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ORIGINAL ARTICLE

Determining basil production functions under simultaneous water, salinity, and nitrogen stresses

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Abstract

One of the priorities in the management of agricultural inputs, such as water and fertilizers, involves investigating the variations in the crop yields under actual field conditions, subjected to the effects of various simultaneous stresses. The current study is mainly aimed at investigating the simultaneous effects of triple water, salinity, and nitrogen stresses on basil, Mazandaran mass cultivar, and determining its production functions in such situations. The study was conducted at Doshan Tappeh Agricultural Experiment Station with an area of one ha in Tehran, Iran. A factorial experiment was conducted in the form of a randomized complete block design with different irrigation levels as the main treatment. In addition, two subtreatments, i.e., salinity and fertilization, were conducted in three replications by a water and soil laboratory in 2016 and 2017. The irrigation treatments included full irrigation (FI) in 100% (W_1) and deficit irrigation (DI) in 80% (W_2), 60% (W_3), and 40% (W_4) of crop water requirements. The salinity treatment involved 1.175 ds m^{-1} (S_1) (control treatment), 3 ds/m (S_2), and 5 ds/m (S_3), while the fertilization treatment involved 100% (F_1) (control treatment), 75% (F_2), and 50% (F_3) of the recommended fertilizer requirement. Overall, results indicated that under a constant fertilizer treatment, the rise in the salinity and water stress reduced the basil yield, while under the water-fertilizer double stress, the basil yield rate first decreased and then had a notable increase. By applying water and salinity stresses, the crop yield experienced a steeper reduction under the water stress than the salinity stress. Contrary to expectations, fertilization reduced basil yield under these conditions.

Keywords Completely randomized blocks · Production functions · Simultaneous water- salinity- nitrogen stress · Basil

Introduction

Nowadays, given the population growth and the increasing need for food and healthcare, saving water resources requires more attention. Researchers always seek workable solutions for reducing water consumption. On average, by allocating more than 70% of water resources to the agricultural sector in arid and semi-arid regions, irrigated agriculture can be considered the main water consumer (Fereres and Soriano, 2007). Nitrogen is mostly the first nutrient whose deficiency arises in arid and semi-arid regions (Babazadeh et al., 2017a, b). Various studies have been conducted to optimize production functions for crops under simultaneous stresses. However, no comprehensive studies have been performed on basil. The following summarizes some of the previous studies. Farahbakhsh et al. (2019a, b) evaluated the conventional methods of estimating crop water demands and the actual water requirement of basil under field conditions. An experiment was carried out with three different methods of estimating basil water requirement, including the standard class A evaporation pan, the TethaProbe soil moisture set, and a weight-drain micro-lysimeter. Besides, they compared four irrigation treatments, including full irrigation (FI) and deficit irrigation at (DI 80%), (DI 60%), and (DI 40%) of water requirement. The highest yield of fresh matter in the direct method of estimating water demand was obtained at 5998 and 5966 kg/ha in full irrigation in 2016 and 2017, respectively. Kaplan et al. (2019) conducted a study to determine the potential effects of water deficit and nitrogen treatments on yield components of sorghum-sudangrass and nutritional composition, fermentation, organic matter digestibility, and methane production of sorghum-sudangrass silage. Plants were grown with combinations of three different irrigation levels (I_{100}: 100%, I_{75}: 75%, and I_{50}: 50% of depleted water from field

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capacity) and three different nitrogen doses (N_1: 100, N_2: 200, N_3: 300 kg/ha). Appropriate nitrogen doses had positive impacts on green herbage yield and feed quality. There was no significant difference between $N_3 \times I_{100}$ and $N_2 \times I_{75}$ treatments. Therefore, a slight water deficit (I_{75}) and normal nitrogen supply (200 kg/ha) was recommended for sorghum-sudangrass culture without any significant losses in yield and quality. Gingada et al. (2018) investigated the influence of organic sources of nutrients on the growth, yield, and quality of sacred basil (purple type) by conducting a field experiment at the ICAR-Directorate of Medicinal and Aromatic Plants Research, Boriavi, Anand, Gujarat for two consecutive seasons during 2015–2016. The experiment was devised in a split-plot design with three main plots. The results revealed that different plant growth parameters with respect to plant height, plant spread, and the number of branches, and yield parameters, such as dry herb yield, and essential oil content of pooled mean of two harvests (5.03 t ha^{-1}, 1.35% and 6.79 kg ha^{-1}, respectively) were recorded the maximum in the treatment which received cluster bean crop residue. Abdzadgohari et al. (2018) studied the yield and production functions of peanut cultivars under various irrigation and salinity conditions. This experiment was conducted in the form of split-split plots based on the complete randomized block design with three replications during a two-year period. The experiment included the main factor of irrigation, including four treatments with 100%, 80%, 60%, and 40% of water requirement, a secondary factor of salinity treatment with 7, 5, 3, and 1 ds/m, and another secondary factor involving four peanut cultivars (i.e., Guil., Gorgani, South, and Egyptian). The results showed that the resistance of the peanut cultivars to salinity was variable, and as salinity increased, the yield components decreased. The highest levels of seed yield under 80% of the water irrigation requirements of 2015 and 2016 were 1177 kg/ha 1169 kg/ha, respectively. The salinity level of 1 ds/m provided the highest seed yield. Overall, the highest seed yield was observed in 80% of the water requirement and at the salinity of 1 ds/m. Asadi et al. (2018) made an effort to optimize irrigation water consumption and investigate the optimum nitrogen level. In this study, two scenarios involving different irrigation and nitrogen treatments were considered. Irrigation water treatments included 75% (I2), 50% (I3), and 25% (I4) of water requirement (deficit irrigation), along with full irrigation. Nitrogen treatments included 150 (N1), 112.5 (N2), and 75 kg/ha (N3). The results showed that among production functions, including simple linear, Cobb–Douglas, quadratic, and transcendental ones, the transcendental model was appropriate for soybean. The optimum level of water and nitrogen consumptions for soybean under double water-nitrogen stress was estimated at 230 mm of H_2O, 216.5 mm of H_2O, and 150 kg of N_2 in two crop years, respectively. Furthermore, under the deficit irrigation (DI) treatment, i.e., I_2, treatment N_3 increased the production by 33.28% compared to full irrigation (FI). Hagai et al. (2017) investigated the response of bell pepper to a range of different concentrations of N and salinity (NaCl) in soilless and field experiments under greenhouse conditions. The pepper plant biomass and yield increased with N and decreased with salinity. Chloride mainly accumulated in the stems, and the fraction of Cl in leaves increased as a function of increased exposure to salinity. Increasing the nitrogen fertilizer application resulted in reduced Cl uptake and accumulation in pepper organs, including leaves and petioles. Although N significantly reduced Cl concentration in leaves and petioles, it did not compensate for the negative effects of increasing salinity. This indicated that salinity itself and not Cl-N competition was the limiting factor affecting growth and yield. Babazadeh et al. (2017a, b) conducted a study in order to to introduce and evaluate derived models under simultaneous water and nitrogen deficit stress conditions and consequently calibrating their parameters for basil. In this regard derived models from the composition of Mitscherlich–Baule (MB) for nutrient stress conditions and the models of Feddes (F), van Genuchten (VG), recommended exponential (EXP) and Homaee (H) for water stress conditions and also the composition model of Liebig–Sprengel (LS) for nutrients and the model of Feddes (F) for water stress conditions were presented and evaluated. This experiment was conducted with four irrigation water quantity levels of 120, 100, 80 and 60% of crop water requirement and four nitrogen fertilizer levels of 100, 75, 50 and 0% of fertilizer requirement based on a soil fertility test with three replicates. The results of calculated statistics to compared models based on the different nitrogen and water irrigation levels indicated that MB-EXP and MB-F using nRMSE statistics were 2.78 and 3.64, and EF statistics of both was 0.99% and they showed the highest accuracy in estimating basil yield. Ma et al. (2016) examined the individual and interactive effects of salinity, water, and nitrogen stresses in different growth stages of sunflowers. The factors in this study included soil salinity, soil moisture, and the level of consumed nitrogen. They found that treatments with higher salinity increased the duration of the vegetative stages by 23.91% and decreased the maturity period by 33.09% compared to the control salinity treatments. Similarly, water deficiency significantly reduced the pollination and overall growth duration.

Babazadeh et al (2017a, b) conducted a study to compare several equations describing the combined effects of water and salinity stress on root water uptake and to improve one of the equations. An experiment was conducted with four irrigation water salinities [1.175 (S1), 3 (S2), 5 (S3), and 8 (S4) dS m–1] and four irrigation levels: 120 (W1), 100 (W2), 80 (W3), and 60% (W4) of crop water requirements, each with three replicates. Because of the high sensitivity of basil to both water and salinity stresses, the root water

Table 1 Physical characteristics of the studied field's soil

Physical characteristics of the soil								
Specific mass (g/cm^3)	Weight loss in suction of 15 atmospheres	Weight loss in suction of 0.3 atmospheres	Saturated moisture percent	Texture	Clay %	Silt %	Sand %	Sample depth (cm)
1.52	10.6	24.9	40.7	Sandy loam	13.5	8.5	78	0–30
1.54	11	25.4	41.4	Sandy loam	13	7	80	30–60

Table 2 Chemical composition of the studied field's soil

Chemical composition of the soil						
Zn mg/Kg (ave)	Cu mg/Kg (ave)	Absorbable potassium (ppm)	Absorbable phosphorus (ppm)	Total nitrogen%	Organic carbon %	Sample depth (cm)
0.43	0.37	75	1.24	0.003	0.11	0–30
0.58	0.4	80	1.48	0.002	0.13	30–60

Table 3 Chemical analysis of the well's water sample from the Doshan Tappeh research site

PH	SAR	EC (ds/m)	Anion (meq/lit)				The sum of anions	Cations (meq/lit)				The sum of cations
			Cl^-	HCO_3^-	CO_3^{-2}	SO_4^{-2}		K^+	Mg^{2+}	Na^+	Ca^{2+}	
8.20	3.81	1.175	3.00	6.60	0.9	0.17	10.67	–	1.2	6.60	4.80	12.60

uptake threshold value was low. Increased salinity decreased the potential at which the root water uptake ceased.

In the current study, the aim is to investigate the basil (Mazandaran mass cultivar) yield in Iran from a different point of view. Moreover, the study sought the optimum PF for each simultaneous stress condition so that it could help to solve the future problems, specifically in saving water. The novelty of this study is the development of a summable or multiplicative derivative model for the basil production function under triple stress conditions of water, salinity, and nitrogen deficiency.

Materials and methods

The location of the studied area

A factorial experiment on basil (*O. Basilicum* L.), Mazandaran mass cultivar, in the form of a randomized complete block design was conducted in a 1-ha research farm at Doshan Tappeh, southeast of Tehran, Iran (35° 4 'N, 51° 28′ E, 1209 m asl) in two years (2016 and 2017) to collect the required experimental data. The basil crop was planted on June 6, 2016, and April 27, 2017. The total period of plant growth was 91 days, and the duration of early, developmental, intermediate, and terminal growth were 13, 36, 26, and 16 days, respectively. Water salinity treatments were obtained by mixing natural Shoor River's saline water with fresh water from the field's well, located in Peik Zarand and Varamin. At the beginning of the experiment, soil samples were taken from different parts of the field and sent to the Karaj Soil and Water Research Institute. According to the type of plant used in the study as well as the soil samples, the institute provided the table for the plant fertilizer requirement. As the basil plant is sensitive to potassium and nitrogen fertilizer during the growing season, the need for potash was completely met, and nitrogen was considered a byproduct provided to the plant as needed (Farahbakhsh et al. 2019a, b). The chemical and physical characteristics of the applied water and soil are summarized in Tables 1, 2, 3, 4.

Determining basil crop's water requirement

To determine the crop's water requirement, this research was done in three one-hectare farms with completely identical conditions. But for each of these farms, a different water requirement method was chosen to enable the comparison of Theta Probe (indirect method based on soil index), evaporation pan (indirect method based on climatic index), and the suggested weight-drain micro-lysimeter (direct method based on soil and water balance) under the same conditions. A suggested weight-drain micro-lysimeter, located in the middle of the farm, was utilized

Table 4 Chemical factors of the field's soil

pH	EC (ds/m)	Anion (meq/lit)				The sum of anions	Cations (meq/l)				The sum of cations
		Cl^-	HCO_3^-	CO_3^{-2}	SO_4^{-2}		K^+	Mg^{2+}	Na^+	Ca^{2+}	
7.49	2.13	7.50	12.5	–	4.06	24.06	–	7.50	5.30	11.25	24.05

Fig. 1 Suggested micro-lysimeter in Doshan Tappeh research site

while adding a container to collect the drained water (Sarai Tabrizi 2017). The micro-lysimeter was placed in the middle of the farm. In addition, a container was added to the micro-lysimeter to collect water drainage. The drainage container was weighed every 12 h (6 a.m. and 6 p.m.), and the quality of its content was measured and recorded using the EC gage. (Fig. 1, 2).

In order to determine irrigation scheduling, the water and soil balance method was applied using the treatment without water stress as a reference. First, the amount of absorbable crop moisture had to be calculated (Eq. 1), and then irrigation had to be carried out when the moisture reached that level.

$$\theta\text{CEC} = \theta\text{FC} - (\theta\text{FC} - \theta\text{PWP}) \times \text{MAD} \tag{1}$$

In which θCEC is the volume of the absorbable crop moisture, θFC is the volume of the moisture at field capacity, θPWP is the volume of the moisture at permanent wilting point, and MAD is the maximum available depletion coefficient. The depth of the irrigation water was determined by Eq. 2. The rate of maximum available depletion was considered 30% (Ekren et al., 2012) (Eq. 2).

$$I = (\theta\text{FC} - \theta\text{PWP}) \times \text{MAD} \times \text{Drz} \tag{2}$$

In which I is the irrigation water depth, and Drz is the root zone depth. The level of crop water requirement was calculated using the soil and water balance equation (Eq. 3).

$$\text{ET}_c = I - D_d - \text{Ro} - \Delta S \tag{3}$$

In this equation, ET_c denotes the crop water requirement, D_d is the drain water depth, Ro is the runoff depth, and ΔS is the rate of change in soil moisture storage. In order to determine the exact amount of soil moisture, a Theta Probe set was used and calibrated using the weight method. ΔS was estimated using the following equations:

$$\text{DS} = S_2 - S_1, S = \sum (\theta \times D)_I \tag{4}$$

in which D is the depth of the soil layers.

Applied treatments

The basil crop yield was measured under different levels of water, salinity, and fertilizer, applied as double and triple simultaneous stresses. This experiment was conducted with the different levels of irrigation, salinity, and fertilization. Four irrigation treatments (main factor) with different levels of water application, i.e., full irrigation (FI = 6812 m^3/ha) with 100% (W1) and deficit irrigation (DI) with 80% (W2), 60% (W3), and 40% (W4) of crop water requirements, and three salinity levels (sub-factor), i.e., 1.175 ds/m

Fig. 2 An overview of the test at the Doshan Tappeh research site

Repetition 1			Repetition 2			Repetition 3		
Salinity treatment	Water treatment	Nitrogen treatment	Salinity treatment	Water treatment	Nitrogen treatment	Salinity treatment	Water treatment	Nitrogen treatment
S_1	W_1	N_1	S_1	W_1	N_1	S_1	W_1	N_1
		N_2			N_2			N_2
		N_3			N_3			N_3
	W_2	N_1		W_2	N_1		W_2	N_1
		N_2			N_2			N_2
		N_3			N_3			N_3
	W_3	N_1		W_3	N_1		W_3	N_1
		N_2			N_2			N_2
		N_3			N_3			N_3
	W_4	N_1		W_4	N_1		W_4	N_1
		N_2			N_2			N_2
		N_3			N_3			N_3

Fig. 3 Schematic map of relationship between salinity treatment 1 and other water and Nitrogen treatments

(S1, control treatment), 3 ds/m (S2), and 5 ds/m (S3), as well as three fertilization nitrogen levels (sub-factor), i.e., 100% (F1, control treatment), 75% (F2), and 50% (F3) of recommended fertilizer requirement by the water and soil laboratory. According to the investigations, the soil required 50 kg/ha of nitrogen. The applied treatments on basil crops included 12 scenarios for double water-salinity stress, 12 scenarios for double water-fertilizer stress, nine scenarios for double salinity-fertilizer stress, and 36 scenarios for triple water-salinity-fertilizer stress. The results of crop yield measurements under these stress scenarios were as follows. Figure 3 shows the schematic map of the design for salinity treatment 1 and other water and Nitrogen treatments. Salt treatments 2 and 3 also has a similar plan, which was omitted due to its similarity.

Statistical analysis

The experimental design was in the form of complete randomized blocks with three replicates. Duncan's multiple range test (MRT) at a significance level of 95% ($\alpha = 5\%$) was used to compare the average yields under different treatments. In addition, the determination coefficient (R^2) and standard error were used to determine the accuracy of the yields estimated by the production functions. The optimized fitting for the crop production functions and statistical analysis was carried out using the Sigma Plot and SPSS[1] software applications, respectively.

Results and discussion

Real evaporation and transpiration of basil

To compare the accuracy of estimating actual basil water requirement, three methods are used, i.e., Theta Probe, evaporation pan, and the suggested weight-drain microlysimeter, in the field. Figure 4 demonstrates the schematic form of all three methods in the field.

Figure 5 depicts the trend of daily evapotranspiration changes obtained during planting season, using the microlysimeter method.

[1] SPSS Statistics is a statistical software suite developed by IBM for data management, advanced analytics, multivariate analysis, business intelligence, criminal investigation. Long produced by SPSS Inc., it was acquired by IBM in 2009. Current versions have the brand name: IBM SPSS Statistics.

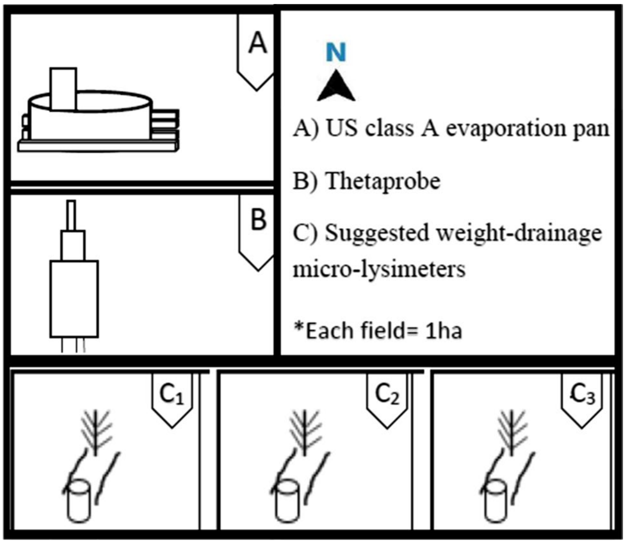

Fig. 4 Schematic view of three different crop water requirement methods in the field

The curve fitted to the basil evapotranspiration diagram in Fig. 5 indicates an upward trend while depicting the different stages of plant growth. This can be explained by the fact that at the beginning of the growth period, due to the small surface area of leaves, the evapotranspiration had the lowest value. However, it increased with the growth of the plant and the leaf area, followed by a reduction at the end of the growth period. The maximum level of basil evapotranspiration was measured at 11.2 mm, 53 days after sowing on July 28 2017. Figure 6 demonstrates the changes in the daily crop coefficient (kc).

It is clearly observed in Fig. 6 that k_c had its lowest value at the early growth stage, increasing significantly as the development stage started. Consequently, the highest value for k_c was 1.26, obtained at the development and middle stages. Unlike most of the crop coefficient diagrams studied by FAO No. 56, the stage of development growth occurred with a steep slope in a short interval, and then, the middle stage occurred in a long interval. Table 5 presents the different reference and crop evapotranspiration values, as well as crop coefficient values, in different basil growth stages based on the micro-lysimeter (direct) method.

Basil yield and water productivity

Table 6 lists the levels of irrigation water, basil yield, and water productivity subjected to dual simultaneous stresses measured under the actual field conditions.

As expected, the highest levels of basil yield and water consumption efficiency were obtained at 5832.1 kg/ha and 0.86 kg.m^3, respectively, in the control treatment ($W_1S_1F_1$). Moreover, the minimum levels of basil yield and water consumption efficiency were found in the $W_4S_3F_1$ treatment, being equal to 693.3 kg/ha and 0.25 kg. m^3, respectively. The results are summarized in Table 6, showing the high sensitivity of basil to salinity and dehydration. Another reason for this claim is the reduction in yield by 3897.7 kg due to the salinity increased from the S_1 (1.175 ds/m) to S_3 (5 ds/m), which is the largest reduction caused by changes in the treatment levels.

Furthermore, the maximum reduction in water consumption efficiency was obtained 0.64 kg.m^3 H_2O in water-salinity treatments $W_4S_1F_1$ and $W_4S_3F_1$. For instance, according to the results of water-fertilizer stress data provided in Table 6, the level of crop yield and water use efficiency were 5832.09 and 0.86 in treatment $W_1F_1S_1$ and 1897.72 and 0.7 in treatment $W_4F_3S_1$, respectively. Moreover, it can be observed that the higher the absolute value of the matric potential and the lower the fertilization potential, the lower the crop yield and the overall water productivity.

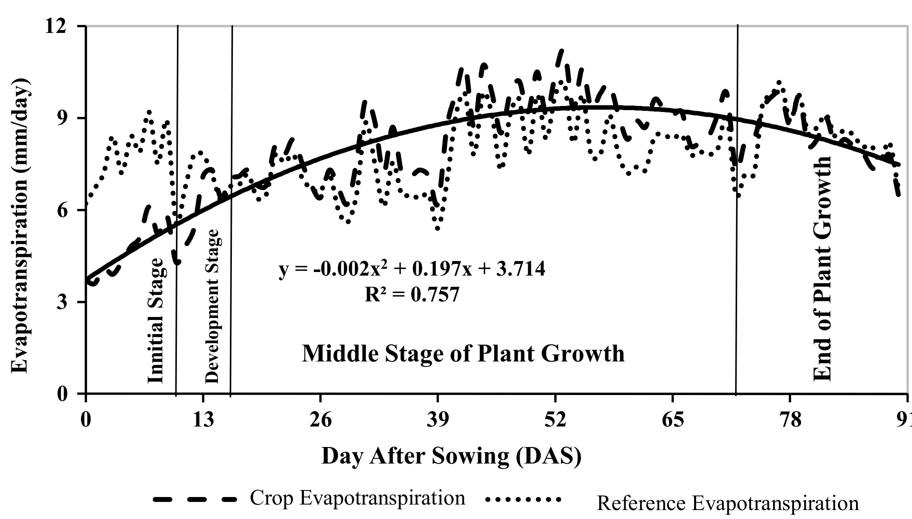

Fig. 5 The trend of changes in the reference and plant evapotranspiration during the growing season of basil

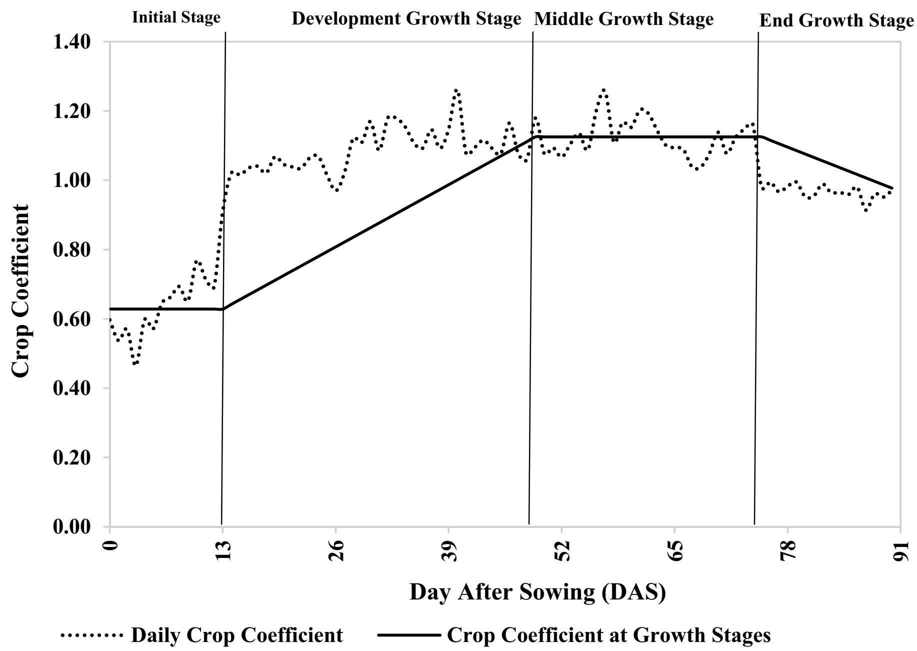

Fig. 6 The trend of plant coefficient changes during the growing season of basil

Table 5 Basil growth stages and plant coefficient values in full irrigation treatment

Plant growth stage	Growth period (days)	Reference evapotranspiration (mm)	Crop evapotranspiration (mm)	Crop coefficient
Primary (vegetative)	10	97.70	61.10	0.63
Development (beginning of flowering)	6	32.14	34.71	1.08
Medium full flowering	59	444.27	497.58	1.12
End (seed maturation)	16	138.45	134.04	0.97

The measured data presented in Table 6 show that under double salinity-fertilizer stress, between treatments $W_1S_2F_1$ and $W_1S_2F_2$ and treatments $W_1S_3F_1$ and $W_1S_3F_2$, as fertilization increased, the yield decreased by 564.9 and 566.2 kg/ha, respectively. This indicates an influence similar to that caused by increasing salinity and fertilizer to prevent the water absorption by plants at the first and second levels of fertilization consumption.

Analysis of variance (ANOVA)

The results of the ANOVA for the levels of yield and water consumption efficiency under simultaneous water-salinity-fertilizer stresses are presented in Table 6. Moreover, the significance of the treatments was calculated at the 1% and 5% significance levels, respectively.

The results in Table 7 indicate that the dry matter yield variations of basil were significant at 1% water-salinity and 5% salinity-fertilizer stresses. The levels of water-salinity and water-fertilizer treatments had a greater effect on changing the crop yield than the fertilizer-salinity treatments.

Crop production functions (CPFs)

Crop production functions under simultaneous double and triple stresses of water, salinity, and fertilizer are presented in Table 8.

It is clearly observed in Table 8 that the best-fitted production function for all simultaneous double stresses (water-salinity, water-fertilizer, and salinity-fertilizer) was the Lorentzian function. Water-salinity production functions with the highest correlation coefficient and the lowest square of error (SE) (0.994 and 157, respectively) were the most accurate fitted functions among all the functions of the simultaneous double stresses. The slope of the crop yield changes under double water-salinity stress is shown in Fig. 7.

According to Fig. 7, the water-salinity stress had a greater impact on the slope of the decreasing yield than the salinity stress. It can be assumed that for certain amounts of water and salinity, the effect of matric potential on basil yield was more significant than the osmotic potential. Compared to the case with high salinity and reduced soil moisture, in the case with high soil moisture and no salinity stress, reducing the level of irrigation water led to an increase in the downward slope. In other words, yield changes were more sensitive to

Table 6 Comparison of yield and water productivity in dual stress treatments of basil

Description	Treatment	Water Use m^3/ha	Yield kg/ha	Description	Treatment	Water Use m^3/ha	Yield kg/ha	WP kg/m^3	Description	Treatment	Water Use m^3/ha	Yield kg/ha	WP Kg/m^3
Water-EC Treatments	W1S1F1	6812.0	5832.1^{a}	Water- Fertilizer Treatments	W1S1F1	6812.0	5832.1^{a}	0.86^{a}	EC-Fertilizer Treatments	W1S1F1	6812.0	5832.1^{a}	0.86a
	W1S2F1		2736.5^{d}		W1S1F2		5210.9^{ab}	0.76^{c}		W1S1F2		5210.9^{ab}	0.76ab
	W1S3F1		1934.4^{ef}		W1S1F3		4496.6^{b}	0.66^{cd}		W1S1F3		4496.6^{b}	0.66bc
	W2S1F1	5459.6	4496.6^{ab}		W2S1F1	5459.6	4496.6^{b}	0.82^{ab}					
	W2S2F1		2106.1^{e}		W2S1F2		3330.2c	0.61^{d}		W1S2F1		2736.5^{d}	0.40d
	W2S3F1		1680.2^{f}		W2S1F3		2913.4^{cd}	0.53^{e}		W1S2F2		3301.4^{c}	0.48d
	W3S1F1	4087.2	3330.2^{c}		W3S1F1	4087.2	3330.2^{c}	0.81^{b}		W1S2F3		3079.9^{c}	0.45d
	W3S2F1		1589.7^{f}		W3S1F2		2412.8d	0.59^{d}					
	W3S3F1		1148.1 g		W3S1F3		2247.6^{d}	0.55^{e}		W1S3F1		1934.4e	0.28f
	W4S1F1	2724.8	2412.8^{ed}		W4S1F1	2724.8	2412.8^{d}	0.89a		W1S3F2		2500.6^{cd}	0.37e
	W4S2F1		1176.9 g		W4S1F2		2131.0^{de}	0.78^{c}		W1S3F3		2407.5^{de}	0.35ef
	W4S3F1		693.3 h		W4S1F3		1897.7^{e}	0.70^{cd}					

* Identical letters (Non-significant N.S.), Different first letters (significant at the level of 1%), and different second letters (significant at the level of 5%) based on Duncan's multiple domain test

salinity treatments than to irrigation treatments. Finally, a three-dimensional graph of the crop yield against synchronous water-salinity stress was plotted in Sigma-plot software application (Fig. 8).

It should be accepted that fertilizers are a type of salt, and by adding them to the irrigation water, the level of salinity increases. Therefore, it is important to determine the amount of fertilizer and its distribution management. From another point of view, the amount of irrigation water can affect fertilizer consumption efficiency (Karimi et al. 2006; Abbasi et al. 2012). The studies have shown that the use of fertilizers in saline soils may have an increasing or decreasing effect on the crop yields. Plant response to the chemical fertilizers also depends on the level of salinity created in the root environment (Maas and Grattan 1999). In addition, at low levels of salinity, deficiency of nutrients can be the most important limiting factor for the plants' growth (Esmaili et al. 2005; Farahmandzad et al. 2005).

According to Fig. 9, it is clear that generally, in full irrigation treatments, as fertilizer decreased, the yield decreased, too. Moreover, in treatments with severe dehydration, increasing the fertilizer led to a decreased yield. This may occur because the fertilizer can act like a salinity factor, which is obvious during water scarcity, increasing the osmotic potential. Therefore, under severe irrigation treatments, further use of the fertilizer did not improve the yield.

Under such conditions, a plant needs to consume more water to absorb a certain amount of water, and, as a result, its yield is reduced. Under the severe irrigation conditions, there is virtually no water in the soil to dissolve nutrients to be consumed by the plant. According to Fig. 9, water irrigation caused greater changes in the yield slope compared to fertilizer. Furthermore, Fig. 10 depicts a three-dimensional graph of the crop yield against the simultaneous water-nitrogen stress obtained using the Sigma-plot software.[2]

Figure 11 shows how changing the fertilization and salinity rates affected plant yield. In treatments with fixed fertilization rates, as salinity increased, the crop yield decreased. However, treatments with variable fertilization and fixed salinity rates did not show this regular trend. In general, the lowest and the highest yield levels were obtained by $W_1F_1S_3$ and $W_1F_1S_1$, respectively. This means that the highest levels of fertilizer and salinity led to the minimum yield. Therefore, when there is salinity stress, increasing the fertilizer cannot have a good effect on crop yield.

When the soil's water level is sufficient, and the plant is not exposed to moisture stress, the application of mineral

[2] SigmaPlot® 8.0 Programming Guide: http://www.physics.udel.edu/~bnikolic/QTTG/shared/docs/SigmaPlotProgrammingGuide.pdf.

Table 7 Analysis of the variance in yield and water productivity of basil water consumption under pairs of water, salinity, and fertilizer stresses

Sources of changes	Water-salinity stress			Water-fertilizer stress			Fertilizer-salinity stress		
	degree of freedom	Dry matter yield (Kg/ha)	Water productivity (Kg/m^3)	degree of freedom	Dry matter yield (Kg/ha)	Water productivity (Kg/m^3)	Degree of freedom	Dry matter yield (Kg/ha)	Water productivity (Kg/m^3)
Repetition	2	0.71	0.89	2	0.79	0.97	2	0.59	0.76
Treatment	3	2104.62*	0.84*	3	5218.62*	0.82*	3	4582.44**	0.82*
Error	6	7.04	6.42	6	5.1	4.8	6	7.04	2.5
C.V		0.22	0.12		0.25	0.18		0.33	0.11

* And **: Significant at the levels of 1% and 5%, respectively

Table 8 Basil plant production functions in dual and triple stresses of water, salinity, and fertilizer

SE	R2	Fitted equation	The main equation	CPF name	Type of SNBES
157	0.994	$Y = \frac{727654.1}{\left[1+\left(\frac{W-8214.7}{4248.5}\right)^2\right]\left[1+\left(\frac{S+3.4}{0.4}\right)^2\right]}$	$Y = \frac{a}{\left[1+\left(\frac{W-W_0}{b}\right)^2\right]\left[1+\left(\frac{S-S_0}{c}\right)^2\right]}$	Lorentzian	WS
171	0.991	$Y = \frac{729721.5}{\left[1+\left(\frac{W-13661.8}{1614.6}\right)^2\right]\left[1+\left(\frac{F-339.6}{103.2}\right)^2\right]}$	$Y = \frac{a}{\left[1+\left(\frac{W-W_0}{b}\right)^2\right]\left[1+\left(\frac{F-F_0}{c}\right)^2\right]}$		WF
342	0.964	$Y = \frac{429584.5}{\left[1+\left(\frac{S+5.6}{0.8}\right)^2\right]\left[1+\left(\frac{F-88.5}{103.0}\right)^2\right]}$	$Y = \frac{a}{\left[1+\left(\frac{S-S_0}{b}\right)^2\right]\left[1+\left(\frac{F-F_0}{c}\right)^2\right]}$		SF
327	0.960	$Y = 0.2W^{1.04}S^{-0.53}F^{0.23}$	$Y = aW^bS^cF^d$	Polynomial	WSF

Note: SE: Standard Error, R^2: The deterrmination coefficient, *CPF*: Crop Production Function name, *SNBES*: Type of Simultaneous Non-Biological Environmental Stress, *WS*: Simultaneous water and salinity stress, *WF*: Simultaneous water and fertilizer stress, *SF*: simultaneous fertilizer and salinity stress, and *WSF*: Simultaneous water, salinity and fertilizer stress

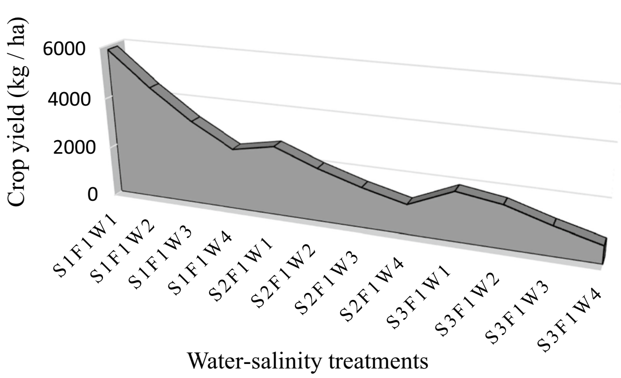

Fig. 7 The slope of crop yield changes in the field (dry leaves) in kilograms per hectare under simultaneous water-salinity stress

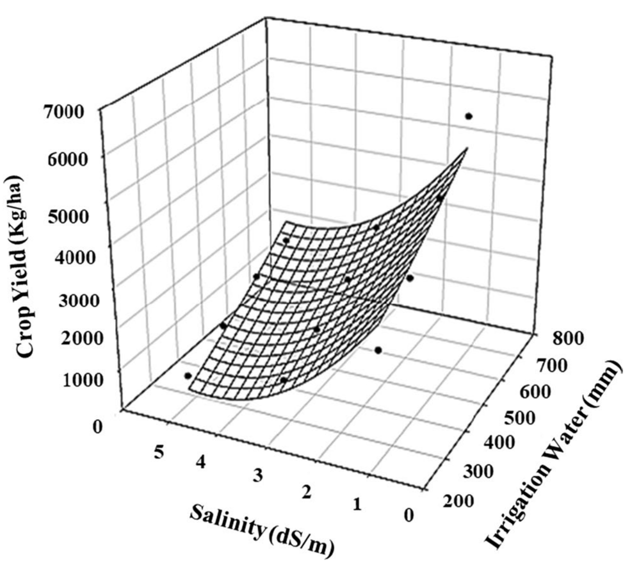

Fig. 8 Yield in kilograms per hectare (dry leaves) as a function of irrigation water and salinity of the used water based on real data in the studied farm

fertilizers would be associated with increasing production to eliminate nutrient deficiencies in the soil. However, the plant's response to mineral fertilizer application is not always the same under the deficit irrigation conditions (Siadat, 2000), and fertilizer productivity declines under the water stress conditions (Malakouti, 2000).

In treatments with a fixed fertilization rate, increasing the matric potential leads to decreased crop yield. In addition, in treatments with fixed irrigation water rate, as fertilizer decreases, the crop yield decreases as well. However, the high yields cannot be expected as fertilization rates

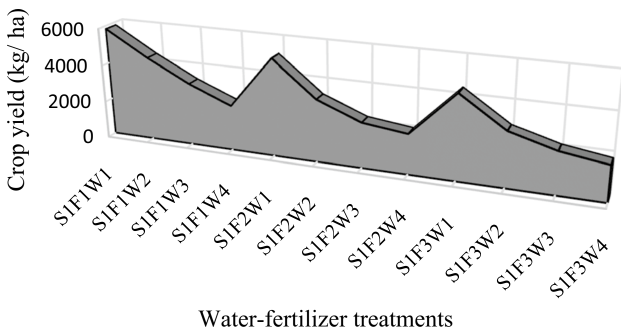

Fig. 9 The slope of crop yield changes in the field (dry leaves) in kilograms per hectare under simultaneous water-fertilizer stress conditions

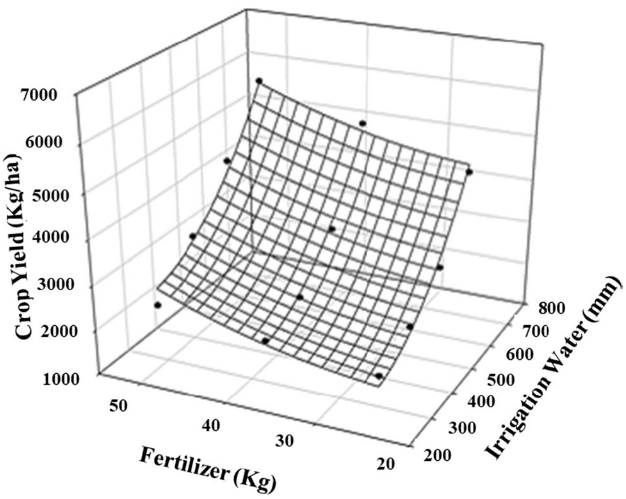

Fig. 10 Basil yield in kilograms per hectare (dry leaves) as a function of irrigation water and fertilizer consumption using real data in the studied farm

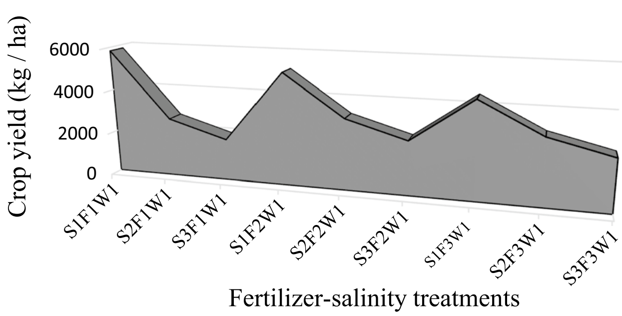

Fig. 11 The slope of crop yield changes in the field (dry leaves) in kilograms per hectare under simultaneous fertilizer and salinity stress conditions

increase in the situation with a severe irrigation deficit. This is because, in such conditions, the water content in the soil is not enough to dissolve the nutrients and provide them for the plant. In addition, an increased level of fertilizer can act as salinity and increase osmotic potential. Figure 12 depicts the basil yield variations against the simultaneous water-salinity-nitrogen stress under farm conditions.

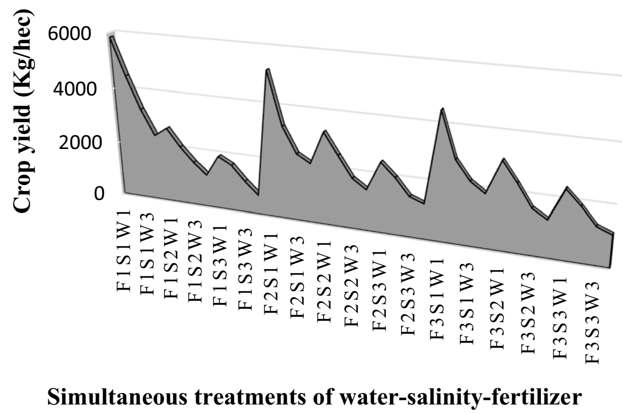

Fig. 12 The slope of crop yield changes in the field (dry leaves) in kilograms per hectare under simultaneous water-salinity-nitrogen stress conditions

Conclusions

In many arid and semi-arid regions in the world where there are droughts, the salinity problem is prominent, and in most cases, plants are affected by both water and salinity stresses. The main impact of salinity stress on the plants involves reduced or interrupted growth (Hasegawa et al. 2000; Kafi et al. 2010). Nitrogen is a key component of the first cellular compounds. It is needed for plant growth, and it is mainly the first nutrient whose deficiency arises in arid and semi-arid regions (Babazadeh et al., 2017a, b). In the cases with no water stress, fertilization can increase the yield, while in severe water stress, chemical fertilizers can decrease the crop yield (Esmaili et al. 2005; Farahmandzad et al. 2005). In general, decreasing the absolute values of the matric potential and the osmotic potential in the plant growth environment increases the yield. However, given the lower plant energy due to water absorption, it is evident that both stresses cause more disturbances and have a more significant impact on the yield. The results of the present study are consistent with those of Kiani et al. (2006) and Feng et al. (2003 a, b). Kiani et al. (2006) investigated wheat yield under simultaneous water and salinity stresses. They showed that in treatment W_1S_1 with no salinity stress (50% water requirement and 1.5 ds/m salinity), and in treatment W3S4, with no water stress (100% water requirement and 14.2 ds/m salinity), relative yields were 82% and 87%, respectively. Moreover, in treatment W_1S_4 (with both water and salinity stresses), the relative yield was 73%. According to Fig. 7, the highest basil yield was obtained in treatment

$S_1F_1W_1$ (with no water and salinity stresses). In addition, the highest yield reduction was observed in treatment $S_3F_1W_4$, which had the highest amount of salt in irrigation water and the lowest requirement for plant water. The results of the study carried out by Feng et al. (2003 a, b) on maize showed that simulated relative yields using van Genuchten compact model in the treatment involving only water stress (21 days and water salinity of 1.7 ds/m) and in the treatment under salinity stress (4 days and water salinity of 10.2 ds/m) were 68% and 60%, respectively. In the treatment involving both stresses, the relative yield was 52%.

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Declarations

Conflict of interest The author declares that there is no conflict of interest.

Consent to participate All authors designed the study, collected data, wrote the manuscript and revised it.

Consent to publish All authors agree to publish this manuscript. There is no conflict of interest.

Ethical approval The present study and ethical aspect was approved by Department of Water Engineering and Sciences, Faculty of Agricultural Sciences and Food Industries, Science and Research Branch, Islamic Azad University (SRBIAU), Tehran, Iran.

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