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Effect of initial soil salinity and subirrigation water salinity on potato tuber yield and size

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Abstract

A field lysimeter study was conducted to investigate the effect of initial soil salinity and salinity level of brackish subirrigation water on tuber weight and tuber size of three potato (*Solanum tuberosum* L.) cultivars (Kennebec, Norland and Russet Burbank) under simulated arid conditions. Both saline and non-saline initial soil conditions were simulated in a total of 36 lysimeters. Eighteen lysimeters were flushed with fresh water (0.2 dS/m), while the remaining 18 lysimeters were flushed with brackish water (2 dS/m). For each soil condition, two subirrigation water concentrations, 1 and 9 dS/m, were used in nine lysimeters each. For each subirrigation water treatment, three potato cultivars were grown. In all lysimeters, water table was maintained at 0.4 m from the soil surface. Arid conditions were simulated by covering the lysimeter top with plastic mulch, allowing the potato shoots to grow through a cut in the mulch. The average root zone salinities (EC_w) were found to be 1.2 and 1.5 dS/m in non-saline lysimeters subirrigated with 1 and 9 dS/m waters, respectively. The corresponding salinities were 3.2 and 3.7 dS/m in the saline lysimeters. Across cultivars, there was no significant effect of either initial soil salinity or subirrigation water salinity on total tuber weight. However, the weight of Grade A tubers was higher in non-saline soil than in saline soil. Kennebec and Russet Burbank Grade A tuber weights were not affected by the initial soil salinity. On the contrary, a significant reduction in Grade A and total tuber weight under initially saline soil was evident for the Norland cultivar.

Keywords: Initial soil salinity; Irrigation water salinity; Soil solution salinity; Subirrigation; Potato

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1. Introduction

Potatoes are amongst the world's main food crops and their demand is increasing at a greater rate than many other food crops (FAO, 1995a). Potatoes are relatively sensitive to salinity (Maas and Hoffman, 1977), particularly in the early growth stages (Levy, 1992; Nadler and Heuer, 1995). About 74% of the normal yield of a cultivar can be obtained under surface irrigation with water salinity of 2–4 dS/m (Paliwal and Yadav, 1980). In general, potato yields have been known to decrease as salinity increases with either surface irrigation water of 1–2 dS/m (Paliwal and Yadav, 1980; Van Hoorn et al., 1993) or drip irrigation water of 3–4 dS/m (Singh et al., 1978; Levy, 1992). However, the effect of salinity level of irrigation water depends on the cultivar (Zhang et al., 1993).

There is little scope for the expansion of irrigated land area in humid regions because land and water resources have already been exploited (Umali, 1993). On the other hand, irrigated areas can be expanded in arid regions, given the extent of unirrigated areas (Thorne, 1970; Gupta and Abrol, 1990). Even with fresh water, irrigation projects pose salinity problems in arid regions (Gupta and Abrol, 1990; FAO, 1995b).

Arid regions are often characterized by the availability of limited fresh water but adequate brackish water. Although brackish water can be used for irrigation, its use in surface and sprinkler irrigation can harm plants. Therefore, irrigation water with salinity higher than 3 dS/m should be used carefully under such conditions (Bernstein, 1981; FAO, 1985; Von Hoyningen Huene, 1994). To the best of our knowledge, subirrigation has not been used with brackish water in arid or semi-arid conditions.

Subirrigation with brackish water can prevent major problems, such as (1) direct contact of brackish water with salt-sensitive plant tissues and (2) excessive evaporation from soil (due to lower moisture content at soil surface). Fresh water present in the soil profile (above drains) is pushed up into the active root zone due to upward movement of brackish water. Furthermore, reuse of brackish water can resolve problems concerning the disposal of brackish drainage water (Willardson et al., 1997). It is easier to subirrigate sandy soils due to their higher hydraulic conductivity. However, subirrigation is only economically feasible if there is either a shallow water table or impermeable barrier.

However, the problem of salt build-up in the crop root zone should also be considered. In many semi-arid regions of the world, monsoon rains occur only for a few months, and no significant rainfalls thereafter. The monsoons can thus flush-out salts that would have accumulated in the crop root zone due to subirrigation with brackish water. The salts can also be flushed out using good quality irrigation water. The initial soil salinity is also an important factor that determines the salt build-up in the root zone under subirrigation and, in turn, affects the crop yield.

The effect of saline soil/water environment on tuber yield and size under subirrigation has not been reported in the literature. This study was undertaken in subirrigated field lysimeters to investigate the effect of initial soil salinity and salinity of brackish water on tuber yield and tuber size of Kennebec, Norland and Russet Burbank cultivars of potatoes in a sandy soil under simulated arid conditions. Subirrigation water of salinity 1 and 9 dS/m were used, the latter being greater than the maximum used by some researchers (Levy, 1992; Van Hoorn et al., 1993; Nadler and Heuer, 1995). It was hypothesized that the different patterns of salt build-up created by the experimental methods would affect the tuber yield and size.

2. Materials and methods

Thirty-six lysimeters, 1 m long with 0.45 m i.d., were constructed from PVC pipes and packed with a sandy soil (91.2% sand, 4.2% silt, 1.1% clay and 3.5% organic matter) to a bulk density of 1.4 mg/m^3. The lysimeters were kept above ground level in an open field at the Macdonald Campus Farm of McGill University, Ste-Anne de Bellevue, Que., Canada. The lysimeters were placed in three rows of 12 lysimeters each. The spacing between the rows was 1.2 m and the center to center distance between the lysimeters was 0.6 m. Twelve treatments were made from different combinations of two initial soil salinities, two salinity levels of subirrigation water and three cultivars, and were randomly allocated to the lysimeters. The mean average temperatures were 18.9, 21.3, 18.0 and 14.3°C in June, July, August and September, respectively. However, daily maximum temperatures during these months were 33.8, 32.6, 28.6 and 24.2°C, respectively. It was observed that the soil temperature was almost equal to the ambient air temperature. Although rainfall occurred in these months, arid conditions were simulated by preventing rain entry into the lysimeters using plastic mulches.

To simulate non-saline and saline soils, each lysimeter was flushed with either two pore volumes of fresh water (0.2 dS/m) or brackish water of 2 dS/m (natural saline groundwater, containing sodium 4100 mg/l, calcium 375 mg/l, magnesium 307 mg/l, chlorides 6548 mg/l, carbonates 457 mg/l and total dissolved solids 12 713 mg/l, obtained from a well and diluted to a salinity level of 2 dS/m) until the effluent salinity at bottom of the lysimeters was equal to that of the supply water. Tubers of Kennebec, Norland and Russet Burbank cultivars were planted on 30 May 1995, 2 days after flushing the lysimeters. Until initiation of subirrigation, the pipe at the bottom of the lysimeter was kept open. Subirrigation with 1 or 9 dS/m water (diluted natural saline groundwater) started 13 days after planting. A steady state water table was maintained at 0.4 m from the soil surface with the help of Mariotte bottles. No surface irrigation was applied during the entire cropping period. Ammonium nitrate, super phosphate and muriate of potash were applied on the day of planting at the rate of 200 kg/ha N, P and K, each. The lysimeters were covered with plastic mulch during rainy periods until the plants were 0.1 m high. At the time, the plastic was slit so that the plantlets could grow through the film and the film was left on permanently.

Time domain reflectometry (TDR), a Tektronix model 1502b cable tester, was used to determine the bulk soil salinity (Bonnell, 1991). Salinity probes fixed horizontally in the lysimeters at 0.1 and 0.3 m depths from the soil surface were connected to the TDR for salinity measurements. Soil solution salinity (EC_w) was calculated from bulk soil salinity data by using the following equation (Rhoades et al., 1976).

$$EC_a = EC_w \theta \tau + EC_s \tag{1}$$

where EC_a is the bulk soil salinity (dS/m), θ the volumetric moisture content, τ the transmission coefficient and EC_s is the surface conductance (dS/m).

Patel (1997) found surface conductance (EC_s) value for this soil to be negligible and gave the following relationship for transmission coefficient (τ):

$$\tau = 0.0575 + 0.95190\theta \quad (2)$$

Thus, EC_w was calculated from EC_a in this study using the following equation:

$$EC_w = \frac{EC_a}{0.05750\theta + 0.95190\theta^2} \quad (3)$$

The potatoes were harvested 85 days after planting and the weight of each tuber recorded. The potato tubers were divided into three grades based on the longest dimension of the potato tuber: greater than 45 mm (Grade A), from 30 to 45 mm (Grade B) and smaller than 30 mm (Grade C) (Leclerc, 1993). At the end of the experiment, fresh and dry weight of plants as well as that of roots were recorded. General linear model (GLM) was used to analyze total tuber weights and weights by grade as well as fresh and dry shoot weights, and fresh and dry root weights. In addition, tuber weights of Grades A and B, and total tuber weights of each cultivar were analyzed separately. The soil solution salinity data on different days were also analyzed using GLM.

3. Results and discussion

The three potato cultivars were grown successfully in the non-saline and saline soils under subirrigation with water at both salinity levels. Total tuber weights and weights by grade of these cultivars are shown in Table 1. It was expected that initial salinity would affect the tuber yield because of salt-sensitivity of potatoes at the early growth stages; however there was no significant difference ($P<0.05$) in total tuber weight due to initial soil salinity. Therefore, it was not possible to conclude that initial soil salinity affected the total tuber yield. However, the average total yield across all cultivars was 20% higher in non-saline soil compared to saline soil and significantly different ($P<0.13$). This indicated that initial soil salinity cannot be ignored in potato cultivation. Significantly lower root dry weight in saline soil strengthens this suspicion (Table 1). There was no significant difference in total tuber yield due to irrigation water salinity. This implies that brackish water of up to 9 dS/m salinity could be used with subirrigation for potato production. It may be recalled that similar salinity levels were reported to have an adverse effect on crop yield when used with surface and drip irrigation (Singh et al., 1978; Paliwal and Yadav, 1980; Levy, 1992; Van Hoorn et al., 1993).

Analysis of each grade tuber weights indicated that Grade A tuber weight was significantly ($P<0.05$) higher in the initially non-saline lysimeters compared to saline lysimeters (Table 1). This was partly compensated by the greater ($P<0.05$) weight of Grade B tubers in the saline lysimeters, compared to non-saline lysimeters (Table 1). Though not significant ($P<0.05$) and representing at most 1% of total tuber weight, Grade C tuber weight was similarly greater for saline lysimeters. Thus, the tuber size decreased in saline soil compared to non-saline soil. Nevertheless, the relatively small tuber sizes in all cultivars are a reflection of the relatively short growing season.

Table 1
Potato tuber, shoot fresh and dry weights, and root fresh and dry weights[a]

Variable[b]	Tuber grade				Shoot		Root	
	A	B	C	Total	Fresh	Dry	Fresh	Dry
Initial soil salinity								
Ns	400.1±30.7 a	11.9±5.1 b	1.5±0.8 a	413.5±32.6 a	256.0±37.3 a	35.3±4.4 a	37.8±4.6 a	3.7±0.5 a
S	307.9±33.9 b	30.0±7.6 a	5.3±2.3 a	343.2±32.4 a	218.3±44.0 a	34.4±5.0 a	29.5±4.1 a	2.6±0.4 b
Salinity level in subirrigation water								
Ir_1	379.5±38.0 a	22.1±6.7 a	3.1±1.7 a	404.7±35.9 a	260.8±44.2 a	36.9±5.4 a	36.5±4.7 a	3.5±0.5 a
Ir_9	328.5±28.7 a	19.8±6.9 a	3.7±1.9 a	351.9±29.8 a	213.5±36.7 a	32.8±3.8 a	30.8±4.2 a	2.8±0.4 a
Cultivar								
Ken	378.0±34.1 a	9.6±4.4 b	2.2±1.2 a	389.8±33.3 a	296.4±41.3 a	41.7±3.5 a	34.3±4.4 b	3.3±0.4 b
Nor	352.1±47.4 a	37.8±11.0 a	6.1±3.5 a	396.1±44.9 a	58.7±10.6 b	13.8±1.5 b	15.9±2.9 c	1.3±0.2 c
RB	331.9±43.8 a	15.3±5.9 b	1.9±0.9 a	349.1±44.8 a	356.3±42.3 a	49.2±5.3 a	50.7±3.7 a	4.8±0.5 a

[a] All weights are in g/plant. Mean weight (±S.E.) with same letters in each column under initial soil salinity, salinity level in subirrigation water and cultivar are not significantly different (P<0.05).

[b] Ns: non-saline soil, S: saline soil, Ken: Kennebec, Nor: Norland, RB: Russet Burbank and Ir: subirrigation water. Subscripts 1 and 9 represent salinity level in subirrigation water (dS/m).

Table 2
Soil solution salinity (EC_w) averaged over 0.1 and 0.3 m depths in the lysimeters under various treatments[a]

IS[b]	Ir[c]	Cultivar[d]	EC_w at planting	EC_w on days after planting				Weighted average
				7	21	42	77	
Ns	Ir_1	Ken	0.2	1.1±0.2	1.0±0.1	1.2±0.1	1.6±0.3	1.2
Ns	Ir_1	Nor	0.2	1.1±0.1	0.9±0.1	1.3±0.2	2.0±0.3	1.2
Ns	Ir_1	RB	0.2	1.0±0.1	0.9±0.1	1.3±0.2	1.9±0.3	1.2
Ns	Ir_9	Ken	0.2	1.2±0.1	0.9±0.1	1.2±0.2	2.2±0.5	1.3
Ns	Ir_9	Nor	0.2	1.5±0.4	0.9±0.1	1.9±0.5	4.5±1.0	2.0
Ns	Ir_9	RB	0.2	1.0±0.1	0.9±0.1	1.2±0.2	3.1±0.8	1.4
S	Ir_1	Ken	2.0	3.1±0.4	2.9±0.2	3.7±0.3	3.5±0.4	3.3
S	Ir_1	Nor	2.0	3.2±0.0	2.9±0.1	3.3±0.2	3.3±0.3	3.1
S	Ir_1	RB	2.0	3.2±0.2	2.9±0.1	3.4±0.4	3.5±0.4	3.2
S	Ir_9	Ken	2.0	3.0±0.2	2.9±0.1	4.1±0.5	6.5±0.2	4.0
S	Ir_9	Nor	2.0	2.8±0.3	2.8±0.2	3.5±0.4	4.8±0.5	3.4
S	Ir_9	RB	2.0	3.3±0.2	3.0±0.1	4.0±0.3	5.9±0.6	3.9

[a] Mean EC_w±S.E. are in dS/m.
[b] IS: initial soil conditions, Ns: non-saline and S: saline.
[c] Ir: subirrigation water. Subscripts 1 and 9 represent salinity level of subirrigation water (dS/m).
[d] Ken: Kennebec, Nor: Norland and RB: Russet Burbank.

The tuber weights of Grades A, B and C in lysimeters subirrigated with 1 dS/m water were similar (P<0.05) to those subirrigated with 9 dS/m water. This was due to delayed effect of subirrigation water salinity on soil solution salinity (Table 2). The delay can be seen as a beneficial effect of subirrigation. There were significant (P<0.05) cultivar differences in the Grade B tuber weights, but not in total tuber weight or Grade A tuber weight. However, Grade B tubers made up only 5.5% to the total tuber weight. This indicates that the total tuber weights were similar under the experimental conditions, irrespective of the cultivars, while there were differences in tuber weight by grades.

There was no significant (P<0.05) effect of initial soil salinity or salinity level of subirrigation water and interaction on total and Grade A tuber weights of Kennebec and Russet Burbank cultivars (Table 3). However, the weight of Grade A tubers of Norland cultivar was significantly (P<0.05) lower in saline soil compared to non-saline soil (Table 3). Though non-significant, the weight of Grade B tubers was higher in saline soil compared to non-saline soil (Table 3). These results indicated that the tuber size of Norland cultivar decreased with increased soil salinity. The total tuber weight of Norland cultivar was significantly (P<0.05) lower in saline soil compared to non-saline soil (Table 3). It appears that Norland cultivar is more sensitive to soil salinity. The significant effect of initial soil salinity on tuber weights of grades A and B exhibited in Table 1 is explained by the sensitivity of Norland cultivar. The greater sensitivity of this cultivar to salt stress than that of the other cultivars supports the results of Zhang et al. (1993), who found Norland to be the most salinity-susceptible of many cultivars (including Kennebec and Russet Burbank). However, their experiment was conducted in the laboratory over a few weeks and did not yield tubers. We found that tuber yield of Norland cultivar was affected by soil solution salinity levels in the field conditions.

Table 3
Grade A, Grade B and total tuber weights of Kennebec, Norland and Russet Burbank cultivars[a]

IS[b]	A	B	Total	Ir[c]	A	B	Total
Kennebec							
Ns	341.1±39.8 a	4.8±1.9 a	348.4±40.2 a	Ir_1	384.7±69.7 a	11.6±7.7 a	399.1±67.9 a
S	414.9±54.8 a	15.2±8.3 a	431.3±50.7 a	Ir_9	371.3±15.5 a	7.7±4.9 a	380.6±15.3 a
Norland							
Ns	462.2±46.2 a	24.9±13.9 a	487.1±53.6 a	Ir_1	396.7±54.2 a	32.5±17.0 a	434.2±38.0 a
S	242.1±53.6 b	50.8±16.6 a	305.0±51.7 b	Ir_9	307.6±78.4 a	43.1±15.3 a	357.9±82.6 a
Russet Burbank							
Ns	396.9±66.4 a	6.6±4.2 a	404.9±66.5 a	Ir_1	357.2±82.2 a	22.1±7.8 a	380.9±82.5 a
S	266.9±48.5 a	24.0±10.2 a	293.3±56.1 a	Ir_9	306.6±37.9 a	8.5±8.5 a	317.3±40.1 a

[a] All weights are in g/plant. Mean weights (±S.E.) with same letters under Kennebec, Norland and Russet Burbank in respective columns are not significantly different ($P<0.05$); weights of Grade C tubers are not shown because these were only 0.6, 1.5 and 0.5% of total tuber weight of Kennebec, Norland and Russet Burbank cultivars, respectively.

[b] IS: initial soil conditions, Ns: non-saline and S: saline.

[c] Ir: irrigation water. Subscripts 1 and 9 represent salinity level of subirrigation water (dS/m).

In most cases, soil salinity is expressed as the salinity of saturated soil extract (EC_e). It is determined in the laboratory from soil samples collected from the field. EC_e is always lower than the actual soil solution salinity (EC_w) under field conditions. The moisture content of the saturated soil paste is usually two to four times greater than that in the field (Smedema and Rycroft, 1983). Thus, EC_w is two to four times higher than that of EC_e. At the beginning of the experiment, the average volumetric moisture content (average of the volumetric moisture contents at 0.1 and 0.3 m depths) in the lysimeters was 16%, whereas the moisture content of the saturated paste was 37%. Thus, EC_w should be 2.3 times higher than EC_e. Therefore, the threshold salinity (EC_w) for this experiment was set at 3.9 dS/m (assuming a threshold EC_e of 1.7 dS/m, as per Maas and Hoffman (1977)). The average EC_w under various treatments varied from 1.2 to 4.0 dS/m (Table 2). Thus, the average salinities in lysimeters were less than the threshold level in most cases. Moreover, the soil salinity was quite low during the initial critical growth stages of potatoes. Therefore, there may not be any treatment effect on total tuber yield in this experiment. This was found to be true for Kennebec and Russet Burbank cultivars. However, tuber size and yield of Norland cultivar was affected by salinity in this range. It may be recalled that Norland cultivar is quite sensitive to salinity (Zhang et al., 1993).

Similar total tuber yield with irrigation waters having salinity levels of 1 and 9 dS/m indicates the possibility of using waters having salinity greater than 9 dS/m under subirrigation for all three cultivars. However, further experimentation is needed to confirm these results and also to determine the highest level of irrigation water salinity that can be used with subirrigation to obtain reasonable yields. It is also necessary to leach salts out of the soil profile that would accumulate due to subirrigation with brackish water. Leaching can be accomplished by either rainfall or surface irrigation with good quality water. In many semi-arid regions of the world, the monsoon rainfalls may be used to full advantage in getting rid of the salts on a year-by-year basis, thus making such irrigation practices sustainable in the long run.

The average North American potato tuber yield is 32 t/ha (Lorenz and Maynard, 1988), while the average Canadian yield is 27 t/ha (FAO, 1995b). In this experiment, the average yield in initially non-saline lysimeters was 26 t/ha (413 g/plant). Drastic reductions in yield (24%) have been reported when irrigation water salinity was increased from fresh water to 2 dS/m in field experiments on potatoes under surface irrigation (Paliwal and Yadav, 1980). Although the non-saline lysimeters were flushed with 0.2 dS/m water, the initial root zone salinity was at least 1 dS/m in the first week of planting (Table 2). This may be due to slow dissolution of residual salts in the lysimeters. Thus, it is possible that the tuber yield would have been significantly higher in the lysimeters flushed with fresh water if the salinity had not increased to 1 dS/m. However, further investigations are needed. It should also be noted that yield obtained in the experiment was 59% greater than average world yield of 15 t/ha (FAO, 1995a). Thus, subirrigation may be used with brackish water to grow potatoes in both saline and non-saline soils.

4. Conclusions

This study was conducted to determine the effect of initial soil salinity and salinity levels of irrigation water on total tuber yield and tuber size distribution under subirrigation. There was no significant effect of initial soil salinity or subirrigation water salinity on the performance of Kennebec or Russet Burbank cultivars. Significant inhibitory effects of salinity on Norland cultivar indicate that some cultivars can be affected by saline soil–water system under subirrigation. However, successful production of potatoes with brackish water having salinities from 1 to 9 dS/m indicates the possibility of using brackish water having salinity even higher than this. Subirrigation systems may prove to be quite useful for food production with poor quality irrigation water in the areas where monsoon rains can flush-out salts accumulated in the crop root zone. The system will also be sustainable if good quality water for surface irrigation is available at some other time during the year.

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