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The impact of climate change and soil salinity in irrigation water demand on the Gaza Strip

Husam Al-Najar and Ehab K. Ashour

Husam Al-Najar (corresponding author)
Environmental Engineering Department,
The Islamic University of Gaza,
P.O. BOX 108 Al-Rimal,
Palestinian Territories
E-mail: *halnajar@iugaza.edu.ps*

Ehab K. Ashour
Environmental and Earth Science Department,
The Islamic University of Gaza,
P.O. BOX 108 Al-Rimal,
Palestinian Territories

ABSTRACT

The presented work analyzes the potential impacts of the temperature, precipitation changes and water salinity on agricultural water demand. The study was carried out on five representative orchard crops (olive, palm, grapes, citrus and guava) that cover around 83% of the orchard farms in Gaza Strip. To achieve this goal, CropWat modeling software version 8.0 is used to calculate the reference evapotranspiration rate and crop water requirement under different temperature and precipitation scenarios. Furthermore, a survey was conducted to evaluate the farmers' current irrigation practices and the impact of water salinity on leaching requirements and production yield. The increased temperatures by 1 or 2 °C caused an increase of the annual average evapotranspiration by 45 and 91 mm relative to the current climate condition and leading to increase of irrigation requirements by 3.28 and 6.68%, respectively. Leaching requirements do not exceed 15% for electrical conductivity (EC) value less than 2 dS/m, while it begins to increase for the EC value between 3 and 4 dS/m and account for 114, 89 and 36% for grape, citrus and guava. Generally, the impact of salinity increase on irrigation requirements is much higher than the impact of evapotranspiration increase due to the temperature increase by 2 °C and 10% precipitation reduction.

Key words | climate change, Gaza Strip, irrigation requirements, salinity and leaching fraction

INTRODUCTION

Agriculture is by far the largest water-use sector, accounting for about 70% of all water withdrawn worldwide from rivers and aquifers for agricultural, domestic and industrial purposes. In several developing countries, irrigation represents up to 95% of all water withdrawn, and it plays a major role in food production and food security (Max *et al.* 2009). In arid and semiarid climates, irrigation is essential to achieve optimal crop productions. The expected global warming impacts are represented by higher and more variable temperatures, erratic precipitation patterns and higher frequency of extreme events. According to climate models concerned with the Mediterranean environment, an increase in winter temperature combined with changes in rainfall amount and distribution would be expected (Mimi & Jamous 2010). Gaza Strip, like other parts in the Mediterranean environment, has serious water shortage and quality problems (Palestinian Water Authority 2004; Qahman *et al.* 2009; Shomar *et al.* 2010). Groundwater is the only available resource of water and agriculture consumes more than 50% of the total groundwater extraction in the Gaza Strip (Lautze & Kirshen 2009; PWA 2012). Many investigations revealed that the annual recharge is less than the extracted quantities: thus resulting in serious mining of the groundwater resources in the area. Simulations of sea water intrusion corresponding to various combinations of groundwater extraction and sea-level rise established that groundwater extraction is the predominant driver of sea water intrusion (Loáiciga *et al.* 2012). The spatial changes of ionic ratios of $r\mathrm{Ca}^{2+}/(r\mathrm{HCO}_3^- + r\mathrm{SO}_4^{2-})$ and the relationship between sodium and chloride in the coastal area in the Gaza Strip indicate that the aquifer experienced seawater intrusion, leading to a severe increase of salinity in groundwater which is currently used for irrigation (PWA 2004; Qahman *et al.* 2009; Al-Khatib & Al-Najar 2011). However, during the 21st century, the

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Mediterranean basin is expected to observe: (i) an increase in air temperature of between 2.2 and 5.1 °C; (ii) a decrease in rainfall of between 4 and 27%; (iii) an increase in drought periods related to a high frequency of days during which the temperature would exceed 30 °C; and (iv) an increase of the sea level of around 35 cm and saline intrusion (Rui *et al.* 2012).

It is forecast that the Palestinian territories would be facing a severe water deficit, likely to be intensified within the coming years due to the consequence of global warming and excessive use of irrigation water in the area. Changes in climate along the Mediterranean coast have received particular attention in the literature owing to their potential impact on water resources in the region (Moratiel *et al.* 2010).

Agriculture constitutes 25% of the total export revenues, 9% of the GDP and employs around 20% of the Palestinian labor force (www.pcbs.gov.ps). Agricultural production in the Palestinian Territories has already been affected by recent droughts and climate predictions suggest that these will become more pronounced over time. Thus, a great challenge for the Palestinian Authority in the coming decades will be the task of increasing food security (by domestic production and/or imports) in conditions of increased water stress (Kafle & Bruins 2009). The farmers use about 20–30% excess irrigation water than required for the common cultivated crops (Al-Najar 2011). Prudent planning requires that a strong water resources research program be established, and the risks and benefits of agricultural economy be incorporated into all long-term water planning. Further discussion about future water planning and management must be flexible. Increased temperatures lead to more groundwater pumping to meet the escalating crop water demand. Annual precipitation rates are likely to fall in the eastern Mediterranean, decreasing by 20% by 2050, with an increased risk of summer droughts. This means agricultural production will be reduced for rain-fed agriculture, thus the price of vegetables, fruits, and other agriculture products will rise, bringing about a further negative effect on marginalized communities (UNDP/PAPP 2010). Despite its small area (365 km^2) and predominantly flat terrain, there is significant variation in the Gaza Strip's temperate climate; the average seasonal rainfall being 522 mm in the northern Beit Lahia governorate and 225 mm in the southern Rafah governorate (PWA 2007). Further, the Gaza Strip experiences hot, dry summers and mild winters, with some evidence of global warming affecting the Gaza Strip (El-Kadi 2005; Krichak *et al.* 2007). This implies that there is an urgent need to address climatic changes on agricultural livelihoods; climatic variables such as temperature and precipitation that are essential inputs to agriculture. Thus, it is important to assess the potential effect of climate change, not only the direct effects of climate on crop yields and farm profit, but also the effects of climate change on the effective water requirements and the availability of water for irrigation (Schlenker *et al.* 2007). The overall objective of the current study was to review the current irrigation practices and to analyze the potential impact of climate change and water salinity on the agricultural water demand for five representative crops. The main climate change factors were the temperature and precipitation change.

METHODOLOGY

CropWat model

CROPWAT, version 2008, is a computer program that uses the UN Food and Agriculture Organization (FAO) Penman–Monteith model to calculate reference evapotranspiration (ETo), crop water requirements (CWR) and crop irrigation requirements (FAO 2008). Four main datasets are used as inputs in the CropWat estimation: climatic, crop, soil and irrigation. Crop data are obtained from the FAO CLIMWAT database (FAO 2003). The climatic data are maximum and minimum temperatures on a monthly basis, mean daily relative humidity (in %), daily sunshine (in hours) and wind speed. Gaza city meteorological station located at 34°27E and 31°30N is the source of the climatic data input to the model. The crop parameters include: water stress coefficient (K_s), length of the growing season and critical depletion level. The soil data include total available soil water content and the maximum infiltration rate for runoff estimates in addition to the initial soil water content at the start of the season (see FAO 2003). The model is used to calculate the CWR for the five chosen orchards, namely olive, palm, grape, citrus and guava, which cover around 83% of the orchard farms in the entire Gaza Strip (PCBS

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& MoA 2011). Additionally, the model is used to simulate the expected changes in agricultural water demand under different climate change scenarios. Water salinity is another factor considered for the calculation of irrigation water requirements (IWR) to maintain the productivity of the trees at the threshold value.

Data on farmers and survey analysis

To define the number of farmers to be surveyed, the following equations were used to calculate the number of potential samples:

$$n = \frac{Z^2 \delta^2}{D^2}$$

where $n =$ sample size; $Z =$ tabulated value of the standard normal distribution (for 99% it is 2.58, for 95% it is 1.96 and for 90% it is 1.65), for this study, the confidence level adopted was 95%; $\delta =$ standard deviation, which is calculated through (start) a sample of 10 farmers before setting the final number of sample farmers; $D =$ maximum error, in the sample calculation 5% as a margin of error could be accepted. While the above equation calculated the sample size regardless of the population number; which is the total number of farmers cultivating the potential orchards in the Gaza Strip, the following equation is used to finite the population correction of the targeted population (Glenn 1992). It is used if the population is small – 7,957 farmers – then the sample size calculated through the first equation can be adjusted and reduced slightly. This is because a given sample size provides proportionately more information for a small population than for a large population.

$$n = \frac{n_0}{1 + \frac{(n_0 - 1)}{N}}$$

where n is the sample size, n_0 is the sample size calculated in the first equation and N is the total number of the farmers in the three governorates (Gaza, Dair Al-Balah and Khan Yuonis governorates). Table 1 summarizes the number of surveyed farmers according to the above equations based on the percentage of each orchard type among the total orchard farms in the Gaza Strip.

With respect to the above-mentioned number of samples, more than 200 farmers were interviewed and 187 valid questionnaires were completed. The questionnaire contained different data about the farmer as well as measuring the electrical conductivity (EC) value for the irrigation water, but the main goal of the questions was to estimate the irrigation quantity applied by the farmers. The data were processed in an Excel sheet in order to compare them with recommended irrigation requirements by the Ministry of Agriculture (MoA) and with the outputs of the CropWat model for each orchard type at various temperature and precipitation rates.

RESULTS AND DISCUSSION

Gaza Strip climate change indicators

Gaza Strip temperature records in the three decades between 1976 and 2006 showed a rising temperature trend for both the minimum and maximum averages, this increase being more pronounced in the minimum temperature averages as compared with the maximum temperature averages. As shown in Figure 1, the trend for minimum averages of the three intervals (1976–1985, 1986–1995 and 1996–2005) accounted for 15.91, 16.70 and 17.64 °C, respectively. In general, Gaza Strip temperature analysis of 1976 and 2005 data showed a rising trend; in the second decade compared to the first decade, the average temperatures showed an increase of 0.79 and 0.29 °C for the

Table 1 | Surveyed farmers' distribution number for the selected orchards of the research area

				Citrus			
Orchards	**Olive**	**Palm**	**Grape**	**Valencia**	**Lemon**	**Guava**	**Total**
Sample No.	82	18	11	14	21	8	154

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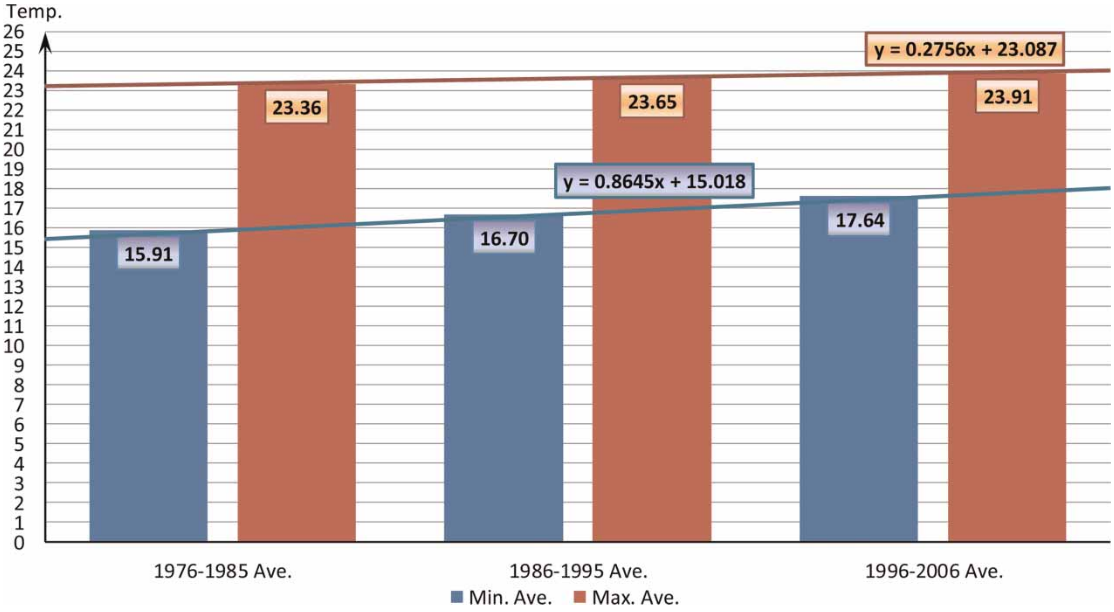

Figure 1 | Minimum and maximum temperature averages with trends for three decades in the Gaza Strip 1976–2005.

minimum and maximum temperatures, respectively. In the third decade compared to the second decade, the average temperatures showed an increase of 0.94 and 0.26 °C for the minimum and maximum temperatures, respectively. Hence, overall, the temperature increase in the Gaza Strip within the past 30 years was clear by about 1.73 °C in the average minimum temperatures, and around 0.55 °C in the average maximum temperatures. It appears almost certain that climate change will have a negative impact on both Palestinian water resources. It is already known that during the 20th century there was an average increase in annual mean temperature between 1.5 and 4 °C for the region. Globally, the mean temperature is expected to increase by an additional 1.8 and 4 °C by the end of the 21st century, relative to the 1980–1999 period (IPCC 2007; Bates *et al*. 2008).

For Palestine, the temperature is expected to rise by 3.5–5 °C by 2071–2100 in comparison to 1961–1990 (IPCC 2007; Alpert *et al*. 2008; Bar-Or 2008; Golan-Engleco & Bar-Or 2008). The full consequence of temperature and rainfall changes are wide ranging and a variety of studies have described the possible impact of these changes on nearly all aspects of the environment and society (Bates *et al.* 2008). Nearly all research in the region confirms that climate change will have a direct effect on regional water resources (Ben-Gai *et al*. 1998; Dayan & Koch 1999; Pe'er & Safriel 2000; Alpert 2004). Temperature analyses by Saaroni *et al.* (2003) for the period of 1948–2002 reported an increase of 0.013 °C per year for the months of July and August and statistically significant warming trends were observed for the decades of 1961–1970 and 1991–2000 (Saaroni *et al.* 2003). For the period of 1964–1994, Ben-Gai *et al*. (1994) observed an increase in both minimum and maximum temperatures. Furthermore, there has been an increase in the number of hot and cool days per year, which implies an increase in temperature extremes. Between the years 1948 and 1977, August was the hottest month of the year; however, since then July has been observed to be the hottest month, a finding which implies the onset of earlier summers (Saaroni *et al.* 2003).

Evapotranspiration response to temperature and precipitation changes

Assumptions of climate change scenarios

Different climate change scenarios were applied for this study. The scenarios were formulated based on changing temperature (T) and precipitation (P); the other metrological data, soil data and crop data were kept without any

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changes. The assumed scenarios for the climate change used in the study were as follows:

1. Temperature change: increase in temperature by 1 and 2 °C while keeping precipitation not changed was the first assumption; this assumption was based on the notion that the trend of increase in temperature is highly expected during the current century in the Mediterranean basin countries as well as in the Palestinian territories.
2. Precipitation change: a decrease in precipitation is predicted in the Mediterranean basin countries from 5 to 10%, and this prediction is shown in the Gaza Strip historical meteorological data relating to precipitation records (UNDP/PAPP 2010).

Therefore, since the increase in precipitation to a certain level in the Gaza Strip is likely desirable; the decrease in precipitation scenarios only was considered. The combination of the change in temperature and precipitation resulted in different scenarios as described in Table 2.

Reference evapotranspiration rate – CropWat model outputs

Based on the assumed temperature change scenarios of the present study, the ETo estimates as given by CropWat software for studied orchards in the Gaza Strip are listed in Table 3. As can be observed, the increase in temperature caused a significant increase in the ETo rate. CropWat reference evapotranspiration results for different assumed temperature variations indicate a clear relation between IWR and temperature changes (Al-Najar 2007). The precipitation rate is not an essential factor for the evapotranspiration rate, therefore the evapotranspiration rate is affected by the increase in temperature. Based on global prediction by the IPCC (2007), a 10–30% decrease in annual precipitation is expected by the second half of the 21st century for this region. Bates *et al.* (2008) predicted an approximate 20% decrease in precipitation for the Mediterranean region. Temporal climatic patterns are also likely to be affected, as changes in the region's climate are expected to produce a truncated but more intense winter rainfall period followed by a longer, drier summer season, the consequences of which are numerous. Using a high resolution model (Kitoh *et al.* 2008), simulating two future climatic scenarios for the region; both scenarios yielded a decrease in future precipitation. This decrease is predicted to occur mostly in the winter and spring seasons, along with an increase in evaporation rates. Therefore, even in areas where precipitation is predicted to increase under the Kitoh *et al.* (2008) model, such as the Gulf Coast region, water resources will probably not increase because of the increased rates of evaporation. Normally the evapotranspiration increased with the increased temperatures if other factors such as humidity, CO_2 concentration, solar radiation and wind speed stayed constant as proposed in the current research. Snyder *et al.* (2011) reported that as the oceans and other water bodies warm and evaporate more water into the atmosphere, global humidity is likely to increase. Thus, while climate change is likely to increase

Table 2 | The assumed climate change scenarios (temperature increase by 1 and 2 °C associated with 5 and 10% precipitation reduction)

T	*P* Aver.	*P*-5%	*P*-10%
T Aver.	Scenario 0	Scenario 3	Scenario 6
T + 1	Scenario 1	Scenario 4	Scenario 7
T + 2	Scenario 2	Scenario 5	Scenario 8

T = Temperature (°C), *P* = Precipitation (mm/year).

Table 3 | Monthly reference evapotranspiration (ETo) predictions by CropWat for temperature change by 1 and 2 °C

Temperature Month	*T* Ave. ETo (mm/month)	*T* + 1	*T* + 2
January	73.2	75.9	78.9
February	79.8	82.8	85.8
March	98.7	102	105.6
April	124.5	128.4	132.3
May	137.1	141.3	145.5
June	151.2	155.7	159.9
July	164.4	169.2	173.7
August	167.7	172.5	177.3
September	149.1	153.3	157.8
October	121.8	125.7	129.6
November	95.1	98.4	101.4
December	80.7	83.4	86.4
Total (mm/year)	1,443.3	14,886	1,534.2

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air temperature, the effect of higher humidity and CO_2 concentration could partially offset the temperature effect on evapotranspiration.

Based on the entire 1976–2005 monthly data records, a single average climatic data value was used for each input climatic parameter to the CropWat to get a single ET_0 (mm/month) value and the same procedure was also employed for other months for each scenario. Changing temperature impacts on ET_0 could vary widely in the Gaza Strip with temperature change. The average actual ET_0 is 1,443 mm/year, while in the case of an increase by 1 and 2 °C, the ET_0 account for 1,488 and 1,534 mm/year respectively, corresponding to a 3.2 and 6.3% increase in the annual ET_0 as compared to the last decade's climatic conditions in the area.

Without the effects of climate change, rising CO_2 will cause an increase in crop Water-Use Efficiency (WUE). However, if temperatures rise, transpirational water use will increase, and WUE will decline. Higher temperatures, and especially less rainfall, would raise the irrigation requirements of crops (Allen 1999). According to Anderson *et al*. (2008), an evapotranspiration increase of 18.7% resulted from a 3 °C rise in air temperature in California with an annual average precipitation of 640 mm and a mean temperature of about 15 °C. While Goyal (2004) reported that a 1 °C temperature increase could increase evapotranspiration by 12.69% in arid regions of Rajasthan, India, where the annual rainfall varies from 100 to 400 mm and mean temperature varies by about 25 °C.

Table 4 presents the irrigation requirements in mm/year for the studied orchards in the Gaza Strip as a sequence of reference evapotranspiration increase. The table represents the CropWat model results for irrigation requirements under the real historical climatic data and the irrigation requirements under eight different assumed climate change scenario as presented in Table 2.

There is an average predictable decrease in precipitation by 20% within the coming decades, therefore the impact of decreases in precipitation by only 5 and 10% were considered as a possible decrease in the next few years for this study. As can be observed, the average response of irrigation requirements to the precipitation decrease by 5 and 10% was by an average increase of 0.45 and 1.73%, respectively, based on the 1976–2005 actual temperature conditions. The overall increase of water requirements for olive, palm, grape, citrus and guava trees considering the worst scenario (*T* increased by 2 °C and precipitation reduction by 10%) are accounted for, 7.7, 10.9, 10.4, 9.3 and 7.9%, relative to the actual temperature and precipitation, respectively.

Plant response in marginal areas with respect to water face increased climatic vulnerability and risk under climate change, due to factors that include, for instance, degradation of land resources through soil erosion, overextraction of groundwater and associated salinization, and over-grazing of dry land. Water plays a crucial role in food production regionally and worldwide. On the one hand, more than 80% of global agricultural land is rain-fed; in these regions, crop productivity depends solely on sufficient precipitation to meet evaporative demand and associated soil moisture distribution. At the same time, during this century, climate change may further reduce water availability for global food

Table 4 | Average irrigation water requirements (IWR mm/year) for the studied orchards for different predicted by CropWat software scenarios

	Irrigation requirements (mm/year)								
Trees	***T* Ave. *P* Ave.**	***T* + 1 *P* Ave.**	***T* + 2 *P* Ave.**	***T* Ave. *P* 5%**	***T* + 1 *P* 5%**	***T* + 2 *P* 10%**	***T* Ave. *P* 10%**	***T* + 1 *P* 10%**	***T* + 2 *P* 10%**
Scenario	0	1	2	3	4	5	6	7	8
Olive	686	707	729	687	710	732	693	716	739
Palm	1,022	1,060	1,100	1,033	1,071	1,111	1,055	1,093	1,133
Grape	584	606	627	590	611	633	602	623	645
Citrus	656	676	699	658	681	704	670	693	717
Guava	1,036	1,071	1,106	1,041	1,075	1,110	1,049	1,084	1,118

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production, as a result of projected mean changes in temperature and precipitation regimes, as well as due to projected increases in the frequency of extreme events, such as droughts and flooding (Rosenzweig *et al.* 2002). Climate changes are expected to affect plant growth and agricultural production (Schlenker *et al.* 2007) as a consequence of the effect of temperature on plant phenology, and in turn crop cycle length, as well as of CO_2 concentration on carbon assimilation and WUE (Olesen & Bindi 2002; Rubino *et al.* 2012). Nevertheless, the simulation of crop growth and water requirements is complicated by the high uncertainty both on the future variability of climatic parameters and on the combined effect of their variation on plant response.

Leaching requirements and farmers' irrigation practices

CWR depend upon several climatic parameters, including rainfall, radiation, temperature, humidity and wind speed. Therefore, any change in climatic parameters due to global warming will also affect evapotranspiration and, as a consequence, will affect the IWR (Goyal 2004). The aridity of climate regulates the modern salt accumulation in hydromorphic landscapes: the higher the aridity, the stronger the accumulation of salts in the upper horizons of salt-affected soils. The aridization of the climate may have different effects on the degree of soil salinity and on the distribution of salts in the soil profiles (Pankova *et al.* 2010).

In the study area, 187 farmers cultivating orchards were surveyed; one of the main aims of the farmers' survey was to measure the EC of the used irrigation water throughout the survey using field portable EC device (HACH – HQ 40d field case), and to estimate the applied irrigation quantities. Unfortunately, farmers in the surveyed area never measured the used quantities of irrigation water. Flow meters were not installed on the irrigation wells. Therefore, data are collected about the pump capacity and irrigation scheduling applied by the farmers to calculate the irrigation water quantity that had been pumped for irrigating their orchards. For each orchard type, farmers were categorized depending on the used irrigation water EC value, then the average irrigation quantities applied by each farmer group were calculated. The processed data of applied irrigation quantities were compared with the recommended result of CropWat for each orchard type in addition to the recommended excess of leaching water to maintain the orchard's productivity at the threshold value.

Since salinity control is critical to obtaining good yields for water in the moderate to high salinity range (>1.5 dS/m), which is the case in most areas in the Gaza Strip, it is recommended to use the EC value for threshold yield potential (FAO website, salinity problems). Table 5 shows the studied orchard tolerance and yield potential as influenced by irrigation water salinity (EC_w) or soil salinity (EC_e). To maintain the highest productivity level at 100%; the threshold EC_w values are 2.5, 2.7, 1.0, 1.1 and 1.7 dS/m for the olive, palm, grape, citrus and guava, respectively.

After calculating the irrigation requirements for the studied orchards using the CropWat modeling software, the leaching requirements for different levels of salinity had been calculated to maintain productivity at the level of threshold yield potential. An increase in EC values caused a significant increase in IWR, the excess of IWR was higher in the sensitive and the moderately sensitive

Table 5 | Orchard tolerance and yield potential as influenced by irrigation water salinity (EC_w) and soil salinity (EC_e)

	100%		90%		75%		50%		0%	
Potential yield	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w
Olive	3.75	2.5	6.3	4.2	10.2	6.8	16.8	11.2	28.5	19
Palm	4	2.7	6.8	4.5	11	7.3	18	12	32	21
Grape	1.5	1	2.5	1.7	4.1	2.7	6.7	4.5	12	7.9
Citrus	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8	5.3
Guava	2.5	1.7	3.8	2.6	6	4	9.4	6.3	16	11

Source: FAO website, salinity problems.

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orchards, while the increased IWR were lower for the tolerant and the moderately tolerant orchards.

Olive orchards

The recommended irrigation quantity for the olive orchards depending on the CropWat results was 686 mm/year (Table 4). Most of the surveyed farmers applied the recommended amount of irrigation water or apply excessive amounts depending on the salinity levels of their water. Despite the fact that olive orchards are known as tolerance trees, it is still required to add a certain amount of leaching water in order to maintain the trees' productivity. Generally, most of the olive orchard farmers did not reach the recommended amount of irrigation water, including the required leaching quantities. The farmers who irrigate with water of EC_w values less than 5 dS/m are concurrent with the model results. High water use in comparison to the model results is noticed for farmer having irrigation water higher than 5 dS/m. As shown in Figure 2, the current

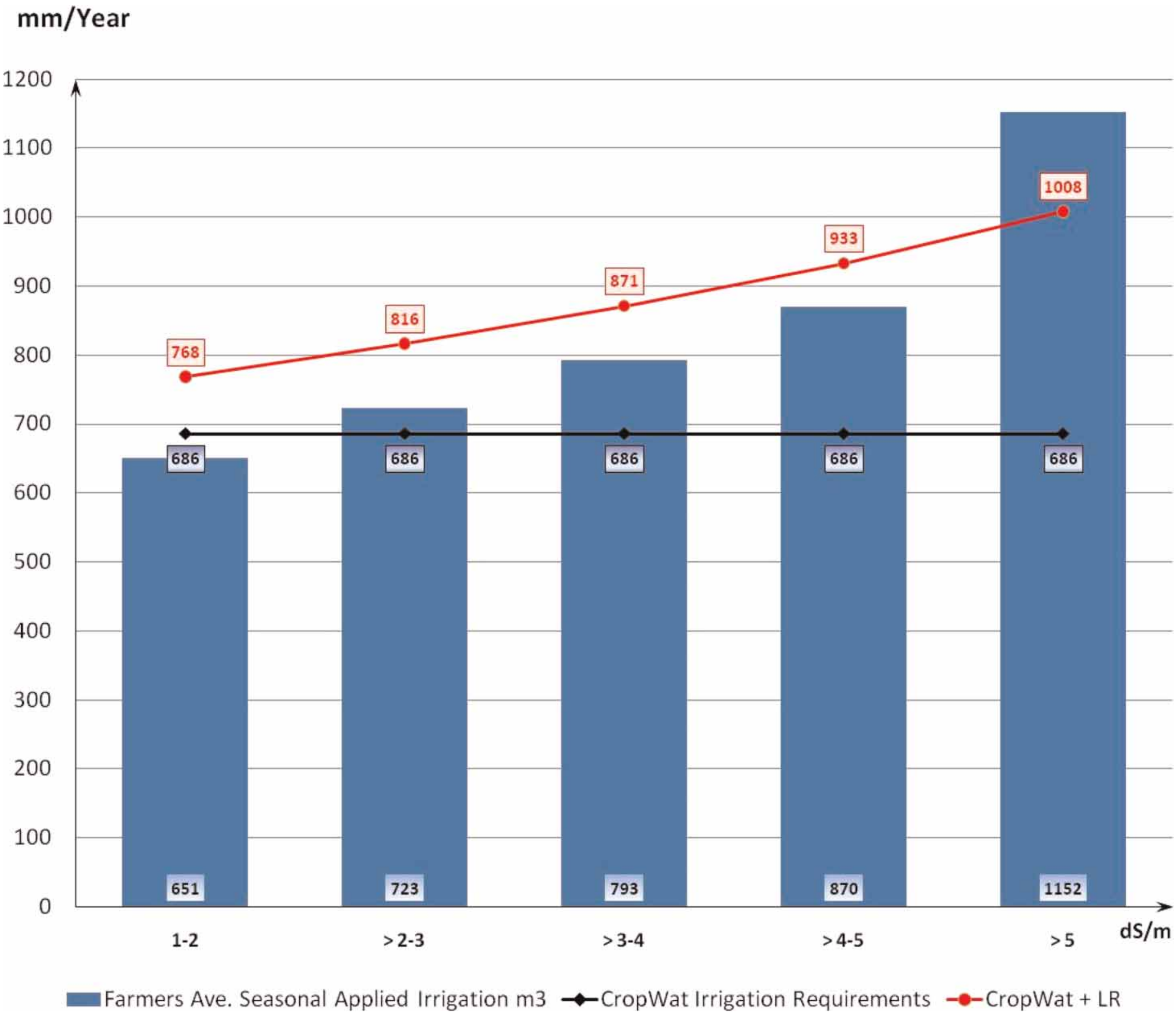

Figure 2 | Applied irrigation quantities by the olive farmers for different level of salinity, compared to CropWat and leaching requirements.

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practice shows that the irrigation water is 1,150 mm/year, while the model results (CropWat + LR) accounted for 1,008 mm/year in the case of EC_w greater than 5 dS/m.

Palm trees

The recommended irrigation quantity for the palm trees as given by the CropWat software is 1,060 mm/year. As shown in Figure 3, most of the surveyed farmers applied excessive amounts of water. The current practices are 1,536, 1,666, 2,040, 1,853 and 2,269 mm/year, while the CropWat model, including leaching requirements (CropWat +LR), shows lesser values and accounts for 1,172, 1,251, 1,325, 1,410 and 1,516 mm/year for irrigation water with EC_w values of 1–2, >2–3, >3–4, >4–5 and >5, respectively.

Grape farmers

Generally, grapes are cultivated in two areas in the Gaza Strip, the first one is the south west of Gaza city where farmers did not irrigate the grapes frequently, especially for the old trees, and exceptionally they irrigate between one and three times in February up to April depending on the rain season. Consequently, grapes in the Gaza city governorate are considered as rain-fed grapes, and their irrigation requirements were neglected. The second area in the Gaza Strip where grapes are cultivated widely is the eastern area of Khan Younis governorate. The grape in this area is extensively irrigated despite the extreme shortage of water in the area. The recommended irrigation quantities for the grapes in Khan Younis governorate depending on the CropWat results is 584 mm/year. As shown in Figure 4, most of the surveyed farmers applied

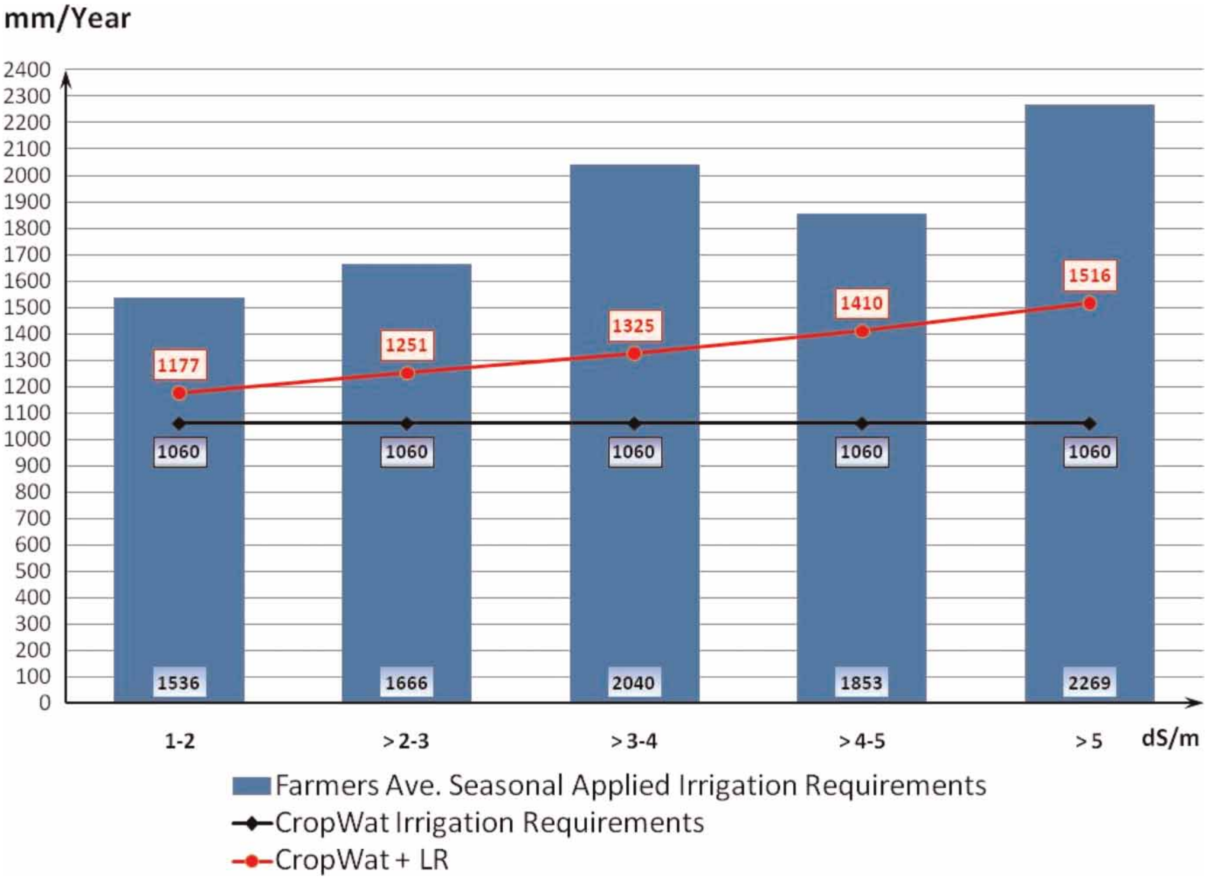

Figure 3 | Applied irrigation quantities by the palm farmers for different level of salinity, compared to CropWat and leaching quantity.

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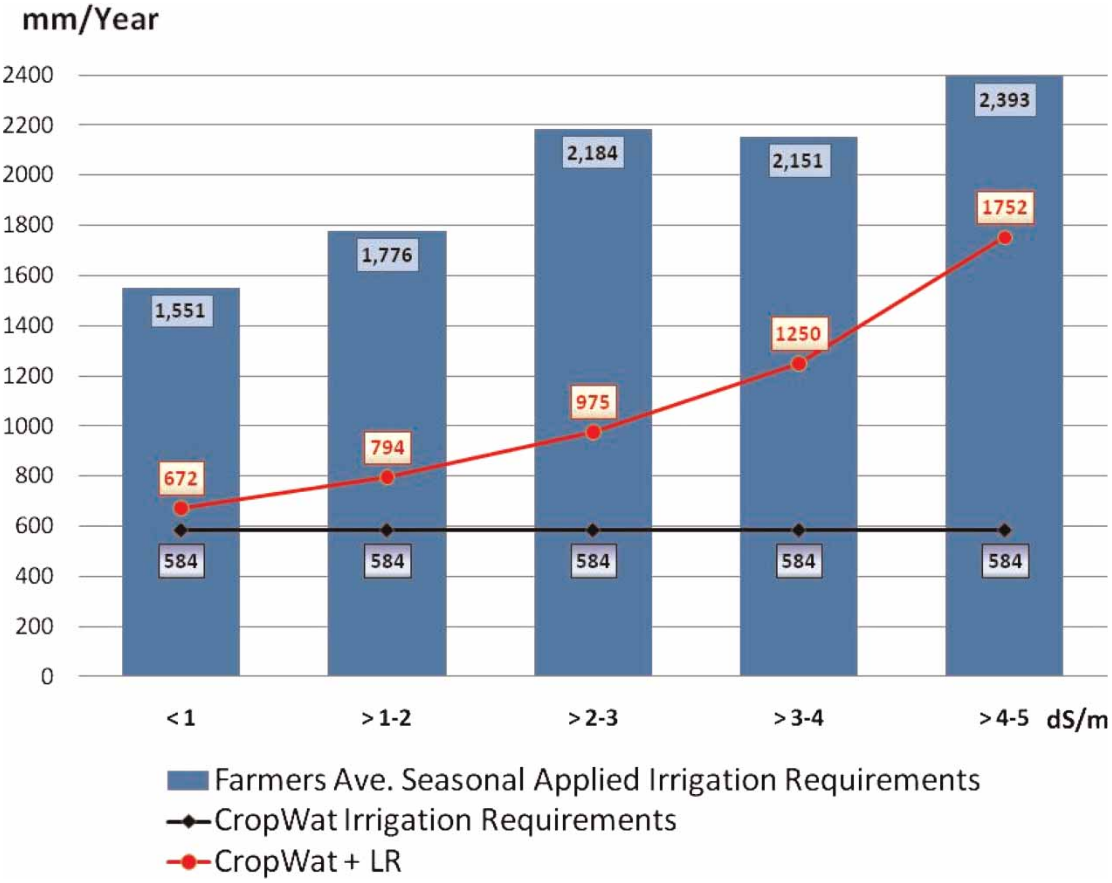

Figure 4 | Applied irrigation quantities by the grape farmers for different level of salinity, compared to CropWat and leaching quantity.

excessive amounts of water measured at 1,551, 1,776, 2,184, 2,151 and 2,393 mm/year, while the model results including the leaching requirements account for 672, 794, 975, 1,250 and 1,752 mm/year for irrigated farms with EC_w values; 1–2, >2–3, >3–4, >4–5 and >5, respectively.

Citrus farmers

Citrus groups are mainly cultivated in the Dair Al-Balah, Gaza and north Gaza governorates. The average recommended irrigation quantity for the citruses in Gaza and Dair Al-Balah governorates as given by the CropWat results is 657 mm/year. Figure 5 shows that most of the surveyed farmers applied lesser amounts of water compared to the CropWat results, including the leaching requirements. For instance, the farmers apply 1,135, 1,143, 1,244 and 1,303 mm, while the model results including leaching requirements (CropWat + LR) account for 1,018, 1,242, 1,597 and 2,234 mm for irrigation water EC_w values; 1–2, >2–3, >3–4, >4–5 and >5, respectively.

Guava farmers

Guava orchards are mainly cultivated in the Dair Al-Balah and Khan Yuonis governorates. The average recommended irrigation quantities for the Guava trees given by the CropWat results was 1,040 mm/year.

Most of the surveyed farmers, as shown in Figure 6, applied excessive amounts of water except for the fields irrigated with EC_w values less than 1 dS/m. Farmers' current practices are 1,166, 1,800, 2,309, 3,825, 3,548 and 5,572 mm/year, while the model results including the leaching requirements account for 1,113, 1,196, 1,300, 1,414, 1,560 and 1,737 mm/year for irrigation

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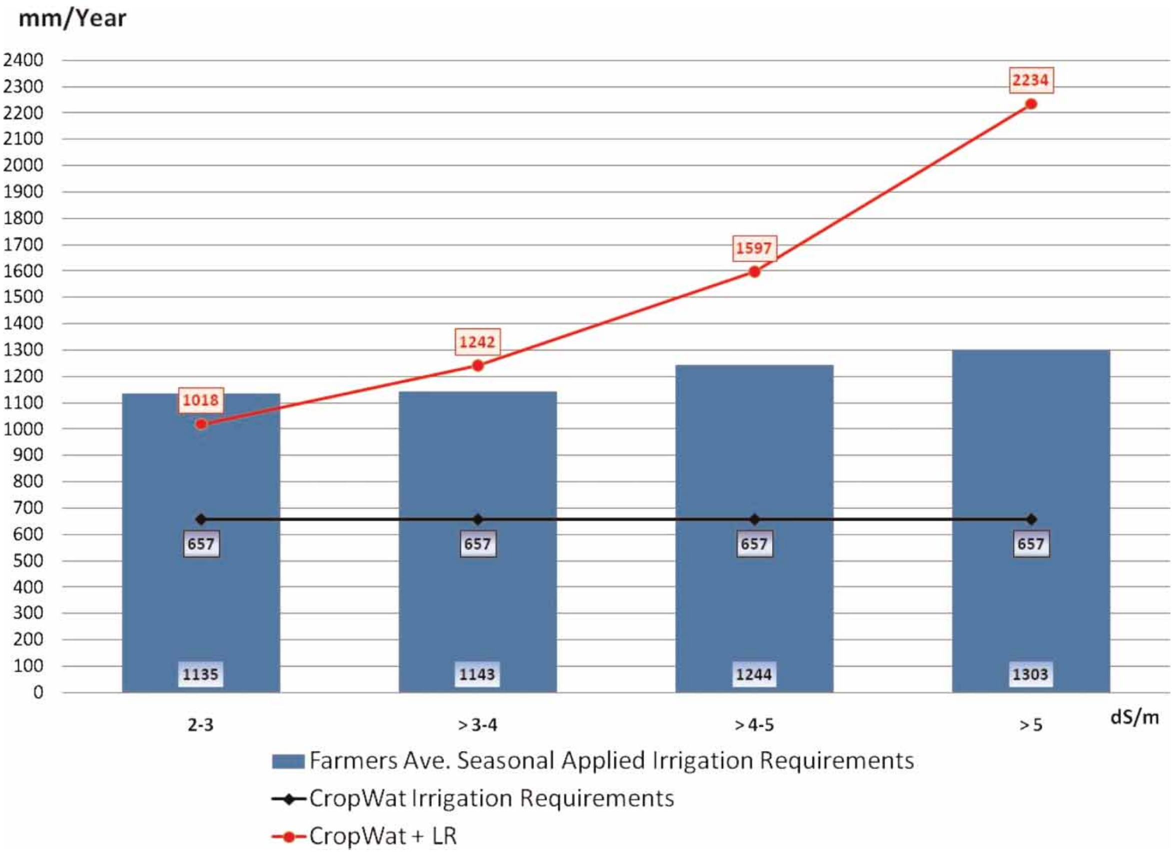

Figure 5 | Applied irrigation quantities by the citrus farmers for different levels of salinity, compared to CropWat and leaching quantity.

water EC_w values; 1–2, >2–3, >3–4, >4–5 and >5, respectively.

In particular, most of the farmers in the west of Khan Yuonis governorate applied highly excessive amounts of irrigation water, they even tripled the applied irrigation for the guava trees including the leaching requirements.

CONCLUSION

The results of the present study provide a preliminary idea about the potential impact of climate change on agricultural water demand, taking into consideration that these results present the impact on six different trees only, which means that the deficit in agricultural water demand will become greater when considering the impact of climate change on all the irrigated agriculture.

The analysis of 30 years' climatic data revealed that there was an increase in the minimum temperatures by $+0.79$ and $+0.94\,^{\circ}$C in the last decades, and an increase in the maximum temperatures by $+0.29$ and $+0.26\,^{\circ}$C in the same period. Normally, the ET_0 was increased with the increase in temperatures; increasing of $+1$ or $+2\,^{\circ}$C caused an increase of the annual average ET_0 by 45 and 91 mm, therefore the irrigation requirements were increased by an average of 3.28 and 6.68% for the total cultivated area of the studied orchards. In the worse scenario of increasing temperatures $+2\,^{\circ}$C, and decreasing precipitation by 10%, the irrigation requirements will be increased ranging from 7.75% (olive) to 10.9% (palm) orchards.

Concerning salinity impact, the leaching requirements were calculated for the studied orchards. All leaching requirements exceed 15% when EC values are less than 2 dS/m. While the leaching requirements begin to increase rapidly

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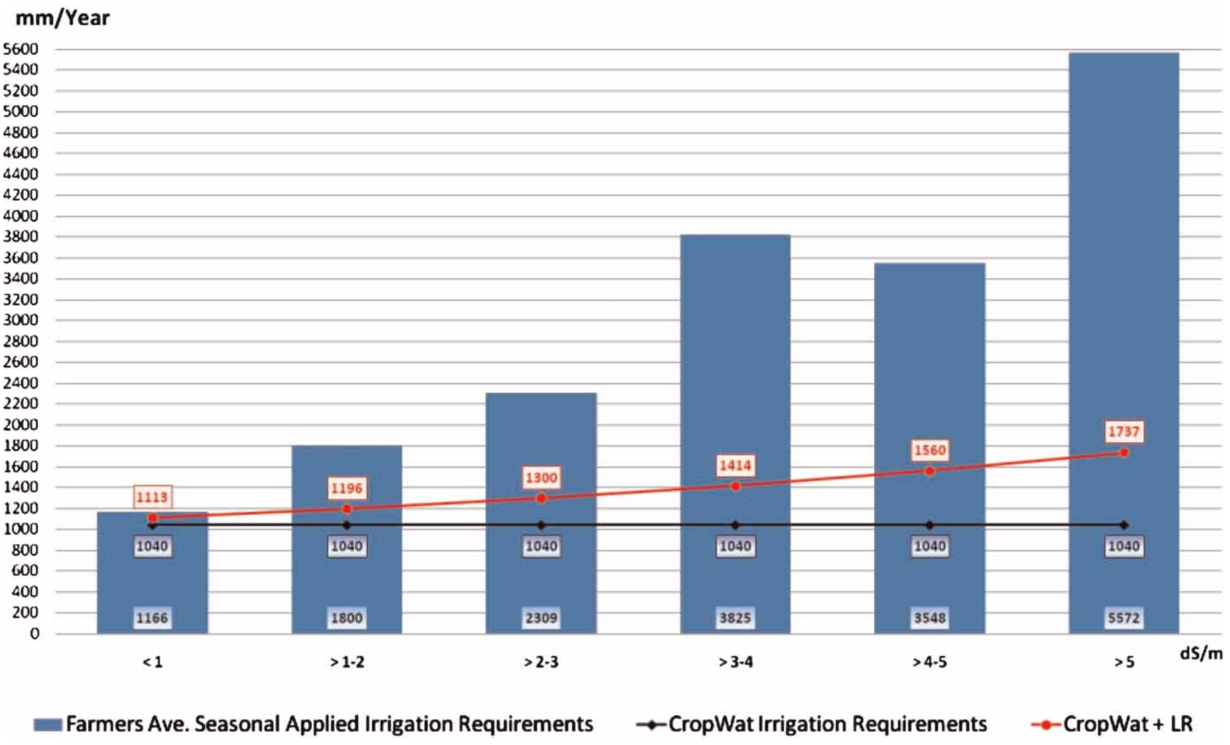

Figure 6 | Applied irrigation quantities by the guava farmers for different levels of salinity, comparing to CropWat and leaching quantity.

after the EC value passed 3 dS/m in the moderately sensitive orchards like grape, citrus and guava, it will increase steadily in the tolerant orchards like olives and palm. The impact of salinity increase on the irrigation requirements is much higher than the impact of climate change. As a matter of fact, water and soil salinity are likely to be increased in parallel with the temperatures increase as a result of raising the evapotranspiration, consequently irrigation demand appeared to be increased dramatically.

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