potatoes were chosen for this study because of their global importance, amongst non-cereals (FAO, 1995b), and due to their moderate salt sensitivity (Maas and Hoffman, 1977). Both tuber yield and quality are more sensitive to salinity than many cereal crops. Potato cultivation under subirrigation with brackish water, in a saline soil under arid conditions, has not been reported. However, field experiments indicate that potatoes can be grown using surface-applied brackish water in non-saline soils (Paliwal and Yadav, 1980; Levy et al., 1988; van Hoorn et al., 1993; Nadler and Heuer, 1995). Levy (1992) applied 10 cm of brackish water (salinity level 6.1–6.9 dS/m) to simulate saline soil conditions, and grew potatoes under drip irrigation with brackish water. Potato tuber size and shape were affected by salt stress. Tuber weight of all grades, especially the largest grade, decreased due to increased salinity, caused by surface irrigation with brackish water (Paliwal and Yadav, 1980). Similarly, when potatoes were drip-irrigated with brackish water, the proportion of extra large tubers decreased, and that of large tubers increased (Nadler and Heuer, 1995).

Water stress usually results in smaller or lower quality tubers. Deformed tubers increased due to water stress (Painter and Augustin, 1976). Potato tuber size increased when the water table was maintained at shallow depths (Barnett et al., 1992). A shallow water table was beneficial even in poorly drained soils. Tuber quality improved under sprinkler irrigation as a result of lower water stress (Trout et al., 1994).

The effects of subirrigation water's salinity levels and water table depths on the total weight and size distribution of tubers in an initially saline sandy soil under arid conditions, were investigated.

2. Methods

Thirty-six lysimeters, 100 cm in height and inner diameter of 45 cm, packed with St-Amable sand (Ferrow-Humic podzol) having 91.2% sand, 4.2% silt, 1.1% clay and 3.5% organic matter, were salinized on 15 June 1994 by applying 3.5 dS/m water at the surface until effluent at their bottoms had a salinity equivalent to that of the water supply. Natural saline ground water (375 mg/l Calcium, 307 mg/l Magnesium, 4100 mg/l Sodium, 95 mg/l Potassium, 457 mg/l Carbonates, 6548 mg/l Chlorides, 375 mg/l Nitrates and 12,713 mg/l total dissolved solids) was pumped from a well and diluted to this salinity level. Twelve treatments comprising two water tables, three salinity levels of subirrigation water and two potato cultivars were arranged in a randomized complete block design.

'Atlantic' and 'Russet Burbank' tubers were planted on 17 June 1994. The lysimeter tops (with plants) were covered with plastic mulch during rainy days and every night to simulate arid conditions. The mulch was fixed at the top of the lysimeter, exposing plants to the atmosphere through a cut in the mulch when plants reached a height of 10 cm. Subirrigation was initiated on 30 June with diluted saline groundwater having EC_i levels 1, 5 or 9 dS/m. Water table depths near the drains are shallow and gradually increase towards the middle of the drains under subirrigation systems in the field. Therefore, water tables were established at 40 cm (shallow) and 80 cm (deep) from the soil surface to represent the water tables under field conditions, and maintained using Mariotte bottles. No surface irrigation was applied during the experiment. Ammonium nitrate, super phosphate and muriate of potash were incorporated at the soil surface at the locally recommended rate of 200 kg/ha of N, P, and K, respectively, one-day after the start of subirrigation.

Bulk soil salinities (EC_a) were measured weekly, 10 and 30 cm below the surface, using the Time Domain Reflectometry (TDR) method via a Tektronix 1502B cable tester (Bonnell, 1993). The lysimeters were calibrated to convert EC_a to soil solution salinities (EC_w), as per Liaghat (1993). Root zone salinity was determined by averaging the EC_w values at 10 and 30 cm depths. Potatoes were harvested on 24 September (99 days after planting) and the weight and grade of each tuber was recorded. Tuber grade was decided by its longest dimension. The potatoes were divided into three classes (Leclerc, 1993): greater than 4.5 cm (grade A), from 3.0 cm to less than 4.5 cm (grade B) and smaller than 3.0 cm (grade C).

3. Results and discussion

Although potatoes were planted in a salinized soil and subirrigated with brackish water, without either application of water or entry of rainwater at the soil surface, potatoes could be grown in the lysimeters. There was no significant effect of blocks on potato yield, therefore, analysis was done as a completely randomized design. Although differences in yield were expected due to different salinities and water stresses applied, no significant differences in total tuber weights were observed (Table 1). Total weights of grade A and B tubers were significantly different due to water table depth, but not to subirrigation water salinity. Therefore, the trends in the root zone salinities were investigated to determine whether they were sufficiently different to cause yield variations (Table 2). The EC_w levels were 3.5 dS/m in all lysimeters when seed tubers were planted. The EC_w levels (averaged over cultivar, block and measurement depth) ranged from 3.7 to 4.1 dS/m 11 days after

Table 1
Potato tuber, fresh shoot, dry shoot, fresh root and dry root weights in g/plant

Variable	Tuber grades				Shoot		Root	
	A	B	C	Total	Fresh	Dry	Fresh	Dry
Water table								
WT_{40}	280 ± 17 [a]	79 ± 10 [b]	23 ± 03 [a]	383 ± 17 [a]	152.9 ± 17.1 [a]	37.5 ± 2.6 [a]	21.9 ± 1.5 [a]	3.0 ± 0.3 [a]
WT_{80}	222 ± 22 [b]	105 ± 14 [a]	16 ± 03 [a]	342 ± 18 [a]	149.5 ± 17.1 [a]	29.9 ± 1.8 [b]	20.3 ± 1.0 [a]	3.1 ± 0.2 [a]
Subirrigation water								
$Irri_1$	257 ± 30 [a]	93.21 [a]	21 ± 04 [a]	371 ± 25 [a]	122.7 ± 12.8 [a]	33.4 ± 2.7 [a]	19.1 ± 1.4[b]	2.9 ± 0.3 [a]
$Irri_5$	251 ± 26 [a]	82 ± 08 [a]	20 ± 04 [a]	353 ± 25 [a]	172.6 ± 23.4 [a]	32.4 ± 2.8 [a]	23.6 ± 1.1 [a]	3.3 ± 0.2 [a]
$Irri_9$	246 ± 21 [a]	99 ± 15 [a]	18 ± 05 [a]	363 ± 18 [a]	158.3 ± 24.6 [a]	35.4 ± 3.5 [a]	20.6 ± 1.9 [a,b]	2.9 ± 0.3 [a]
Cultivar								
Atl	247 ± 20 [a]	65 ± 08 [b]	16 ± 03 [a]	329 ± 17 [b]	124.5 ± 12.8 [b]	26.9 ± 1.4 [b]	20.4 ± 1.2 [a]	2.9 ± 0.2 [a]
RB	255 ± 21 [a]	118 ± 13 [a]	23 ± 03 [a]	396 ± 15 [a]	178.0 ± 19.2 [a]	40.5 ± 2.1 [a]	21.9 ± 1.4 [a]	3.3 ± 0.2 [a]

WT: Water table, Irri: subirrigation water, Atl: 'Atlantic' and RB: 'Russet Burbank'.
Subscripts 40 and 80 represent water table depths in cm, and subscripts 1, 5 and 9 represent subirrigation water salinity in dS/m.
Mean weights (±SE) with same letters under water table, subirrigation water and cultivar in each column are not significantly different ($\alpha = 0.05$).
Results for water table are summed across subirrigation water salinity and cultivar, those for subirrigation water salinity are summed across water table and cultivar, and the ones for cultivar are summed across water table and subirrigation water salinity.

planting (before initiation of subirrigation). EC_w values were almost the same 13 days after planting, when subirrigation started. These values ranged from 4.8 to 6.1 dS/m 49 days after planting. Thus, there was a gradual increase in soil solution salinity levels over time. Thereafter, the salinity declined in the lysimeters with the 40 cm water table, subirrigated with 1 dS/m, but continued to increase in remaining lysimeters. EC_w levels were between 3.5 and 7.6 dS/m 89 days after planting.

Considering that the soil solution salinity (EC_w) is about 3 times the salinity of saturated soil extract, EC_e (Smedema and Rycroft, 1983), the threshold EC_w for potatoes is about 5.1 dS/m, based on Mass and Hoffman's (Maas and Hoffman, 1977) estimate of 1.7 dS/m for EC_e above which potato yield decreases. Therefore, salinities (EC_w) in the lysimeters were below threshold for at least 27 days after planting, and never exceeded the threshold in lysimeters with a shallow water table maintained by 1 dS/m water. Salt tolerances found here confirm results presented by Paliwal and Yadav (1980) and Nadler and Heuer (1995), although application of brackish water and cultivars were different in this study. Laboratory studies by Zhang et al. (1993) and Sabbah and Tal (1995) indicate that Russet Burbank had more vegetative growth and was relatively salt-tolerant compared to Atlantic. In this study, greater haulm weight as well as higher tuber yield for Russet Burbank was observed, thus agreeing with the laboratory results of Zhang et al. (1993) and Sabbah and Tal (1995). However, there was no significant cultivar–salinity interaction. Therefore, a comparison of the sensitivity of these two cultivars could not be conducted under field conditions.

Moisture stress was probably the more important factor, at these ranges of subirrigation water salinity/ root zone salinity, affecting the grade distribution of both cultivars but not their total yield (Tables 1 and 3). Grade A tuber yield of Russet Burbank was significantly greater for the 40 cm water table depth, and the grade B tuber yield was correspondingly less. The trend was similar but not significant for Atlantic. There was a significantly higher yield of grade C Atlantic for the 40

Table 2
Soil solution salinities averaged over 10 and 30 cm depths in the lysimeters

		*	Days after planting					
			11	13	27	49	70	89
WT_{40}	$Irri_1$	3.5	4.0 ± 0.1	4.1 ± 0.1	4.4 ± 0.2	4.8 ± 0.4	4.1 ± 0.4	3.5 ± 0.4
	$Irri_5$	3.5	4.1 ± 0.1	4.2 ± 0.1	4.7 ± 0.3	5.7 ± 0.4	6.0 ± 0.5	6.4 ± 0.5
	$Irri_9$	3.5	3.9 ± 0.1	4.2 ± 0.1	4.5 ± 0.1	5.6 ± 0.4	6.7 ± 0.3	7.5 ± 0.4
WT_{80}	$Irri_1$	3.5	3.7 ± 0.2	3.9 ± 0.1	5.1 ± 0.2	5.8 ± 0.4	6.5 ± 0.3	7.2 ± 0.4
	$Irri_5$	3.5	3.7 ± 0.2	3.9 ± 0.2	5.2 ± 0.3	5.8 ± 0.6	6.8 ± 0.7	7.6 ± 0.5
	$Irri_9$	3.5	3.7 ± 0.1	3.8 ± 0.1	5.2 ± 0.1	6.1 ± 0.4	6.8 ± 0.4	7.2 ± 0.5

WT: Water table, Irri: salinity level of subirrigation water.
Subscripts 40 and 80 represent water table depths in cm, and subscripts 1, 5 and 9 represent subirrigation water salinities in dS/m.
* Flushed with 3.5 dS/m water two days before planting.
Soil solution salinities, mean of 12 values, (±SE) are in dS/m.

Table 3
Mean weight of potato tubers of Atlantic and Russet Burbank in g/plant

Variable	Atlantic				Russet Burbank			
	A	B	C	Total	A	B	C	Total
Water table								
WT_{40}	258 ± 29 [a]	60 ± 16 [a]	23 ± 05 [a]	341 ± 20 [a]	303 ± 18 [a]	97 ± 10 [a*]	24 ± 05 [a]	424 ± 20 [a]
WT_{80}	237 ± 31 [a]	70 ± 06 [a]	10 ± 03 [b]	316 ± 29 [a]	207 ± 32 [b]	139 ± 22 [a*]	22 ± 05 [a]	368 ± 20 [a]
Subirrigation water								
$Irri_1$	262 ± 41 [a]	50 ± 16 [a]	21 ± 05 [a]	333 ± 32 [a]	251 ± 48 [a]	137 ± 30 [a]	21 ± 07 [a]	409 ± 31 [a]
$Irri_5$	217 ± 41 [a]	79 ± 10 [a]	21 ± 06 [a]	317 ± 35 [a]	284 ± 28 [a]	86 ± 12 [a]	19 ± 05 [a]	389 ± 32 [a]
$Irri_9$	263 ± 24 [a]	67 ± 15 [a]	06 ± 03 [b]	335 ± 29 [a]	229 ± 35 [a]	132 ± 19 [a]	29 ± 06 [a]	391 ± 18 [a]

WT: water table, Irri: subirrigation water.
Subscripts 40 and 80 represent water table depths in cm, and subscripts 1, 5 and 9 represent subirrigation water salinities in dS/m.
Mean weights (±SE) with same letters under water table and subirrigation water under each column are significantly not different ($\alpha = 0.05$).
* Significant at $P < 0.08$ level.

cm water table, but the contribution of this to the total yield was only about 5%.

Moisture contents were different in lysimeters having two different water tables maintained by the subirrigation system. The volumetric moisture contents (averaged over two measurement depths, subirrigation waters, cultivars and blocks) in lysimeters with the 40 cm water table was about 0.28 cm^3/cm^3 and that in lysimeters with the 80 cm water table was about 0.16 cm^3/cm^3 (Fig. 1). The difference in root zone moisture contents may have affected the tuber size distribution.

The average yield of Atlantic was 328.5 g/plant, which can be extrapolated on a per hectare basis to 20.7 t/ha. The average yield of Russet Burbank was 396.2 g/plant (24.9 t/ha). The average North American potato yield is about 32 t/ha, but the global average is 15 t/ha (FAO, 1995b). It should be noted that the potatoes were grown in saline soil with brackish water under simulated arid conditions without any surface irrigation. A reasonable yield in such extreme conditions appears to be the result of the irrigation technique, subirrigation.

The shoot fresh, root fresh and dry weights were not affected by water table depth (Table 1). The shoot dry

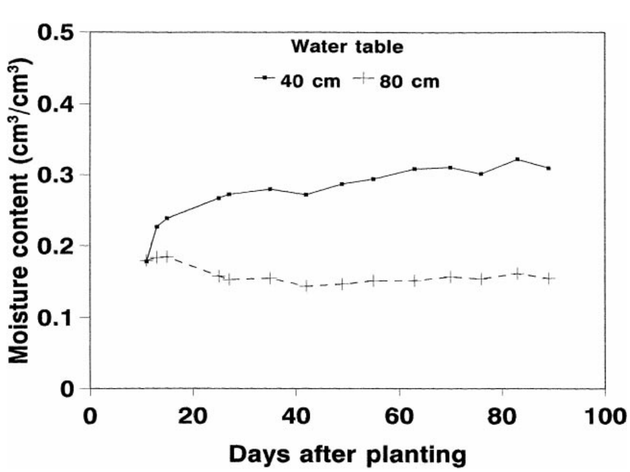

Fig. 1. Moisture contents under 40 and 80 cm water tables.

weights of plants grown with a 40 cm water table were significantly greater than with an 80 cm water table. This indicates that the shallow water table had a positive impact on vegetative growth. There was a significant difference ($P < 0.05$) between the shoot fresh as well as dry weights of the two cultivars, with Russet Burbank giving higher vegetative yields. These results, combined with those on tuber grades, show that under the conditions used, larger tubers and greater haulm growth of certain cultivars can be obtained if the water table is shallow rather than deep. The salinity level of subirrigation water demonstrated no significant effect on shoot fresh and dry weights as well as root dry weight (Table 1).

4. Conclusions

Subirrigation with brackish waters resulted in yields that were 29% below the North American average, but 59% above the global average. These results must be seen as favourable, given the extreme conditions to which these plants were subjected. Potatoes were planted in saline soil (soil solution salinity $\geqslant 3.5$ dS/m) and arid conditions were simulated throughout the experiment. Such a condition is to be expected in a real cropping system in arid regions. The experiment indicated that salt build-up in the root zone, due to the subirrigation system, was not severe. Therefore, this irrigation system appears to be a promising technique for crop production, including that of relatively salt-sensitive vegetables in arid areas, where fresh water for irrigation is a limited resource. However, more experiments should be carried out before drawing any concrete conclusions. Salts accumulated in the root zone over the long term due to subirrigation with brackish water should be removed by natural rain and/or available good quality water during the off-season. Periodical salt removal with surface irrigation or rainfall should maintain favourable soil conditions for successful production of subsequent crops in the same soil and should permit sustained use of brackish water with subirrigation. A subsurface drainage system can be used as a subirrigation system (Broughton, 1995; Workman et al., 1990). Therefore, installation expenditure is minimal where drainage system is already installed.

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