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Basic economics on deficit irrigation and water quality dynamics for horticulture production in a greenhouse environment

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Abstract

The objective of this paper is to examine the impact of varying deficit irrigation level and water quality scenarios on economic responses of tomatoes (Solanum lycopersicum cv. *Izmir*) produced in a greenhouse environment. Groundwater, recycled wastewater and a blend of both were selected as water qualities. Four irrigation scenarios were maintained including soil moisture at 60%, 70%, 80% and 100% of field capacity. The treatment maintaining soil moisture at 100% field capacity was control in this study for each water quality. The selected irrigation method and the soil texture were the drip and loamy sand respectively. The effects of deficit irrigation and water quality on the benefit-cost ratio, revenue generated per m^3 of water usage, cost function and net financial return were examined. Benefit-cost ratio was a maximum of 1.37 for the control treatment of recycled wastewater. All the selected deficit irrigation treatments produced the benefit-cost ratio more than one except 60% field capacity level. Revenue generation per m^3 of water usage was found the highest in treatments maintaining soil moisture content at 80% field capacity despite of water quality. Based on the benefit-cost ratio, cost function and revenue generated per cubic meter of water use, this study recommended the deficit irrigation level at 80% field capacity as the most cost-effective and water efficient strategy for greenhouse grown tomatoes.

Key words: benefit-cost analysis, deficit irrigation, greenhouse tomato, water quality, cost-benefit revenue.

Abbreviations: BCR_Benefit-Cost Ratio, DI_Deficit Irrigation, FC_Field Capacity, GR_Gross Return, GW_Groundwater, GWI_Treatment with groundwater irrigation maintaining SMC at 100% FC, GWI_1_Treatment with groundwater irrigation maintaining SMC at 80% FC , GWI_2_Treatment with groundwater irrigation maintaining SMC at 70% FC, m GWI_3_Treatment with groundwater irrigation maintaining SMC at 60% FC, ML_Mega Litre, MW_Mixed Water, MWI_Treatment with mixed water irrigation maintaining SMC at 100% FC, MWI_1_Treatment, with mixed water irrigation maintaining SMC at 80% FC, MWI_2_ Treatment with mixed water irrigation maintaining SMC at 70% FC, MWI_3_Treatment with mixed water irrigation maintaining SMC at 60% FC, NAP_Northern Adelaide Plains, NR_Net Return, RW_Recycled wastewater, RWI_Treatment with recycled wastewater irrigation maintaining SMC at 100% FC , RWI_1_Treatment with recycled wastewater irrigation maintaining SMC at 80% FC, RWI_2_ Treatment with recycled wastewater irrigation maintaining SMC at 70% FC, RWI_3_Treatment with recycled wastewater irrigation maintaining SMC at 60% FC , SA_South Australia, SMC_ Soil Moisture Content, TC_Total Cost, VC_ Variable Cost.

Introduction

The focus of this study is to analyse basic economics of tomatoes production in a protected environment particularly in water-limiting conditions for sustainability. The 2030 Agenda of the United Nations was approved in 2015, consisting of 17 sustainable development goals, with overall aim to “end hunger, achieve food security, and promote sustainable agriculture” (Valipour, 2015; Du et al., 2018; Duque-Acevedo et al., 2020) and water is one of the principal inputs that supports to achieve those through increased productivity. 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). However, competitive users of water have put tremendous pressure on agriculture sector to use water as the most scare resources (Montazar, 2019). Insufficient supply of water for crop production will be the norm rather than the exception, and irrigation management will shift from emphasising production per unit area towards maximising the production per unit of water consumed

(Fereres and Soriano, 2007; Zhang et al. ,2017). In the view of increasing water demand by other sectors, and expected reduction of water availability in the future, it is necessary to adopt water management strategies aimed at water saving while maintaining satisfactory levels of production (Costa et al., 2007; Montesano et al., 2015).

Tomato is a high-yielding and high-valued horticultural crop (Beckles, 2012; Klunklin and Savage, 2017; Aghaie et al., 2018; 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). Moreover, tomatoes are a highly water-dependent crop and are unfavourably affected by water shortage (Marjanovic et al, 2012; Klunklin and Savage, 2017; Giuliani et al., 2018). However, in greenhouse tomato, over-irrigation creates anaerobic soil conditions and consequently causes root death, delayed flowering, and fruit disorders (Yahyaoui et al., 2016; Haifa, 2018). Applying too much water can lead to a higher pumping cost and more disease pressure on the tomato crop (Scherer et al., 2017). Recent research in Canada indicated that tomato yield can be increased up to 81% through proper irrigation scheduling (Ministry of Agriculture Food and Rural Affairs, 2017). The Ministry further highlighted that as irrigation is one of the expensive parameters in tomato production, the maximum economic returns will only be justified when the most effective irrigation management design is employed.

Deficit irrigation (DI) is defined as the irrigation management strategy through which water consumption is deliberately made lower than crop water requirements and field capacity (FC) to improve water productivity (English and Raja, 1996; Wakrim et al., 2005; Lu et al., 2019; Zhou et al., 2020). A DI strategy exposes crops, in a pre-programmed manner, to some water stress during a specified period or over the entire growing season (Djurovic et al., 2016; Lahoz et al., 2016; Giuliani et al., 2018). Tomato cultivation requires a huge amount of water which can be considerably reduced by applying suitable DI regimes (Costa et al., 2007; Lu et al., 2019).

Water resources are limited for irrigation especially for the arid and semi-arid regions; therefore, there is an urgent need to reassess an alternative technique for both conventional irrigation method and irrigation source (Hakim et al., 2019). Using alternative sources of water and employing efficient irrigation management strategies are the two immediate remedies for sustainable agricultural development where water supply is limited (Birhanu and Tilahun, 2010; Hassanli et al., 2010; Hashem et al., 2018). Most of the agricultural operations do not have direct access to municipal water supply pushing them to consider alternative sources of water (Clark Tanks, 2018). Water can come from several sources including surface water (rivers and creeks), groundwater (GW) from bores and aquifers, rainwater and treated wastewater. However, the quality of water varies from one source to another which requires water quality testing for suitability in crop production.

The investigation into the effects of DI strategies in different water quality scenarios is considered essential to understand how water can be saved efficiently and economically while maintaining or improving crop productivity. Although the effects of varying water stress level on greenhouse tomato production have already been widely investigated, a limited literature is available explaining the effects of DI and water quality on economical parameters for establishing a sustainable environment in greenhouse tomato production. It is important to explore the effects of water quality and DI on economics because freshwater resources are becoming limited for irrigation especially in the arid and semi-arid regions; and there is an urgent need to reassess an alternative source of water for agricultural production. Thus, a study examining effects of both water quality and irrigation scenarios from a tomato field is essential to perform a comprehensive assessment and to develop a novel water management plan. Moreover, an economic analysis in relation to DI and water quality on greenhouse tomato is evaluated for the first time in this study. The specific objectives of this paper are: a) to investigate the effects of water quality and DI on profitability analysis through net returns (NR), b) to examine the effects of water quality and DI on benefit-cost ratio (BCR) and percentage reduction on BCR, c) to investigate the effects of water quality with DI on incremental cost and revenue generated, d) to investigate the effects of water quality with DI on cost and revenue per cubic meter of water usage, and e) to investigate the effects of water quality with DI on and cost function.

Results and discussion

Net return and benefit cost analysis

Table 1 and 2 indicate the variable cost (VC), fixed cost, total cost (TC), NR and BCR of greenhouse tomato production during experimental years 2017-2018 and 2018-2019 respectively. The VC decreased with an increase in irrigation deficit level regardless of water quality, i.e. in treatments maintaining soil moisture content (SMC) at 60% FC (GWI_3, RWI_3 and MWI_3), the lowest VC was observed which led to minimizing TC compared to other treatments. This was primarily due to the supply of a minimum quantity of inputs (water and fertilizers) in those treatments. In contrast, the highest TC was measured in control treatments which contained maximum VC.

NR was highest for the control treatments in both years and decreased with an increased DI applied. This occurred because the highest marketable yield was measured in control treatment, while yield decreased as DI level increased. Treatments GWI_3 and MWI_3 had the lowest mean marketable yield which made NR a negative value, producing an economic loss from tomato production if applying these DI strategies in production scale.

The BCR was greater than one in all treatments except GWI_3 in experimental year 2018-2019 (Table 2). The BCR in DI treatments in year 2017-2018 were recorded less than one (Table 1) because of reduced yield measured due to early blight disease in some tomato plants. The Highest BCR was recorded in RWI (1.37 in 2018-2019), followed by GWI (1.34, in 2018-2019). According to Michael (2003), any irrigation project with BCR more than one is suitable and cost-effective in water-limited conditions and a BCR more than 1.5 considered as acceptable in both water surplus and water deficit conditions.

Average revenue, total cost, and benefit cost ratio

Comparative analyses of the average revenue, TC, BCR and percentage change in BCR over two growing seasons are presented in Table 3. The NR and BCR in general are influenced by irrigation techniques, operating cost, and yield production (Shang and Tisdell, 1997). The highest BCR (average of two experimental years) was observed in treatment RWI, followed by GWI and MWI where while the lowest BCR was observed to be in treatment GWI_3, followed by MWI_3 and RWI_3. Importantly, the average BCR of two experimental years was found to be greater than one in every treatment except treatments maintaining SMC at 60% FC regardless of water quality. According to Paudel and Adhikari (2018) and Subedi et al. (2020), any irrigation project with a BCR over one indicates economic viability. Hence, this study suggests that DI level can be as low as 70% of FC without sacrificing economic viability in greenhouse tomato production.

Overall, RW produced a better BCR at each deficit level compared to GW and MW. The Percentage reduction in BCR at each DI level was calculated by taking the respective control treatment as the base (Table 3). The highest change in BCR was found to be in GWI_3 (30%) and lowest was observed in MWI_1 (3.3%) indicating that MW at 80% FC is more profitable compared to the other treatments.

Water savings due to application of deficit irrigation

In this study, water saving due to application of DI was analyzed following Ali et al. (2007) and Sarker et al. (2017). Gross water saving in DI scenarios was first calculated by taking the control treatment as the reference. Subsequently, the size of equivalent farm area that can be cultivated by thus saved water was calculated. The results are summarized in Table 4 which showed that around one mega liter (ML) of water per ha could be saved when treatments maintaining SMC at 60% FC is adopted. This saved water is enough to irrigate additional 0.4 ha tomato farm which is considered as the opportunity cost of water. The study of Chand et al., (2020) indicated that irrigating one ha land for greenhouse-grown tomatoes under full irrigation conditions, 3.52 ML water was needed in GW, whereas these values for RW and MW were 3.54 ML and 3.53 ML respectively. They also demonstrated that treatment maintaining SMC at 80% FC was optimum in terms of yield performance and water productivity. When the DI scenario where SMC is maintained at 80% FC was adopted to grow greenhouse tomato, an average of 0.45 ML/ha water could be saved which subsequently can be used to place an additional 0.15 ha land under cultivation. This could be significant because irrigated acreage in some arid reasons in the world is shrinking due to water limitations in agriculture and increasing competition for water among different sectors (Haghverdi et al., 2019). Supply of freshwater to agriculture in arid and semi-arid regions, such as the Mediterranean, is expected to decrease because most available potable water resources have already been mobilized (Bekmirzaev et al., 2019). The Food and Agricultural Organization believes that there is a world food shortage which can only be alleviated if agricultural yields can be increased in significant and sustainable fashion, and this will depend on an increase in the use of irrigable area and improvements in water management (Aranda-Martin, 2009; Zhang et al., 2017).

Incremental cost and revenue analysis

The additional benefit generated using the saved water to grow tomatoes on extra land could make a DI strategy cost-effective and economic compared to full irrigation. The incremental revenue generation from the additional land (saved water through DI) in water-limiting conditions was calculated based on the average VC and revenue per ha land and presented in Table 5. Total VC in DI strategies was higher compared to full irrigation due to increased acreage, and associated increase in cost for water, fertilizer use and labor. This finding agrees with Ali et al. (2007). Dunage et al. (2009) and Sarker et al. (2016) analyzed the profitability of tomatoes in water-stressed sceneries and recommended that DI could be a practicable and profitable method in the field of tomato production where availability of freshwater resources is limited and scarce. The result of this study showed that the treatments maintaining SMC at 80% and 70% FC were able to generate positive incremental revenue compared to control treatment despite of water quality. The highest incremental revenue was generated by the treatments maintaining SMC at 80% FC. In contrast, treatment maintaining SMC at 60% FC showed negative incremental revenue compared to the control. It indicated that growers could generate significant profit by adopting DI strategies maintaining SMC up to 70% FC. Beyond that economic loss starts to occur despite acquiring additional land to cultivate using the saved water.

Cost and revenue per cubic meter of water use

Figures 1 presents the comparison of average cost and revenue generated in 12 selected treatments in this study. Average cost and revenue generated per m^3 of water usage in all treatments were calculated following the method adopted by Ali et al. (2007). They had applied this technique for analyzing cost and revenue from applied water in wheat production using a DI strategy. They found that DI produced better revenue per m^3 water use compared to full irrigation. Our result showed that cost per m^3 of water use increased in DI strategies due to increased acreage and an associated increase in inputs used for production which is consistent with the findings of Ali et al. (2007). In addition, this study found that revenue generated per m^3 of water use was highest in treatment maintaining SMC at 80% FC. This was due to the highest water productivity in those treatments without significant yield reduction compared to the control treatment (Chand et al., 2020). Although yield per ha was reduced in 80% FC treatment compared to the control, the reduction in irrigation cost and the increased opportunity cost of water more than compensates for the lower yield. Decision of using economic water productivity indicators significantly improves on-farm irrigation management (Fernandez et al., 2020).

Average yield and cost functions

The average yield and cost functions of two experimental years is presented in Figure 2 which shows that the difference in total VC among each treatment was very minimal regardless of water quality. However, the yield difference among the treatments was significant except treatment maintaining SMC at 80% was statistically similar to that of the control (Chand et al., 2020). Hence, based on cost and yield functions analysis, the treatment at 80% FC represented the best DI strategy in water-limiting condition due to minimal cost difference compared to control and significant yield increment compared to treatments at 70% and 60% FC level.

Table 1. Summary of profitability analysis of greenhouse tomato in 12 selected treatments during 2017-2018.

Treatment	VC ($/ha)	TC ($/ha)	Mean marketable Yield (ton/ha)	GR ($/ha)	NR ($/ha)	BCR	% Change in yield	% Change in VC
GWI	174756.1	177851.1	76.5	178312.1	461.0	1.00	-	-
GWI_1	174100.4	177195.4	69.3	161471.5	-15723.8	0.91	9.4	0.4
GWI_2	173773.0	176868.0	55.3	128781.0	-48087.0	0.73	27.8	0.6
GWI_3	173454.7	176549.7	49.5	115407.6	-61142.2	0.65	35.3	0.7
RWI	175125.7	178220.7	78.9	183760.5	5539.8	1.03	-	-
RWI_1	174445.4	177540.4	71.9	167415.3	-10125.2	0.94	8.9	0.4
RWI_2	174094.0	177189.0	61.6	143640.3	-33548.7	0.81	21.8	0.6
RWI_3	173760.5	176855.5	55.7	129771.6	-47083.9	0.73	29.4	0.8
MWI	174892.7	177987.7	74.8	174349.6	-3638.09	0.98	-	-
MWI_1	174279.3	177374.3	70.6	164443.4	-12930.9	0.93	5.7	0.4
MWI_2	173939.2	177034.2	59.5	138687.2	-38347.0	0.78	20.5	0.5
MWI_3	173595.7	176690.7	51.2	119370.0	-57320.6	0.68	31.5	0.7

Note: TC was calculated by adding constant fixed cost value (1500$/ha for land leasing and 1595$/ ha for irrigation pipe and fittings) to total VC.GWI: Treatment with groundwater irrigation maintaining SMC at 100% FC; GWI_1: Treatment with groundwater irrigation maintaining SMC at 80% FC; GWI_2: Treatment with groundwater irrigation maintaining SMC at 70% FC; GWI_3: Treatment with groundwater irrigation maintaining SMC at 60% FC; RWI: Treatment with recycled wastewater irrigation maintaining SMC at 100% FC; RWI_1: Treatment with recycled wastewater irrigation maintaining SMC at 80% FC; RWI_2: Treatment with recycled wastewater irrigation maintaining SMC at 70% FC; RWI_3: Treatment with recycled wastewater irrigation maintaining SMC at 60% FC; MWI: Treatment with mixed water irrigation maintaining SMC at 100% FC; MWI_1: Treatment with mixed water irrigation maintaining SMC at 80% FC; MWI_2: Treatment with mixed water irrigation maintaining SMC at 70% FC; MWI_3: Treatment with mixed water irrigation maintaining SMC at 60% FC.

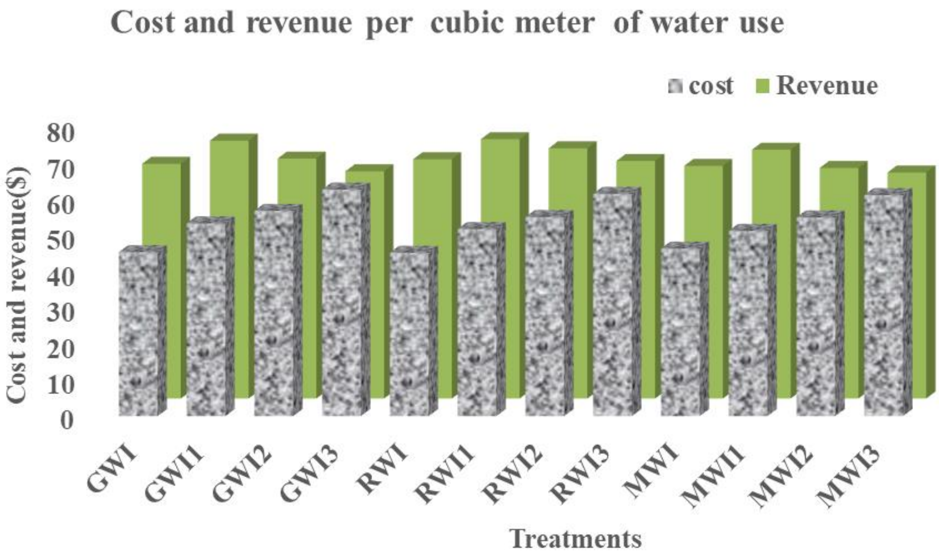

Fig 1. Comparison of cost and revenue generated in 12 treatments.

Table 2. Summary of profitability analysis of greenhouse tomato in 12 selected treatments during 2018-2019.

Treatment	Total VC ($/ha)	TC ($/ha)	Mean marketable Yield (ton/ha)	GR ($/ha)	NR ($/ha)	BCR	% change in yield	% change in VC
GWI	179241.8	182411.8	101.5	244686.8	62275.0	1.34		
GWI_1	178542.9	181713.0	96.7	233005.8	51292.9	1.28	4.8	0.4
GWI_2	178282.3	181452.0	90.3	217636.0	36183.7	1.20	11.1	0.5
GWI_3	177950.6	181121.0	74.7	180133.8	-986.8	0.99	26.4	0.7
RWI	179577.7	182748.0	103.6	249605.1	66857.5	1.37		0.0
RWI_1	178918.7	182089.0	100.5	242227.7	60138.9	1.33	3.0	0.4
RWI_2	178639.7	181810.0	94.9	228702.3	46892.6	1.26	8.4	0.5
RWI_3	178227.4	181397.0	76.5	184437.3	3039.9	1.02	26.1	0.8
MWI	179355.6	182526.0	98.0	236079.7	53554.1	1.29		0.0
MWI_1	178783.7	181954.0	96.2	231776.2	49822.5	1.27	1.8	0.3
MWI_2	178490.8	181661.0	84.4	203495.8	21835.0	1.12	13.8	0.5
MWI_3	178130.1	181300.0	75.5	181978.1	678.0	1.00	22.9	0.7

Note: TC was calculated by adding constant fixed cost value (1575 $/ha for land leasing and 1595 $/ ha for irrigation pipe and fittings) to total VC.

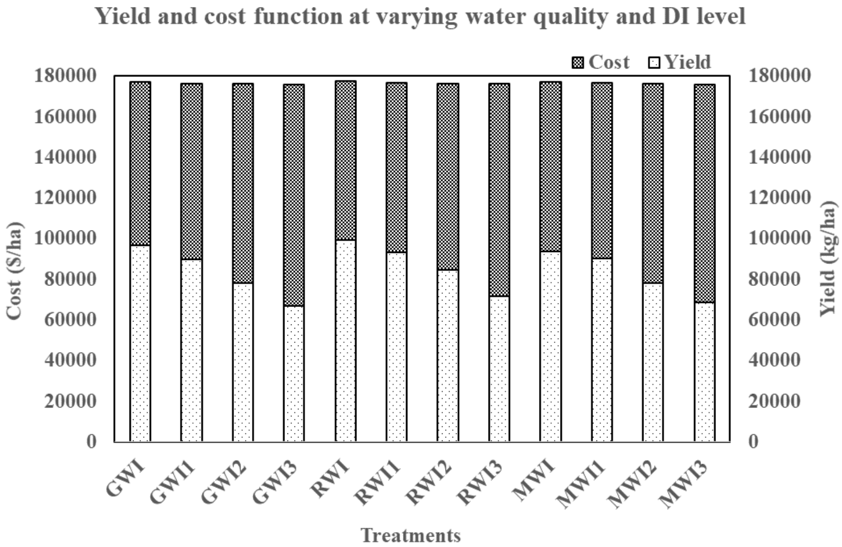

Fig 2. Comparison of cost and average yield in 12 treatments.

Table 3. Summary result of the benefit cost analyses over the two growing seasons.

T	Average revenue (000 $/ha)			Average TC (000$/ha)			Average BCR			% reduction in BCR		
	GW	RW	MW	GW	RW	MW	GW	RW	MW	GW	RW	MW
100% FC	180.1	180.5	180.3	229.3	235.1	222.7	1.27	1.30	1.24	-	-	-
80% FC	179.5	179.8	179.7	213.4	221.6	214.6	1.19	1.23	1.19	6.6	5.4	3.3
70% FC	179.2	179.5	179.3	186.1	200.5	185.0	1.04	1.12	1.03	18.4	14.2	20.4
60% FC	178.8	179.1	179.0	159.3	170.1	162.6	0.89	0.95	0.91	30.0	27.1	26.4

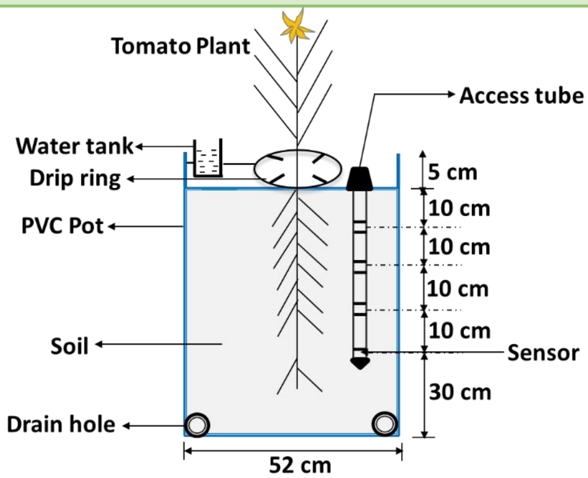

Fig 3. Layout of an experimental pot (Chand et al. 2021).

Table 4. Comparison of average water saving and potential extension of irrigation in nine treatments with respect to control over the two growing seasons.

Treatments	Applied water (ML/ha)	Mean water saving (ML/ha)	Potential extension of irrigation area by the saved water (ha)
GWI	3.52	-	-
GWI_1	2.98	0.53	0.18
GWI_2	2.79	0.72	0.26
GWI_3	2.52	0.99	0.40
RWI	3.54	-	-
RWI_1	3.07	0.46	0.15
RWI_2	2.88	0.65	0.23
RWI_3	2.58	0.96	0.37
MWI	3.53	-	-
MWI_1	3.10	0.34	0.11
MWI_2	2.89	0.55	0.19
MWI_3	2.59	0.85	0.33

Table 5. Incremental revenue from additional land use in nine DI treatments with respect to control in water limiting conditions

Treatment	Variable cost ($ /ha)	Revenue ($/ha)	Total irrigated area (1ha+ additional area ha)	Total operating cost ($)	Total revenue ($)	Incremental revenue compared to control ($)
GWI	176998.9	229332.3	1.00	176998.9	229332.3	-
GWI_1	176321.6	213387.3	1.18	208059.5	251797.1	22464.6
GWI_2	176027.6	186087.8	1.26	221794.8	234470.6	5138.2
GWI_3	175702.6	159312.5	1.40	245983.6	223037.5	-6294.8
RWI	177351.7	235060.6	1.00	177351.7	235060.6	-
RWI_1	176682.1	221564.5	1.15	203184.4	254799.2	19738.6
RWI_2	176366.8	200536.6	1.23	216931.2	246660.1	11599.4
RWI_3	175993.9	170082.8	1.37	241111.7	233013.5	-2047.1
MWI	177124.1	222651.2	1.00	177124.1	222651.2	-
MWI_1	176531.5	214555.6	1.11	195949.9	238156.8	15505.5
MWI_2	176214.9	184961.5	1.19	209695.8	220104.2	-2547.1
MWI_3	175862.9	162612.2	1.33	233897.6	216274.2	-6377.1

Materials and methods

Experimental Site

This experimental research program was carried out at University of South Australia, Mawson Lakes Campus Mawson Lakes, South Australia (SA). The study was executed in two consecutive years (2017-2018 and 2018-2019) and followed tomato growing conditions in the Northern Adelaide Plains (NAP) which is popularly known as the "Veggie Bowl" of SA. NAP is the largest greenhouse zone in all over the Australia (Kelly et al. 2017; Primary Industries & Regions SA 2019). The entire experimental set up for crop production was built inside the greenhouse where the research was undertaken from August 2017 till May 2019. The greenhouse in this research was equipped with an automatic temperature control system (Power Plant OMNIGROW, Horticultural Technology, Melbourne, Australia). Four exhaust fans were provided in the greenhouse to remove hot air. Day time temperature was maintained at 25°C and the night-time temperature was maintained at 17°C inside the greenhouse. A 7.6 m (length) by 6.2 m (width) space in the greenhouse was used, resulting in a row to row distance of 75 cm and plant to plant distance of 52 cm, which corresponds with common practice for greenhouse tomato production throughout the world. Relative humidity inside the greenhouse was maintained at 60 - 65%.

Plant Materials

It was a pot-based experiment having design dimensions presented in Figure 3. The selected soil was loamy sand with dry bulk density 1.57 g/cm^3 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, directly extracted from the T2 aquifer from a bore hole in Virginia, SA); 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). The physico-chemical analysis of waters has been presented in Supplementary Table S1.

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). A complete detail of experimental design and irrigation treatments is presented in Supplementary Table S2.

Measurement of soil moisture content

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) following the method suggested by Savic et al. (2011) and Soulis et al. (2015). The PR2/4 Profile Probe consists of a sealed polycarbonate rod (25 mm diameter) with electric sensors (seen as pairs of stainless-steel rings) arranged at fixed intervals along its length. When taking a reading, one end of the probe was inserted into an access tube and another end with HH2 moisture meter. The access tube is a specially constructed thin walled (1 mm) tube, which maximize the penetration of the electromagnetic field into the surrounding soil. PR2/4 sensors were at 10, 20, 30 and 40 cm and each sensor had a pair of rings 10 cm apart vertically. Sensors were highly sensitive to soil moisture but unaffected by temperature and conductivity. HH2 moisture meter read, and stored measurements taken with PR2/4 Profile Probe. The moisture meter applied power to the sensor, received readings as serial data, processed these, calculated volumetric SMC and displayed in the monitor.

Irrigation application

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). To illustrate the process, irrigation volume for control treatment as full irrigation (100% FC) on day i was calculated using Equation 1.

$$I_{vol,i} = V \times [\theta_{FC} - \theta_i]$$

Where,
$I_{vol,i}$ = Irrigation water to meet soil FC at day i (liter)
V = Volume of soil in the effective root zone area (liter)
θ_{FC} =Volumetric soil moisture content (%) at FC
θ_i = Volumetric soil moisture content (%) at day i (just prior to irrigation)
Based on the $I_{vol,i}$ value, the volume of water to be applied for DI treatments was calculated accordingly. For example, in GWI_1, 80% of $I_{vol,i}$ was supplied using GW.

Evaluation of yield
This study followed commercial greenhouse tomato farmer practices in the NAP region for harvesting the yield. Only first quality fruits with no defects were picked manually and weighed on a precision scale with an accuracy of ±0.01 g.

Economic evaluation
Economic analysis of greenhouse tomato production was performed based on investment, benefits, and production costs. In this study, economic parameters were examined by considering “opportunity cost of water in a water limiting condition”. Techniques were followed as recommended by English (1990), Ali et al. (2007), Dunage et al. (2009) and Sarker et al. (2016). A water limiting condition is a case where there is a surplus land with limited water but there is an opportunity to irrigate additional land if water becomes available (Ali et al., 2007; Dunage et al., 2009).

Profitability analysis
In this study, profitability analysis was conducted to evaluate the effects of water quality with DI levels on tomato production inside the greenhouse. Variable costs (VC) and fixed costs that were incurred during a production cycle were used for analysing profitability as per Sarker et al. (2016) and Ali et al. (2007). VC items were estimated based on operating cost for land preparation using a machine, irrigation pipe and fitting cost, fertilizer cost, human labour, seedlings cost, agrochemical cost, cost of training/pruning/staking materials and the amount of irrigation water applied. Most of the VC items were same among the treatments except the amounts of irrigation water and the chemical fertilizers supplied through fertigation. The rental value of land was considered as a fixed cost. The total cost (TC) item covered all VC and fixed cost items during the production period.
Gross return (GR) was derived by multiplying the total marketable yield and per unit average farm-gate price during crop harvesting period. The total marketable yield considered in this paper is published in Chand et al., (2020). Net return (NR) was calculated by deducting TC from GR. Then BCR was calculated by dividing GR by TC. BCR is widely used and most important criteria for determining profitability in tomato cultivation (Kafle and Shrestha, 2017). VC, TC, GR, NR, and BCR were calculated according to method recommended in Sarker et al. (2016) using Equations 2 to 6.

$$VC_{ij} = \sum_{i=1}^{n} X_{ij} P_{ij} \quad (2)$$
$$TC_j = TVC_j + TFC_j \quad (3)$$
$$GR_j = Y_j P_j \quad (4)$$
$$NR_j = GR_j - TC_j \quad (5)$$
$$BCR_j = \frac{GR_j}{TFC_j} \quad (6)$$

Where,
VC_{ij} = Variable cost in experiment($ /ha)
X_{ij} = Quantity of inputs supplied in experiment (Kg/ha)
TC_j =Total cost of experiment ($/ha)
TVC_j =Total variable cost in experiment ($/ha)
TFC_j =Total fixed cost in experiment ($/ha)
GR_j = Gross return in experiment ($/ha)
Y_j = Yield (kg/ha) from the jth irrigation treatments
P_j = Price ($ /ha) of yields received by jth irrigation treatments
NR_j = Net return in experiment ($/ha),
In this study, the crop growth season was 140 days as counted from transplanting to final harvesting. An extra 10 days was allocated for land preparation prior to transplanting. Irrigation water cost was calculated by multiplying the volume of applied irrigation water with unit price of water. Labor requirement per ha was based on informal discussion with five greenhouse tomato growers in the NAP. They indicated that 12 manpower needs per day on ha basis (with a standard 7.5 working hour per day) for 85 working days to complete one crop growth season of a greenhouse tomato. Unit labor cost for experimental year 2017-2018 was AUSD 18.80 and for 2018-2019 was 19.1 per hour which was the running labor rate (basic unskilled horticultural worker rate) in the NAP (Fair work Ombudsman Australia 2020). The plant density was estimated at 25510 plant per ha, based on worldwide standard practice of maintaining average row to row 75 cm and plant to plant 50 cm distance in greenhouse tomato production as followed by Chen et al. (2014) and Wei et al. (2018). Total seedling cost was estimated by multiplying the actual price of per seedling by the number of plants.
The average farm gate price of tomato for the experimental year 2017-2018 was taken as AUSD 2.33 per kg, and this value for year 2018-2019 was AUD 2.41. Cost of land renting, land preparation, drip irrigation system installment and tomato farm gate price were estimated based on existing practices and informal discussion among five greenhouse tomato farmers in the NAP due to an absence of published data. These selected five growers were using GW, RW and MW in their farm for tomato production in greenhouses. Their average farm size was 1.2 to 5.5 ha with 102 Mt/ha average annual tomato production.

Statistical analysis
To examine the experiment performance; water quality and DI level were taken as independent variables while the yield and economic parameters were the dependent variables. Differences between means were evaluated for significance using the Least Significance Differences test at 95% confidence ($P < 0.05$). In addition, the data were analyzed using the Microsoft Excel 2019.

Conclusions

Water is an often expensive and scarce input for crop production for the arid and semi-arid regions around the world. The scientific and technical approaches for reducing irrigation volume saves extra water that can be utilized for producing crops over an additional area of arable land with positive economic gain. In this study, treatments maintaining SMC at 80%, and 70% FC showed average BCR greater than one, indicating the economic viability of adopting a DI strategy. Most of the VC in this study were the same except irrigation water and fertilizer cost. NR in DI treatments also showed positive economic indicators. Based on revenue generated per m^3 water use, BCR and additional potential land for irrigation, DI strategy maintaining SMC at 80% FC could be the most cost-effective and water saving technique for greenhouse tomato production. In areas where water resources are scarce and costly, farmers should distillate their efforts to maximize net income per unit water used rather than per unit land by selecting water saving irrigation methods, like DI or any smart irrigation management system.

Declaration of competing interests

The authors declare that they have no competing interests.

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