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Farm-Scale Water Productivity For Tomato With Mulched Drip Irrigation

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ABSTRACT

Water productivity relates to the amount of yield per unit of water used. Water productivity is not reported for most crops in Iraq and the Kurdistan Region of Iraq (KRI) where water scarcity recently forces farmers to shift from traditional farming methods including surface irrigation on bare soil to modern practices including drip irrigation and mulch. This study is the first attempt in Iraq and KRI to calculate and report water productivity for tomato (*Solanum lycopersicum*) under drip irrigation with plastic mulch at the farm scale. Data of yield production, the number of irrigation, irrigation duration, and data of cost and benefit of production were collected in 2021 from 32 farmers who produced tomato from an area of 95 ha. The yield, water use, and water productivity were then calculated. The mean values were 82.7 ton ha^{-1}, 31,083 m^3 ha^{-1}, and 2.8 kg m^{-3} for yield, water use, and water productivity, respectively. Hence, to produce 1 kilogram of tomato, 350 liter of water was applied. Farmers irrigate the farms each time 2-3 times longer than in previous years. Thus, this water productivity value is lower than many values reported in the literature for drip irrigation and surface irrigation even, likely due to lower rainfall amount in 2020-21 compared to the previous season. Cost-benefit analysis shows that 21% of production benefits are water use, 14% is production cost and the remaining 65% is a net benefit. Although a substantial amount of water is used, tomato production is a profitable emerging business in the area. The recent shift from surface irrigation on bare soil to drip irrigation and mulch is a successful strategy in adaptation to current water scarcity in the region.

Keywords: tomato, yield, water economy, water productivity, drought, Kurdistan Region of Iraq.

1. Introduction

The world's population continues to grow from an estimated 7.7 billion people worldwide in 2019 to around 9.7 billion in 2050[1]. Food production, therefore, needs to be increased by 60% in developed countries and up to 100% in developing countries[2]. Agriculture is responsible for about 60% to 90% of global freshwater withdrawals, mostly through irrigation[3].

Surface, sprinkler, and drip irrigation are types of irrigation which each uses a different amount of water. Surface irrigation is the application of water by gravity flow to the surface of the field. Drip irrigation is the application of water to the soil at very low rates (2-20 L hr^{-1}) from a system of small diameter plastic pipes fitted with outlets. Water is applied close to plants so that only a part of the soil (15-60%) is wetted. In drip irrigation, water applications are more frequent (usually every 1-3 days) than with other methods, providing optimum moisture level in the soil to flourish plant growth[4]. Several studies such as[5-7] noticed a significant reduction (35% to 80%) of water is used in drip irrigation which compared to surface irrigation. Other benefits of drip irrigation may include better crop survival, minimal yield variability, and improved crop quality[6].

Plastic mulch modifies the environmental conditions and energy balance at the soil surface, creating more favorable conditions for plant growth[8]. Mulch conserves soil moisture, retained heat, as well as it suppresses weed growth[9]. Surveys by Ingman *et al.*[10] indicated that farmers perceive water savings of 24–26% when plastic mulch is used. Plastic mulches can be used with drip irrigation to enhance crop production and quality[11, 12]. Thus, a combination of drip irrigation with plastic mulch can significantly conserve water in agriculture.

For many years, the Kurdistan Region of Iraq (KRI) was known as the "breadbasket of Iraq" as great variety of grains, fruits, and vegetables have traditionally been grown there. Both Iraq and

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KRI are considered rich due to the presence of the Tigris and Euphrates Rivers and their tributaries. However, water shortage due to dams by upstream countries and climate changes is appearing as one of the major threats to the agricultural sector in the region. About 80% of water in Iraq and 40% of water in KRI is controlled by their neighbors. Turkey and Syria have built more than 30 dams on the Euphrates River, causing only a 25% to 50% of Euphrate's normal flow to reach Iraq. Iran has also built many dams on tributaries of the Tigris River flowing mostly through KRI[13, 14]. The two most recent examples are the completion of the Daryan Dam on the Sirwan River and the Sardasht dam on the Lesser Zab River. A river diversion tunnel is being built for each dam to change the flow of the rivers to other parts of Iran. With the completion of both dams and their tunnels, water flows to the KRI would be completely cut[15]. In addition, climate changes including drought, desertification, increased evapotranspiration, and rising temperature are posing more burdens on water resources in the region[16]. To adapt to this, farmers in Kurdistan have shifted in the last decade from traditional farming involving surface irrigation on bare soil to more modern practices such as drip irrigation with mulch.

Tomato is one of the most important crops cultivated throughout the world. It is an essential food for human health that includes many minerals and vitamins[17]. It is a crop with high water demand, and it is sensitive to water stress[18]. In KRI, tomato is the most produced vegetable. The production amount of tomato in 2020 in KRI was 277,289 ton[19]. It is usually conducted during the summer season in the open fields. There is no rainfall during summer in the KRI, thus irrigation water usually comes from streams and wells.

Water productivity (kg m^{-3}) is generally defined as crop yield (kg ha^{-1}) per water supply to the crop (m^3 ha^{-1}), including water (effective rainfall) for rain-fed areas and water (diverted from water systems) for irrigated areas[20]. Therefore, water productivity illustrates how much water is used for growing a particular crop. As it is known knowledge, water productivity for tomato has not been calculated and reported in Iraq and the KRI.

Furthermore, to date, the majority of researches on water productivity has come from controlled plot scale studies which typically fail to represent real values of yield, water use, and water productivity in large and commercial farms. Consequently, there is a need for more farm-scale studies to help better inform farmers and government decision-making on agri-environmental policy. Addressing these deficiencies, this study is the first work in Iraq and KRI to calculate and report farm-scale water productivity for an intense agricultural area of tomato production under plastic mulch with a drip irrigation system. Another objective of this work is to answer the question of whether it is economically better to save water and import tomato or grow tomato in this area.

2. Materials and methods

This study is carried out in Penjwen district, east of Sulaimani province in KRI in northeastern Iraq (Figure 1). The region is characterized by a semi-arid climate with an average annual temperature of 14 ^{0}C, and mean annual precipitation total of 1032 mm[21]. However, in 2021, the country and the whole region experienced a significant reduction in precipitation and drought declared. Total precipitation for year 2021 for Penjwen was only 672 mm.

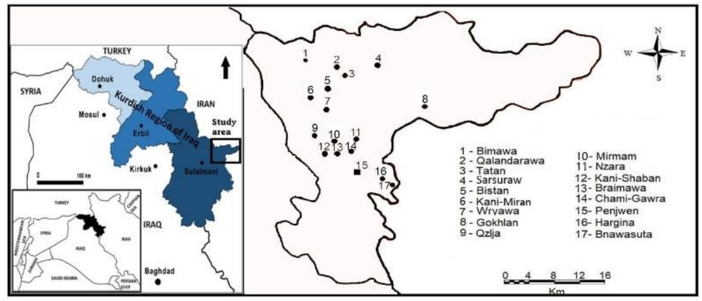

Figure 1: Map shows the location of the study area.

In the last decade, the area experienced unprecedented production of tomato by using mulch and drip irrigation. The raw data in this study was collected in 2021 from 32 farmers who produced tomato from 32 farms on an area of 95 ha. Seeds of tomato (*Solanum lycopersicum*) were sown from April and May and grew until October when they were harvested (Figure 2). The fertilizers of 21-0-0+24(S), 12-61-0, 8-4-32, 20-20-20, 0-0-51+24(S), and 15.5-0-0+26.5(Ca) were applied as sources of Nitrogen (N), Phosphorus (P), Potassium (K), Sulfur (S), and Calcium (Ca)by all farmers. The application rates of the fertilizers were 66 kg ha^{-1} for Nitrogen, 69 kg ha^{-1} for Phosphorus, 80 kg $ha^{-1}$for Potassium, 73 kg ha^{-1} for Sulfur, and 30 kg ha^{-1} for Calcium.

Figure 2: Photos of tomato production in Bnawasuta farm in the study area (A) on 11 June 2021 and (B) on 31 August 2021.

For calculating water productivity, yield production (ton) and water use (m^3) for each farm is needed. Data of yield production, duration of first irrigation, number of irrigation, and duration of routine irrigation were obtained from the farmers (Table 1). Water use is calculated as follows. Drip tapes (1 drip tape was 1,000 m in length) and mulch were installed at about 1.5 m distance from each other. One hectare had 6.4 drip tapes. There were 10,000 holes in one drip tape to irrigate the roots of the tomato. The calculated average flow from one hole was 2.95 L hr^{-1}. Only water diverted from wells, streams, canals, and ponds are used for tomato production, so no water from rainfall was included in the water use calculation of water productivity as there is no rainfall in the summer season when the tomato is grown. The drainage water and soil evaporation were amused to be zero from sowing to harvest for all farms.

Table 1: locations, drip tapes and area, harvested weight, and irrigation related parameters.

Code of farmers	Location	Number of drip tapes	Cultivated area (ha)	First irrigation duration (hr)	Number of irrigation (n)	Duration of irrigation (hr)	Water use (m^3)	Yield production (ton)
1	Chamigawra	53	8.3	4	58	4	368,986	636
2	Braimawa	27	4.2	1	53	3.5	148,547	459
3	Braimawa	4	0.6	1.25	53	3	18,910	40
4	Braimawa	7	1.1	1.25	53	2.5	27,671	84
5	Braimawa	8	1.3	1	53	2.5	31,506	81
6	Braimawa	24	3.8	1.5	56	3.5	139,830	372
7	Mirmam	8	1.3	1.5	51	3	36,462	82
8	Mirmam	8	1.3	1	63	5	74,576	120
9	Qizilja	9	1.4	2.5	56	2.5	37,834	108
10	Qizilja	11	1.7	2.5	59	2.5	48,675	132
11	Sarswraw	45	7	1	47	2.25	141,711	360
12	Bnawasuta	4	0.6	1	51	3	18,172	53
13	Bnawasuta	35	5.5	1.5	59	3.25	199,531	525
14	Hargina	4.5	0.7	1.5	46	2.5	15,465	36
15	Bistan	15	2.3	2	55	4	98,235	176
16	Bistan	8	1.3	2	60	4	57,112	118
17	Bistan	6.5	1	2.25	52	3	30,344	91
18	Nzaraiy	42	6.6	2	49	2.5	154,256	630
19	Nzaraiy	19.5	3	2	44	2.5	64,428	244
20	Kanishaban	8	1.3	2.5	51	3	36,698	83
21	Kanishaban	16	2.5	1.5	55	3.25	85,078	221
22	Gokhlan	42	6.6	3	60	3	226,737	590
23	Gokhlan	23	3.6	3	49	3	101,775	320
24	Gokhlan	29	4.5	3.25	57	2.5	124,689	375
25	Kanimiran	14	2.2	2.5	50	2.5	52,658	180
26	Kanimiran	35	5.5	2	54	3.25	183,269	525
27	Qalandarawa	8	1.3	1.5	48	2.5	28,674	95
28	Tatan	29	4.5	1.5	61	2.5	131,747	435
29	Bimawa	26	4.1	1.5	49	3	113,900	286
30	Wiryawa	10	1.6	2.5	51	3	45,873	138
31	Wiryawa	12	1.9	2	60	3	64,428	185
32	Wiryawa	18	2.8	2.25	58	2.5	78,190	273

Table 2: Items for tomato production and their cost.

Items	Cost	Unit
Drip tape cost	18.3	USD/tape
Mulch cost	26	USD/km
Mulch & tapes install labor	12.5	USD for installing one tape and mulch
Plowing cost	106	USD/ha
Seed cost	560	USD/ha
Seeding labor	53	USD/ha
Fertilizer& pesticide cost	704	USD/ha
Fuel	320	USD/ha
Harvesting & Loading labor	6.25	USD/ton
Transportation cost	18.3	USD/ton
Farmland renting	1,333	USD/ha

Costs of tomato production are presented in table (2). All costs were in Iraqi Dinar (IQD) which were then converted to US Dollar using the 2021 exchange rate (1 USD= 1,480 IQD). Some costs such as initial costs of farms setup, well drilling cost, generator pumps, and tubes are not included.

3. Results and discussion

3.1 Yield

The total cultivated area of all 32 farms is 95 ha which produced a total of 8,053 ton of tomato, accounting for approximately 2.9% of total tomato production in KRI of 277,289 ton[19]. Yield varied between 51 to 109 ton ha^{-1} among the farms with a mean value of 82.7 ton ha^{-1} (Figure 3). As it is mentioned previously, there is no study regarding yield and water productivity for tomato in the country, so we are unable to compare the finding of this study to the others. However, there are some studies carried out in neighboring countries and around the world. Alizadeh *et al.*[22]

reported a yield of approximately 60 ton ha^{-1} tomato with drip irrigation in Iran. Demir *et al.*[23] observed (50 - 70 ton ha^{-1}) on Turkish soil. According to FAO[24], a good commercial yield under irrigation is 45 to 65 ton ha^{-1}. Compared to the above studies, the mean value of 82.7 ton ha^{-1} for tomato yield calculated in this study is in the normal range or above the average even.

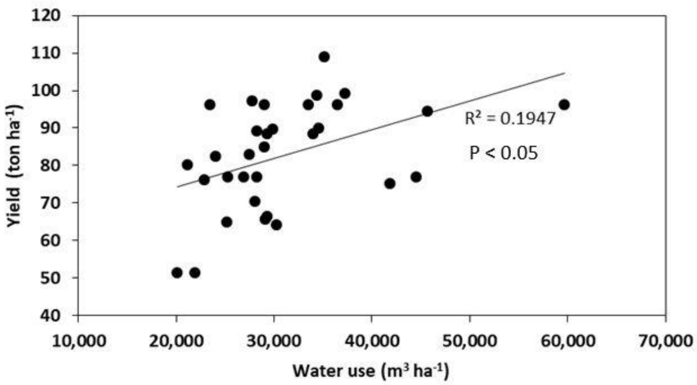

Figure 3: Yield and water use of tomato production.

3.2 Water use

The tomato plants are irrigated 54 times on average, with a mean of 3 hours duration of irrigation. Water use per unit of the area considerably changed among the farms from 20,154 to 59,661 m^3 ha^{-1} with a mean value of 31,083 m^3 ha^{-1} (Figure 3). It is noticed that the amount of water use in this study is significantly higher than that in other studies with drip irrigation and with surface irrigation even. For instance, Alizadeh *et al.*[22] reported 5,000 m^3 ha^{-1} for drip irrigation and 11,000 m^3 ha^{-1} for surface irrigation methods in Iran, Al-Said *et al.*[25] reported 8,050 m^3 ha^{-1} for drip irrigation in Oman, and Gebru *et al.*[26] reported 8,254 m^3 ha^{-1} for surface irrigation in plot study in Ethiopia. The reason for high water use is most likely the reduced soil moisture in the area due to the drought. To achieve the high yields mentioned above, farmers revealed that they irrigated the farms each time 2-3 times longer than the previous years when there were adequate precipitations. The water use showed a significant ($p < 0.05$) positive relationship with yield, other studies also noticed such a relationship between these two figures[27, 28].

3.3 *Water productivity*

The calculated mean value of water productivity is 2.8 kg m^{-3}, with a range of (1.6-4.1 kg m^{-3}). It is observed that this value was lower than many values reported in the literature for drip irrigation and surface irrigation even (Table 3). Alizadeh *et al.* [22], for instance, reported water productivity of 13 kg m^{-3} for a drip system study on a farm-scale in Iran. Kuşçu *et al.*[29] recorded a mean value of 20 kg m^{-3} for a drip system on a plot scale in Turkey. El-Marsafawy *et al.*[30] reported 5-10 kg m^{-3} for surface irrigation system on Egyptian soil. The calculated value here is also notably lower than 10-12 kg m^{-3} suggested by FAO[24]. The relatively low water productivity value calculated in this study is likely due to the excessive amount of water use for irrigation. In addition, a significant amount of water might be wasted during irrigation because this study is carried out in a large and commercial farm compared to plot study in which irrigation water is very well controlled.

Table 3: Comparison between water productivity (PW) values for tomato reported in some publications and PW value in this study. Values are reported either as range or mean.

PW value kg m^{-3}	Irrigation method	Type of study	Country	Source
3	Surface	Farm	Iran	[22]
3-11	Surface	Plot	Iran	[31]
5-10	Surface	Farm	Egypt	[30]
1.8	Surface	Plot	Ethiopia	[26]
13	Drip	Farm	Iran	[22]
14	Drip	Plot	Spain	[27]
13.7	Drip	Farm	India	[32]
11.9	Drip	Farm	Oman	[25]
20	Drip	Plot	Turkey	[29]
10-12	Drip or Surface	-	-	[24]
2.8	Drip + Mulch	Farm	Kurdistan Region, Iraq	This study

3.4 *Tomato and water economy*

One of the objectives of this study was to answer the question of whether it is economically better to save water and import tomato or grow tomato in this area. To answer this, an economic assessment is carried out among the benefit of tomato production, cost of tomato production, and cost of water use (Figure 4). The average selling price is 0.52 USD for 1 kilogram of tomato. Considering the average yield of 82.7 ton ha^{-1}, the total production value is 43,000 USD ha^{-1}. The total cost of production (as detailed in the Methods section) is 6,097 USD ha^{-1}., excluding some initials costs. Therefore, the actual cost of production is likely higher than this reported value. Regarding the cost of water use, some farmers had to give 20% of their production profits to well owners, and some others do not pay for water as they get it from streams and canals. Nevertheless, the cost of water use is calculated here so that comparisons can be made between the cost of water use and the production benefit. According to the general directorate of agriculture and water in KRI, the cost of water is 0.298 USD for 1 m^3. The average water use is 31,083 m^3 ha^{-1} in this study which makes the cost of water use of 9,266 USD ha^{-1}. Hence, 21% of production benefits spent to water use and 14% to production cost and the remaining 65% is a net benefit. It should be noticed that the water cost in this study was 21% of the production benefit. This ias very close to the 20% that farmers who do not own water had to pay to the well owners. It is also observed that the cost of water use in this study (i.e. 9,266 USD ha^{-1}) is higher than the cost of tomato production (i.e. 6,097 USD ha^{-1}), perhaps due to the excessive water usage for irrigation as a result of the low rainfall amount in 2020-21. It is concluded that although a substantial amount of water is used, tomato production is still a profitable business in the area.

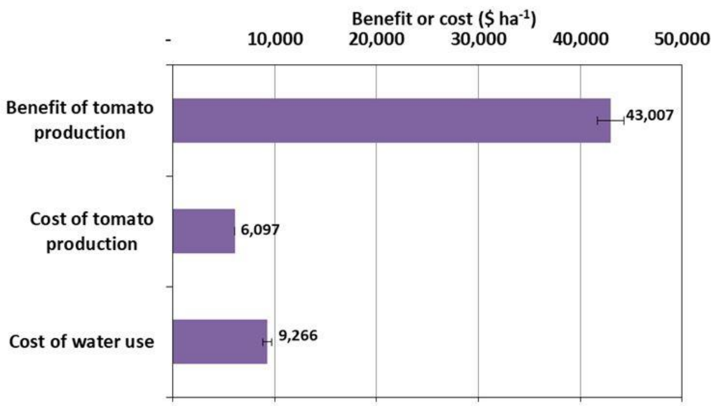

Figure 4: Cost and benefit of tomato production in the study area, and cost of water use. Values are presented as mean, and the error bar represents one standard error.

4. Conclusion

Water productivity is not reported for most crops in Iraq and KRI. This study is the first attempt in Iraq and KRI to calculate and report farm-scale water productivity for an intense agricultural area of tomato production under plastic mulch with a drip irrigation system. A high yield is achieved in the area; however, water use was extremely high, giving a relatively low value for water productivity. To produce 1 kilogram of tomato, 350 liter of water is applied. Drought is likely the cause of the high application of water as the farmers irrigated the farms each time 2-3 times longer than in previous years. According to a cost-benefit analysis, water use accounted for 21%, production costs for 14%, and net benefits for 65% of the total production benefits. Hence, tomato production is a profitable emerging business in the area. This study shows that a combination of drip irrigation and mulch can result a high yield even after drought occurrence. Further research to calculate and report water productivity in the country is recommended.

Author's contribution

Zanist Hama-Aziz analyzed the data and wrote the first draft of the manuscript. Rebwar Mustafa collected the data in the field, idealized the work and guided the first author. Hemin Neima also idealized the work and analyzed the data. All authors read and approved the final manuscript.

Conflict of interests

None

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