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CAN APPLICATION OF NITROGEN FERTILIZERS AND SALICYLIC ACID IMPROVE GROWTH AND FRUIT YIELD OF CORIANDER UNDER WATER DEFICIT?

Farhood Yeganehpoor✉, Saeid Zehtab-Salmasi, Jalil Shafagh-Kolvanagh, Kazem Ghassemi-Golezani, Soheila Dastborhan

Department of Plant Eco-physiology, Faculty of Agriculture, University of Tabriz, Tabriz, Iran

ABSTRACT

To investigate the changes in selected morphological traits and yield of coriander (*Coriandrum sativum* L.) in response to fertilization and salicylic acid foliar spraying under different irrigation intervals, two field experiments were conducted as split-factorial based on randomized complete block design with three replicates in 2014 and 2015. Treatments were three irrigation intervals (irrigation after 60, 90 and 120 mm evaporation from class A pan) and combination of fertilization (control, urea 100 kg ha^{-1}, Nitrokara (bio-fertilizer), and 50% urea + Nitrokara) and salicylic acid (0 and 1 mM) that were allocated to the main and sub-plots, respectively. The results showed that plant height, length of the longest internode, stem diameter, branches per plant, dry weights of roots and leaves and fruit yield of coriander were reduced and root length enhanced with increasing the irrigation intervals. However, all of the nitrogen fertilizers, especially combined application of 50% urea and Nitrokara, and salicylic acid spraying, improved the selected morphological traits, and consequently fruit yield per unit area under favorable and limited irrigations.

Key words: coriander, irrigation, morphological traits, Nitrokara, salicylic acid, urea

INTRODUCTION

Water limitation is one of the most important limiting factors in the growth and production of many plants, which occurs when available water in the soil is reduced, and atmospheric conditions cause continuous loss of water by transpiration or evaporation [Sankar et al. 2014]. Water stress affects various physiological and metabolic processes in plants. The responses of plants to water limitation depend on the severity and duration of water deficit, species and genotype, and the plant growth stages [Bray 1997]. The major effect of drought is the reduction in photosynthesis, which arises by a decrement in leaf expansion, impaired photosynthetic system, premature leaf senescence and reduction in production [Wahid and Rasul 2005]. One of the approaches to improve growth and productivity of plants under water stress is the fertilization and hormonal treatments, which are capable to withstand unfavorable environmental conditions.

Salicylic acid (SA) is a phenolic compound naturally produced by the plants in very low amounts *via* the phenylpropanoid pathway [Metraux 2002]. The application of SA results in the enhancement of plant resistance against biotic and abiotic stresses through different mechanisms [Hayat et al. 2010]. The effect of SA application in stress tolerance depends on the species and growth stage of the plant, application

✉ farhoodyeganeh@yahoo.com

method and the concentration of SA, and stress degree (intensity and duration) [Arfan et al. 2007, Hayat et al. 2010]. Hussain et al. [2008] in sunflower and Vaisnad and Talebi [2015] in chickpea found that exogenous application of SA was effective in reducing the adverse effects of drought stress on these plants.

Another important effective factor on growth and development of plants is the availability of nutrients, especially nitrogen. Nitrogen is a main component of proteins, nucleic acids and other essential biomolecules [Bockman 1997]. Although nitrogen fertilizers have a key role in enhancing the plants yield, but inappropriate use of it causes ecological and human health risks, depletion of nonrenewable resources, reduction in the plants resistance to pests and diseases [Brandt 2008], leaching, pollution of water resources, destruction of micro-organisms and useful insects as well as reduction in soil fertility [Chen 2006]. Bio-fertilizers play a major role in the productivity and sustainability of soil and maintaining its fertility and can be a suitable alternative for chemical fertilizers to improve the plant production in sustainable farming [Wu et al. 2005]. Seed treatment with bio-fertilizers increases the plant growth and also the colonization of beneficial microorganisms in plant root region [Mahdi et al. 2010].

Plant growth promoting rhizobacteria (PGPR), such as *Azorhizobium caulinodans*, are a group of free-living soil bacteria, which can affect the growth and yield of plants by direct (biological nitrogen fixation, increasing the availability of nutrients in the rhizosphere and phytohormones production) and indirect mechanisms (production of inhibitory substances or increasing the natural resistance of the host) [Verma et al. 2010]. Some studies showed that with combined application of bio-fertilizers and chemical fertilizers, vegetative growth, grain and essential oil yields of medicinal plants can be improved [Mahfouz and Sharaf-Eldin 2007, Kumar et al. 2009, Abdollahi et al. 2016].

Coriander (*Coriandrum sativum* L.) is an annual medicinal plant that is widely distributed and mainly cultivated for its fruits. This plant is one of the most valuable plants in the pharmaceutical industry of developed countries and is cultivated in different regions of the world, as well as Iran. Therefore, this research was undertaken to investigate the selected morphological characteristics of this medicinal plant in response to combined application of biological and chemical nitrogen fertilizers, and SA under water deficit.

MATERIAL AND METHODS

Location and experimental design. Two field experiments were conducted at a Research Farm in Kangavar (latitude 34°39'N, longitude 47°34'E, altitude 1200 m above sea level), Kermanshah province, Iran, in 2014 and 2015. The site is in a temperate mountainous zone with mean annual rainfall of 350.5 mm and mean annual temperature of 13.4°C. Average monthly temperature and rainfall during the experiment in 2014 and 2015 are shown in Table 1. Before the field preparation, soil sampling was done from different regions of 0–30 cm depth, randomly. The physical and chemical properties of the soil in the experimental area are presented in Table 2.

The experiments were established as split-factorial on the basis of randomized complete block design with three replications. Treatments were three irrigation intervals including irrigation after 60 (I_1), 90 (I_2) and 120 mm (I_3) evaporation from class A pan in main plots, and combination of fertilization (no fertilizer, 100 kg ha^{-1} urea, Nitrokara as bio-fertilizer, and 50% urea + Nitrokara) and foliar application of SA (0 and 1 mM) in sub-plots.

In bio-fertilizer treatment, coriander seeds were inoculated with Nitrokara, a bio-fertilizer containing *Azorhizobium caulinodans* bacteria with 10^8 cfu g^{-1}, just before sowing. All seeds were sown manually in plots (4 × 1.2 m) with 6 rows and the spacing of 10 cm between the plants and 20 cm between the rows (with a density of 40 plants per m^2) on May 2nd 2014 and April 9th 2015. Nitrogen fertilizer (urea) was applied on the basis of plant requirement and soil test (1/3 at sowing date, 1/3 after thinning and 1/3 at the vegetative stage). All plots were irrigated immediately after sowing by flooding irrigation method, but subsequent irrigations were carried out according to the treatments. The plants were sprayed twice with distilled water (control) or SA (1 mM) at stages of stem elongation and flowering, using a hand pump sprayer at the time of 7.00 to 8.00 AM, until both sides of the leaves became completely wet. Weeds were controlled by hand during plant growth and development as required.

Table 1. Average monthly temperature and rainfall during experiment in 2014 and 2015

Month	Temperature (°C)						Number of rainy days		Rainfall (mm)	
	min		max		mean					
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
21 March – 20 April	–6.6	–2.6	27.4	26.2	10.7	10.5	6	10	22.9	75.9
21 April – 21 May	3.4	–1.2	30.0	31.5	16.6	16.9	5	4	15.2	14.5
22 May – 21 June	4.0	7.0	37.0	36.7	21.3	23.1	3	2	11.9	5.7
22 June – 22 July	9.8	8.8	40.5	41.0	27.2	27.7	0	0	0.0	0.0
23 July – 22 August	11.2	12.2	41.0	39.2	27.0	27.1	0	0	0.0	0.0

Table 2. Physical and chemical properties of experimental field soil

Depth	Soil type	Sand (%)	Clay (%)	Silt (%)	EC (dS m^{-1})	pH	OC (%)	Fe (ppm)	K (mg kg^{-1})	P (mg kg^{-1})	N (%)
0–30	Loamy	29	26	45	0.4	8.09	2	1.38	232	14.1	0.2

Measurements. At physiological maturity, plant height (cm), stem diameter (cm), length of the longest internode (cm), branches per plant, root length (cm), and dry weights of both root and leaf (g per plant) were determined on 10 plants that were randomly selected from the middle of four rows of each plot. To remove the roots with minimal damage, the soil around the plants was dug out with 10 cm radius and about 30 cm depth and carefully removed. Then the roots were washed with tap water and the remaining soil particles were separated by sodium hexametaphosphate solution. After separating different parts of the plants from each other, the length of roots was measured and the leaves and roots were dried in an oven at 75°C for 48 hours. Then dry weight of roots and leaves were recorded with a digital scale and subsequently, the mean morphological traits for each treatment and replicate were calculated.

Also to determine the fruit yield, the plants of $1m^2$ from the middle part of each plot were harvested and after drying in the shade, fruit yield per unit area was obtained.

Statistical analysis. The data were analyzed by MSTAT-C and SAS 9.1.3 software and Duncan's Multiple Range Test at $p \leq 0.05$ was applied to compare means of traits.

RESULTS AND DISCUSSION

Plant height and the longest internode. According to the results of combined analysis, effects of irrigation, fertilization and interaction of irrigation × fertilization were significant on the plant height and length of the longest internode. Plant height was also significantly affected by SA, irrigation × SA and fertilizer × SA (Tab. 3). In all levels of fertilization, the plant height and the longest internode decreased with increasing irrigation intervals. However, application of different nitrogen fertilizers (especially 50% urea + Nitrokara) in all irrigation treatments led to an increase in these traits. The highest plant and the longest internode were obtained with combined application of 50% urea and Nitrokara under normal irrigation (I_1) (Tab. 4).

Coriander plant height was improved by application of SA in all irrigation intervals, and this additive effect was remarkable under severe water stress (irrigation after 120 mm evaporation) (Tab. 5). Also, SA foliar spraying in different fertilizer treatments (especially non-fertilized condition) increased the plant height (Tab. 6).

The reduction in plant height under water deficit might be associated with declined cell elongation and

Table 3. Analysis of variance of effects of irrigation, fertilizer and salicylic acid on selected morphological traits and fruit yield of coriander

Sources of variance	df	Mean squares							
		plant height	stem diameter	longest internode	branches per plant	root length	root dry weight	leaf dry weight	fruit yield
Year (Y)	1	39.6 ns	0.0014 ns	0.0742 ns	155.70 **	0.536 ns	0.007 ns	0.0039 ns	7641.1 **
R / Y	4	0.98 ns	0.0052 ns	0.045 ns	0.756 ns	0.008 ns	0.00015 ns	0.00085 ns	12.8 ns
Irrigation (I)	2	826.3 **	0.3843 **	17.33 **	231.08 **	13.54 **	0.285 **	0.9761 **	9973.6 **
Y × I	2	0.05 ns	0.00033 ns	0.760 ns	0.262 ns	0.005 ns	0.0049 ns	0.0028 ns	38.5 ns
E_a	8	177.1	0.0065	0.863	17.21	0.611	0.066	0.0059	107.3
Fertilizer (F)	3	918.6 **	0.00105 *	10.61 **	117.97 **	7.97 **	0.2435 **	0.7715 **	7934.2 **
Y × F	3	18.2 ns	0.00071 ns	0.055 ns	0.105 ns	0.059 ns	0.0021 ns	0.0031 ns	22.1 ns
I × F	6	552.5 **	0.1781 **	7.14 **	1.66 *	0.2825 *	0.2053 **	0.6938 **	6971.4 **
Y × I × F	6	10.8 ns	0.00039 ns	0.0138 ns	0.158 ns	0.083 ns	0.0055 ns	0.0022 ns	17.5 ns
Salicylic acid (SA)	1	66.9 *	0.00015 ns	0.0710 ns	103.52 **	0.2703 *	0.1907 **	0.6511 **	6712.8 **
Y × SA	1	5.2 ns	0.0004 ns	0.046 ns	0.435 ns	0.037 ns	0.0017 ns	0.0020 ns	10.9 ns
I × SA	2	105.3 **	0.0002 ns	0.0502 ns	1.70 *	0.2817 *	0.1780 **	0.6615 **	6064.1 **
Y × I × SA	2	8.8 ns	0.00013 ns	0.0846 ns	0.561 ns	0.058 ns	0.0012 ns	0.0033 ns	7.4 ns
F × SA	3	67.5 *	0.00027 ns	0.0252 ns	0.603 ns	0.2605 *	0.1563 **	0.0113 *	5195.3 **
Y × F × SA	3	8.1 ns	0.00033 ns	0.0159 ns	0.324 ns	0.069 ns	0.0021 ns	0.0018 ns	4.1 ns
I × F × SA	6	4.5 ns	0.00005 ns	0.0081 ns	0.066 ns	0.052 ns	0.0011 ns	0.0036 ns	2367.9 **
Y × I × F × SA	6	0.9 ns	0.00001 ns	0.003 ns	0.097 ns	0.038 ns	0.0004 ns	0.0007 ns	2.4 ns
E_b	84	25.5	0.0004	0.0922	0.573	0.102	0.025	0.0042	32.3
CV (%)	–	8.95	7.83	12.91	10.77	11.30	7.46	9.36	14.29

ns, *, **: no significant and significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

cell growth due to the low turgor pressure [Liang et al. 2006]. Baher et al. [2002] reported that water stress decreases the plant height and total dry weight of *Satureja hortensis*. Also, diminution of the leaf area and chlorophyll content [Yeganehpoor et al. 2016], and leaves per plant [Yeganehpoor et al. 2017] under water limitation reduce photosynthetic products, leading to a reduction in plant height.

However, combined application of Nitrokara, 50% urea and SA slightly decreased the negative effects of drought stress on length of the longest internode and plant height. The increment in the plant height by application of nitrogen fertilizer can be attributed to the production of growth stimulating agents by existing bacteria in Nitrokara, as well as the appropriate amount of urea fertilizer that promotes growth and division of plant cells and consequently plant growth [Almodares et al. 2006] and increases the number and length of the internodes in this condition. Moosavi et al. [2013] reported that application of 80 kg N ha^{-1} has improved the height of coriander plants by 19.8% compared to control treatment.

SA can increase the internode length and plant height by increasing division and elongation of cells, and improving enzymatic activity and photosynthetic products [Bakry et al. 2012], and preventing decomposition of auxin hormone through activating the antioxidants. In pumpkin plants, application of SA under drought stress has also increased plant height [Sure et al. 2011].

Table 4. Interaction effect of irrigation × fertilizer on selected morphological traits of coriander

Treatment	Plant height (cm)	Stem diameter (cm)	Longest internode (cm)	Branches per plant	Root length (cm)	Root dry weight (g)	Leaf dry weight (g)
$I_{60}\times F_0$	53 c	0.47 c	9.2 d	8.9 d	12.6 f	0.25 c	0.44 c
$I_{60}\times F_1$	59 b	0.51 b	10.3 b	13.1 b	13.8 e	0.28 b	0.467 b
$I_{60}\times F_2$	61 b	0.52 b	9.8 c	12.2 c	14.0 e	0.28 b	0.472 b
$I_{60}\times F_3$	65 a	0.54 a	11.0 a	14.5 a	14.5 de	0.31 a	0.486 a
$I_{90}\times F_0$	39 e	0.38 f	6.7 f	5.8 f	15.4 d	0.23 d	0.422 e
$I_{90}\times F_1$	44 d	0.42 e	7.4 ef	7.6 e	16.0 cd	0.24 cd	0.430 e
$I_{90}\times F_2$	45 d	0.43 e	7.6 ef	7.4 e	16.5 c	0.25 c	0.431 e
$I_{90}\times F_3$	46 d	0.45 d	7.9 e	7.9 e	17.1 c	0.26 c	0.441 d
$I_{120}\times F_0$	27 h	0.30 h	4.3 i	4.2 g	17.5 bc	0.18 f	0.370 g
$I_{120}\times F_1$	31 g	0.33 g	5.4 gh	5.4 f	18.0 b	0.20 e	0.402 f
$I_{120}\times F_2$	33 fg	0.34 g	5.0 h	5.3 f	18.4 b	0.21 e	0.406 f
$I_{120}\times F_3$	35 f	0.37 f	5.7 g	5.5 f	19.7 a	0.22 e	0.407 f

Different letters in each column indicate significant difference at $p \leq 0.05$ (Duncan test)
I_{60}, I_{90}, I_{120}: irrigation after 60, 90 and 120 mm evaporation from class A pan, respectively
F_0, F_1, F_2, F_3: no fertilizer (control), urea, Nitrokara (bio-fertilizer), 50% urea + Nitrokara, respectively

Table 5. Interaction effect of irrigation × salicylic acid on some morphological traits of coriander

Treatment	Plant height (cm)	Branches per plant	Root length (cm)	Root dry weight (g)	Leaf dry weight (g)
$I_{60}\times SA_0$	43 c	9.6 b	12.5 f	0.25 c	0.459 b
$I_{60}\times SA_1$	58 a	10.9 a	13.9 e	0.30 a	0.478 a
$I_{90}\times SA_0$	38 d	6.5 d	15.2 d	0.22 d	0.439 c
$I_{90}\times SA_1$	50 b	7.4 c	16.4 c	0.27 b	0.455 b
$I_{120}\times SA_0$	29 e	3.9 f	17.3 b	0.19 e	0.390 e
$I_{120}\times SA_1$	47 bc	4.7 e	18.9 a	0.24 cd	0.409 d

Different letters in each column indicate significant difference at $p \leq 0.05$ (Duncan test)
I_{60}, I_{90}, I_{120}: irrigation after 60, 90 and 120 mm evaporation from class A pan, respectively
SA_0 and SA_1: no salicylic acid and application of 1mM salicylic acid, respectively

Stem diameter. Water supply, fertilization and interaction of irrigation × fertilization had significant effects on stem diameter of coriander, but effect of SA on this trait was not significant (Tab. 3). In all fertilization treatments, stem diameter decreased with increasing irrigation intervals. On the other hand, application of nitrogen fertilizer (especially Nitrokara + 50% urea) at all irrigation intervals (particularly under severe stress) resulted in a significant increment in stem diameter compared with non-fertilization condition (F_0). Therefore, by combined application of 50% urea and Nitrokara, the stem diameter under normal irrigation (I_1), moderate (I_2) and severe stress (I_3) was 14.9%, 18.4% and 23.3%, respectively, which was more than non-fertilization condition in the same irrigation treatments, respectively (Tab. 4).

In the present research, increasing water deficit reduced the stem diameter of coriander, while the simultaneous application of urea and Nitrokara by increasing the cell division had a positive effect on

Table 6. Interaction effect of fertilization × salicylic acid on some morphological traits of coriander

Treatment	Plant height (cm)	Root length (cm)	Root dry weight (g)	Leaf dry weight (g)
$F_0 \times SA_0$	28 f	11.0 e	0.18 f	0.410 f
$F_0 \times SA_1$	50 c	14.0 cd	0.24 cd	0.419 e
$F_1 \times SA_0$	38 e	12.7 d	0.21 e	0.424 d
$F_1 \times SA_1$	56 b	16.0 b	0.26 c	0.438 c
$F_2 \times SA_0$	38 e	12.3 d	0.23 d	0.427 d
$F_2 \times SA_1$	57 b	14.9 c	0.28 b	0.443 b
$F_3 \times SA_0$	42 d	13.9 cd	0.26 c	0.450 b
$F_3 \times SA_1$	61 a	17.3 a	0.31 a	0.477 a

Different letters in each column indicate significant difference at $p \leq 0.05$ (Duncan test)
F_0, F_1, F_2, F_3: no fertilizer (control), urea, Nitrokara (bio-fertilizer), 50% urea + Nitrokara, respectively
SA_0 and SA_1: no salicylic acid and application of 1mM salicylic acid, respectively

growth and stem diameter in this herb. Since nitrogen plays a major role in the formation of chlorophyll, it can be concluded that application of Nitrokara and urea *via* increment of the leaf chlorophyll and leaf area [Yeganehpoor et al. 2016] increases the plant height and stem diameter.

Branches per plant. The number of branches was significantly affected by year, water supply, fertilization, SA and interactions of irrigation × fertilization and irrigation × SA (Tab. 3). Branches number in 2015 was significantly more than that in 2014 (Tab. 7). Since in the second year, the rainfall was higher than in the first year and the coriander plants were cultivated at the time of rainfall occurrence and earlier than in the first year (Tab. 1), producing more branches in the second year was not unexpected. Increasing irrigation intervals caused a significant decrease in the number of branches, but the utilization of different nitrogen fertilizers reduced the adverse effect of water deficit. Under normal irrigation (I_1), the incremental effect of fertilization (especially application of Nitrokara and 50% urea) was remarkable on the number of branches (Tab. 4). SA foliar spraying at all irrigation intervals resulted in a significant increase in the number of branches. Although plants sprayed with SA under normal irrigation had the highest number of branches (10.9), under severe stress, the positive effect of SA on the number of branches was higher (Tab. 5).

Reduction in the number of branches per plant under drought stress is a type of adaptation mechanism that maintains water for more critical stages [Farooq et al. 2009] such as flowering stage. Improvement of the coriander branches number by application of different nitrogen fertilizers could be attributed to the nitrogen fixation by biological fertilizer and the role of nitrogen in increasing vegetative growth and leaf area [Yeganehpoor et al. 2016, 2017]. Foliar application of low concentration of SA promotes the growth, development and differentiation of cells and tissues of plants and enhances the plant's growth parameters [Opik and Rolfe 2005].

Root length. Coriander root length was significantly affected by irrigation, fertilization and SA. Interactions of irrigation × fertilizer, irrigation × SA and fertilizer × SA were also significant for this trait (Tab. 3). Decreasing the water supply had an additive effect on root length, thus at all fertilization treatments, decreasing water supply increased the root length of the coriander plants. Application of nitrogen fertilizer in all irrigation intervals (especially under severe stress) led to an increase in root length. The longest roots (19.7 cm) were obtained by irrigation after 120 mm evaporation and application of 50% urea and Nitrokara. The shortest roots (12.6 cm) were also related to plants irrigated with 60 mm evaporation intervals and non-fertilization (control) (Tab. 4). The results of Table 6 showed a positive and significant effect of SA on root length under favorable and limited irrigations. Foliar application of SA and irrigation of plants after 120 mm evaporation produced longer roots in coriander (Tab. 5). SA spraying at all levels of fertilization was associated with a significant increase in root length, and this increment in non-fertilized condition was more than other fertilization treatments (Tab. 6). In general, application of SA and nitrogen fertilizers was effective in coriander root development. On the other hand, water deficit increased the root length of this plant to access to more water in the soil.

Plant root is the first organ to be exposed to water deficit. Changes in soil moisture not only affect the spatial distribution of plant roots and the efficiency of nutrition and water adsorption, but also directly affect the biomass of shoots. When water and nutrients are favorable, the roots and shoots of plants will function normally and benefit each other, but their functions would be weak [Woodall and Ward 2002, Benjamin and Nielsen 2006]. Increasing the root length under drought stress has been also confirmed in coriander [Gabler 2002], Hemp [Amaducci et al. 2008] and Peanut [Sankar et al. 2014].

Root dry weight. Based on the results of the analysis of variance (Tab. 3), there was no significant difference between the two years in terms of root dry weight, but this trait was significantly affected by water supply, fertilization, SA application and interactions of irrigation × fertilization, irrigation × SA and fertilization × SA. Root dry weight of plants under moderate (I_2) and severe water limitation (I_3) was significantly lower than that of plants under normal irrigation (I_1) at all fertilization treatments. At all irrigation intervals, the utilization of nitrogen fertilizers, especially the combination of 50% urea and Nitrokara, improved root dry weight. Therefore, the highest root dry weight (0.31 g per plant) was related to the plants irrigated with 60 mm evaporation intervals and treated with 50% urea and Nitrokara. Untreated plants under severe water stress had the lowest root dry weight (0.18 g per plant) (Tab. 4). At all irrigation intervals, especially under severe stress, plants treated with SA had higher root dry weight compared to untreated plants (Tab. 5). The dry weight of coriander root was increased by SA spraying at all levels of fertilization and this increment was remarkable in non-fertilized condition. However, the maximum dry weight of roots was obtained by simultaneous application of 50% urea, Nitrokara and SA (Tab. 6).

Results of the present research showed that with combined application of 50% urea, Nitrokara and SA, in addition to providing enough nitrogen for coriander growth, improved the development of root system, root weight and water absorption under drought stress. Under normal irrigation (I_1), the coriander roots were filled and thick, while under severe water limitation (I_3), plants had long and thin roots; therefore with increasing irrigation intervals, the dry weight of coriander roots decreased which is consistent with the findings of Gabler [2002]. El-Mekawy [2013] on *Achillea santolina* L. showed that irrigation every 7 days, significantly increases the plant height, branches per plant, fresh and dry weights of shoots and roots compared to irrigation every 14 and 21 days.

Table 7. Means of branches per plant and fruit yield of coriander in 2014 and 2015

Year	Branches per plant	Fruit yield (kg ha^{-1})
2014	9.8 b	1603 b
2015	11.3 a	1892 a

Different letters in each column indicate significant difference at $p \leq 0.05$

Leaf dry weight. Dry weight of coriander leaves was significantly affected by irrigation intervals, fertilization and hormonal treatments. The interactions of irrigation × fertilizer, irrigation × SA and fertilizer × SA were also significant for this trait (Tab. 3). Mean dry weight of leaves was generally decreased with increasing irrigation intervals. In all irrigation treatments, application of nitrogen fertilizer improved the dry weight of leaves. However, the positive effect of nitrogen fertilizers on leaf dry weight under normal irrigation (I_1) and severe water stress (I_3) was higher than that under moderate water limitation (I_2). The highest dry weight of coriander leaves (0.486 g) was obtained in plants irrigated with intervals of 60 mm evaporation and utilization 50% urea and Nitrokara (Tab. 4). Foliar application of SA had a positive and significant effect on leaf dry weight under all irrigation intervals. However, the incremental effect of SA on the dry weight of leaves was remarkable under severe water deficit. Thus, SA spraying on plants irrigated with 60 mm (I_1), 90 mm (I_2) and 120 mm (I_3) evaporation intervals led to 4.1%, 3.6% and 4.9% increase in leaf weight, compared to untreated plants under the same irrigation treatments, respectively (Tab. 5). Means comparison for the interaction of fertilization × SA application showed a significant improvement in leaf dry weight of plants treated with SA in different fertilization treatments (especially 50% urea + Nitrokara) (Tab. 6).

Reduced turgor pressure is the first sign of water shortage in most of the plants, which reduces the cell growth and development, especially in stems and leaves. Depending on the intensity and duration of the drought, plants tend to minimize transpiration water loss by reducing the number and area of their leaves [Farooq et al. 2009]. Moreover, the small size of leaves means that their ability for intercepting the light and thus their photosynthetic efficiency is reduced, which is reflected in the plants growth [Gamalei 2002]. In an experiment on two grass of Lemon species (*Cymbopogon nardus* and *C. pendulus*), drought stress significantly reduced plant height, leaf area and leaf weight [Sing-Sangwan et al. 1994].

Nitrogen is an important factor in leaf growth, which is supplied by the application of Nitrokara, urea and SA. On the other hand, these compounds improve the absorption of nutrients, especially under stress conditions, which can increase the growth and weight of coriander leaves. The utilization of bio-fertilizers can improve organic matter [Durve-Gupta et al. 2016] and the beneficial microorganisms in the soil [Mahdi et al. 2010] and ultimately enhance the dry weight of different parts of the coriander plant, especially its leaves.

Fruit yield. According to Table 3, year, irrigation intervals, fertilization and hormonal treatments had significant effect on fruit yield of coriander. The interactions of irrigation × fertilizer, irrigation × SA, fertilizer × SA and irrigation × fertilizer × SA were also significant for this trait (Tab. 3). The fruit yield in the second year was significantly higher than that in the first year (Tab. 7), which can be attributed to early cultivation and appropriate weather conditions (Tab. 1) and more branches per plant in this year (Tab. 7). Water deficit significantly reduced the fruit yield of coriander. Application of urea, Nitrokara and

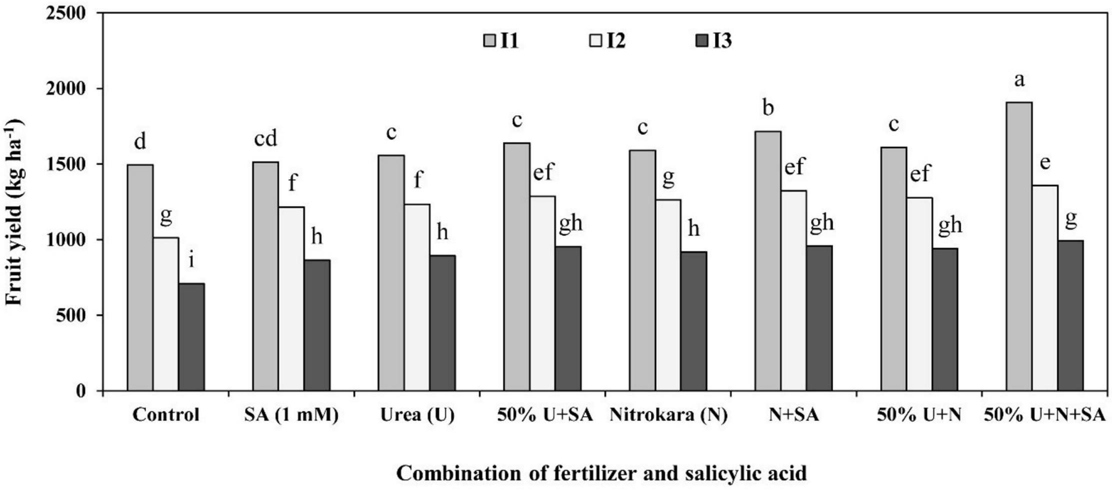

Fig. 1. Means of fruit yield of coriander affected by irrigation × fertilizer × salicylic acid (SA). I_1, I_2, I_3: irrigation after 60, 90 and 120 mm evaporation from class A pan, respectively. Different letters indicate significant difference at $p \leq 0.05$

SA (especially their combined application) enhanced fruit yield at all irrigation treatments. However, the incremental effect of these compounds on fruit yield in plants irrigated with 120 mm evaporation (I_3) was higher than other irrigation intervals. The highest fruit yield was observed with combined application of 50% urea, Nitrokara and SA under normal irrigation ($I_{60} \times F_3 \times SA_1$), which was 27.7% more than control treatment ($I_{60} \times F_0 \times SA_0$). Untreated plants under severe water limitation had the lowest fruit yield ($I_{120} \times F_0 \times SA_0$) (Fig. 1).

Under water limitation, coriander plants reduce the leaf area [Yeganehpoor et al. 2016], leaves per plant [Yeganehpoor et al. 2017], plant height and number of branches (Tab. 4), which leads to reduction in photosynthesis and fruit yield. Reducing the fruit yield under water shortage has been also reported in coriander [Gabler 2002, Hassan and Ali 2014] and borage [Dastborhan and Ghassemi-Golezani 2015].

Increment of the fruit yield as a result of the application of biological or chemical nitrogen fertilizers can occur because of the formation of strong sinks (more fruits per plant) and source activity (higher LAI with more leaf durability) in this condition. Generally, in the present research, increasing the fruit yield by application of nitrogen fertilizers can be attributed to better growth of plants and subsequently better canopy development, which ultimately leads to a better use of solar irradiance and more photosynthesis. Efficient application of nitrogen from organic and inorganic sources effectively enhances the yield and quality of coriander and soil health [Ali et al. 2015]. Inoculation of coriander seeds with Nitrokara by increasing absorption of nutrients had a positive and significant effect on fruit yield. Combined application of chemical and biological fertilizers also increased the grain yield, 1000-grain weight and biomass in maize [Amujoyegbe et al. 2007] and this increment could be attributed to better compatibility of soil nitrogen with plant requirements in these conditions [Mooleki et al. 2004].

Application of 0.5 mM SA under water deficit led to 49% increment in garlic yield [Bideshki and Arvin 2010]. Arfan et al. [2007] reported that foliar application of SA increases growth and grain yield of spring wheat in water limitation conditions. Exogenous application of SA could regulate the activities of antioxidant enzymes and increase plant tolerance to abiotic stresses [He et al. 2002, Eraslan et al. 2007, Hassan et al. 2017]. The sustained level of SA may be a prerequisite for the auxin and/or cytokinin synthesis [Metwally et al. 2003].

CONCLUSIONS

Increasing irrigation intervals led to a decrease in the plant height, length of the longest internode, stem diameter, branches per plant, roots and leaf dry weights and consequently fruit yield, and an increase in root length in coriander plant. However, SA foliar spraying and/or combined utilization of urea and Nitrokara decreased the adverse effect of water limitation on studied traits. In general, growth and yield of coriander can be improved by simultaneous application of urea, Nitrokara and SA under favorable and limited irrigations.

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