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Increasing water productivity in arid regions using low-discharge drip irrigation: a case study on potato growth

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Abstract Potato is sensitive to excess or deficit irrigation and therefore requires the efficient use of water, especially in arid regions. Low-discharge drip irrigation has been suggested as an efficient irrigation method, providing an optimal amount of water and fertilizer directly to the root zone. However, field studies using a continuous irrigation system with low discharge have rarely been reported, in particular for arid regions. The main objective of the current study was to optimize the irrigation regime of low-discharge drip irrigation under potato growth. Specifically, we examined combinations of dripper discharge, dripper spacing, and irrigation doses. We report the results from two subsequent years of potato growth in the Arava Desert, Israel. The results obtained suggest that the lower the irrigation dose, the higher the water productivity (i.e., yield/dose), regardless of the dripper discharge (first year 0.6 vs. 1.6 L h^{-1} and second year 0.6 L h^{-1}) or spacing (first year 20 vs. 40 cm and second year 25 vs. 50 cm). In terms of economic viability and/or food production, the results of this study imply that one may consider using low irrigation doses relative to the optimal. Specifically, for a given field, the total tuber yield will be smaller. However, if available agricultural lands are not a limiting factor (such as in the Arava Desert), higher yields can be obtained with a small irrigation dose in a larger area, with no significant reduction in tuber quality.

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Introduction

In arid regions, the major constraint on agriculture activity is the lack of available water, in contrast to populated areas, where the lack of available land presents the greatest limitation. Globally, the plant absorbs an average of only 30–50% of the water applied using conventional irrigation practices (e.g., sprinkler, furrow, and basin) (Wallace 2000; Deng et al. 2006). The remaining water is unused by the plant, due to direct evaporation from the soil, surface runoff, and seepage below the root zone. Furthermore, arid and semi-arid regions usually depend on marginal water sources, such as brackish water, saline water, and treated wastewater (Sharma and Minhas 2005; Rozema and flowers 2008). Therefore, it is necessary to establish suitable irrigation techniques that will take into consideration both the quantity and the quality of the available water in order to achieve profitable yield.

Potato is one of the most important crops globally, both in terms of consumption on a local level and production for export. Global production of tubers is about 320 million tons (Lutaladio and Castaldi 2009). In Israel, the annual average production is estimated at 625 thousand tons, with the western Negev and Avshalom regions (75%), the Sharon region (20%), and the Southern Arava and Galilee regions (5%) acting as the major production centers. The potatoes are grown not only in the usual cycle (spring–summer) but also in the winter–spring cycle (November to April) for early production. Potatoes grown for early production are also particularly sensitive to water stress, which adversely influences tuber yield (Ierna et al. 2011). The off-season

production is highly, economically valuable because tubers are usually exported to European markets with large profits.

Two major factors limiting potato growth are lack of water and high temperatures (Shalhevet et al. 1983). In fact, both excessive and insufficient irrigation regimes cause deficiencies in crop yield, with noticeable effects beginning when the change is 10% of the required water (Shock and Pereira 2007). Severe shortages of fresh water in recent years have led to a significant reduction in this resource's allocation for potato growth, which has been compensated (especially in southern arid region of Israel) with brackish water.

In places where brackish water is employed for irrigation, farmers must allocate additional water to prevent the accumulation of salt in the root zone (Aragüés et al. 2014). Potato growth is characterized as a shallow-root crop where the most of the root activity takes place at the top 30 cm (Lesczynski 1976; Opena and Porter 1999; Satchithanantham et al. 2014). An appropriate irrigation regime of doses and intervals should be designed based on the local conditions, such as climate, soil hydraulic properties, plant type, and water quality. Potato is customarily irrigated using sprinklers, due to an advantage in germination, use of herbicides, tillage, and peel formation processes (Lamm 2002; Shock 2006). However, the main drawback of sprinkler irrigation is its low water and fertilizer use efficiency. Furthermore, frequent wetting of the landscape and foliage by sprinklers creates conditions that encourage the development of harsh diseases such as "potato blight" (Lapwood 1977; Cohen et al. 2000; Johnson et al. 2003). When brackish irrigation water is the major or only water source, sprinkler irrigation may be utilized only for the germination phase; after germination, the foliage can suffer from extensive burns, leading to plant death.

Efficient water application can be achieved by drip irrigation with low discharge (Skaggs et al. 2010). This irrigation method causes partial wetting of the soil and allows the roots to grow in areas where water and oxygen availability is high (Mmoloawa et al. 2000). In addition, a low-discharge drip irrigation regime can improve the water productivity by maintaining an optimum and constant water content in the root zone. This in turn will increase the availability of water and nutrients, due to a high soil water pressure head and hydraulic conductivity in the root zone (Shenker et al. 2003; Silber et al. 2003). In order to achieve the desired water content distribution in the root zone, one should consider the dripper discharge, the spacing between drippers, and soil properties (Ben-Asher et al. 2003; Lazarovitch et al. 2009; Elmaloglou and Diamantopoulos 2010; Hinnell et al. 2010). Therefore, for each combination of soil texture and crop type, the necessary wetted area will be different. In potato growth, the wetted area should be continuous along the entire bed due to the nature of tuber distribution. To enhance water use efficiency, it is necessary to minimize seepage beneath the shallow potato root zone, while maintaining optimal water content for potato growth (Lesczynski 1976; Opena and Porter 1999). Furthermore, growing potatoes are characterized by frequent application of nitrogen fertilizer, usually by fertigation, due to its necessity in the proper development of plants and tubers. By using fertigation rather than solid fertilizer, both the rate and the timing of fertilizer inputs can meet the requirements of each stage of plant growth (Papadopoulos 1988). Nitrogen surplus may cause groundwater contamination and the emission of greenhouse gases, as well as economic losses. It is important to mention that the amount of water that is applied in conjunction with the fertilizer will affect its availability to the plant (Shahnazari et al. 2008).

Despite significant research on drip irrigation, to the best of our knowledge, the literature lacks studies that conducted field experiments with low-discharge dripping in conjunction with continuous irrigation during the entire growing season. Therefore, the main objective of the current study was to optimize the irrigation regime of low-discharge drip irrigation under potato growth. Specifically, we examined combinations of dripper discharge, dripper spacing, and irrigation doses.

Materials and methods

Site description

Two experiments were carried out during 2012/13 and 2013/14 in the fields of Kibbutz Yotvata in the Arava Desert, Israel. The region is characterized by a dry desert climate with a yearly average temperature that varies between 16 and 31 °C (min. and max., respectively). The temperature distribution during the growing season (November to April) is presented in Fig. 1. The cumulative precipitations during the first and second year were 27.4 and 31 mm, respectively, and distributed over five significant rain events. These amounts found to be insignificant relative to the measured pan-A evaporation (891.6 and 839.6 mm for the first and second years, respectively) and thus, could not be considered as reliable source of irrigation water (Fig. 1).

The most common crops grown in the Arava region are date palms, onions, and potatoes. The soil texture is loamy sand (83% sand, 8% silt, and 9% clay), the bulk density is 1.3 g cm^{-3}, and the hydraulic conductivity is 0.15 m h^{-1}. The saturated water content is 0.36, field capacity is 0.13, and the wilting point is 0.05 (v v^{-1}) (Arevalo 2016). Representative characteristics of the irrigation water employed are presented in Table 1.
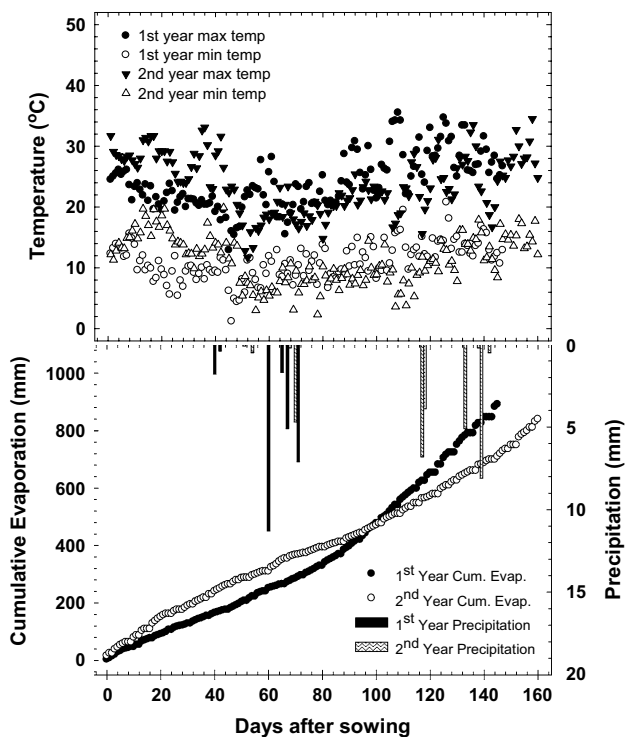
Fig. 1 Minimum and maximum, cumulative evaporation, and daily precipitation during the growing season starting from the sowing date for the first and second years of the study

Table 1 Water quality of the irrigation water (concentration in mg l^{-1})

Ca^{+2}	192.2 ± 3.7
Mg^{+2}	139.4 ± 5.1
K$^+$	12.9 ± 2.6
Na$^+$	290.0 ± 5.7
PO$_4^{-3}$	0
NO$_3^-$	4.0 ± 0.3
NH$_4^+$	0
SO$_4^{-2}$	758.5 ± 17.6
Cl$^-$	506.9 ± 7.1
HCO$_3$	226.7
EC	2.5 ± 0.6
pH	7.2 ± 0.1

In the first year, the selected field (29.906264, 35.077606) was reported to have had no agricultural activity for 5 years before the experiment. In the second year, a different field was selected (29.884297, 35.075624) with similar initial conditions.

Experimental design

The experimental field was about 0.2 ha ($A = L \times W = 180$ m $\times 10.8$ m). The experimental design in each year consisted of 12 treatments with four replicates (i.e., 48 plots). Each replicate consisted of three beds; each bed was 15 m long and 0.9 m wide. The treatments of the study comprised the following combination: (i) irrigation dose, (ii) dripper discharge, and (iii) spacing between drippers. In the followings, the selected treatments for each year of the study are detailed. In the first year, the irrigation doses in the treatments were 40, 50, 80, 100, and 120% of full irrigation. Based on the common practice in potato growth for the Arava region, and previously collected data of potential evaporation, we set the 100% drip irrigation dose (defined as full irrigation) for the entire growth period as 600 mm. The actual irrigation doses, without the germination dose, for both years for each treatment are shown in Table 3. The irrigation doses were further examined for the effect of dripper discharge (0.6 and 1.6 L h^{-1}) and spacing between drippers (20 or 40 cm). For further discussion, we marked the treatments as the following: I:d0.6s20-40%, in which 'I' refers to the first year, a discharge of 0.6 L h^{-1}, a spacing between drippers of 20 cm, and a 40% dose.

As will be detailed latter, the results from the first year of the study suggested no significant effect of dripper discharge and spacing on potatoes yield. Therefore, in the second year of the study, we examined additional irrigation doses of 40, 50, 60, 80, 100, and 120% in combination with only one dripper discharge (0.6 L h^{-1}) and increased the spacing between the drippers (0.25 vs. 0.5 m).

Sowing the potato tubers (*Solanum tuberosum L. cv. Hermes*) took place on 27/11/12 and 23/10/13 for the first and second years, respectively. Sowing was followed by the placement of shallow subsurface drip irrigation laterals (5 cm depth in the middle of each bed) on 2/12/12 and 25/10/13 for the first and second year, respectively. In the Arava Desert, the potatoes' growth during the winter–spring cycle (November to April) is aimed for early production. The main difference between the 2 years of the study was expressed in a shift in the sowing timing. However, the climate conditions (precipitation and cumulative evaporation) within this growing season were similar (Fig. 1). The available irrigation water in Yotvata varies in its electrical conductivity (EC) during the growing season in the range of 2–2.5 dS m^{-1} (Table 1). The germination was carried out by sprinkler irrigation providing irrigation doses in 3-day intervals. The cumulative dose of irrigation water for germination was about 100 mm.

Regarding fertilization, composted cattle manure was applied in the rate of 40 m^3 ha^{-1} before sowing. Selected properties of the compost are shown in Table 2. In addition, fertigation with nitrogen fertilizer, 100 mg N l^{-1} of "Arava" liquid fertilizer was constantly supplied with each irrigation session. This fertilizer consists of ammonium nitrate and potassium nitrate as the sources of nitrogen. In addition, it is adjusted to be used with the irrigation water that

Table 2 Selected properties of the cattle manure compost employed as a soil amendment

	Dry matter	Organic matter	C	N	P	K	C/N	EC*	pH
	%	%	%	%	%	%		dS m^{-1}	
	90	35	21.0	1.55	1.02	2.0	13.5	11.7	8.2

*EC and pH from 1:10 compost to water ratio

Table 3 Measured cumulative irrigation amounts for each target irrigation regime at the first and second years of the study

1st year treatments	Cumulative irrigation (mm)	2nd year treatments	Cumulative irrigation (mm)
I:d0.6s40-40%	271.9	II:d0.6s50-40%	248.4
I:d0.6s20-50%	318.8	II:d0.6s25-40%	248.5
I:d1.6s20-50%	330.4	II:d0.6s50-50%	310.3
I:d0.6s40-80%	491.3	II:d0.6s25-50%	309.3
I:d0.6s20-80%	492.6	II:d0.6s50-60%	372.4
I:d1.6s20-80%	509.3	II:d0.6s25-60%	366.8
I:d0.6s40-100%	624.1	II:d0.6s50-80%	496.3
I:d0.6s40-120%	711.3	II:d0.6s25-80%	495.4
I:d0.6s20-120%	747.0	II:d0.6s50-100%	619.2
I:d1.6s20-120%	748.3	II:d0.6s25-100%	617.6
		II:d0.6s50-120%	742.9
		II:d0.6s25-120%	741.8

is common to the Arava region, thus having a low Cl⁻ concentration (<1%) and an acidic pH (Table 1).

It should be noted that the nitrogen amount for each irrigation regime is proportional to the irrigation dose. However, since a continuous irrigation regime is employed, the available nitrogen concentration in the soil solution is comparable. Noteworthy that the fertigation is halted when the canopy is no longer functional ("burned"). However, the irrigation was continued for about three more weeks for the purpose of cooling the soil to facilitate peel formation before tuber harvesting.

Sampling and analysis

During the experiment, measurements and sampling of the growth stages were performed on the middle bed (out of the three) of each replicate in order to prevent the "edge effect." The yield was evaluated by collecting tubers from an area of about 2 m² (2.2 m length and 0.9 m width) from the center of the middle bed of each replicate. The total yield from all four replicates was weighed. Additionally, two random replicates from each treatment were examined for tuber length, width and mass distribution, and the total number of tubers. Several quality analyses of dextrose concentration and total solid percentages were tested. In addition, during the second year, the soil profile beneath

the dripper was sampled to a depth of 60 cm at the beginning and at the end of the growing season. The soil samples were collected from the following depths: 0–5 (i.e., above the dripper), 5–20, 20–40, and 40–60 cm. Chemical analyses (EC, NO_3^- and Cl^-) of the soil samples were performed on 1:1 DDW (double distilled water) extracts.

Statistical analysis

Multifactorial analysis was performed only for the second year of the study, where the irrigation amount and emitter spacing was comparable for all treatments. Significant effect was found only for the irrigation dose ($P < 0.0001$). Accordingly, we preformed our statistical analysis based on the treatment. Data were analyzed by analysis of variance (ANOVA) using JMP code (version 12, 2015, SAS Institute). The means were separated using the student-t comparison test at probability level of 0.05. Differences with $P < 0.05$ were considered as significant. The error bars with standard deviation and the indications for significant differences between the irrigation regimes presented in the figures below.

Results and discussion

Water inputs and outputs

The actual irrigation doses that were monitored during the growing seasons are given in Table 3. It can be seen that the values corresponded well to the planned ones in both years. As mentioned, the contribution of rainfall during the growing seasons was relatively small and comprised about 9% of the lower dose (i.e., 40%) and 3.5% of the higher one (i.e., 120%). Furthermore, the low precipitation was distributed over five significant rain events (Fig. 1) and thus, the net contribution to the water balance is negligible due to direct evaporation from the soil and the canopy.

The absolute value of the 100% irrigation dose (i.e., full irrigation) was about 620 mm (Table 3); along with the germination dose (100 mm), the total water applied was 720 mm. The cumulative potential evaporation during the growth season was about 865 mm. The average crop coefficient for potatoes in the Arava Desert is about 0.8 (local farmer practices), which is in agreement with the ratio

between the applied irrigation water and potential evaporation detailed above. In this regard, the available water in the soil storage should also be considered. In this study, the available water in the soil storage is about 8% (based on the field capacity—wilting point approach). Considering the width of the bed (90 cm), and the active root zone (30 cm), it can be estimated that the water storage (i.e., available water) is about 22 mm. Assuming that this amount is comparable for all treatments, it comprised about 7.5% from the low irrigation dose and 3% of the higher one. It should be noted; however, the differences in the water storage between the beginning and the end of the growing season are small and thus the net contribution to the water balance is negligible.

Tuber yield

Average yields of 47.6 ± 7.7 and 46.9 ± 9 ton ha^{-1} were obtained for the first and second years, respectively (Fig. 2). The highest yield obtained in the first year of the study was for the 80% treatment (I:d0.6s40-80% with 60.2 ± 0.53 ton ha^{-1}, I:d0.6s20-80% with 57.6 ± 0.43 ton ha^{-1}, I:d1.6s20-80% with 58 ± 0.49 ton ha^{-1}) with no significant differences between the dripper discharge and spacing. Moreover, no other treatments differed significantly between each other with obtained yield of about 40 ton ha^{-1}. As for the second year, the highest yield was obtained by the 120% treatments (II:d0.6s50-120% with 61.12 ± 9.84 ton ha^{-1} and II:d0.6s25-120% with 62.34 ± 3.36 ton ha^{-1}) followed by the 80% (II:d0.6s50-80% with 49.82 ± 8.29 ton ha^{-1} and II:d0.6s25-80% with 55.02 ± 3.77 ton ha^{-1}). Other treatments showed more variation (II:d0.6s25-50% with 50.49 ± 11.38 ton ha^{-1}, II:d0.6s50-60% with 44.96 ± 8.12

ton ha^{-1}, II:d0.6s50-100% with 46.79 ± 8.26 ton ha^{-1}) than the first year but still, the rest of the treatments resulted in a similar yield—about 40 ton ha^{-1}. The results from the 2 years of the study clearly demonstrated that the yield under low-discharge drip irrigation is similar or at times even higher from the ones reported for sprinkler irrigation (30–50 ton ha^{-1}) in semi-arid regions (Ojala et al. 1990; Waddell et al. 1999; Unlu et al. 2006; Starr et al. 2008) or even more humid regions (Matović et al. 2016). In addition, the lack of differences between the two discharges (i.e., 0.6 vs. 1.6 L h^{-1}) implied that higher water use efficiency can be achieved with lower discharge. However, the higher water productivity under deficit irrigating (i.e., small irrigation doses) may be reduced due to employment of brackish water for irrigation in this area. Specifically, an additional leaching fraction should be considered to avoid long-term salinization and/or sodification of the soil. As oppose to sprinkle irrigation, low-discharge irrigation increases the leaching from the soil profile due to continuous application of water, thus, reducing salt accumulation (Brandt et al. 1971). The additional leaching fraction can be applied during the irrigation season and/or at the germination phase when sprinklers are employed.

Water productivity

In the following, the term "water productivity" is related to the amount of irrigation water provided to obtain a given tuber yield. The results obtained for the water productivity (Fig. 3) demonstrated that the lower the irrigation dose, the higher the water productivity. This can be seen clearly in the first year, but the general trend is similar for both years. In terms of economic viability and/or food production, the
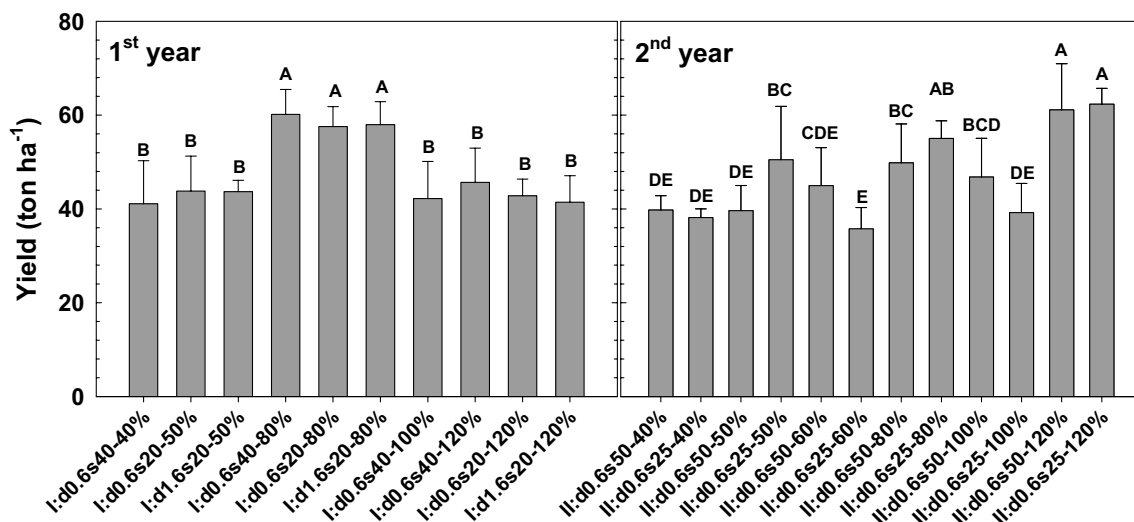
Fig. 2 Potato tuber yield (ton ha^{-1}) as a function of irrigation regime for the first and second years of the study
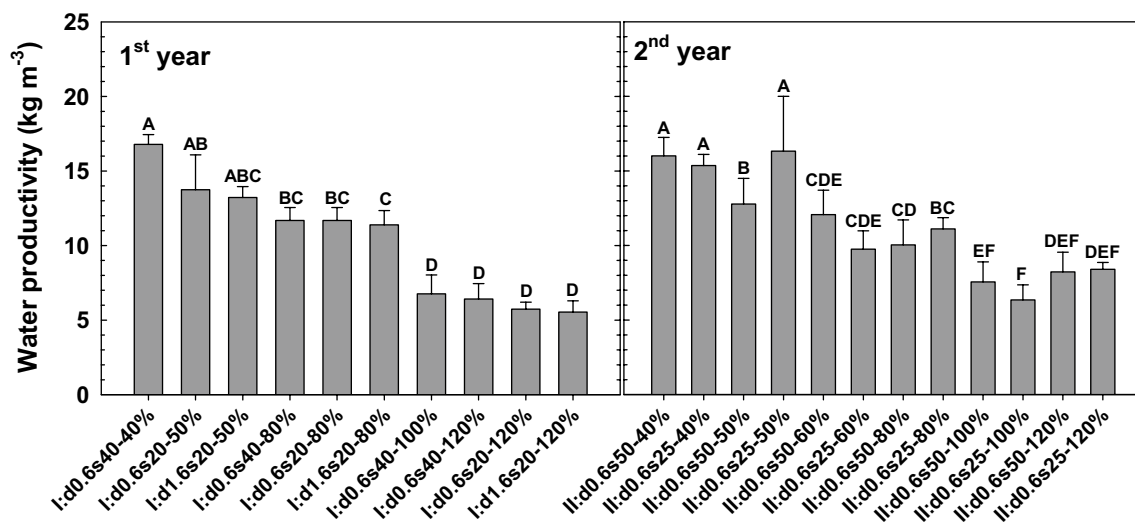
Fig. 3 Water productivity (kg m^{-3}) as a function of irrigation regime for the first and second years of the study

results of this study imply that the farmer may consider using smaller doses of irrigation water (e.g., 40–50%). Specifically, if agricultural lands are not a limiting factor (such as in the Arava region), more yield can be obtained with a smaller irrigation dose and a larger area. This, however, has to be examined against other costs (fixed and variable) and must also consider the long-term consequences of using brackish water for irrigation. Moreover, the quality of the tuber may be affected by the above regime and thus must be evaluated. Considering the results from both years of the study, we can suggest that the 80% irrigation dose is optimal to obtain a high yield with an acceptable water productivity compared to the other treatments.

Potato tuber size distribution

The mass-based analysis of tuber yields does not necessarily indicate its commercial marketability and value. In this regard, the tuber size and mass distribution can be a major factor, rating the quality of the tuber yield. For this reason, a detailed analysis was carried out to evaluate the size and mass distribution of about 1700 tubers. The results of the cumulative width distribution of all treatments are shown in Fig. 4. We adopted a commercial criterion of marketing potatoes with a larger than 50-mm tuber width (diameter); (vertical lines in Fig. 4). In the following, we compare the cumulative width distribution based on this criterion. The results obtained show that the average values of tuber widths higher than 50 mm that were obtained from all treatments were 67.59% ± 8.73 and 65.78% ± 5.04 for the first and second years, respectively. Detailed values are given in Fig. 4 for each of the treatments. A closer look suggested that the 80 and 100% irrigation doses exhibited higher

percentages of tuber widths larger than 50 mm. As mentioned, in addition to tuber width, we also examined tuber length and mass. A good correlation was found between tuber length/width and tuber mass/width for both years (Table 4). Therefore, the selection of one tuber parameter, such as the width distribution, is adequate. In summary, the tuber size and mass distribution did not exhibit large differences between the irrigation regimes examined in either year of the study. These results are surprising considering the large differences in irrigation doses employed. This may be related to the irrigation method employed of low discharge and a shallow subsurface drip irrigation that provides water and nutrients directly to the shallow active potato root zone. Adopting this irrigation regime for potato growth will likely enhance both water productivity and water use efficiency.

Additionally, common quality parameters, aside from size and mass distribution, were further examined for representative samples from each treatment. The tuber color was evaluated optically in which 60 (arbitrary units) and above is considered as valid for marketing. In both years of the study, we found no significant differences in the color. The average values obtained were 63.3 ± 1.7 and 64 ± 1.8 for the first and second years, respectively. The total solid or the dry matter percentage was calculated from the differences in mass in water and air. The values ranging from 19 to 26% were considered as marketable. The results obtained were 19.4 ± 0.4 and 21 ± 1% for the first and second years, respectively. The *Hermes* cultivar is mainly used for potato chips. When marketing for this purpose, values between 0 and 0.1 g l^{-1} dextrose are desirable. Higher dextrose concentrations will cause the tuber color to be darker, which is an unwanted characteristic. Compared to the
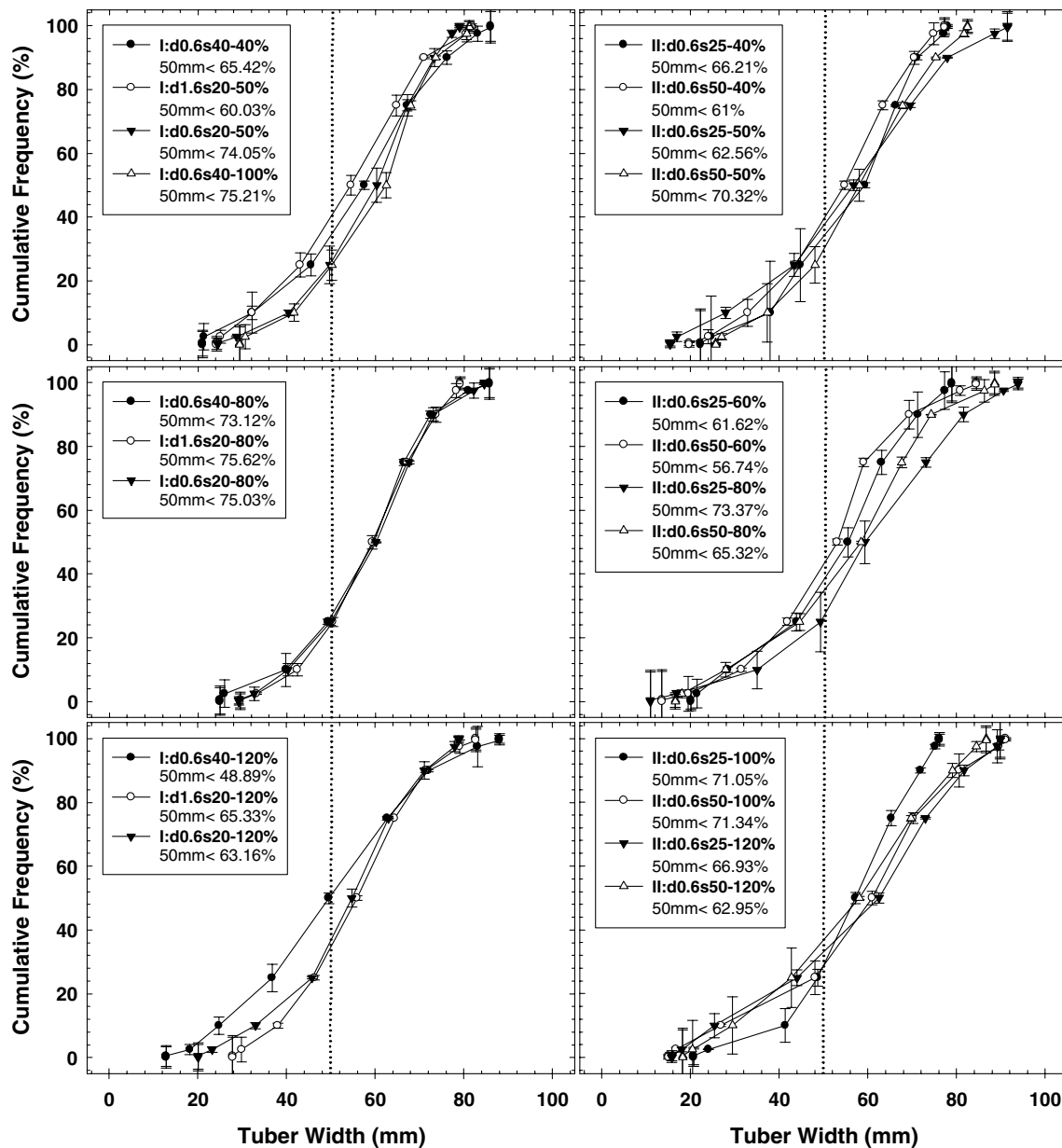
Fig. 4 Cumulative frequency of tuber width according to the treatments for the first and second years of the study

Table 4 Correlations between tuber mass, length, and width

1st year	2nd year
$Mass_1 = 0.0009\ Width_1^{2.91}$	$Mass_2 = 0.001\ Width_2^{2.85}$
$R^2 = 0.94$	$R^2 = 0.95$
$Length_1 = 0.8235\ Width_1^{1.11}$	$Length_2 = 0.8734\ Width_2^{1.08}$
$R^2 = 0.8$	$R^2 = 0.92$

color and total solid results, dextrose showed more variation between the treatments. The values were 0.01 ± 0.007 and 0.037 ± 0.023 g l^{-1} for the first and second years,

respectively, with no significant difference between the treatments.

Soil analysis

The first sampling event of the soil profile took place following the germination phase, after 100 mm were applied through sprinkler irrigation. Given that the saturated water content of the soil is 0.36 (v v^{-1}), an amount of 100 mm, is equivalent to about 0.36 pore volume at a soil depth of 27.7 cm. Theoretically, for non-reactive solute transport, a full displacement of native salts from a given soil

layer will require two pore volume of saturated water flow through this layer. The results obtained for the EC, Cl⁻, and NO_3^- distribution (Fig. 5) after the germination event implied that the salts accumulated at the top soil layer were displaced to a depth of about 20 cm. This is in agreement with the solute transport characteristics discussed above. The values obtained at the top soil layer for the EC (1.24 dS m⁻¹), Cl⁻ (84 mg l⁻¹) and NO_3^- (3.1 mg l⁻¹) from the 1:1 extracts and suggest that system is approaching chemical equilibrium with the irrigation water (Table 4) after the germination irrigation.

The second sampling of the soil profile was carried out at the same day of the tuber harvesting. As mentioned, the soil samples were collected from the top soil layer (5 cm) above the dripper and beneath it. At this location, the water

content is highest and subjected to continuous irrigation during the entire growth season. Considering the lowest irrigation dose of 40% with 248 mm, the irrigation water provided at the dripper location is equivalent to 1.7 pore volume of the 20–60 cm soil layer. Given the initial conditions in the soil profile following the germination irrigation, this amount is sufficient to leach the solute from the active root zone. Obviously, the irrigation water provided with the higher irrigation doses was sufficient to continuously leach the soil profile beneath the dipper location to a 60 cm depth and beyond it. Furthermore, since the fertigation was halted about 20 days before the harvesting and transpiration was negligible due to removal of the foliage, the leaching of solute during this period was more efficient. Specifically, the salinity of the irrigation water was lower and more water was available for leaching due to minimal water uptake by the plant.

It should be noted, that during the entire growing season, the top soil layer is subjected to continuous salt accumulation since the dripper was buried at 5 cm. Therefore, processes, such as evaporation and solute capillary rise, may further contribute to the increased salinity at this soil layer. As demonstrated above, the accumulated salts can be leached to dipper soil layer only by surface irrigation such as sprinkler.

Summary and conclusions

The main limiting factors for potato growth are water and nitrogen. Therefore, to obtain an economic yield, an optimized fertigation regime is highly important, in particular for arid regions. Excess or deficit irrigation regimes may result in significant reductions in tuber yields. Under excess irrigation, bad aeration conditions, lack of oxygen for the root system, and enhanced vegetative growth are the main reasons for reductions in yields and quality. For deficit irrigation regimes, reductions in tuber yields and their quality are caused by reductions in foliage surface area and photosynthesis per unit leaf area.

The findings from this study demonstrate that a combination of sprinkler irrigation for germination and drip irrigation with low discharge could supply potato yields similar to the ones reported for sprinkler irrigation without harming tuber marketability (size and quality). In comparison to the 100% irrigation doses, in the 2 years of this study (i.e., about 620 mm for the 2 years—as calculated from the local potential ET), the 80% treatment showed that this dose is sufficient for optimal potato growth in conjunction with water and fertilizer savings. It was also concluded that a 0.6 L h⁻¹ dripper is applicable for a spacing range of 20–50 cm. This again can be converted to economic savings for the farmer. Furthermore, the water productivity
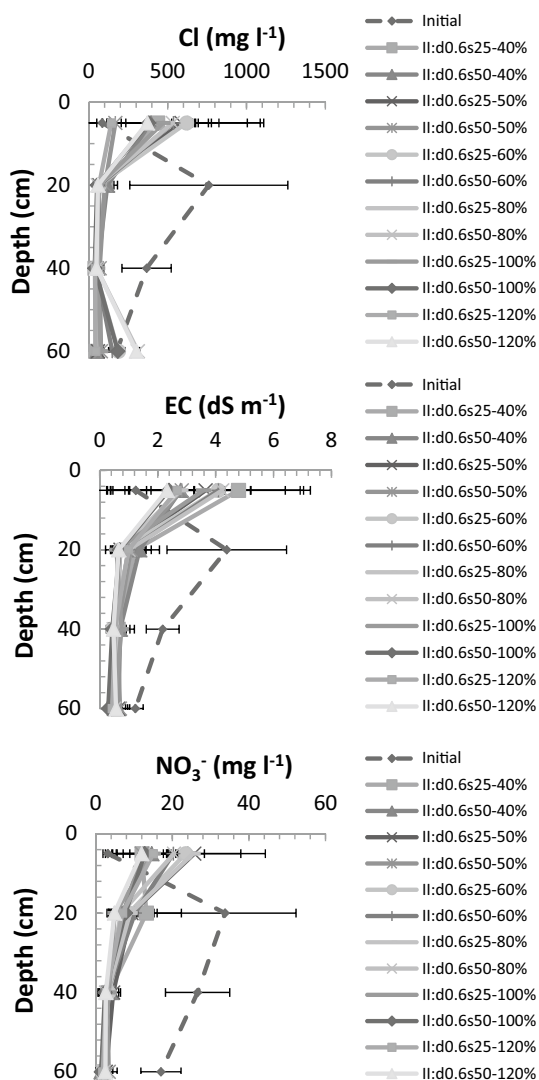

Fig. 5 Soil profiles of chloride concentration (Cl, mg l⁻¹), electrical conductivity (EC, dS m⁻¹), and nitrate concentration (N–NO₃, mg l⁻¹) for the twelve irrigation regimes

(i.e., yield/dose) is higher for the lower irrigation doses, regardless of the dripper spacing. In terms of economic viability and/or food production, the results of this study imply that one may consider using smaller irrigation doses relative to the optimal. Specifically, for a given field, the total tuber yield will be smaller. However, if areas agricultural lands are not a limiting factor (such as in the Arava Desert), higher yields can be obtained with the small irrigation dose in a larger area, with no significant reduction in tuber quality. This, however, must be examined against other costs (fixed and variable), as well as the long-term consequences of using saline water for irrigation.

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