International Journal of Agriculture, Environment and Bioresearch

Vol. 07, No. 03; 2022

ISSN: 2456-8643

EFFECTS OF WATER STRESS AND QUALITY ON RESIDUAL SOIL MACRONUTRIENTS AND ROOT-ZONE SALINITY FOR TOMATO PRODUCTION IN A PROTECTED CROPPING ENVIRONMENT

Dr Jeet Bahadur Chand[1], Guna Hewa [2], Ali Hassanli [2] and Baden Myers[2]
[1]Government of Nepal, Ministry of Agriculture & Livestock Development, Kathmandu, Nepal
[2]UniSA STEM, Mawson Lakes Campus, University of South Australia, Mawson Lakes, 5095, Australia.

https://doi.org/10.35410/IJAEB.2022.5727

ABSTRACT

Improvement of water productivity from irrigated tomatoes while maintaining yield and soil health is a global challenge. This study aimed to examine the effect of varying water quality and water stress (deficit irrigation) scenario on different soil parameters of tomatoes in a greenhouse setting to establish an optimum soil-water-plant environment for sustainable production. The study was completed by simulating tomato growing conditions in the Northern Adelaide Plains of South Australia in two consecutive years (2017-2018 and 2018-2019). Three water sources selected as varying water quality were: groundwater, recycled wastewater and mixed of both. Water was applied via drip irrigation system in four irrigation scenarios maintaining irrigation frequency of two days. The results showed that irrigation with recycled wastewater had the highest residual nutrients accumulated in soil after completion of a crop growth season. The study also indicated that the residual soil macronutrients in the 80% FC treatment were not significantly different to that of the 100% FC regardless of water quality. The results thus suggested that a considerable amount of water and fertilizer can be saved through application of DI technique - especially at 80% FC level without having a significant difference of soil macronutrient compared to full irrigation. This study also found that salt accumulation in the effective root-zone was affected by both water quality and irrigation scenarios and was highest in the case of recycled wastewater.

Keywords: Deficit Irrigation, Greenhouse Tomatoes, Salinity, Soil Macronutrients, Water Quality.

1. INTRODUCTION

Fresh water resources are limited for irrigation especially in the arid and semi-arid regions; therefore, there is an urgent need to reassess an alternative source of water for agricultural production (Hassanli and Pezzaniti, 2013). This paper is concerned with sustainable tomato production in a greenhouse environment particularly in a water-limiting condition and the regions where fresh water resources are expensive to use for agricultural purpose. Water is a valuable resource and is fundamental for human life, the economy, and the natural environment (Valipour, 2015; Du et al., 2018). Agricultural irrigation represents the main water use sector accounting for about 70% of the global freshwater withdrawals and 90% of consumptive water uses (Siebert et al., 2010; Pulido-Bosch et al., 2018; Montazar, 2019). Current situation is different as competitive users of water have put pressure on agriculture to use water as the most scare resources with high productivity (Montazar, 2019).

Tomato (Lycopersicon esculentum L.) farming was originated from Peru-Ecuador region and belongs to the Solanaceae family (Jones, 2007; Klunklin and Savage, 2017; Aghaie et al., 2018). Tomato is a high-yielding and a high-valued horticultural crop (Johnstone et al., 2005; Beckles, 2012; Maham et al., 2020) which can be cultivated in both open field and greenhouse facilities (Hao et al., 2013; Liu et al., 2019; Cui et al., 2020). There is a rapid increment of tomato production in protected cropping system which not only contributes in supply of fresh tomato in market year-round but also provides an opportunity of high-income to growers through off-season farming (Bao and Li 2010; Pereira and Marques 2017, Chand et al. 2020). Tomatoes are a highly water-dependent crop (Marjanovic et al., 2012; Klunklin and Savage, 2017). However, excessive irrigation pollutes the environment through offsite runoff of fertilisers, pesticides, and sediments (Yahyaoui et al., 2016, Giuliani et al., 2018). In greenhouse tomato, over-irrigation creates anaerobic soil conditions and consequently causes root death, delayed flowering, and fruit disorders (Haifa, 2018).

To fulfil the food security of rapidly increasing population, the agricultural sector worldwide is in pressure to improve resources use efficiency particularly water and fertilizer use efficiency. Nitrogen, phosphorus and potassium as major soil nutrients (macronutrients) are essential for crop production. Measurement of macronutrient content in soil before and after a crop growth season is important for maximizing fertilizer and water use efficiencies. Soil macronutrient plays a crucial role in the production process, and is vital to the smooth functioning of agri-ecosystem (Ju and Gu 2014, Liang et al. 2017). Nutrient fertilisation contributes a major role in plant development process from crop establishment stage to final harvesting, and nitrogen, phosphorus and potassium are known to affect production quantity and quality significantly (Isitekhale et al., 2013). Nitrogen is the most important nutrient which affects tomato transpiration and WUE and studies have shown that inadequate nitrogen application restrict crop yield (Zhou et al., 2020). However, excess nitrogen increases the osmotic potential of soil solution, thereby decreasing water uptake and crop transpiration (Kang et al., 2011). Phosphorus is important for strong root growth and makes plant physically sturdy, is one of the most limiting plant nutrients (Sun et al., 2015). Phosphorus losses through leaching are negligible in non-irrigated environments due to the low mobility into the soil profile (Bünemann et al., 2013; Fixen and Bruulsema 2014). Moreover, high soil moisture content often leads to greater phosphorus availability under full irrigation scenarios compared to water-stressed conditions (Suriyagoda et al., 2014). The addition of potassium in soil through fertiliser is required for plant development which also improves tomatoes fruit setting, yield and eventually fruit quality (Kafkafi and Tarchitzky 2011).

Resources conservation and management in agriculture is essential which can be made possible by applying less production inputs with proper planning (Dunage et al., 2009). From resources use maximization point of view in tomato horticulture, different irrigation strategies have been practiced and one of the strategies is deficit irrigation (DI) integrating with drip method (Agbna et al., 2017; Dunage et al., 2009). The main objective of DI is to maximise water productivity (Chand et al., 2021) which might more beneficial to farmers in water limiting regions compared to yield expansion (Geerts and Raes, 2009). However, there are still some controversies about application of DI when using different water qualities for agricultural production. Success of non-conventional water sources like recycled wastewater in agriculture is only possible if soil health and underground water quality could be saved by reducing over-loading of water with

high nutrient content (Alrajhi et al., 2015). In contrast, the probability of salt accumulation in root-zone is higher under DI scenarios because of less leaching opportunity in DI (Kaman et al., 2006) which can create unfavourable plant growth environments if not managed properly.
This paper primarily focuses on how soil and plant system get affected by using three water qualities as irrigation source with four DI levels while producing one of the most popular greenhouse tomato cultivars, named Izmir. The specific objectives are:

1.To investigate the effects of water quality and DI on soil macronutrients available to plants
2.To examine the effects of water quality and DI on distribution of soil salinity in effective root-zone area

2. MATERIALS AND METHODS

2.1Experimental Site

This experimental research program was carried out in two consecutive years (2017-2018 and 2018-2019) at a laboratory greenhouse of the University of South Australia. A 7.6 m (length) by 6.2 m (width) space in the greenhouse was used, maintaining row to row distance of 75 cm and plant to plant distance of 52 cm, which corresponds with common practice for tomato growers in the Northern Adelaide Plains (NAP) regions. NAP is the largest greenhouse zone in all over the Australia (Kelly et al. 2017; Primary Industries & Regions SA, 2019) which generates over one-third of South Australia's horticulture production, approximately 170,000 tons of fresh produce, valued over $340 million per annum (Primary Industries & Regions SA, 2019).

2.2 Details of experiment

It was a pot-based experiment, with a polyvinyl chloride pot of 75 cm depth and 52 cm diameter. Figure 1 (Chand et al., 2021) shows the detailed information about the location of plant, irrigation system, soil moisture sensor with access tube and a water tank.

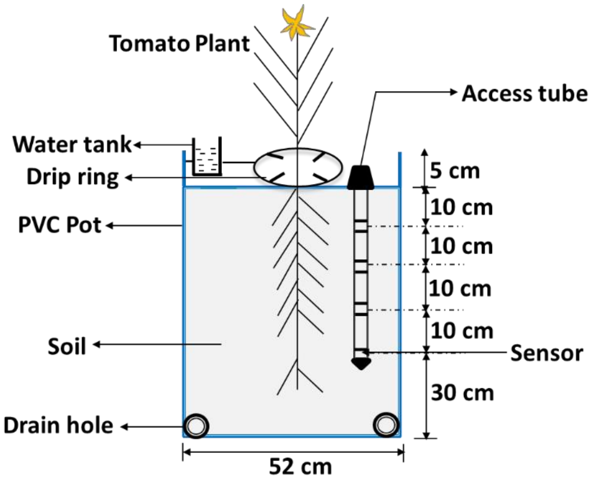

Figure 1: Layout of an experimental pot

The selected soil was loamy sand with dry bulk density 1.57 g/cm3 and the field capacity (FC) 17.3%. The crop variety was Izmir which is an indeterminate greenhouse tomato cultivar popularly used by NAP farmers. The seedlings were transplanted at the centre of pot, with one plant per pot in accordance with the procedures explained in Wang et al., (2015), Alrajhi et al.,

(2017) and Liu et al., (2019). Three major source water qualities used in the NAP as irrigation were selected. These were: groundwater (GW); recycled wastewater (RW, Class A) from Bolivar Wastewater Treatment Plant at Bolivar, SA; and mixed water (MW, consisting of 50% GW and 50% RW by volume) which is a typical of local farmers who routinely use both RW and GW in a blend.

The initial chemical and physical characteristics of the experimental soil and irrigation waters were analysed in the laboratory located at the University of South Australia. Three samples of soil and each water type were selected randomly for analysis. The results are presented in Table 1 and Table 2 respectively.

Table 1: Initial chemical and physical characteristics of experimental soil

Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)	K (mg/kg)	B (mg/kg)	N (mg/kg)	P (mg/kg)	C (mg/kg)	pH	EC
3030	1070	80	2020	3.1	1550	1720	2.95	7.35	1.05

Table 2: Chemical and physical characteristics of experimental irrigation waters

Water	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	B (mg/L)	N (mg/L)	P (mg/L)	C (mg/L)	pH	EC (dS/m)
GW	41	41	229	9	0.2	0.1	0.01	41	7.1	1.9
RW	70	44	325	38	0.5	5.7	0.02	61	7.3	2.1
MW	58	43	280	24	0.4	2.7	0.01	46	7.2	2

Note: GW=Groundwater; RW=Recycled wastewater; MW=Mixed water

2.3 Experimental design

This study applied a 2-factorial randomized design with four replications where the first factor represented water quality (three levels: GW, RW and MW) and the second factor represented irrigation scenarios (four levels: 100% FC, 80% FC, 70% FC and 60% FC). There were 12 treatments in the experiment, producing a total of 48 pots. A detail of experimental design and irrigation treatments is presented in Table 3.

Table 3: Details of the experimental design treatments

Water Quality	Treatment No.	Treatment Name	Irrigation Supply Level	Scenario
GW	1	GWI	100% of FC	Control

GW	2	GWI_1	80% of FC	Test
GW	3	GWI_2	70% of FC	Test
GW	4	GWI_3	60% of FC	Test
RW	5	RWI	100% of FC	Control
RW	6	RWI_1	80% of FC	Test
RW	7	RWI_2	70% of FC	Test
RW	8	RWI_3	60% of FC	Test
MW	9	MWI	100% of FC	Control
MW	10	MWI_1	80% of FC	Test
MW	11	MWI_2	70% of FC	Test
MW	12	MWI_3	60% of FC	Test

2.4 Soil moisture measurement

Volumetric soil moisture content (SMC) was measured before each irrigation event using a PR2/4 Profile Probe (Delta-T Devices Ltd, PR2-UM-5, www.delta-t.co.uk) and following the method suggested by Savic et al., (2011). An access tube was installed in the effective root-zone area of each monitoring pot (Figure 1) as described in Soulis et al., (2015).

2.5 Application of irrigation

This study was designed with irrigation frequency of two days following Chen et al. (2014), Alrajhi et al. (2015) and Wang et al. (2017). Based on the SMC data of particular day in each treatment, the actual quantity of irrigation was determined. Detailed information of irrigation application is provided on Chand et al. (2021).

2.6 Evaluation of soil nutrients

Soil nutrients evaluation and analysis was carried out by taking three soil samples from each treatment before transplanting and soon after finishing the fruits harvesting. The soil samples were collected from each side and different depths of pot and mixed homogeneously. Then they were air-dried in laboratory for 48 hours and homogenised using a 2mm sieve.

The method employed in this study for calculating soil nitrogen was compliant with NEPM (2013) Schedule (B3). Nitrogen content in experimental soil was evaluated at the University of South Australia laboratory using a Seal AA3 segmented nutrient analyser (Seal Analytical USA). Phosphorus and potassium content in experimental soil was evaluated at ALS laboratory, Adelaide. The method employed in this study for calculating phosphorus and potassium was compliant with Australia's National Environment Protection Measures NEPM (2013) Schedule B3- Guideline on laboratory analysis of potentially contaminated soil.

2.7 Soil Salinity monitoring

Continuous movement and distribution of soil salinity within the root-zone were measured on fortnightly basis. For this, a low flow porous ceramic cup (LOW-2172 Sentek Solu SAMPLER) was inserted 25 cm below from soil surface as shown in Figure 2. There were altogether 36 ceramic cups; three for each treatment. Soil water was directly extracted from porous cup with the help of 60 ml disposable syringe and collected in a 100 ml beaker as done by Hassanli and Pezanity (2013). The beakers were taken to lab and put in a mechanical vibrator for 30 minutes. Soil salinity of each sample was monitored using Waterproof EC Meter (HI 9814, HANNA Instruments, and SN: 02350106991).

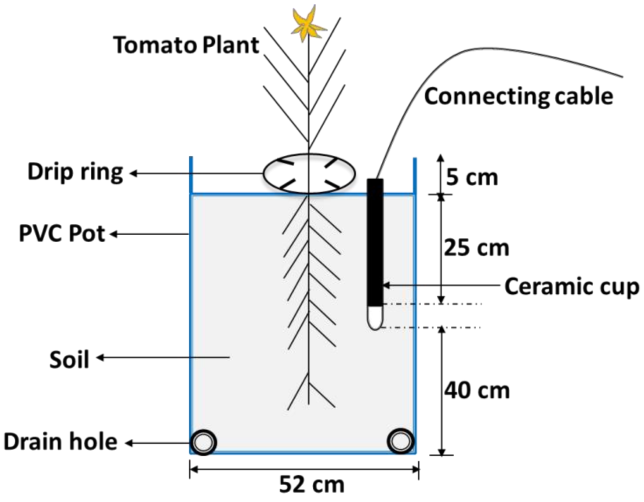

Figure 2: Layout of porous ceramic cup in experimental pot

2.8 Statistical analysis

To achieve the objective of this paper, soil samples collected from 12 treatments before the transplanting and after the harvesting of tomatoes were tested. The data were analysed to understand if the differences in mean parameter values of the 12 treatments were significantly different from each other. Water qualities and DI levels were taken as independent variables. Soil nutrients and salinity were considered as the dependent variables. Differences between means were evaluated for significance using the LSD test at 5% level of confidence ($P< 0.05$). Duncan's Multiple Range Test for significance comparison of two individual treatments was applied. A two-way ANOVA was conducted to compare the mean difference between groups (water qualities and DI levels) and the interaction between the groups.

3.RESULTS AND DISCUSSION

3.1 Effects on soil macronutrients

In this section, results showing effects of varying DI level and water qualities on soil nitrogen accumulation within a crop growth season is analyzed and explained in detail. The initial N content in the experimental soil was 1550 mg/kg.

Table 4 summarises the mean residual soil macronutrients in the samples collected from 12 treatments after harvesting tomato fruits. Soil irrigated with RW showed the highest residual N among the three water qualities followed by MW and GW, which is consistent with the amount of N added through irrigation. The result showed that the N uptake rate by plants decreased with the increase in water stress imposed which is consistent with the findings of Kirda et al., (2005) and Wang et al., (2009). The main reason could be that fewer nutrients were supplied in DI scenarios because of less water applied compared to the control treatment. This finding agrees with recent studies by Sun et al., (2015), Liu et al., (2015), Shirgure and Srivastave (2013), Wang et al., (2009) and Arienzo et al., (2009) who concluded that the greater volume of water supplied in full irrigation compared to DI, results in a higher level of nutrient uptake by plants.

Table 4: Residual soil macronutrients across three water qualities and four irrigation scenarios in experimental years 2017-2018 and 2018-2019

Year	Treatment	N (mg/kg)	P (mg/kg)	K (mg/kg)
2017-2018	GWI	1486.67±0.88f	1695.33±0.88f	1911.67±0.88h
	GWI	1485.33±1.20f	1696.33±0.33f	1913.67±0.66h
	GWI$_1$	1476.33±0.88f	1700.00±0.57ef	1916.67±0.88gh
	GWI$_2$	1467.67±0.88h	1702.67±0.88d	1920.67±0.88f
	GWI$_3$	1543.67±0.66a	1705.67±0.33bc	1936.67±0.88c
	RWI	1543.00±0.57a	1706.33±0.33b	1939.33±0.66b
	RWI$_1$	1535.00±1.15b	1708.67±0.33a	1941.33±0.88ab
	RWI$_2$	1529.00±1.15c	1709.67±0.66a	1943.33±0.88a
	RWI$_3$	1535.00±0.57b	1702.33±0.88d	1925.33±0.88f
	MWI	1533.67±0.33b	1704.00±0.57cd	1928.33±0.88e
	MWI$_1$	1523.33±0.88d	1706.67±0.66b	1929.67±0.882e
	MWI$_2$	1513.67±1.20e	1709.00±0.57a	1931.67±0.88d
2018-2019	GWI	1488.00±1.00f	1697.67±0.33g	1918.67±0.88i
	GWI$_1$	1486.67±0.33f	1698.67±0.88g	1920.67±0.88i
	GWI$_2$	1480.33±0.88g	1702.00±0.57f	1923.33±0.88h
	GWI$_3$	1476.67±0.66h	1704.33±0.33de	1926.67±0.66g
	RWI	1542.33±0.88a	1706.00±0.57cd	1937.33±0.88d
	RWI$_1$	1542.00±0.57a	1707.00±0.57cd	1940.33±0.88c
	RWI$_2$	1537.33±0.88b	1709.67±0.88ab	1943.33±0.88b
	RWI$_3$	1531.33±0.88c	1711.33±0.33a	1946.67±0.88a

MWI	1533.33±0.88c	1702.33±0.88f	1926.33±0.88g
MWI_1	1532.33±0.88c	1703.33±0.88ef	1927.67±0.33fg
MWI_2	1526.33±0.88d	1706.67±0.66c	1929.67±0.88f
MWI_3	1517.67±0.88e	1708.67±0.33b	1933.33±0.66e

Table 4 also indicates that residual soil N (accumulated N after a crop growth season) values in the treatments with 70% FC and 60% FC were significantly different from that of the control (100% FC) while the accumulated N values in 80% FC treatment was statistically similar to the control regardless of water quality. It means, there was no significant difference in N accumulation in soil when the SMC is reduced from 100% FC to 80% FC. Table 4 also confirms that the residual P and K content of soil in different treatments compared to control follow the same pattern as observed in N.

Figure 3 indicates the percentage loss in soil N content after a crop growth season. The avreage percentage reduction of both years in control treatments; GWI, RWI and MWI were 19.2%, 34.1% and 19.9% respectively. Also observed from Figure 3 is that the percentage reduction was less when level of water deficeincy was increased.

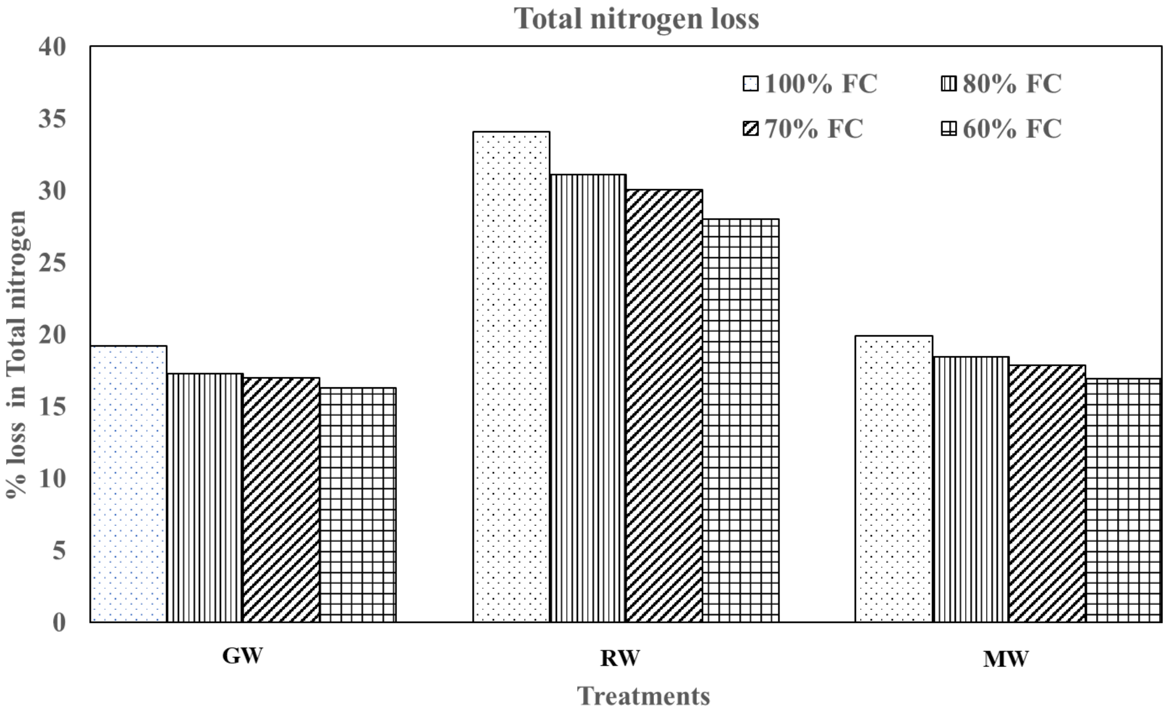

Figure 3: Average percentage loss in soil N in the 12 selected treatments after a crop growth season in 2017-2018 and 2018-2019

From the results presented so far demonstrate the pattern of how residual soil macronutrients vary in different treatments according to water quality as well as irrigation deficiency levels. However, it was not known whether these variations are significantly different from one another and how significant the interaction of water quality with the irrigation deficiency levels is. Therefore, a two-way ANOVA analyses of soil macronutrients under three water qualities (W), four irrigation scenarios (I) and their interactions (W × I) were completed, and results are presented in Table 5. The results indicate that W, I and W × I all had significant effects on residual soil N at the 5% level of significance. For example, in treatments maintaining SMC at 80% FC, the average values of soil N were 1485, 1542 and 1533 mg/kg for GW, RW and MW respectively, and were significantly different from one another at the 5% significance level. This observation confirms that water quality had a significant effect on residual soil N. Similarly, both W and I individually had significant effects on residual soil P and residual soil K; however, their interaction was not significant.

Table 5:Two-way ANOVA for soil macronutrients under four irrigation scenarios (I) and three water qualities (W) and their interactions (W × I)

Nutrient	Year	Source	Df	SS	MS	F-value	P-value
N	2017-2018	W	2	23266.72	11633.36	4705.63	0.00
		I	3	1996.31	665.44	269.16	0.00
		W × I	6	41.94	6.99	2.83	0.03
	2018-2019	W	2	20637.56	10318.78	5088.71	0.00
		I	3	927.86	309.29	152.53	0.00
		W × I	6	33.56	5.59	2.76	0.03
P	2017-2018	W	2	532.72	266.36	228.31	0.00
		I	3	201.33	67.11	57.52	0.00
		W × I	6	11.50	1.92	1.64	0.18
	2018-2019	W	2	329.39	164.69	131.76	0.00
		I	3	238.53	79.51	63.61	0.00
		W × I	6	4.39	0.73	0.59	0.74
K	2017-2018	W	2	3607.06	1803.53	832.40	0.00
		I	3	262.08	87.36	40.32	0.00
		W × I	6	12.50	2.08	0.96	0.47
	2018-2019	W	2	2367.17	1183.58	591.79	0.00
		I	3	329.44	109.81	54.91	0.00
		W × I	6	6.39	1.06	0.53	0.78

Table 6 compares the summary results of macronutrient analyses, from which it can be postulated that RW supplied considerably higher amounts of nutrients to the soil through irrigation compared to GW and MW. As a result, available nutrients to the plants were higher in treatments which were irrigated with RW and hence the residual soil nutrients. Percentage loss in nutrient (or uptake) in Table 6 was prepared based on balance equation that how much nutrient was added through irrigation water and how much was in soil prior to irrigation equal to how much nutrient drained out and how much remained in the soil after experiment.

Table 6: Summary result of soil macronutrients analysis

	Initial TN in soil 1550 mg/kg				Initial P in soil 1720 mg/kg				Initial K in soil 2020 mg/kg			
Treatment	N Concentration in water (mg/L)	N Added through irrigation (mg/L)	Residual N in soil (mg/kg)	% uptake /loss	P Concentration in water(mg/L)	Added through irrigation	Residual P in soil (mg/kg)	% uptake/ loss	K Concentration in water (mg/L)	Added through irrigation (mg/L)	Residual K in soil (mg/kg)	% uptake /loss
GWI	2.1	290	1487	19.2	0.1	14	1696	2.2	9	1242	1915	41.3
GWI$_1$		246	1486	17.3		12	1697	2.0		1052	1917	37.6
GWI$_2$		230	1478	16.9		11	1701	1.7		986	1920	36.1
GWI$_3$		208	1472	16.3		10	1703	1.5		892	1923	33.9
RWI	5.7	791	1543	34.1	0.3	42	1705	3.2	38	5274	1937	73.4
RWI$_1$		688	1542	31.1		36	1705	2.9		4587	1939	70.6
RWI$_2$		645	1536	30.0		34	1709	2.6		4303	1942	69.3
RWI$_3$		576	1530	28.0		30	1710	2.3		3843	1945	66.8
MWI	2.7	365	1534	19.9	0.2	27	1702	2.6	24	3245	1925	63.4
MWI$_1$		329	1533	18.4		24	1703	2.3		2924	1928	61.0
MWI$_2$		306	1524	17.8		23	1706	2.1		2720	1929	59.3
MWI$_3$		274	1515	16.9		20	1708	1.8		2440	1932	56.7

As shown earlier in Table 6, soil irrigated with GW had the lowest residual N, P and K after harvesting, since concentrations of these nutrients in GW were lower which led to a lower loading in the soil. In this study, there was no evidence for leaching of N, P and K because irrigation was applied to reach, not exceed, the FC level for control treatments and less water was added for DI treatments. Previous studies have demonstrated that DI techniques can improve nutrient use efficiency (Liang et al., 2017; Kirda et al., 2005; Wang et al., 2017). This study also confirmed that, compared to the control treatments, there was no significant difference in soil macronutrient accumulation when irrigation was supplied at 80% FC. The results thus suggested that a considerable amount of water and fertilizer can be saved through application of DI technique - especially at 80% FC level without having a significant difference of soil macronutrient compared to full irrigation.

3.2 Salinity distribution in the root-zone

Before the transplantation, soil salinity was 1.05 dS/m. The salinity of the irrigation waters-GW, RW and MW were 1.9, 2.1 and 1.95 dS/m respectively. Table 7 shows the variation of soil salinity at the end of each harvesting season across different treatments of GW, RW and MW in both experimental years.

Table 7: Soil salinity within root-zone in the 12 selected treatments after a crop growth season in experimental year 2017-2018 and 2018-2019

Treatment	Soil salinity (dS m^{-1})	
	2017-2018	2018-2019
GWI	2.77±0.009i	2.81±0.009i
GWI_1	2.96±0.009j	2.90±0.007j
GWI_2	3.12±0.009g	3.10±0.018h
GWI_3	3.31±0.010e	3.25±0.009ef
RWI	3.37±0.007d	3.31±0.017de
RWI_1	3.44±0.007c	3.40±0.006cd
RWI_2	3.50±0.009b	3.47±0.009b
RWI_3	3.76±0.012a	3.66±0.024a
MWI	2.95±0.006hi	2.95±0.015i
MWI_1	3.10±0.007g	3.14±0.007g
MWI_2	3.24±0.009f	3.27±0.009ef
MWI_3	3.45±0.009c	3.51±0.012bc

The result presented here was based on the EC values of soil-water samples collected at 25 cm below the topsoil surface using porous ceramic cups. Soil irrigated with RW showed significantly higher EC among the three water qualities at the same deficit level. This could be attributed due to higher EC of RW compared to GW and MW. The control treatments attained the lowest level of salinity with GW (2.79 dS/m), RW (3.34 dS/m) and MW (2.95 dS/m). In contrast, DI caused an increase in soil salinity despite of the water sources. This was evident in the treatments maintaining SMC at 60% FC where the EC reached to the maximum levels of 3.28, 3.71 and 3.48 dS/m in GW, RW and MW respectively.

Irrigation waters irrespective of their source contain salts in different amounts which results increment in soil salinity during crop production, particularly in the absence of leaching. Salt accumulates within the root-zone due to less leaching and higher concentrations of nutrients in water, or a combination of these two factors (Adhikari et al., 2014; Alrajhi et al., 2015). For example, in the present study, the salt accumulation within the root-zone (top 25 cm depth) in DI treatments was attributed to both no leaching facilities and high concentration of nutrients input from RW. Also, the experimental soil was loamy sand which has relatively higher infiltration rate that might cause more salt movement to the depth below 25 cm in full irrigation scenario compared to that in the DI. In addition, the amount of water applied to the soil contributed to the redistribution of salt within the root-zone. It is generally expected that more salts would be leached from soil surface and effective root-zone in full irrigation conditions. The results of this study agree with the findings of Diaz et al., (2013), Ghrab et al., (2013) and Aragues et al., (2014) who reported that soil salinity and sodicity were generally higher in DI scenarios. Kaman et al., (2006) investigated soil salinity in DI for tomato crop and reported that highest salt accumulation took place in top 20 cm and soil EC under DI at the end of harvesting was 35% higher than that of full irrigation. Similar findings were observed by many other reserachers who mentioned that soil salinity and sodicity were mainly concentrated on top layers of root-zone (Amiri et al., 2008; Laurenson et al., 2010).

Table 8 shows the output of the two-way ANOVA for soil salinity after harvesting under four irrigation scenarios (I), three water qualities (W) and their interactions (W × I).The results indicated that W, I and their interaction all had significant effects on soil salinity at the 5% level of significance. For example, in treatments maintaining SMC at 70% FC, the average EC values were 3.11, 3.49 and 3.26 dS/m for GW, RW and MW respectively which were significantly different from each other. It proved that water quality imposed a significant effect on soil salinity at each deficit level.

Table 8: Output of the two-way ANOVA for soil salinity under four irrigation scenarios (I) and three water qualities (W) and their interactions (W × I)

Particular	Year	Source	Df	SS	MS	F-value	P-value
Salinity	2017-2018	W	2	1.44	0.72	3283.90	0.00
		I	3	1.10	0.37	1666.85	0.00
		W × I	6	0.04	0.01	30.84	0.00
	2018-2019	W	2	1.18	0.59	1188.81	0.00
		I	3	1.00	0.33	667.22	0.00
		W × I	6	0.05	0.01	16.32	0.00

Table 9 indicates how the mean value of EC (average of both years) in a crop growth season varied within the root-zone in different treatments and its effect on soil salinity hazard. The results showed that all the treatments selected in this study were classified into slightly saline group according to FAO (2018) definition except GWI which came into non-saline category.

Table 9: Mean EC (dS/m) and soil salinity hazard among different combinations of three water qualities and four irrigation scenarios

Treatment	Mean EC (dS/m)	Soil salinity hazard
GWI	1.85	Non saline
GWI_1	2.07	Slightly saline
GWI_2	2.13	
GWI_3	2.27	

RWI	2.10
RWI$_1$	2.10
RWI$_2$	2.25
RWI$_3$	2.53
MWI	2.09
MWI$_1$	2.10
MWI$_2$	2.24
MWI$_3$	2.40

Note: FAO (2018) Soil salinity hazard, Non saline: <2 dS/m, slightly saline: (2-4) dS/m, moderately saline: 4-8, very saline: 8-16 and highly saline: >16.

4. CONCLUSIONS

This paper studied the key effects of varying water quality and DI on different parameters of experimental soil with an aim to provide additional insights on the improvement of resources use efficiency (particularly water and nutrients) under limited-water availability. The assessment of residual soil macronutrients demonstrated that DI scenario maintaining SMC at 80% FC produced statistically similar effects with that of the control on availability of soil macronutrients to the plant. Although the salinity within the root-zone was higher in DI conditions (particularly 60% FC in RW), the level of salinity hazard was classified under slightly saline group. The maximum salt accumulation within the root-zone was 3.76 dS/m in treatment RWI$_3$ which indicated that the risk of salt build-up can be higher in the absence of suitable leaching facilities in 60% FC conditions. Therefore, this study recommends that DI strategy maintaining SMC at 80% FC could be a latent approach for saving resources (primarily water and nutrients). In addition, this study recommends arranging leaching facilities either at the end or start of cropping season for salinity management particularly when RW is used as an irrigation source.

REFERENCES

Adhikari P, Shukla M, Mexal J, et al. (2014) Irrigation with treated wastewater: quantification of changes in soil physical and chemical properties. *Irrigation and Drainage System Engineering* 3: 1-11.

Agbna GH, Dongli S, Zhipeng L, et al. (2017) Effects of deficit irrigation and biochar addition on the growth, yield, and quality of tomato. *Scientia Horticulturae* 222: 90-101.

Aghaie P, Tafreshi SAH, Ebrahimi M, et al. (2018) Tolerance evaluation and clustering of fourteen tomato cultivars grown under mild and severe drought conditions. *Scientia Horticulturae* 232: 1-12.

Alrajhi A, Beecham S, Bolan NS, et al. (2015). Evaluation of soil chemical properties irrigated with recycled wastewater under partial root-zone drying irrigation for sustainable tomato production. *Agricultural Water Management* 161: 127-135.

Alrajhi A, Beecham S, Hassanli A, (2017). Effects of partial root-zone drying irrigation and water quality on soil physical and chemical properties. *Agricultural Water Management* 182: 117-125.

Amiri SS, Maralian H, Aghabarati A, (2008) Heavy metal accumulation in under crown Olea europaea L forest irrigated with wastewater. *African Journal of Biotechnology* 7: 3912-3916.

Aragues R, Medina E, Claveria I, et al. (2014) Regulated deficit irrigation, soil salinization and soil sodification in a table grape vineyard drip-irrigated with moderately saline waters. *Agricultural Water Management* 141: 1-9.

Arienzo M, Christen E, Quayle, et al. (2009) A review of the fate of potassium in the soil-plant system after land application of wastewaters. *Journal of Hazardous Material* 164: 415-422.

Beckles DM, (2012) Factors affecting the postharvest soluble solids and sugar content of tomato (*Solanum lycopersicum* L.) fruit. *Postharvest Bio Technology* 63: 129-140.

Bunemann EK, Keller B, Hoop D, et al. (2012) Increased availability of phosphorus after drying and rewetting of a grassland soil: processes and plant use. *Plant and Soil* 370: 511-526.

Chand J, Hewa GA, Hassanli A, et al. (2020) Evaluation of deficit irrigation and water quality on production and water productivity of tomato in greenhouse. *Agriculture* 10: 1-18.

Chand J, Hewa GA, Hassanli A, et al. (2021) Deficit irrigation on tomato production in a greenhouse environment: A review. *Journal of Irrigation and Drainage Engineering* 147: 1-10.

Chen J, Kang S, Du T, et al. (2014) Modelling relations of tomato yield and fruit quality with water deficit at different growth stages under greenhouse condition. *Agricultural Water Management* 146: 131-148.

Cui J, Shao G, Lu J, et al. (2020) Yield, quality and drought sensitivity of tomato to water deficit during different growth stages. *Scientia Agricola* 77: 1-9.

Diaz FJ, Tejedor M, Jimenez C, et al. (2013) The imprint of desalinated seawater on recycled wastewater: consequences for irrigation in Lanzarote Island, Spain. *Agricultural Water Management* 116: 62-72.

Du Q, Zhang D, Jiao X, et al. (2018) Effects of atmospheric and soil water status on photosynthesis and growth in tomato. *Plant, Soil and Environment* 63: 13-19.

Dunage VS, Balakrishnan P, Patil MG, (2009) Water use efficiency and economics of tomato using drip irrigation under net-house conditions. *Karnataka Journal of Agricultural Science* 22: 133-136.

FAO, (2018) Handbook for saline soil management. Food and Agriculture Organization of United Nations, Rome, Italy.

Fixen P, Bruulsema T, (2014) Potato management challenges created by phosphorus chemistry and plant roots. *American Journal of Potato Research* 91: 121-131.

Geerts S, Raes D, (2009) Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agricultural Water Management* 96: 1275-1284.

Ghrab M, Gargouri K, Bentaher H, et al. (2013) Water relations and yield of olive tree (cv. Chemlali) in response to partial rootzone drying (PRD) irrigation technique and salinity under arid climate. *Agricultural Water Management* 123: 1-11.

Giuliani MM, Carucci F, Nardella E, et al. (2018) Combined effects of deficit irrigation and strobilurin application on gas exchange, yield and water use efficiency in tomato (Solanum lycopersicum L.). *Scientia Horticulturae* 233: 149-158.

Haifa (2018) Nutritional recommendations for tomato in open-field, tunnels and greenhouses. https://www.haifa-group.com/crop-guide/vegetables/tomato/crop-guide-tomato-plant-nutrition (accessed 5 September 2021).

Hao L, Ai-wang D, Fu-sheng, SUN et al. (2013) Drip Irrigation Scheduling for Tomato Grown in Solar Greenhouse Based on Pan Evaporation in North China Plain. *Journal of Integrative Agriculture* 12: 520-531.

Hassanli AM, Pezzaniti D, (2013) Crop irrigation scheduling in South Australia: a case study. *Water* 40: 92-97.

Isitekhale H, Osemwota I, Amhakhian S, (2013) Poultry manure and NPK fertilizer application and their residual effects on the yield and yield components of tomato (Lycopersiconesculentum. Mill) in two distinct ecological zones of Central Southern Nigeria. *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)* 3: 40-47.

Johnstone PR, Hartz TK, LeStrange M, et al. (2005) Managing fruit soluble solids with late-season deficit irrigation in drip-irrigated processing tomato production. *HortScience* 40: 1857-1861.

Jones JB, (2007) Tomato Plant Culture in the field, greenhouse and home garden, CRC Press, New York, USA.

Ju XT, Gu, BJ, (2014) Status-quo, problem and trend of nitrogen fertilization in China. *Plant Nutrition and Fertiliser Science* 20: 783-795.

Kafkafi U, Tarchitzky J, (2011) Fertigation: A tool for efficient fertilizer and water management. International Fertilizer Industry Association and International Potash Institute, Paris, France.

Kaman H, Kird, C, Cetin M, et al. (2006) Salt accumulation in the root-zone of tomato and cotton irrigated with partial root-drying technique. *Irrigation and Drainage* 55: 533-544.

Kang YI, Park JM, Kim SH, et al. (2011) Effects of root-zone pH and nutrient concentration on the growth and nutrient uptake of tomato seedlings. *Journal of Plant Nutrition* 34: 640-652.

Kelly J, Stevens D, White T, (2017) Achievements of the Virginia Pipeline Scheme: Horticultural production with reclaimed water'. http://www.recycledwater.com.au/uploads/File/documents/Jim%20Abstract%20Brisbane.pdf>(Accessed *7 September 2021).*

Kirda C, Topcu S, Kaman H, et al. (2005) Grain yield response and N-fertilizer recovery of maize under deficit irrigation. *Field Crops Research* 93: 132-141.

Klunklin W, Savage G, (2017) Effect on Quality Characteristics of Tomatoes Grown Under Well-Watered and Drought Stress Conditions. *Foods* 6: 1-10.

Laurenson S, Kunhikrishnan A, Bolan NS, et al. (2010) Management of recycled water for sustainable production and environmental protection: A case study with Northern Adelaide Plains recycling scheme. *International Journal of Environmental Science and Development* 1: 176-180.

Liang L, Ridoutt BG, Lal R, et al. (2017) Nitrogen footprint and nitrogen use efficiency of greenhouse tomato production in North China. *Journal of Cleaner Production* 208: 285-296.

Liu C, Rubaek GH, Liu F, et al. (2015) Effect of partial root zone drying and deficit irrigation on nitrogen and phosphorus uptake in potato. *Agricultural Water Management* 159: 66-76.

Liu H, Li H, Ning H, et al. (2019) Optimizing irrigation frequency and amount to balance yield, fruit quality and water use efficiency of greenhouse tomato. *Agricultural Water Management* 226: 1-11.

Maham SG, Rahimi A, Subramanian S, et al. (2020) The environmental impacts of organic greenhouse tomato production based on the nitrogen-fixing plant (Azolla). *Journal of Cleaner Production* 245: 1-9.

Marjanovic M, Radmila S, Biljana VR, et al. (2012) Growth and proteomic analysis of tomato fruit under partial root-zone drying. *OMICS: A Journal of Integrative Biology* 16: 343-356.

Montazar A (2019) *Agricultural Irrigation*. MDPI, Basel, Switzerland.

NEPM (2013) *National environment protection measure, National Environment Protection Council*. Canberra, Australia.

Pereira H, Marques RC (2017) An analytical review of irrigation efficiency measured using deterministic and stochastic models. *Agricultural Water Management* 184: 28-35.

Primary Industries and Regions SA, (2019) Northern Adelaide Plains Horticulture Region, Primary Industries and Regions South Australia, 2019, <https://www.pir.sa.gov.au/primary_industry/horticulture/northern_adelaide_plains_horticulture_region#toc1> (Accessed 1 September 2021).

Primary Industries and Regions SA, (2017) ‘North Adelaide Plain Agribusiness Initiative. http://www.pir.sa.gov.au/major_programs/northern_adelaide_plains_agribusiness_initiative> (Accessed 2 September 2021).

Pulido-Bosch A, Rigol-Sanchez JP, Vallejos A, et al. (2018) Impacts of agricultural irrigation on groundwater salinity. *Environmental Earth Sciences* 77: 1-14.

Savic S, Stikic R, Zaric V, et al. (2011) Deficit irrigation technique for reducing water use of tomato under polytunnel conditions. *Journal of Central European Agriculture* 12: 597-607.

Shirgure P, Srivastava A, (2013) Nutrient-water interactions in citrus-recent developments. *Agricultural Advances* 2: 224-236.

Siebert S, Burke J, Faures, JM, et al. (2010) Groundwater use for irrigation—A global inventory. *Hydrology and Earth System Sciences* 14: 1863–1880.

Soulis KX, Elmaloglou S, Dercasn N, (2015) Investigating the effects of soil moisture sensors positioning and accuracy on soil moisture-based drip irrigation scheduling systems. *Agricultural Water Management* 148: 258-268.

Sun Y, Cui X, Liu F, (2015) Effect of irrigation regimes and phosphorus rates on water and phosphorus use efficiencies in potato. *Scientia Horticulturae* 190: 64-69.

Suriyagoda LD, Ryan MH, Renton M, et al. (2014) Plant responses to limited moisture and phosphorus availability–a meta-analysis. *Advances in Agronomy* 124: 143-200.

Valipour M, (2015) Future of agricultural water management in Africa. *Archives of Agronomy and Soil Science* 61: 907-927.

Wang CX, Gu F, Chen JL, et al. (2015) Assessing the response of yield and comprehensive fruit quality of tomato grown in greenhouse to deficit irrigation and nitrogen application strategies. *Agricultural Water Management* 161: 9–19.

Wang J, Niu W, Zhang M, et al. (2017) Effect of alternate partial root-zone drip irrigation on soil bacterial communities and tomato yield. *Applied Soil Ecology* 119: 250-259.

Wang Z, Liu Z, Zhang Z, et al. (2009) Subsurface drip irrigation scheduling for cucumber (Cucumis sativus L.) grown in solar greenhouse based on standard pan evaporation in Northeast China. *Scientia Horticulturae* 123: 51-57.

Yahyaoui I, Tadeo F, Segatto MV (2016) Energy and water management for drip-irrigation of tomatoes in a semi- arid district. *Agricultural Water Management* 183: 4-15.

Zhou H, Kang S, Li F, et al. (2020) Nitrogen application modified the effect of deficit irrigation on tomato transpiration, and water use efficiency in different growth stages. *Scientia Horticulturae* 263, 1-10.