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Effects of saline water and N levels on the eggplant (*Solanum melongena* L.) fruit yield, water productivity, and nitrogen use efficiency by drip and surface flood irrigation

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Abstract: Due to a scarcity of freshwater resources, agriculture is dependent on the use of poor quality water for irrigation in arid and semi-arid regions. Hence, the effective use of poor quality water requires pioneering water management and nitrogen fertiliser practices to increase the yield and resource efficiency. This study aimed to investigate the effect of saline water levels, nitrogen fertiliser, and irrigation methods on the eggplant yield, water productivity, NPK uptake, and nitrogen use efficiency (NUE). The experiment was conducted in 2019 and 2020 under drip (IM1) and surface flood irrigation (IM2). The treatments included three saline water levels, i.e., canal water (SW1), electrical conductivity of the irrigation water (ECiw) = 2.5 dS/m (SW2), and ECiw = 5.0 dS/m (SW3) along with the three nitrogen levels of 75% (N1), 100% (N2), and 125% (N3) of the recommended dose of nitrogen. Application of saline water using IM1 reduced the electrical conductivity (ECe) by 41.8% (SW2) and 34% (SW3) over IM2. The fruit yield, water productivity (WP), NPK uptake, and NUE was increased by 22%, 127.6%, 39.8%, 16.6%, 11.8%, and 23.8% under IM1 over IM2, respectively. A high saline water level under IM2 can cause larger reduction in the fruit yield, NPK uptake, and water use. Applying saline water through IM1 improves the fruit yield, WP, and NUE by 13–32.8%, 104.1–147.3%, and 10.5–35.2%, respectively, as compared to IM2. We found that saline water and N applied by drip improved the eggplant yield, water productivity, and NPK uptake. It is concluded that the irrigation water and nitrogen fertiliser consumption are optimised when saline water is applied through drip irrigation.

Keywords: fruit weight; nutrient uptake; nitrogen fertiliser; plant height; poor quality water

The ever-growing population is driving an increase in the food demand and increasing the need for water in agriculture. Therefore, keeping food security in view, agricultural production requires the continuous improvement of irrigation practices due to the global constraints on freshwater availability and increasing demand of water in the agricultural, industrial, and urban sectors (Dalin et al. 2017; Ma et al. 2020). In the face of dwindling freshwater supplies, and an increasing require-

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ment for more water to irrigate crops when available resources are scarce, poor quality water is being used in agriculture (Ragab 2005). About 62% of the area of Haryana state is underlain with poor quality water (Anonymous 2019), which has led to the development of soil salinity, deteriorating soil health, and decreasing crop productivity (Ankush et al. 2021). To overcome this water scarcity, many countries are adopting the use of poor quality water for irrigation purposes. Studies have demonstrated that excessive salts disrupt the ionic distribution (Ankush et al. 2020) and water potential equilibrium, resulting in physiological changes and reduced plant growth (Phogat et al. 2010). Therefore, there is a need for the efficient use of poor quality water and balanced fertilisation to have better crop production and make effective use of the input resources.

In India, irrigation mostly depends on conventional systems with an irrigation efficiency of about 40–45% (Choudhary et al. 2016). Integrated drip irrigation is the most effective system for increasing crop yields with a limited supply of irrigation water and precise fertiliser applications. Drip irrigation has proved to show an advantage over conventional methods of irrigation (Sezan et al. 2008) particularly in row crops due to the more precise and direct application of water in the plant root zone which helps to increase the water use efficiency. Using a drip irrigation system for the application of saline water at a low rate and frequent watering over a period of time can keep the high water potential near the rooting area, resulting in improved plant growth whilst compensating with a higher osmotic potential (Kang et al. 2004). In salty conditions, N fertiliser management is critical to minimise the adverse effects of salinity on the plant growth and yield (Albassam 2001). This can be achieved by a proper fertilisation method and scheduling, as well as by the fertiliser source and rate of fertilisation (Machado, Serralheiro 2017). Fertigation increases the efficiency of water and nutrient use, improves the crop yield, allows the efficient use of saline water, and reduces the soil reclamation as compared to other conventional irrigation methods (Machado, Serralheiro 2020).

Salinity in the soil caused by the continuous use of saline water or poor quality water decreases the productivity of many crops, including vegetable crops that have a low tolerance to salt stress. Thus, an extensive increase in the vegetable crop production and consumption has become a global priority. The productivity of vegetable crops per unit of applied water is higher than that of agricultural field crops and requires more fertiliser and irrigation inputs (Machado, Serralheiro 2017). Hence, it is advantageous for small farmers as vegetables can be grown in small areas with intensive agricultural practices. The eggplant (*Solanum melongena* L.) is one of the most popular and widely cultivated vegetable crops in the tropical regions of central, southern, and south-east Asia and some African countries (Hazra et al. 2003). It is a warm-season crop and popularly known as 'the king of vegetables' in Asian subtropical regions (Caruso et al. 2017). The eggplant is low in calories with a high mineral content, containing vitamins, nutritional fibre, protein, and anti-oxidants (Whitaker, Stommel 2003; Caguiat, Hautea 2014). The eggplant is one of the top five most important vegetable crops in Asia and the Mediterranean (Frary et al. 2007) which is a moderately salt-sensitive crop, although categorised as sensitive to salinity (Maas 1990; Hanson et al. 2006). Therefore, it is important to study the efficient use of saline water as an irrigation source for eggplants on the crop growth, yield and water productivity at various salinity levels under different irrigation management strategies. Drip irrigation with varying levels of saline water and nitrogen fertiliser is not studied as extensively as conventional irrigation and fertilisation methods. Therefore, an attempt was made, in this study, to test the efficacy of a drip irrigation system over the conventional method (surface flooding). The objective of this study was to evaluate the effects of the irrigation methods, saline water and nitrogen fertiliser treatment on the crop growth, yield, water productivity and nitrogen use efficiency. In addition, it was intended to evaluate their interactions.

MATERIAL AND METHODS

The experiment was conducted at the Research Farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar, from July to December (2019 and 2020). The location is situated in a semi-arid, sub-tropic area at 29°9'N latitude, 75°41'E longitude at an elevation of 215 meters above the mean sea level. The experimental soil was sandy in texture with an initial soil pH of 7.34; with low organic carbon (0.28%), available nitrogen (124.3 kg/ha), medium available phosphorus (30.3 kg/ha) and available potassium (256.2 kg/ha). The mean maximum temper-

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ature ranged from 22.6–37.6 °C and the mean minimum temperature ranged from 7.7–27.5 °C during both seasons.

Treatment details. The experiment was laid out in a split-split plot design with three replications. The experiment consisted of two irrigation methods – drip (IM1) and surface flood irrigation (IM2); three levels of irrigation water, i.e., canal water of electrical conductivity of the irrigation water (ECiw) = 0.46 dS/m (SW1), ECiw = 2.5 dS/m (SW2) and ECiw = 5.0 dS/m (SW3) of saline water, and three N fertiliser levels (N1, N2, N3), i.e., 75% of the recommended dose of nitrogen (RDN), 100% RDN and 125% RDN. In order to achieve the desired salinity of irrigation water, saline water (EC 25 dS/m) from the tubewell near the experimental site and fresh water were mixed together and stored in large storage tanks for further use during the study.

The 'Hisar Shyamal' variety of eggplant was used during the experiment for two consecutive years. Urea, single super phosphate (SSP) and muriate of potash (MOP) were used to apply the reommended doses of nitrogen (100 kg N/ha), phosphorus (50 kg P_2O_5/ha) and potassium (25 kg K_2O/ha). In surface flood irrigation, 1/3 of the nitrogen fertiliser as well as the full doses of phosphorus and potassium fertilisers were applied prior to transplanting the seedlings, and the remaining nitrogen was applied in two splits at 30 and 60 days after transplanting (DAT). In the drip irrigation, the full dose of phosphorus and potassium were applied before the transplanting and the nitrogen fertiliser along with the irrigation water was applied in six equal splits at 15 day intervals.

Irrigation of 40 mm per week was applied under the surface flood method up to 90 DAT and then fortnightly until the end of the growing season according to the package of practices of vegetable crops adopted in Haryana state. Under the drip system, the irrigation was applied on alternate days on account of the daily crop evapotranspiration data (CROPWAT model). The amount of applied irrigation water was calculated based on the plant potential evapotranspiration loss (*ETc*) using the following equation:

$$V = \frac{ETc \times Ls \times Es \times Wa}{EU} \tag{1}$$

where: V – the applied irrigation water (L/day/emitter); Ls, Es – the lateral and emitter spacing; ETc – the crop evapotranspiration; Wa – the wetted surface area (0.8); EU – the emission uniformity of the system, which was considered as 90% (Kaulage 2017).

Electrical conductivity of the soil. Soil samples from 0–15 cm and 15–30 cm depths were collected at the start and end of the experiment and were taken to determine the electrical conductivity of the saturated paste (ECe) according to Rhoades (1996). The determination was carried out by measuring the electrical conductivity of 1 : 2 soil : water suspension by standard methods. A linear regression ECe = $a + b$ ($EC_{1:2}$) for each layer was established.

Crop observations and measurements. When the fruits reached full size, they were harvested six times for vegetable consumption. The total yield of the fruit was recorded by accumulating the yield per picking and converting it to Mg per hectare. Several yield attributes and growth parameters were measured at harvest. The number of fruits per plant, the weight of the fruits, and the size of the fruits were recorded for five randomly selected fruits from the sample plants in each treatment, and the average was calculated. The plant height of the five randomly selected plants was recorded at 60 DAT, 90 DAT, and at harvest. At the time of harvesting, the fresh weight of the leaves, roots, and stems were measured. The roots were rinsed with tap water and dried with absorbent paper. The dry weight (DW) of the shoots and roots were recorded after being dried at 80 °C for 72 h (Bray 1963).

Nitrogen, phosphorus and potassium uptake (NPK). The total nitrogen content in the plants was determined by Nessler's reagent using spectrophotometry (Snell, Snell 1959), the phosphorus content was determined by the Vanadomolybdate phosphoric acid yellow colour method (Jackson 1967), and the potassium content was determined by a Flame photometer (Jackson 1967). The NPK uptake is calculated by multiplying the nutrient concentration by the dry matter and is expressed in kg/ha.

Water productivity and nitrogen use efficiency. The water productivity (WP) is the relationship between the yield and the irrigation water used. The water productivity was calculated from the marketable yield per hectare divided by the amount of water applied in each treatment during the growing season and is expressed as kg/m^3.

$$\text{Water productivity (kg/m}^3\text{)} = \text{fruit yield (kg/ha)/} \\ \text{/amount of water applied (m}^3\text{/ha)} \tag{2}$$

The nitrogen use efficiency (NUE) is the relationship between the yield and the nitrogen input. NUE

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was calculated by comparing the amount of nitrogen applied to the fruit yield per hectare for the different treatments.

$$\text{NUE (kg of yield/kg of N applied)} = \text{fruit yield (kg/ha)/} \\ \text{/amount of nitrogen applied (kg/ha)} \quad (3)$$

Statistical analysis. The data for the two years were pooled due to the measurement similarities obtained in the years 2019 and 2020. An analysis of variance (ANOVA) was performed to obtain the results of the different treatments using SPSS 17 (SPSS Inc., Chicago, USA). The least significant difference (LSD) test was used to determine if there was any significance for each treatment. The probability level for determining the significance was 5%.

RESULTS AND DISCUSSION

Soil electrical conductivity. The initially electrical conductivity (ECe) of the soil was 1.89 dS/m and increased under the SW2 and SW3 treatments. Using SW3, we obtained ECe values of 3.52 dS/m at 0–15 cm and 3.8 dS/m at 15–30 cm under IM1 (Table 1). However, among the saline water levels, the lowest ECe values (0.59 and 0.68 dS/m) at both depths were recorded with the canal water (SW1). The interaction of the irrigation method and the saline water levels (Table 1) suggests that drip irrigation has the potential to reduce the salt accumulation in sandy soils by 34.2% (0–15 cm) and 23.5% (15–30 cm) over the conventional irrigation method applied with poor quality water. The application of N fertiliser at different doses reduced the ECe values under both irrigation methods. Similar results were reported by Malik et al. (2015) and Manzoor (2019).

Effect of irrigation methods, saline water, and nitrogen levels on the yield and yield components. The statistical analyses indicated that the irrigation methods had a significant effect on the fruit yield and yield components, i.e., the plant height, number of branches per plant, number of fruits per plant, average fruit weight, and fruit diameter. Using IM1 instead of IM2 resulted in an increase of 22%, 22.9%, 21.6%, and 24.2% in the fruit yield, number of branches per plant, fruit diameter, and weight, respectively. At 60, 90 DAT, and harvest, the plant reached 69.99, 99.03, and 132.83 cm in height, respectively, when it was irrigated by the drip system. These results are similar to those of Ozbahce and Tari (2010) and Tagar et al. (2012). A study by Pandey et al. (2013) found drip irrigation resulted in an increase in the fruit yield and increased net income.

The application of saline water had a detrimental effect on the yield and yield components in all the treatments (P < 0.05). The increasing salinity level of ithe rrigation water (SW1 to SW3) resulted in a lower yield and the highest yield was in SW1 (24.1 Mg/ ha). A reduction in the fruit yield of 16.8% and 30.8% was recorded with the SW2 and SW3 treatments compared with SW1 (Table 2), respectively. A similar trend was observed for the plant height at 60, 90 DAT, and harvest; the lowest values of 51.6, 76.57, and 99.9 cm were recorded with SW3, respectively. The highest number of branches per plant (14.78),

Table 1. Effect of the irrigation methods, saline water and nitrogen levels on the electrical conductivity (ECe) of the soil

Treatments	Soil depth (cm)	
	0–15	15–30
Irrigation method		
IM1	1.98^{b}	2.21^{b}
IM2	3.25^{a}	3.02^{a}
Saline water levels		
SW1	0.59^{c}	0.68^{c}
SW2	2.83^{b}	2.78^{b}
SW3	4.40^{a}	4.38^{a}
Nitrogen levels		
N1	2.70^{a}	2.69^{a}
N2	2.62^{ab}	2.61^{ab}
N3	2.54^{b}	2.55^{b}
Irrigation method × saline water (IM × SW)		
IM1 × SW1	0.34^{e}	0.60^{e}
IM1 × SW2	2.08^{c}	2.24^{d}
IM1 × SW3	3.52^{b}	3.80^{b}
IM2 × SW1	0.83^{d}	0.76^{e}
IM2 × SW2	3.58^{b}	3.34^{c}
IM2 × SW3	5.35^{a}	4.97^{a}

*IM1 – drip irrigation; IM2 – surface flood irrigation; SW1 – saline water of ECiw = 0.46 dS/m; SW2 – saline water of ECiw = 2.5 dS/m; SW2 – saline water of ECiw = 5.0 dS/m, N1 – 75% of recommended dose of nitrogen (RDN); N2 – 100% RDN; N3 – 125% RDN; different letters indicate a significant difference between all the treatments (P < 0.05) (pooled data of two years)

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number of fruits per plant (16.2), average fruit weight (219.96 g), and fruit size (10.3 cm) were achieved with SW1. The increased saline water levels from SW1 to SW3 significantly reduced the dry matter (DM) of the plant by 26.2%. This may be due to the soil salinity reducing the osmotic potential causing ionic toxicity and a nutritional imbalance due to the salt accumulation in the root area. Similar results were reported by Bashir et al. (2015), Kristin and Keast (2016), and Kausar et al. (2017), as they reported a yield reduction in plants irrigated with an increased salinity of irrigation water as compared to freshwater.

Averaged over two growing seasons, the different nitrogen levels influenced the eggplant yield components significantly (Table 3). The crop was found to be responsive to the increasing nitrogen fertiliser levels. Compared with N1, the yield of eggplants was significantly higher in the N3 treatment receiving 125% nitrogen fertiliser (22.92 Mg/ha) and lower in the N1 treatment (17.54 Mg/ha). Similarly, the plant height (at harvest), the number of fruits, average fruit weight, and fruit size increased by 18.9%, 27.7%, 22.4%, and 26.4%, by the increment of the applied nitrogen from N1 to N3, respectively. It was found that the increased N levels had a significant effect on the DM and raised the values from 158.11 g/plant to 172.42 g/plant. The saline water levels and irrigation methods have profound effects on the eggplant yields and yield components. It was highly responsive to the amount of water and lower salt concentration in the root zone of the soil which is in agreement with results from similar research (Soomro et al. 2012; Jha et al. 2017).

Effect of the irrigation methods, saline water and nitrogen levels on the WP, nutrient uptake and NUE. The application of the different saline water and nitrogen levels under drip non-significantly improved the nutrient uptake except for the nitrogen during both years of the study. In the plants, the maximum uptake of NPK was observed with IM1, which could be attributed to the better and higher availability of water and nutrients. Comparatively to IM2, IM1 increased the NPK uptake by 39.8%, 16.6% and 11.8%, respectively (Table 3). This could be ascribed to the better and timely availability of water and nutrients. Similarly, IM1 significantly improved the WP and NUE by 127.6% and 23.8% than IM2. Unlukara et al. (2010) and Dingre et al. (2012) supported the study and found that a drip system results in water-savings and increased water use efficiency over surface flood irrigation.

Table 2. Effect of the irrigation methods, saline water and nitrogen levels on the yield, yield components, water productivity and nitrogen use efficiency (NUE)

Treatments	Fruit yield (Mg/ha)	Plant height (cm) at 60 DAT	Plant height (cm) at 90 DAT	Plant height (cm) at harvest	No. of branches per plant	No. of fruits per plant	Average fruit weight (g)	Fruit size (cm)	DM (g/plant)	Nutrient uptake (kg/ha) N	Nutrient uptake (kg/ha) P	Nutrient uptake (kg/ha) K	Water productivity (kg/m³)	NUE (kg of yield/kg of N applied)
Irrigation method														
IM1	22.29^{a}	59.99^{a}	99.03^{a}	132.83^{a}	13.93^{a}	15.03^{a}	202.03^{a}	9.62^{a}	175.24^{a}	72.39^{a}	10.04^{a}	52.91^{a}	7.42^{a}	228.87^{a}
IM2	18.27^{b}	53.36^{b}	83.34^{b}	110.21^{b}	11.33^{b}	10.32^{b}	162.60^{b}	7.91^{b}	157.26^{b}	51.76^{b}	8.61^{a}	46.65^{a}	3.26^{b}	184.91^{b}
Saline water levels														
SW1	24.10^{a}	62.22^{a}	106.33^{a}	143.08^{a}	14.78^{a}	16.20^{a}	219.96^{a}	10.31^{a}	195.58^{a}	82.58^{a}	10.55^{a}	55.29^{a}	6.25^{a}	247.38^{a}
SW2	20.06^{b}	56.19^{b}	90.65^{b}	121.50^{b}	12.37^{b}	11.94^{b}	175.42^{b}	8.65^{b}	158.85^{b}	60.42^{b}	9.17^{b}	48.75^{b}	5.33^{b}	204.26^{b}
SW3	16.68^{c}	51.61^{c}	76.57^{c}	99.90^{c}	10.74^{c}	9.88^{c}	151.55^{c}	7.34^{c}	144.32^{c}	43.22^{c}	8.26^{c}	45.28^{b}	4.44^{c}	162.02^{c}
Nitrogen levels														
N1	17.54^{c}	50.75^{c}	83.52^{c}	110.48^{c}	11.23^{c}	11.13^{c}	162.93^{c}	7.72^{c}	158.11^{b}	48.49^{c}	7.64^{c}	44.58^{b}	4.69^{c}	233.75^{a}
N2	20.38^{b}	57.88^{b}	91.37^{b}	122.70^{b}	12.96^{b}	12.68^{b}	184.53^{b}	8.80^{b}	168.22^{ab}	62.96^{b}	9.37^{b}	49.59^{b}	5.37^{b}	203.74^{b}
N3	22.92^{a}	61.40^{a}	98.67^{a}	131.38^{a}	13.71^{a}	14.21^{a}	199.47^{a}	9.76^{a}	172.42^{a}	74.79^{a}	10.97^{a}	55.16^{a}	5.97^{a}	183.18^{c}

DAT – days after transplanting; DM – dry matter; different letters indicate a significant difference between all the treatments ($P < 0.05$) (pooled data of two years)

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Table 3. Interaction effect of the irrigation methods, saline water and nitrogen levels on the yield components of the eggplant

Treatments	Plant height (cm)			No. of branches per plant	No. of fruits per plant	Average fruit weight (g)	Fruit size (cm)	DM (g/plant)	Nutrient uptake (kg/ha)		
	at 60 DAT	at 90 DAT	at harvest						N	P	K
Irrigation methods × saline water levels (IM × SW)											
IM1 × SW1	63.57^{a}	109.53^{a}	148.77^{a}	15.30^{a}	17.57^{a}	226.29^{a}	10.62^{a}	199.68^{a}	94.76^{a}	11.41^{a}	58.92^{a}
IM1 × SW2	60.29^{ab}	99.31^{b}	133.44^{b}	13.96^{b}	14.78^{b}	198.75^{b}	9.59^{b}	173.46^{b}	70.70^{b}	9.77^{ab}	51.41^{b}
IM1 × SW3	56.11^{bc}	88.25^{c}	116.29^{c}	12.54^{c}	12.73^{c}	181.05^{c}	8.66^{c}	152.59^{c}	51.73^{bcd}	8.93^{b}	48.39^{bc}
IM2 × SW1	60.88^{a}	103.13^{b}	137.40^{b}	14.26^{b}	14.83^{b}	213.63^{ab}	9.99^{ab}	191.48^{a}	70.40^{b}	9.68^{ab}	51.67^{ab}
IM2 × SW2	52.09^{c}	82.00^{d}	109.70^{c}	10.79^{d}	9.10^{d}	152.10^{d}	7.71^{c}	144.24^{cd}	50.15^{bcd}	8.56^{bc}	46.09^{bc}
IM2 × SW3	47.11^{d}	64.89^{e}	83.52^{d}	8.94^{e}	7.02^{e}	122.06^{e}	6.01^{d}	136.05^{d}	34.72^{d}	7.59^{bcd}	42.18^{c}
Irrigation methods × nitrogen levels (IM × NL)											
IM1 × N1	54.75^{c}	92.73^{c}	124.13^{c}	12.61^{c}	13.42^{c}	183.27^{c}	8.62^{cd}	166.37^{abc}	58.19^{bc}	8.40^{bc}	48.24^{bc}
IM1 × N2	61.02^{ab}	98.97^{b}	133.42^{b}	14.22^{b}	15.01^{b}	204.19^{b}	9.62^{b}	177.41^{ab}	73.78^{a}	10.26^{ab}	53.06^{ab}
IM1 × N3	64.19^{a}	105.39^{a}	140.95^{a}	14.97^{a}	16.64^{a}	218.67^{a}	10.63^{a}	181.95^{a}	85.23^{a}	11.59^{a}	57.42^{a}
IM2 × N1	46.73^{d}	74.30^{e}	96.83^{e}	9.85^{e}	8.84^{e}	142.65^{d}	6.83^{e}	149.85^{d}	38.79^{d}	6.88^{c}	40.92^{c}
IM2 × N2	54.75^{c}	83.78^{d}	111.97^{d}	11.70^{d}	10.34^{d}	164.87^{c}	7.98^{d}	159.03^{cd}	52.14^{c}	8.59^{abc}	46.13^{bc}
IM2 × N3	58.60^{b}	91.95^{c}	121.82^{c}	12.45^{c}	11.77^{c}	180.27^{c}	8.90^{bc}	162.89^{bcd}	64.35^{bc}	10.37^{ab}	52.9^{ab}

DAT – days after transplanting; DM – dry matter; different letters indicate significant difference between all treatments ($P < 0.05$)

As a result, increasing the irrigation water salinity reduced the nutrient uptake up to 47% (N), 21.7% (P), 18.1% (K) as well as the WP by 42%. Similar results were observed for the NUE under different irrigation water quality treatments (Table 2). Comparing the different saline water treatments, NUE was 52.7% and 26.1% higher in SW1 and SW2 than in SW3. Higher doses of nitrogen fertiliser had a significant incremental effect on the WP and NPK uptake. The WP increased from 4.69 to 5.97 kg/m^3 (27% increase) with the N1 to N3 treatment. It was observed that the maximum uptake of N (74.79 kg/ha), P (10.97 kg/ha) and K (55.16 kg per ha) was observed at N3 and the minimum at N1. Furthemorer, the NUE was 23.8% higher under IM1 compared to IM2. It was found that the NUE was at a maximum in the N1 treatment that received 75% nitrogen fertiliser (233.75 kg yield/kg of applied nitrogen), while the NUE was the lowest in the case of N3 that received 25% more nitrogen fertiliser (183.18 kg yield/kg of nitrogen applied) than was recommended. The NUE was reduced by 21.6% as a result of the augmented nitrogen dose (N1 to N3). Previous studies have concluded that the water use efficiency (WUE) and WP decrease as the amount of irrigation water increases, due to a decrease in the yield per unit of applied water (Chen et al. 2015). Similarly, Hebbar et al. (2004) reported the highest fertiliser use efficiency (226.5 kg yield/kg of NPK) with fertigation (drip + fertiliser application) followed by drip irrigation (205.5 kg yield/kg of NPK) as compared to furrow irrigation (170.0 kg yield/kg of NPK).

Interaction effects of the irrigation methods and saline water levels on the yield, WP, nutrient uptake and NUE. The amount of irrigation water and the irrigation methods exerted significant interaction effects on the yield, yield components, WP and NUE. A significant interaction between the irrigation method and saline water was observed at $P < 0.05$. Although the maximum yield (25.2 Mg/ha) was received at IM1-SW1, the minimum yield (14.3 Mg/ha) was obtained at IM2-SW3 (Figure 1A). The latter is about 43.3% lower than the maximum (Figure 1A). A salinity-induced fruit yield reduction was most prominent in IM2 as the salinity increased the irrigation water salinity. As shown in Figure 1A, IM1 with the SW2 and SW3 treatments increased the yield by 29.5% and 32.8%, respectively, when compared to the irrigation water treatments with IM2. Similarly, the irrigation method and saline water had significant effects on the yield attributes except for the plant height at 60 DAT. The highest and lowest plant height values (90 DAT and at harvest), number of branches, number of fruits per plant, fruit weight, fruit size, and dry matter were recorded in the treatment of IM1-SW1 and IM2-SW3 (Table 3). As a result, in comparison to the IM1-SW2 treatments, IM2 with the SW2 treatment decreased the mentioned yield attributes ranging between 17.4–38.4%. The salt accumulation in the root area resulted in a reduction in the water and nutrient absorption, thus reducing the yield and yield attributes. The reduction in the fruit yield was probably greater under surface flooding because salts accumulated near the root zone more than under the drip irrigation which caused the effects to be more prominent. These results agreed with the earlier findings of Jha et al. (2017), where they observed that the number of tubers per plant, the weight of the tubers, and the potato tuber yield decreased with the increasing irrigation water salinity, but these values were significantly higher under drip irrigation as compared to furrow irriga-

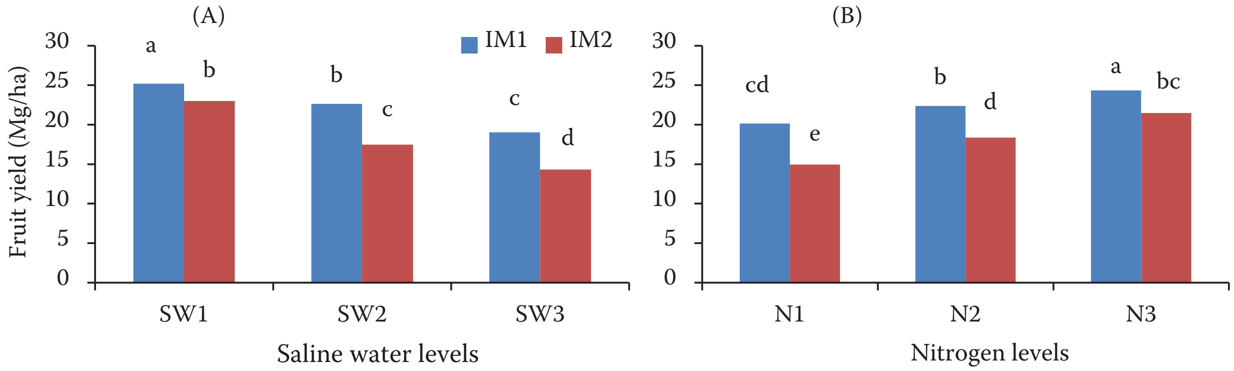

Figure 1. Interaction effect of (A) the irrigation methods ×saline water levels (IM × SW) and (B) the irrigation methods × nitrogen levels (IM × NL) on the fruit yield of the eggplant

Different letters indicate significant difference between all treatments ($P < 0.05$)

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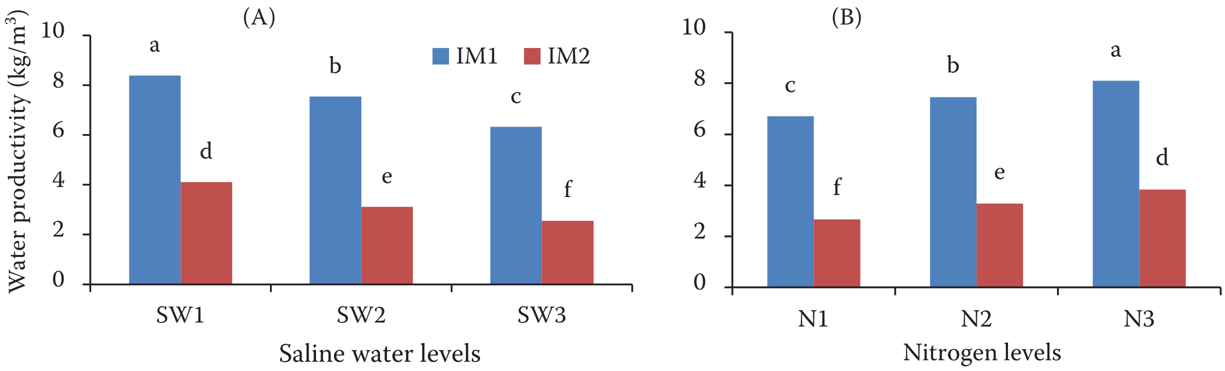

Figure 2. Interaction effect of (A) the irrigation methods × saline water levels (IM × SW) and (B) the irrigation methods × nitrogen levels (IM × NL) on the water productivity of the eggplant
Different letters indicate significant difference between all treatments ($P < 0.05$)

tion. The findings by Kumar et al. (2016) and Machado and Serralheiro (2017) also support the present findings. A drip irrigation system is a better option for achieving an optimal and higher yield under saline water applications, along with providing better quality produce (Hanson, May 2011).

Irrigation techniques and salinity levels affected the WP, NPK uptake and NUE. The WP decreased with an increase in the saline water levels (up to SW3) under both irrigation methods and the trend was similar to the fruit yield. IM1 significantly increased the water productivity by 104.1%, 141.7%, and 147.3% in comparison to IM2 at all the salt water levels (SW1 to SW3) (Figure 2A). The highest WP values for the different water treatments applied through drip and flood irrigation methods were reversely proportional to the quantity of water applied through both irrigation methods. Saxena et al. (2013) reported that the application of saline water of ECiw = 4 dS/m and 8 dS/m reduced the WUE by 6% and 22%, respectively, as compared to fresh water under drip irrigation. Similar results have been reported by Unlukara et al. (2010). A higher NPK uptake (94.76, 11.41, and 58.92 kg/ha) was obtained with IM1-SW1, and a lower uptake (34.72, 7.59, and 42–18 kg/ha) was obtained with IM2-SW3 (Table 3). Similarly, for the NUE, the interaction between the irrigation methods and saline water levels was statistically different. The highest NUE was recorded with IM1-SW1 (259.7 kg yield per kg of applied N) followed by IM2-SW1 (235 kg yield/kg of applied N). Meanwhile, the application of saline water through IM1 improved the NUE by 32.1% under the SW2 treatment and 35.2% under the SW3 treatment over IM2 (Figure 3A). The nutrient uptake and NUE in the saline soil conditions is low due to the salt stress and negative interactions with the cations and anions present in high concentrations, Romero-Aranda et al. (2001).

Interaction effects of the irrigation methods and nitrogen levels on the yield, WP, nutrient uptake and NUE. The interaction of the irrigation methods and nitrogen levels influenced the yield, plant height at harvest, and NUE in a significant way, indicating that both factors did not act separately. The fruit yield was significantly higher in IM1 than IM2 at all N levels. In IM1, in which different saline water levels were applied, the highest fruit yield was produced at N3 (24.3 Mg/ha) and the lowest yield was produced at N1 (20.1 Mg/ha). A similar trend was observed with IM2 at all N levels (Figure 1B). The results suggest that IM1 was the best suited at all N levels because it yielded 35.1%, 27.9%, and 13.3% higher than IM2 at N1, N2, and N3, respectively. There was an increase in the yield attributes with an increase in the rate of the N application (up to N3) in both irrigation methods, and the trend was similar to the fruit yield. In terms of the height and all yield contributing factors, IM1-N3 was the most appropriate combination. It was observed that the highest plant height at 60, 90 DAT, and harvest was observed with the combination IM1-N3, i.e., 64.19, 105.39, and 140.95 cm, respectively, while the lowest was with combination IM2–N1 (46.73, 74.30, and 96.83 cm, respectively). Similarly, the yield parameters, such as the number of branches, number of fruits per plant, average fruit weight, and fruit size, increase with an increase in the N level, and lower values were recorded with IM2 as compared to IM1 at all N levels. The in-

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creased N level from N1 to N3 increased these parameters by 18.7%, 23.9%, 19.3%, and 23.3%, respectively, under IM1. Also, the highest dry matter per plant was recorded at IM1-N3 (181.95 g/plant) and the lowest was recorded at IM2-N1 (149.85 g/plant). This is in agreement with the findings of other studies (Kadam et al. 2007; Singh, Pandey 2014), where N had a significant effect on the yield and yield attributes. The higher yield under fertigation is due to higher N uptake, N use efficiency, and % N derived from the fertiliser in comparison to the soil application (Mohammad 2004). Kumari and Kaushal (2014) reported that drip fertigation increased the yield and water use efficiency while saving 25% fertiliser and 40% water. The increase in the fruit yield is related to an increase in the number of fruits per plant, average fruit weight, and fruit size.

The WP increased with the increased nitrogen levels up to N3 in both the irrigation methods (Figure 2B). However, WP was highest in IM1-N3 (8.09 kg/m^3) and lowest in IM2-N1 (2.67 kg/m^3). The WP was 7.46 kg/m^3 in IM1 as compared to 3.28 kg/m^3 (a difference of 127%) in the IM2 treatment at the N2 level. A higher WP under the drip method was found in melons (Kirnak et al. 2005), when the N fertiliser rate was increased to the optimum. Kumar et al. (2017) also reported similar findings; where the WUE increased by 37.9 and 48.3% with an increased N-fertiliser rate for irrigation with fresh and saline water, respectively. The interaction between the irrigation method and nitrogen level was found to be non-significant for the NPK uptake. At the full recommended dosage of N, IM1 resulted in a 41.5%, 19.4%, and 19% greater NPK uptake than IM2. The results are in agreement with Singh et al. (2013) and Chand (2014). All the N treatments resulted in a higher NUE in IM1 than in IM2. The reduction in the N fertiliser applied through IM1 at N1 (saving 25% N fertiliser) was accompanied by a significant increase of 46% in the NUE as compared to IM2 at N2 (recommended dose of N) as shown in Figure 3B. The NUE tends to decrease with increasing rates of N applications up to the N3 level in IM1 as well as in IM2 (Min et al. 2011; Kuscu et al. 2014). Optimising the irrigation and N supplies is, thus, imperative for improving the WUE and NUE. Similar results were reported by Aujla et al. (2007) and Djidonou et al. (2013), whos demonstrated that drip irrigation was more effective than furrow irrigation in achieving a higher WUE and agronomic efficiency of N.

Interaction effects of the saline water and nitrogen levels on the yield, WP, nutrient uptake and NUE. The interaction effect of the saline water and nitrogen levels on all the mentioned parameters was found to be non-significant ($P < 0.05$) except for the NUE. The highest fruit yield and yield contributing parameter values were obtained with the SW1-N3 treatment and lowest values were obtained with SW3-N1. The highest fruit yield was obtained at SW1-N3, with 26.43 Mg/ha, and the lowest was obtained at SW3-N1 with 13.82 Mg/ha, less than half of SW1-N3. By increasing the 25% N rate, the fruit yields increased by 13% and 16% under the SW2 and SW3 treatments, respectively. No significant differences were observed in the plant height between the saline water and nitrogen treatments at 60, 90 DAT and harvest, with the low-

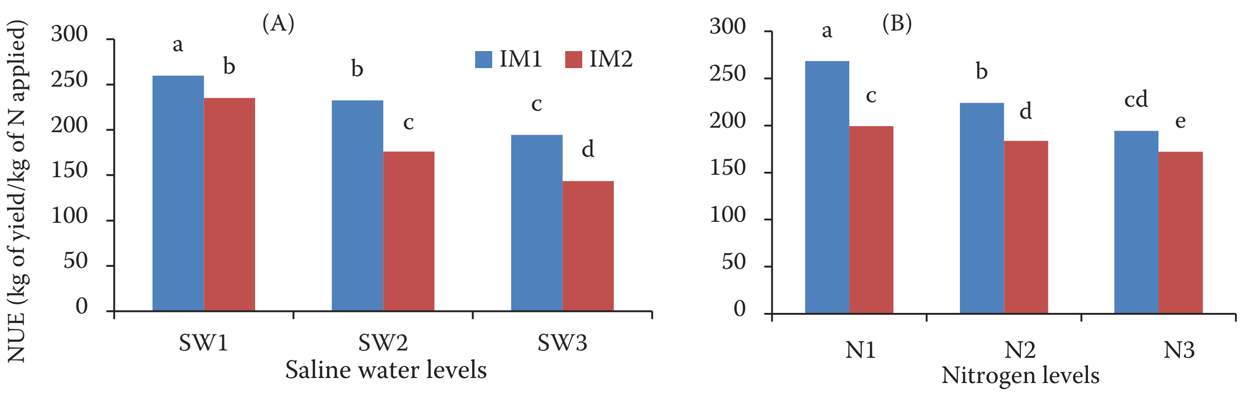

Figure 3. Interaction effect of (A) the irrigation methods × saline water levels (IM × SW) and (B) the irrigation methods × nitrogen levels (IM × NL) on the nitrogen use efficiency (NUE) of the eggplant
Different letters indicate significant difference between all treatments

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est being obtained with SW3 of 45.34, 68.58, and 89.31 cm at the N1 treatment (Table 4), respectively. Furthermore, the highest number of fruits, number of branches, average fruit weight, and size were obtained at N3 under the saline water treatment (SW1 to SW3), and the lowest ones were obtained at N1. The supplemental N rate did not significantly interact with the irrigation water quality and increased the yield-contributing parameters in the saline water treatments (SW2 and SW3). The DM content ranged from 135.99–202.69 g/plant under the different saline water and nitrogen level combinations (Table 4). The N application under saline conditions showed amending effects on the salinity due to the accumulation of amino acids in the plant tissue which helps the plant to survive in salt-stress conditions (Flores et al. 2012). The results of previous studies (Magán et al. 2008; Malash et al. 2008; Song et al. 2019) confirmed that an increased N fertiliser rate significantly influenced the crop growth and yield during salt treatment. A study conducted by Farooq et al. (2021) found that the highest level of nitrogen produced tomatoes with a higher number of fruits and greater fruit firmness under varying irrigation water salinities. On the other hand, Nangare et al. (2013) observed that the interaction effect of salinity and nitrogen significantly increased the number of leaves and seedling dry weight.

The WP of the eggplants decreased as the rate of nitrogen fertiliser decreased. For each nitrogen level, the WP decreased as the saline irrigation water level increased. The highest WP of 6.8 kg/m^3 was obtained with SW1 at N3, while the lowest value of 3.76 kg/m^3 was obtained with SW3 with N1. The WP increased by 19.7% (SW1), 29.4% (SW2), and 35.4% (SW3) from N1 to N3, respectively. The results suggest that the highest WP under salinity stress conditions might have a positive response towards elevated N rates. Similar results have already been reported by Min et al. (2014) and Kumar et al. (2017) as they found that the WUE increased significantly with the application of the N fertiliser at higher rates under saline water treatments that could alleviate the salt damage. The interaction effect due to the different fertiliser treatment and irrigation levels (canal water and saline water) was not found to be significant. The NPK uptake (101.57, 12.49 and 62.56 kg/ha, respectively) was recorded as being higher with the 25% higher N under SW1. Under the saline water treatment of SW3, the NPK uptake increased by 46.6%, 46% and 22.5% with an increase

Table 4. Interaction effect of the saline water and nitrogen levels on the yield components of the eggplant

Sources of variation	Fruit yield (Mg/ha)	Plant height (cm)			No. of branches per plant	No. of fruits per plant	Average fruit weight (g)	Fruit size (cm)	DM (g/plant)	Nutrient uptake (kg/ha)			Water productivity (kg/m^3)	NUE (kg of yield/kg of N applied)
		at 60 DAT	at 90 DAT	at harvest						N	P	K		
SW1 × N1	21.73^{d}	56.86^{cd}	99.98^{c}	133.43^{c}	13.52^{b}	14.73^{bc}	202.76^{b}	9.30^{cd}	186.67^{a}	63.74^{cd}	8.67^{bcd}	49.39^{bc}	5.68^{d}	289.44^{a}
SW1 × N2	24.12^{b}	63.38^{ab}	106.48^{b}	144.25^{b}	15.10^{a}	16.25^{ab}	222.59^{a}	10.34^{b}	197.38^{a}	82.44^{b}	10.48^{ab}	53.92^{ab}	6.26^{b}	241.25^{b}
SW1 × N3	26.43^{a}	66.44^{a}	112.53^{a}	151.58^{a}	15.73^{a}	17.62^{a}	234.59^{a}	11.27^{a}	202.69^{a}	101.57^{a}	12.49^{a}	62.56^{a}	6.80^{a}	211.45^{d}
SW2 × N1	17.06^{f}	50.05^{ef}	81.98^{ef}	108.70^{e}	10.81^{d}	10.25^{ef}	153.42^{d}	7.55^{fg}	151.68^{bcd}	47.35^{de}	7.61^{cd}	43.98^{cd}	4.63^{g}	227.50^{c}
SW2 × N2	20.25^{e}	57.50^{cd}	91.45^{d}	123.80^{d}	12.80^{b}	12.12^{d}	178.67^{c}	8.68^{de}	160.99^{bc}	61.55^{cd}	9.25^{bc}	48.80^{bcd}	5.37^{e}	202.29^{d}
SW2 × N3	22.88^{c}	61.03^{bc}	98.45^{c}	132.21^{c}	13.51^{b}	13.45^{cd}	194.18^{b}	9.71^{bc}	163.89^{b}	72.38^{bc}	10.65^{ab}	53.48^{b}	5.99^{c}	183.00^{e}
SW3 × N1	13.82^{g}	45.34^{f}	68.58^{g}	89.31^{g}	9.36^{e}	8.42^{f}	132.62^{e}	7.77^{fg}	135.99^{d}	34.38^{e}	6.64^{d}	40.36^{d}	3.76^{h}	184.31^{e}
SW3 × N2	16.77^{f}	52.77^{de}	76.18^{f}	100.04^{f}	10.98^{d}	9.67^{f}	152.40^{d}	7.38^{g}	146.30^{cd}	44.88^{de}	8.39^{bcd}	46.06^{bcd}	4.47^{g}	167.67^{f}
SW3 × N3	19.45^{e}	56.77^{cd}	84.95^{e}	110.36^{e}	11.89^{c}	11.55^{de}	169.65^{c}	6.31^{h}	150.69^{bcd}	50.42^{de}	9.75^{bc}	49.434^{bc}	5.09^{f}	155.08^{g}

DAT – days after transplanting; DM – dry matter; NUE – nitrogen use efficiency; different letters indicate a significant difference between all the treatments (P < 0.05) (pooled data of two years)

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in the N rates from N1 to N3, respectively. The interaction effect of saline water and nitrogen levels was found to be statistically significant for the NUE (P < 0.05). For the NUE, the most effective combination was SW1-N1 (289.54 kg yield/kg of applied nitrogen). When the N rates increased from N1 to N3, the reduction in the NUE was 26.9% (SW1), 19.6% (SW2), and 15.9% (SW3). As a consequence, the NUE values in the saline treatments were significantly lower than those in the canal water treatments as the salt-stressed plants were unable to absorb and utilise the N fertiliser as effectively as those in the non-saline conditions. Numerous authors have recognised this reduction as the antagonistic behaviour of Cl^- ions on the nitrate uptake (Chen et al. 2010). Similar findings have also been reported on cotton (Hou et al. 2010) and sweet corn (Flores et al. 2012), where increasing N rates can significantly improve the yield and N uptake in saline conditions. Water and nitrogen are key factors in agricultural production, and these results showed that nitrogen fertilisation could offset the effects of salinity stress.

CONCLUSION

Our results with the eggplant showed that it is possible to use saline water as irrigation water combined with a suitable N rate to achieve high water productivity and N-use efficiency. It showed that among the two irrigation methods, the highest fruit yield, WP and NPK uptake were obtained with drip irrigaiton. So, considering the shortage of fresh water in arid and semi-arid regions, using saline water treatments of SW2 and SW3 with IM1 increased the marketable fruit yield and water use efficiency by about 29.5–23.2% and 142–147%, respectively, over IM2. Additionally, all of the yield components were significantly affected by the irrigation methods, saline water, and nitrogen levels in the same manner as the fruit yield. The interaction between the different factors affects the yield, WP, nutrient uptake and NUE. Moreover, any reduction in the applied nitrogen relative to the eggplant nitrogen requirement led to a yield reduction and deterioration of the WP. Drip fertigation with saline water was shown to be a viable option provided that the fruit yields, water use efficiency and nitrogen uptake were higher than with conventional methods. Therefore, these results reinforce the importance of determining the interactions between saline water and nitrogen levels applied through drip and surface flood irrigation to establish the optimal combinations for sustainably high fruit yields accompanied by the highest WP and NUE.

Conflict of interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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