Chapter 5
Vegetable Crops and Deficit Irrigation in Egypt

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Abstract An assessment of the potential effects of applying deficit irrigation to onion and tomato grown on raised beds on its production was done. Data on the cultivated area and productivity of onion and tomato were collected for both old and new lands on governorate level, as well as weather data in 2017 and water requirements were calculated. Five production alternatives were quantified on governorate level, namely traditional cultivation, raised beds cultivation, application of deficit irrigation, calculation of production without investing the saved water in adding new area, and calculation of production with investing the saved water in adding new area. In all alternatives, water productivity was calculated. The results showed that using the saved water from cultivation on raised beds and application of deficit irrigation to cultivate new areas with onion resulted in 28 and 32% increase in its production, compared to its value under traditional cultivation. Furthermore, cultivation on raised beds and application of deficit irrigation without using the added area to cultivated new lands resulted in increasing total production by 11 and 6%, respectively. With respect to tomato, using the saved water from cultivation on raised beds and application of deficit irrigation to cultivate new areas with tomato resulted in 18 and 24% increase in its production, compared to its value under traditional cultivation. Whereas, cultivation on raised beds and application of deficit irrigation without using the added area to cultivated new lands resulted in increasing total production by 6 and 1%, respectively. In both crops, water productivity was the higher when deficit irrigation was applied and the saved irrigation water was used to cultivate new areas with the crop, compare to traditional cultivation.

Keywords Onion · Tomato · Raised beds cultivation · Irrigation water saving · Water productivity

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5.1 Introduction

Horticulture crops (vegetables and fruits) offers potentials to income generation and job opportunities in the rural areas. It provides the necessary food supplements to assure a balanced diet for a healthy population. In Egypt, the total cultivated areas of vegetable crops and fruit crops are about 240,110 and 697,646 hectares, respectively. Two vegetable crops occupy the largest cultivated area in the winter season, namely onion and tomato. These two crops represent 4% of the total cultivated area of winter crops and consumes 989.4 million cubic meters or 5% of the water assigned to winter crops (Table 5.1). Both onion and tomato productions are higher than its consumption, thus there is a surplus in its production as it stated by Central Agency for Public Mobilization and Statistics (2018).

Onion is an important vegetable crop in Egypt for local consumption, where its cultivated area ranked third after wheat and Egyptian clover. The crop is also one of the most important crops for exportation. The Egyptian onion varieties characterized by high quality due to its high nutritional value and pungency. It is grown mainly for its bulbs, which are stored to meet the increased demand for both local consumption and export (Taha et al. 2019). Tomato is also an important vegetable crop in Egypt. Fresh tomatoes and other processed tomatoes products make a significant contribution to human nutrition owing to the concentration and availability of several nutrients in these products and to their widespread consumption (Sibomana et al. 2013).

Agriculture is a largest consumer of water resources in Egypt, in which its sustainability has become a major concern. The adoption of irrigation water saving strategies and maintaining acceptable yields will probably contribute in preserving this valuable natural resource. Under surface irrigation, which is the prevailing system in Egypt, cultivation on raised beds is considered one of the strategies to save 20–30% of the applied irrigation water under surface irrigation to several crops (Abouelenein et al. 2009, 2010; Karrou et al. 2012; Khalil and Abouenein 2012; Zohry et al. 2019).

Raised beds cultivation allowed the irrigation water to seep inside it through capillary action, while it moves into the ditches dug between the beds. It was reported that both water and fertilizer use efficiency were increased under raised beds cultivation (Ahmad et al. 2009 and Majeed et al. 2015), it improved water distribution and efficiency, it reduced weed infestation, it reduced lodging and it reduced seed rate without sacrificing yield (Hobbs et al. 2000). Raised beds cultivation plays an important role in increasing food availability through increasing land productivity. It was also reported that cultivation on raised beds increased productivity by 15–20%, as a result of increasing in radiation used efficiency because crops are more exposed to solar radiation (Abouelenein et al. 2010). Other studies on raised beds cultivation

Table 5.1 The cultivated area of onion and tomato, its production and water requirements

Crop	Cultivated area (ha)	Production (ton)	Water requirements (m^3)
Onion	75,248	2776,771	626,866,776
Tomato	70,238	3,116,589	362,522,022
Total	145,486		989,388,798

showed that it improved soil quality (Limon-Ortega et al. 2002), which led to enhanced root growth (Dey et al. 2015), it increased microbial functional groups and enzyme activities and it increased availability of essential nutrients for crops by stimulating microbial activity (Zhang et al. 2012). Raised beds planting also created better soil physical environment throughout the crop growth period, which led to higher crop productivity (Aggarwal and Goswami 2003).

Another strategy to face water scarcity is the application of deficit irrigation. Deficit irrigation is a water saving strategy under which crops are exposed to a certain level of water stress either during a particular developmental stage or throughout the whole growing season (Pereira et al. 2002). Applying deficit irrigation for crops grown on raised beds will lower the amount of applied irrigation water and it will involve yield losses. The exception is that any yield reduction will be insignificant compared with the benefits that gained from the conservation of water (Pereira et al. 2002).

Thus, an assessment of the potential effects of applying deficit irrigation to onion and tomato grown on raised beds was done using data on its cultivated area and productivity on governorate level in both the old and new lands. (See Chap. 2 for more details on soil classification). This data was collected from the Ministry of Agriculture and Land Reclamation in Egypt in 2017. Weather data for the winter season of 2016/17 were obtained from NASA Prediction of Worldwide Energy Resource website (https://power.larc.nasa.gov/data-access-viewer). Water requirements for each of these two crops were calculated on governorate level using BISm model (Snyder et al. 2004). Irrigation application efficiency was assumed to be 60% in the old lands under surface irrigation and 85% under drip systems in the new lands.

For onion and winter tomato, five production alternatives were quantified on governorate level as followed:

1. **Traditional cultivation**: The cultivated area and productivity per hectare of each crop in 2017 were multiplied to calculate total production. In addition, water requirements for each crop were calculated.
2. **Raised beds cultivation**: We assumed that cultivation on raised beds will increase productivity per hectare by 15%, and then the increase in the total production was calculated. We also assumed that 20% of the applied water under surface irrigation will be saved. The saved irrigation water will be used to irrigate new areas with each crop and this area will be added to the total cultivated area of the studied crops to increase its total production.
3. **Application of deficit irrigation**: The effect of application of deficit irrigation for both crops cultivated on raised beds. Because the amount of irrigation water resulted from cultivation on raised beds produced higher yield than the traditional cultivation, we applied deficit irrigation to raised beds and the losses in yield resulted from raised beds cultivation was calculated. The saved irrigation water will be used to irrigate new areas with each crop and this area will be added to the total cultivated area of the studied crops to increase its total production and compensate the loss in the productivity per hectare.
4. **Calculation of production without investing the saved water in adding new area**: Under cultivation on raised beds, we assumed that the saved water will be assigned to increase the cultivated area of another winter crop.

5. **Calculation of production without investing the saved water in adding new area:** Under application of deficit irrigation, we assumed that the saved water will be assigned to increase the cultivated area of another winter crop.

Water productivity values for each crop were calculated under the five studied production alternatives. Water productivity is a quantitative term used to define the relationship between crop produced and the amount of water involved in crop production (Igbadun et al. 2006). In our assessment, we used crop water productivity to compare between the five studied production alternatives because both production amount and the applied irrigation water to produce this amount are included.

5.2 Onion Production and Deficit Irrigation

Onion plants have slow growth rate, shallow roots system and its above ground biomass is small. Drinkwater and Janes (1955) reported that because onion plants are a shallow-rooted, most of the roots were found in the top 0.18 m of soil and only a few roots were found deeper than 0.31 m, thus the maximum root penetration was found at 0.76 m. This trait limits the amount of soil water available to onion plants, especially when grown on coarse-textured soils. Therefore, sprinkler and drip irrigation systems are well suited for this crop (Al-Jamal et al. 2001).

5.2.1 Effect of Water Stress on Onion

Onion plants were found to be sensitive to water deficit during the whole growing season, rather than specific growth stage (Kadayifci et al. 2005). Patel and Rajput (2013) indicated that it is better to maintain moderate stress during the whole growing season, rather than creating a stress during non-critical growth stages. Pelter et al. (2004) indicated that the total onion yield was reduced as a result of imposed soil water stress at any growth stage, but the greatest effect was found at the 5-leaf and, 7-leaf stages, which reduced yield by 26% compared with the non-water stress control. Furthermore, the reproductive stage is the most critical stage for water stress because it strongly affect final yield (Patel and Rajput 2013).

5.2.2 Effect of Deficit Irrigation on Onion

Nagaz et al. (2012) reported that applying 60% of crop evapotranspiration caused significant decreases in fresh yield, dry matter, bulbs per hectare, and bulb weight of onion, compared to those under both full irrigation (100% ETc) and regulated deficit irrigation (80% ETc). Taha et al. (2019) indicated that saving 20% of the applied water to onion grown under sprinkler system in sandy soil reduced yield by 8%. Zayton (2007) studied the effect of skipping the last irrigation on the applied irrigation water and the yield of onion. He found that 20% of the applied irrigation water was saved and 15% the yield was lost. Ouda et al. (2010) simulated the effect of applying 80% of full irrigation to onion grown in clay soil under surface system, where onion yield losses were 5%.

5.2.3 Irrigation Water Savings Techniques for Onion

5.2.3.1 Traditional Cultivation of Onion

Under traditional cultivation of onion, Table 5.2 indicated that the highest cultivated area in the old lands in Lower Egypt existed in Gharbia governorate, i.e. 19.9 thousand hectares. In Middle and Upper Egypt, the highest cultivated area existed in Fayoum and Sohag governorates, namely 3.2 and 2.2 thousand hectares, respectively in the old lands. In the new lands, the highest cultivated area existed in Behira governorate in Lower Egypt, i.e. 5.2 thousand hectares. Similarly, the highest cultivated areas in Middle and Upper Egypt were found in Beni Sweif and Sohag gover-

Table 5.2 The old and new cultivated areas of onion, its production and required irrigation water

		Old lands			New lands	
	Area (000 ha)	Production (000 ton)	WR (MCM)	Area (000 ha)	Production (000 ton)	WR (MCM)
Lower Egypt						
Alexandria	0	0	0	0.02	0.4	0.1
Behira	4.4	174.3	33.5	5.2	197.1	29.7
Gharbia	19.9	789.5	177.7	0	0	0
Kafr El sheikh	0.7	25.1	5.4	0	0	0
Dakahlia	10.3	342.0	82.9	0	0	0
Damietta	0.7	21.7	5.4	0.1	2.1	0.4
Sharkia	5.2	171.6	45.6	0.3	10.2	2.0
Ismailia	0.1	2.1	0.6	0.1	2.7	0.6
Suez	0.2	5.1	1.3	0.1	4.0	0.8
Menoufia	0.4	13.4	3.1	0	0	0
Qalyubia	4.7	175.6	39.3	0	0	0
Total	46.6	1720.3	395.0	5.8	216.5	33.6
Middle Egypt						
Giza	0.5	12.2	4.0	0.1	1.2	0.3
Bani Sweif	2.6	81.9	22.6	3.1	100.2	20.5
Fayoum	3.2	114.2	29.5	1.4	50.3	9.7
Minya	0.9	34.9	8.8	1.0	38.4	7.3
Total	7.2	243.2	64.9	5.6	190.2	37.8

(continued)

Table 5.2 (continued)

	Old lands			New lands		
	Area	Production	WR	Area	Production	WR
	(000 ha)	(000 ton)	(MCM)	(000 ha)	(000 ton)	(MCM)
Upper Egypt						
Assiut	0.7	27.1	6.9	0	0	0
Sohag	2.2	94.9	24.9	3.8	173.1	32.9
Qena	0.2	8.2	2.7	0.7	26.4	6.5
Luxor	0.2	6.2	2.3	0.1	2.3	0.7
Aswan	0.1	4.2	1.8	0.5	19.2	5.6
New Valley	0	0	0	1.1	40.6	9.3
Total	3.4	140.6	38.7	6.3	261.6	55.1
Bordered governorates						
Marsa Matrouh	0	0	0	0.3	4.3	1.8
Total	0	0	0	0.3	4.3	1.8
Grand total	57.2	2104.1	498.5	18.0	672.7	128.3

WR water requirements, *MCM* million cubic meter

norates, namely 3.1 and 3.8 thousand hectares. The total cultivated area of onion in the old and new lands were 57.2 and 18.0 thousand hectares, respectively. These areas produced 2104.1 and 672.7 million ton of onion in the old and new lands, respectively and consumed 4985.4 billion cubic meters and 128.3 million cubic meters of irrigation water in the old and new lands, respectively (Table 5.2).

Table 5.3 indicated that the total cultivated area of onion for both old and new lands in 2017 was 75.2 thousand hectares. These areas produced 2776.7 million tons of onion and consumed 626.8 million cubic meters of irrigation water. This amount of national onion production is enough for local consumption (Central Agency for Public Mobilization and Statistics 2018). Table 5.3 also showed that Gharbia, Beni Swief and Sohag governorate in Lower, Middle and Upper Egypt, respectively has the highest cultivated area of onion namely, 19.9, 5.7 and 6.0 thousand hectares, respectively.

5.2.3.2 Cultivation on Raised Beds

Kahlon (2017) indicated that raised beds cultivation for onion saved 33% of the applied irrigation water and increase yield by 14%. We assumed that cultivation of onion on raised beds will increase its yield by 15% and save 20% of its water requirements in the old lands only, no irrigation water saving will practice in the new lands. Furthermore, the saved irrigation water will be used to cultivate more lands and increase the total production of onion without using any more irrigation water than its value under traditional cultivation.

Table 5.4 showed that the saved amount of irrigation water under raised beds cultivation could be invested in cultivating 15.3 thousand hectares, which increase

Table 5.3 Total cultivated area of onion, its production and required irrigation water

	Area (000 ha)	Production (000 ton)	Water requirements (BCM)
Lower Egypt			
Alexandria	0.02	0.4	0.1
Behira	9.6	371.3	63.2
Gharbia	19.9	789.5	177.7
Kafr El Sheikh	0.7	25.1	5.4
Dakahlia	10.3	342.0	82.9
Damietta	0.8	23.8	5.8
Sharkia	5.5	181.8	47.7
Ismailia	0.2	4.8	1.3
Suez	0.3	9.0	2.1
Menoufia	0.4	13.4	3.1
Qalyubia	4.7	175.6	39.3
Total	52.4	1936.8	428.6
Middle Egypt			
Giza	0.6	13.4	4.3
Bani Sweif	5.7	182.1	43.0
Fayoum	4.6	164.6	39.2
Minya	2.0	73.3	16.1
Total	12.8	433.4	102.7
Upper Egypt			
Assiut	0.7	27.1	6.9
Sohag	6.0	268.0	57.8
Qena	0.9	34.6	9.2
Luxor	0.3	8.5	3.0
Aswan	0.7	23.4	7.5
New Valley	1.1	40.6	9.3
Total	9.6	402.2	93.7
Bordered governorates			
Marsa Matrouh	0.3	4.3	1.8
Total	0.3	4.3	1.8
Grand total	75.2	2776.7	626.8

BCM billion cubic meter

the total cultivated area to 90.5 thousand hectares, or 20% increase, compared to its value under traditional cultivation. Furthermore, an increase in the total production to 3544.7 million tons could occur, or 28% compared to its value under traditional cultivation. This increase in onion total production is resulted from increase in productivity per hectare and increase in the cultivated area under raised beds cultivation.

Table 5.4 Potential added cultivated area of onion as a result of cultivation on raised beds, total cultivated area and its total production

	Added area (000 ha)	Total area (000 ha) (Old+ new+ added)	Total production (000 ton)
Lower Egypt			
Alexandria	0	0	0.4
Behira	1.2	10.8	442.0
Gharbia	5.3	25.2	1109.0
Kafr El Sheikh	0.2	0.9	36.1
Dakahlia	2.7	13.0	393.3
Damietta	0.2	1.0	2.1
Sharkia	1.4	6.9	253.6
Ismailia	0	0.2	5.7
Suez	0	0.3	11.2
Menoufia	0.1	0.5	19.0
Qalyubia	1.3	6.0	244.0
Total	12.4	64.9	2547.1
Middle Egypt			
Giza	0.1	0.7	18.2
Bani Sweif	0.7	6.4	100.2
Fayoum	0.9	5.5	212.3
Minya	0.2	2.2	87.9
Total	1.9	14.8	418.6
Upper Egypt			
Assiut	0.2	0.9	39.3
Sohag	0.6	6.6	304.2
Qena	0.1	1.0	37.8
Luxor	0	0.3	11.2
Aswan	0	0.7	25.3
New Valley	0	1.1	40.6
Total	0.9	10.5	458.4
Bordered governorates			
Marsa Matrouh	0	0.3	4.3
Total	0	0.3	4.3
Grand total	15.3	90.5	3544.7

5.2.3.3 Application of Deficit Irrigation

Kandil et al. (2011) reported that application of 83% of full irrigation resulted in 10% yield losses in onion grown under surface irrigation. Whereas, Taha et al. (2019) indicated that saving 20% of the applied water to onion grown under sprinkler system in sandy soil reduced yield by 8%. Thus, we assumed that saving of 6 and 5% of the applied water to onion in the old and new lands, respectively will result in 5% yield losses in both regions.

Table 5.5 indicated that the amount of saved water as a result of deficit irrigation application will be 4.5 thousand hectares and the total cultivated area will be 94.8 million hectares, which will produce 3659.6 million tons of onion, with 31% increase.

Table 5.5 Potential added cultivated area of onion as a result of application of deficit irrigation, total cultivated area and its total production

	Added area (000 ha)	Total area (000 ha) (Old + new + added)	Total production (000 ton)
Lower Egypt			
Alexandria	0.001	0.02	0.4
Behira	0.5	11.33	458.6
Gharbia	1.3	26.51	1092.5
Kafr El Sheikh	0	0.96	34.7
Dakahlia	0.6	13.63	473.3
Damietta	0	1.01	33.6
Sharkia	0.3	7.23	259.1
Ismailia	0	0.22	5.9
Suez	0.02	0.34	11.5
Menoufia	0.03	0.54	18.5
Qalyubia	0.3	6.31	243.1
Total	3.2	68.1	2631.3
Middle Egypt			
Giza	0.03	0.73	18.9
Bani Sweif	0.3	6.73	223.8
Fayoum	0.3	5.73	218.2
Minya	0.1	2.33	90.9
Total	0.7	15.5	551.7
Upper Egypt			
Assiut	0.04	0.90	37.5
Sohag	0.3	6.90	319.2
Qena	0.05	1.02	39.6
Luxor	0.02	0.32	11.4
Aswan	0.04	0.75	26.2
New Valley	0.1	1.18	42.7
Total	0.5	11.1	476.7
Bordered governorates			
Marsa Matrouh	0.02	0.34	4.5
Total	0.02	0.09	0.02
Grand total	4.5	94.8	3659.6

5.2.3.4 Water Conservation and Onion National Production

Cultivation on raised beds and application of deficit irrigation to onion resulted in saving in the applied irrigation water by 99.7 and 30.1 million cubic meters, respectively, or 10 and 5% of the applied irrigation water to onion under traditional cultivation.

We assumed that these amounts of water will not use to cultivated new areas with onion, instead it will be used to irrigate new areas with other crops. Thus, the total cultivated area cultivation on raised beds and application of deficit irrigation will be the same as the cultivated area using traditional method, but its total production will be increase to 3092.3 and 2937.7 million tons, or by 11 and 6% (Table 5.6), compared to the production attained under traditional cultivation of onion.

5.2.4 Water Productivity of Onion Under the Studied Production Alternatives

Table 5.7 presented water productivity of onion under the studied five production alternatives. It worth noting that the total production of onion under traditional cultivation, as well as under raised beds cultivation and deficit irrigation application with added new areas will be produced using the same amount of applied irrigation water under traditional cultivation. The results in Table 5.7 showed that the traditional cultivation of onion will attain the lowest average water productivity on the national level, namely 3.6 kg/ha. The highest average national water productivity value will be attained under raised beds cultivation and the saved water will be used to cultivate new areas and application of deficit irrigation and the saved water will not be used to cultivate new areas, namely 4.4 kg/ha.

Table 5.7 also showed that, in Alexandria governorate, there was no difference between the values of water productivity when raised beds cultivation was applied, either under taking into account added area or without taking it into account. This result attributed to low cultivated area in the old lands, where raised beds cultivation is applied. Furthermore, the highest water productivity was found in Behira governorate as a result of high productivity per hectare in the old lands.

5.3 Winter Tomato Production and Deficit Irrigation

Winter tomato is very important vegetable crop in Egypt in term of local consumption and exportation. It constitutes an important source of potassium, vitamins E and C, and oleic acid (Ali and Ismail 2014). Tomato grows tap deep strong root systems, which facilitate the absorption of soil moisture from deeper layers. Furthermore, the roots of tomato leave the soil in a good mechanical condition for the following crop (Pressman et al. 1997).

Table 5.6 Saved irrigation water and total production of onion as a result cultivation on raised beds and application of deficit irrigation

	Raised beds cultivation		Deficit irrigation application	
	Saved water (MCM)	Total production (000 ton)	Saved water (MCM)	Total production (000 ton)
Lower Egypt				
Alexandria	0	0.4	0.004	0.4
Behira	6.7	397.5	3.1	377.6
Gharbia	35.5	907.9	8.4	862.5
Kafr El Sheikh	1.1	28.8	0.3	27.4
Dakahlia	16.6	393.3	3.9	373.6
Damietta	1.1	27.1	0.3	25.7
Sharkia	9.1	207.5	2.3	197.2
Ismailia	0.1	5.1	0.1	4.9
Suez	0.3	9.8	0.1	9.3
Menoufia	0.6	15.4	0.1	14.6
Qalyubia	7.9	202.0	1.9	191.9
Total	79.0	2194.9	20.4	2085.1
Middle Egypt				
Giza	0.8	15.2	0.2	14.5
Bani Sweif	4.5	194.4	2.1	184.6
Fayoum	5.9	181.7	1.9	172.6
Minya	1.8	78.6	0.8	74.6
Total	13.0	469.9	5.0	446.4
Upper Egypt				
Assiut	1.4	31.2	0.3	29.6
Sohag	5.0	282.2	2.8	268.1
Qena	0.5	35.9	0.5	34.1
Luxor	0.5	9.5	0.1	9.0
Aswan	0.4	24.0	0.4	22.8
New Valley	0	40.6	0.5	38.6
Total	7.7	423.3	4.6	402.1
Bordered governorates				
Marsa Matrouh	0	4.3	0.1	4.1
Total	0	4.3	0.1	4.1
Grand total	99.7	3092.3	30.1	2937.7

5.3.1 Effect of Water Stress on Winter Tomato

Water is the limiting factor in crops production and hence high yield. Thus, attempts should be made to obtain maximum yield with minimum water supply. Under water stress condition, tomato plants tend to grow a denser root system, compared to the root system grown under non-stress water condition (Nuruddin 2001). According to Shamsul et al. (2008), the water stress at earlier stage of growth (20 day stage) has

Table 5.7 Water productivity (kg/ha) of onion under traditional cultivation, raised beds cultivation and deficit irrigation application

	Traditional cultivation	Raised beds cultivation		Deficit irrigation application	
		With added area	Without added area	With added area	Without added area
Lower Egypt					
Alexandria	4.7	4.7	4.7	4.4	4.7
Behira	5.9	7.0	7.0	6.0	6.3
Gharbia	4.4	6.2	6.4	4.9	5.1
Kafr El Sheikh	4.6	6.6	6.6	5.0	5.3
Dakahlia	4.1	4.7	5.9	4.5	4.7
Damietta	4.1	5.7	5.7	4.4	4.7
Sharkia	3.8	5.3	5.4	4.1	4.3
Ismailia	3.8	4.5	4.5	3.8	4.0
Suez	4.3	5.3	5.3	4.4	4.7
Menoufia	4.3	6.1	6.2	5.9	4.9
Qalyubia	4.5	6.2	6.4	6.2	5.1
Average	4.4	5.7	5.8	4.9	4.9
Middle Egypt					
Giza	3.1	4.2	4.4	4.4	3.5
Bani Sweif	4.2	5.0	5.0	5.2	4.5
Fayoum	4.2	5.4	5.5	5.6	4.6
Minya	4.5	5.4	5.5	5.6	4.9
Average	4.0	5.0	5.1	5.2	4.4
Upper Egypt					
Assiut	3.9	5.7	5.6	5.4	4.5
Sohag	4.6	5.3	5.3	5.5	4.9
Qena	3.8	4.1	4.1	4.3	3.9
Luxor	2.8	3.7	3.7	3.8	3.1
Aswan	3.1	3.4	3.4	3.5	3.2
New Valley	4.4	4.4	4.4	4.6	4.4
Average	3.8	4.4	4.4	4.5	4.0
Border governorates					
Marsa Matrouh	2.4	2.4	2.4	2.5	2.4
Average	2.4	2.4	2.4	2.5	2.4
Overall average	3.6	4.4	4.4	4.3	3.9

more inhibitory effect compared to water stress in later stage (30 day stage). Tomato plants are very sensitive to water stress during and immediately after transplanting, at flowering and during fruit development (Nuruddin 2001). Decreases in chlorophyll content and electrolyte leakage were reported by Kirnak et al. (2001) under water stress, which resulted in reduced vegetative growth and fruit yield. Additionally, Nyabundi and Hsia (2009) reported that tomato plants subjected to different levels of water stress under field conditions had inhibited vegetative growth but enhanced fruit development.

The influence of water stress on tomato plants and fruit quality was investigated by Nahar and Gretzmacher (2002). They reported that yield and dry matter production of tomato were adversely affected under application of 40% of the field capacity. Furthermore, Nuruddin (2001) indicated that water stress throughout the growing season significantly reduced yield of tomato and fruit size, but plants stressed only during flowering showed fewer but bigger fruits than completely non-stressed plants. Under water stress conditions, Claussen (2005) found that proline content rise, as early as in 14 h after water stress. Pokluda et al. (2010) indicated that water stress reduced specific leaf area and leaf water content and increase leaf proline concentration in tomato. Reduction in leaf water potential content was also reported by Kirnak et al. (2001) as a result of soil moisture stress, which in turn may reduce transpiration. They also added that specific leaf area and leaf water content were good indicators of water stress in tomato, and proline content was a reliable parameter corresponding to the actual water stress of plants.

5.3.2 Effect of Deficit Irrigation on Winter Tomato

Shalaby et al. (2014) studied the effect of application of deficit irrigation to tomato grown under drip system in calcareous soil. They indicated that saving 25% of the applied irrigation water resulted in 9% yield losses. Furthermore, application of 80% of full irrigation to tomato grown in clay loam soil under subsurface drip system resulted in 15% yield losses (Abdelhady et al. 2017). Additionally, Kamal and El-Shazly (2013) reported that 7% losses in tomato yield grown under drip system in calcareous soil occurred when 75% of full irrigation was applied.

5.3.3 Irrigation Water Saving Techniques for Winter Tomato

5.3.3.1 Traditional Cultivation of Winter Tomato

Table 5.8 indicated that the highest cultivated area of winter tomato in Lower Egypt existed in Sharkia governorate, i.e. 9.0 thousand hectares in the old lands. In Middle, the highest cultivated area existed in Fayoum and Minia governorates, namely 1.6 thousand hectares, respectively. In Upper Egypt, the highest cultivated area existed in Sohag, namely 1.5 thousand hectares. In the new lands, the highest cultivated area existed in Behira governorate in Lower Egypt, i.e. 11.0 thousand hectares. Similarly, the highest cultivated area in Middle and Upper Egypt were found in both Beni Sweif and Sohag governorates, namely 3.2 thousand hectares.

The total cultivated area of winter tomato in the old and new lands were 28.3 and 42.1 thousand hectares, respectively. These areas produced 1338.2 and 1780.9

Table 5.8 The old and new cultivated areas of winter tomato, its production and required irrigation water

		Old lands			New lands	
	Area (000 ha)	Production (000 ton)	WR (MCM)	Area (000 ha)	Production (000 ton)	WR (MCM)
Lower Egypt						
Alexandria	1.1	54.2	6.1	0.6	26.6	2.3
Behira	2.1	70.1	11.8	11.0	440.1	45.4
Gharbia	0.1	1.5	0.4	0	0	0
Kafr El Sheikh	2.1	80.1	11.8	0	0.6	0.1
Dakahlia	0.2	5.5	1.1	1.2	28.4	4.8
Damietta	0.5	7.7	2.9	0	0	0
Sharkia	9.0	512.3	56.3	7.6	431.9	35.5
Ismailia	2.4	131.4	12.5	1.3	66.2	5.0
Port Said	0	0	0	0.3	4.2	1.2
Suez	0.5	15.4	2.7	0.2	11.2	1.0
Menoufia	0.04	1.6	0.2	0.2	10.0	0.8
Qalyubia	0.1	4.2	0.7	0	0	0
Cairo	0.01	0.2	0	0.01	0.3	0.04
Total	18.1	884.2	106.6	22.3	1019.4	96.1
Middle Egypt						
Giza	3.1	143.7	16.3	0.7	24.5	2.7
Bani Sweif	0.7	32.7	3.9	3.2	141.6	13.8
Fayoum	1.6	60.1	9.7	0.3	11.2	1.4
Minya	1.6	67.3	9.8	0.9	41.6	4.2
Total	6.9	303.8	39.7	5.1	218.8	22.1
Upper Egypt						
Assiut	1.0	36.3	6.7	1.2	46.4	6.5
Sohag	1.5	74.3	11.9	3.2	167.0	18.7
Qena	0.2	10.0	1.7	1.0	47.5	6.5
Luxor	0.5	29.1	4.8	2.0	93.8	13.2
Aswan	0.03	0.4	0.3	0.3	5.3	2.3
New Valley	0	0	0	0.1	2.5	0.7
Total	3.2	150.2	25.4	7.9	362.4	48.0
Bordered governorates						
Marsa Matrouh	0	0	0	4.7	128.4	18.3
North Sinai	0	0	0	2.0	50.8	8.3
South Sinai	0	0	0	0.05	1.0	0.2
Total	0	0	0	6.8	180.2	26.8
Grand total	28.3	1338.2	171.6	42.1	1780.9	192.8

WR water requirements, *MCM* million cubic meter million ton of winter tomato in the old and new lands, respectively and consumed 171.6 and 192.8 million cubic meters of irrigation water in the old and new lands, respectively (Table 5.8).

Table 5.9 indicated that the total cultivated area of winter tomato was 70.4 thousand hectares, produced 3.119.1 million tons of winter tomato and consumed 364.4 million cubic meters of irrigation water. This amount of national onion production is enough for local consumption (Central Agency for Public Mobilization and Statistics 2018).

5.3.3.2 Cultivation on Raised Beds

Similar to the previous studied crops, we assumed that cultivation of winter tomato on raised beds will increase its yield by 15% and save 20% of its water requirements in the old lands only. The saved irrigation water could be used to cultivate more lands and increase the total production of winter tomato without using any more irrigation water than the value used under the traditional cultivation of winter tomato. Table 5.10 indicated that the added cultivated area will be 7.5 thousand hectares, which increase the total cultivated area to 77.9 thousand hectares, with 11% increase, compare to the area cultivated with traditional method. Furthermore, the total production of winter tomato will increase to 3669.1 million tons, with 18% compared to its value under traditional cultivation.

5.3.3.3 Application of Deficit Irrigation

Shalaby et al. (2014) and Kamal and El-Shazly (2013) indicated that saving 25% of the applied irrigation water to tomato grown under drip system resulted in 7–9% yield losses. Based on these results, we assumed that 7 and 5% of the applied irrigation water to tomato could be saved in the old and new lands, respectively with yield losses 4 and 5%, respectively. Table 5.11 showed that 5.0 thousand hectares of winter tomato could be added.

Table 5.11 also showed that this added area could increase the total cultivated area to 82.9 thousand hectares, with 18% increase, compare to the area cultivated with traditional method. Thus, the total production of winter tomato will increase to 3873.0 million tons, with 24% compare to its value under traditional cultivation.

5.3.3.4 Water Conservation and Winter Tomato National Production

Cultivation on raised beds and application of deficit irrigation to tomato resulted in saving in the applied irrigation water by 34.3 and 22.7 million cubic meters, respectively, or 9 and 6% of the applied irrigation under traditional cultivation (Table 5.12).

Table 5.9 Total cultivated area of winter tomato, its production and required irrigation water

	Area (000 ha)	Production (000 ton)	Water requirements (MCM)
Lower Egypt			
Alexandria	1.7	80.9	8.5
Behira	13.1	510.3	57.2
Gharbia	0.1	1.5	0.4
Kafr El Sheikh	2.1	80.7	11.9
Dakahlia	1.4	33.8	5.9
Damietta	0.5	7.7	2.9
Sharkia	16.6	944.1	91.7
Ismailia	3.6	197.6	17.5
Port Said	0.3	4.2	1.18
Suez	0.7	26.6	3.7
Menoufia	0.2	11.6	1.0
Qalyubia	0.1	4.2	0.7
Cairo	0.02	0.5	0.1
Total	40.5	1903.6	202.6
Middle Egypt			
Giza	3.7	168.1	19.0
Bani Sweif	3.9	174.3	17.8
Fayoum	1.9	71.3	11.0
Minya	2.5	108.9	14.0
Total	12.0	522.6	61.7
Upper Egypt			
Assiut	2.2	82.8	13.2
Sohag	4.7	241.3	30.6
Qena	1.2	57.5	8.2
Luxor	2.6	122.9	18.0
Aswan	0.3	5.7	2.6
New Valley	0.1	2.5	0.7
Total	11.1	512.6	73.3
Bordered governorates			
Marsa Matrouh	4.7	128.4	18.3
North Sinai	2.0	50.8	8.3
South Sinai	0.05	1.0	0.2
Total	6.8	180.2	26.8
Grand total	70.4	3119.1	364.4

WR water requirements, *MCM* billion cubic meter

Table 5.10 Potential added cultivated area of winter tomato as a result of cultivation on raised beds, total cultivated area and its total production

	Added area (000 ha)	Total area (000 ha) (Old+ new+ added)	Total production (000 ton)
Lower Egypt			
Alexandria	0.3	1.9	103.0
Behira	0.6	13.7	543.7
Gharbia	0.02	0.1	1.7
Kafr El Sheikh	0.6	2.7	111.5
Dakahlia	0.1	1.5	36.0
Damietta	0.1	0.6	8.9
Sharkia	2.4	19.0	1158.0
Ismailia	0.6	4.2	250.6
Port Said	0	0.3	4.2
Suez	0.1	0.8	34.7
Menoufia	0.01	0.3	12.4
Qalyubia	0.03	0.2	6.6
Cairo	0.002	0.02	0.7
Total	4.8	45.3	2272.1
Middle Egypt			
Giza	0.8	4.5	219.6
Bani Sweif	0.2	4.1	187.2
Fayoum	0.4	2.3	96.2
Minya	0.4	2.9	138.4
Total	1.8	13.8	641.5
Upper Egypt			
Assiut	0.3	2.5	97.7
Sohag	0.4	5.1	273.8
Qena	0.1	1.2	61.5
Luxor	0.1	2.7	134.0
Aswan	0	0.4	5.9
New Valley	0	0.1	2.5
Total	0.9	12.0	575.4
Bordered governorates			
Marsa Matrouh	0	4.7	128.4
North Sinai	0	2.0	50.8
South Sinai	0	0.05	1.0
Total	0	6.8	180.2
Grand total	7.5	77.9	3669.1

Table 5.11 Potential added cultivated area of winter tomato as a result of application of deficit irrigation, total cultivated area and its total production

	Added area (000 ha)	Total area (000 ha) (Old+new+added)	Total production (000 ton)
Lower Egypt			
Alexandria	0.1	2.1	108.4
Behira	0.9	14.7	575.6
Gharbia	0	0.1	2.1
Kafr El Sheikh	0.2	2.8	118.1
Dakahlia	0.1	1.5	38.4
Damietta	0	0.7	10.8
Sharkia	1.2	20.3	1217.9
Ismailia	0.3	4.5	264.2
Port Said	0	0.3	4.2
Suez	0.1	0.9	35.1
Menoufia	0	0.3	13.1
Qalyubia	0	0.2	5.8
Cairo	0	0	0.6
Total	2.9	48.3	2394.3
Middle Egypt			
Giza	0.3	4.8	235.7
Bani Sweif	0.3	4.4	199.6
Fayoum	0.1	2.5	100.6
Minya	0.2	3.0	144.2
Total	0.9	14.7	680.1
Upper Egypt			
Assiut	0.2	2.6	103.2
Sohag	0.3	5.4	288.7
Qena	0.1	1.3	65.5
Luxor	0.2	2.9	143.0
Aswan	0	0.4	6.3
New Valley	0	0.1	2.7
Total	0.8	12.8	609.4
Bordered governorates	0.8		
Marsa Matrouh	0.3	5.1	137.4
North Sinai	0.0	2.0	50.8
South Sinai	0.0	0.0	1.0
Total	0.3	7.1	189.1
Grand total	5.0	82.9	3873.0

These water amounts will not use to cultivate new area with winter tomato. Thus, the total cultivated area under raised beds and application of deficit irrigation will be the same as the cultivated area using the traditional method, but its total production will be increased to 3319.8 and 3156.4 million tons (Table 5.12), or by 6 and 1%, compared to the production using the traditional method.

Table 5.12 Saved irrigation water and total production of winter tomato as a result cultivation on raised beds and application of deficit irrigation

	Raised beds cultivation		Deficit irrigation application	
	Saved water (MCM)	Total production (000 ton)	Saved water (MCM)	Total production (000 ton)
Lower Egypt				
Alexandria	1.2	89.0	0.5	84.5
Behira	2.4	520.8	3.9	494.7
Gharbia	0.1	1.7	0.02	1.6
Kafr El Sheikh	2.4	92.8	0.7	88.1
Dakahlia	0.2	34.7	0.4	32.9
Damietta	0.6	8.9	0.2	8.4
Sharkia	11.3	1021.0	5.7	969.9
Ismailia	2.5	217.3	1.1	206.4
Port Said	0	4.2	0	4.0
Suez	0.5	28.9	0.2	27.4
Menoufia	0	11.9	0.1	11.3
Qalyubia	0.1	4.8	0.04	4.5
Cairo	0.1	0.5	0.01	0.5
Total	21.3	2036.3	12.8	1934.5
Middle Egypt				
Giza	3.3	189.7	1.1	180.2
Bani Sweif	0.8	179.2	1.2	170.3
Fayoum	1.9	80.3	0.7	76.3
Minya	2.0	119.0	0.9	113.1
Total	7.9	568.2	3.8	539.8
Upper Egypt				
Assiut	1.3	88.2	0.8	83.8
Sohag	2.4	252.4	2.0	239.8
Qena	0.3	59.0	0.6	56.1
Luxor	1.0	127.2	1.2	120.9
Aswan	0.1	5.8	0.2	5.5
New Valley	0	2.5	0.1	2.4
Total	5.1	535.1	4.8	508.4
Border governorates				
Marsa Matrouh	0	128.4	1.3	122.0
North Sinai	0	50.8	0	50.8
South Sinai	0	1.0	0	1.0
Total	0	180.2	1.3	173.7
Grand total	34.3	3319.8	22.7	3156.4

MCM million cubic meter

5.3.4 *Water Productivity of Winter Tomato Under the Studied Practices*

Table 5.13 presented water productivity of winter tomato under the five studied production alternatives. The total production of winter tomato under traditional cultivation, as well as under raised beds cultivation and deficit irrigation application with added new areas will be produced using the same amount of applied irrigation water under traditional cultivation.

The results in Table 5.13 showed that the traditional cultivation attained the lowest value of winter tomato water productivity, namely 6.8 kg/ha. The highest water productivity values were attained under application of deficit irrigation and the saved water will be used to cultivate new areas to increase total production of winter tomato. In Gharbia, and Demietta governorates, low water productivity existed as a result of low cultivated area in the old lands. In Port Said and New Valley governorates, there was no difference between the values of water productivity under traditional cultivation, and when raised beds cultivation was applied, either under taking into account added area or without taking it into account. This result attributed to no cultivated area in the old lands. Furthermore, the highest water productivity in Lower Egypt on national level was attained in Menoufia governorate as a result of high productivity per hectare in the old lands.

It can be also noticed from the table that the values of water productivity in North Sinai and South Sinai are similar under the five production alternatives, either cultivation on raised beds or application of deficit irrigation. This is attributed to the soil of these two governorates are sandy and its source of irrigation is groundwater. Thus, these two water saving techniques were not applied.

5.4 Conclusion

Deficit irrigation application to onion and winter tomato grown on raised beds allowed saving large amounts of irrigation water. This amount could be used to increase the cultivated area of another crop has production-consumption gap. The results showed that cultivation on raised beds and application of deficit irrigation to onion resulted in increasing its total production by 11 and 6%, respectively. With respect to tomato, cultivation on raised beds and application of deficit irrigation resulted in increasing its total production by 6 and 1%, respectively. In both crops, application of deficit irrigation on raised beds resulted in higher water productivity value than the value obtained under traditional cultivation.

Table 5.13 Water productivity (kg/ha) of winter tomato under traditional cultivation, raised beds cultivation and deficit irrigation application

	Traditional cultivation	Raised beds cultivation		Deficit irrigation application	
		With added area	Without added area	With added area	Without added area
Lower Egypt					
Alexandria	9.5	12.1	12.3	12.8	10.4
Behira	8.9	9.5	9.5	10.1	8.8
Gharbia	3.8	4.4	5.5	5.4	4.5
Kafr El Sheikh	6.8	9.4	9.8	10.0	7.9
Dakahlia	5.7	6.1	6.1	6.5	5.6
Damietta	2.7	3.0	3.8	3.7	3.1
Sharkia	10.3	12.6	12.7	13.3	11.0
Ismailia	11.3	14.3	14.5	15.1	12.3
Port Said	3.5	3.5	3.5	3.5	3.4
Suez	7.2	9.4	9.2	9.5	7.8
Menoufia	11.6	12.4	12.3	13.1	11.4
Qalyubia	6.3	10.1	9.1	8.9	7.4
Cairo	5.5	7.3	6.6	6.8	5.7
Average	7.2	8.8	8.8	9.1	7.6
Middle Egypt					
Giza	8.9	11.6	12.1	12.4	10.0
Bani Sweif	9.8	10.5	10.6	11.2	9.7
Fayoum	6.5	8.7	8.8	9.1	7.3
Minya	7.8	9.9	9.9	10.3	8.4
Average	8.2	10.2	10.3	10.8	8.9
Upper Egypt					
Assiut	6.3	7.4	7.5	7.8	6.6
Sohag	7.9	8.9	8.9	9.4	8.0
Qena	7.0	7.5	7.5	8.0	6.9
Luxor	6.8	7.4	7.5	7.9	6.8
Aswan	2.2	2.3	2.3	2.4	2.1
New Valley	3.4	3.4	3.4	3.6	3.2
Average	5.6	6.2	6.2	6.5	5.6
Border governorates					
Marsa Matrouh	7.0	7.0	7.0	7.5	6.7
North Sinai	6.1	6.1	6.1	6.1	6.1
South Sinai	5.0	5.0	5.0	5.0	5.0
Average	6.0	6.0	6.0	6.2	5.9
Overall average	6.8	7.8	7.8	8.2	7.0

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