Plant Growth, Yield, Macro and Micro-Nutrients Uptake of Fennel (*Foeniculum vulgare* Mill.) Positively Affected by N-Sources and Rates as well as Foliar Application of Micronutrients

El-Seifi S. K.; M. A. Hassan; M. W. M. Elwan* and O. G. Haggag
Department of Horticulture, Faculty of Agriculture, Suez Canal University, Ismailia, Egypt

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Abstract: This study was carried out in order to give some information that could improve fennel nutritional status and productivity. We studied the effect of two N fertilizers [ammonium nitrate (AN) and ammonium sulphate (AS)], two nitrogen rates (60 and 90 kg N/fad.) and two levels of micronutrients (without and with FeEDTA, MnEDTA and ZnEDTA) on growth, yield and nutrient (N, P, K, Fe, Mn and Zn) uptake on fennel plants cv. Florence. The results indicated that, ammonium sulphate at level of 90 kg/fad. enhanced plant growth, production of dry matter and improved yield (foliage, bulb and total). Nutritional status of fennel plants was improved, whereas the ammonium sulphate at level of 90 kg/fad. and spraying of the micronutrient mixture increased the uptake of macronutrients (N, P and K) and micronutrients (Fe, Mn and Zn). The present study suggests that foliar application of micronutrients could be an effective strategy in bio-fortifying fennel plants with Fe, Mn and Zn to produce foliage and bulb yield with high nutritional quality.

Keywords: Fennel, nitrogen fertilizer, yield, essential elements

INTRODUCTION

Recently, an increasing interest in the cultivation and production of un-traditional vegetable crops has been noticed in Egypt in order to cover the increasing demand of the local consumption as well as export purposes. Among them sweet fennel (*Foeniculum vulgare* Mill.) is one of the most promising new crops in Egypt. Also, it is considered as the most important economic medicinal and aromatic plant grown within the Mediterranean region (Kandil *et al.,* 2002).

Mineral fertilizers application is essential for plant growth, development and productivity of plants. Nitrogen is one of the chemical elements required for plant growth and reproduction. It is an essential nutrient which is a determining factor in crop production and it absorbed primarily in the form of nitrate (Tisdale and Nelson, 1990). The dry weight of many crops contain about 1.5-6% N a apart from being a constituent of many organic compounds, nucleic acids and protein compounds (Sanjuan *et al.,* 2003). On the other hand, frequent or excessive amounts of nitrogen fertilizer would lead to un-favorite effect on the growth and yield of plants and will increase the losses of nitrogen fertilizer. So, the adequate amounts of nitrogen fertilization led to improve growth, yield and quality. It is well reported that N fertilization increased plant growth and yield components of fennel (Hussain and Abo El-Magd, 1993; Ayub *et al.,* 2011; Ehsanipour *et al.,* 2012). On the other hand, other researchers found that application of N had no marked effect on fennel yield components (Buntain and Chung, 1994; Kandil *et al.,* 2002; Chatzopoulou *et al.,* 2006). There are some supporting studies that N fertilization affects yield of other medicinal plants (Arabaci and Bayram, 2004; Barreyro *et al.,* 2005; Ashraf *et al.,* 2006; Ozguven *et al.,* 2006; Abbaszadeh *et al.,* 2009; Sotiropoulou and Karamanos, 2010; Jabbari *et al.,* 2011). In crops whose commercial yields are the leaves, such as lettuce, spinach, endive, cabbage, etc., a great number of studies have been done on the influence of N fertilization (rate and form) on yield and ion composition (Wang and Tadashi, 1997; Santamaria and Elia, 1997; Simonne *et al.,* 2001; Wang and Li, 2004).

Iron (Fe) is a cofactor for approximately 140 enzymes that catalyze unique biochemical reactions (Brittenham, 1994). Hence, iron fills many essential roles in plant growth and development, including chlorophyll synthesis, thylakoid synthesis and chloroplast development (Miller *et al.,* 1995). Iron is required at several steps in the biosynthetic pathways. Zinc (Zn) is an essential element for plant that act as a metal component of various enzymes or as a functional structural or regulatory cofactor and for protein synthesis, photosynthesis, the synthesis of auxin, cell division, the maintenance of membrane structure and function, and sexual fertilization (Marschner, 1995). Manganese also is a micronutrient plays important role in life cycle of the plant. It involved in the oxygen-evolving step of photosynthesis and membrane function, as well as serving as an important activator of numerous enzymes in the cell (Wiedenhoeft, 2006).

Said-Al Ahl and Mahmoud (2011) found that the addition of micronutrients had an active effect comparing with control on sweet basil (*Ocimum basilicum* L.). Results of Jabbari *et al.* (2011) showed that the application of iron had a suppressing effect on the vegetative yield of thyme. Mineral elements like Zn and Fe are as crucial for human health as organic compounds such as carbohydrates, fats, protein and vitamins.

It is clear that micronutrients plays a positive role in plant growth and yield, however, little information has been reported about the role of micronutrients in N-nutrition of vegetable crops (Assimakopoulou, 2006) and no literature was found on the role of micronutrients in N-nutrition of fennel. Therefore, the main objectives of the current proposed study are: Firstly to assess the effect of nitrogen source and rates on growth, yield and chemical analysis of fennel cv. Florence. Secondly to

*Elwan_wasfy@yahoo.com

determine the effect of foliar application of micronutrients, such as iron, zinc and manganese on the efficiency of nitrogen fertilizer for enhancing growth, yield, macro-nutrients and micro-nutrients uptake by fennel plants cv. Florence.

MATERIALS AND METHODS

Two field experiments were carried out at the Experimental Research Farm, Faculty of Agriculture, Suez Canal University, Ismailia Governorate, Egypt, during the two successive winter seasons of 2012-2013 and 2013-2014. The experiments were designed to investigate the effects of nitrogen sources, nitrogen levels, spraying of micronutrients and their interactions on plant growth, yield and macro and micronutrients concentration in fennel plants (*Foeniculum vulgare* Mill.) cv. Florence.

Random soil samples were collected from 0.0–50.0 cm depth, before each plantation and homogenized together to determine the physicochemical characteristics of air-dried, crushed and sieved (<2mm) soil in accordance to the methods of Gee and Bauder (1986) and Sparks *et al*. (1996). Soluble cations Na^+, K^+, Ca^{2+} and Mg^{2+} and anions HCO_3^- and Cl^- were determined in the soil solution (Richards, 1954). Sulfate (SO_4^{2-}) was precipitated by barium chloride as barium sulfate and gravimetrically determined (Jackson, 1967). Electrical conductivity of the saturated soil paste extract expressed as dSm^{-1} was measured using a conductivity meter model Jenway 3310 (Jenway Ltd., Essex, Cambridge, UK) according to Richards (1954). Soil pH was determined by bench type Beckman glass electrode pH meter, in 1: 2.5 soil–water suspensions according to Page *et al*. (1982). The soil of the experimental site was sandy soil (85.21% sand, 11.5% silt and 3.29% clay) with pH 8.27, electrical conductivity (EC) 0.47 dSm^{-1}, calcium (Ca) 0.4 mM, magnesium (Mg) 0.3 mM, potassium (K) 0.3 mM, Na 3.0 mM, bicarbonate (HCO_3) 1.6 mM, chloride (Cl) 3.0 mM, and sulfate (SO_4) 0.05 mM. Available inorganic soil N (4.10 $mgkg^{-1}$ soil) was extracted using 2.0 M potassium chloride and determined according to the Kjeldaha method (Bremner, 1996). The available inorganic P (10.32 $mgkg^{-1}$ soil) was determined by the spectrophotometer (Jenway 6105) in 0.5 M $NaHCO_3$-soil extract according to the Olsen method (Kuo, 1996). The available micronutrients (Fe; 0.78 mg kg^{-1} soil, Mn; 0.63 mg kg^{-1} soil and Zn; 0.36 mg kg^{-1} soil) were determined using the atomic absorption spectrophotometer (Thermo-electron, Series GE711838) in diethylene triaminepentaacetic acid (DTPA) extract. Before planting, the experimental location was prepared. During preparation the soil of the site was cleared, ploughed, harrowed and divided into plots.

The experiments were laid-out in a split split-plot in randomized complete block design with three replicates. Experiment was subjected to combinations of two nitrogen sources (ammonium nitrate 33.5% and ammonium sulphate 20.5%), two nitrogen rates (60 and 90 k N/fad.) and two concentrations of micronutrients mixtures (without and with). Nitrogen was added at rates of 60 and 90 k N/fad., which equivalent to about 180 and 270 kg ammonium nitrate or 300 and 450 kg ammonium sulphate per faddan, respectively. The micronutrients mixtures containing Fe-EDTA 13.5% (one g/l) + Mn-EDTA 13% (0.5 g/l) + Zn-EDTA 14% (0.5 g/l) after dissolving in water (separately) and mixed before spraying. The volume of sprayed solution ranged from 1 L to 2 L per plot each time, depending on plant developmental stage. The same amount of water was sprayed to the control plants. The sprays in all cases were carried out with a manual pump in the morning.

Seeds of fennel cv. Florence were sown in nursery of the Horticulture Department, Faculty of Agriculture for seven weeks staring from August 28^{th}, in the first season and from September 10^{th}, in the second season. After emergence, the fennel seedlings received the normal agriculture practices.

Plot area was one row (25 m in length and 1.0 m in width) containing about 83 plants at a spacing of 0.3 m within the row. The environmental conditions were as follows: a 10-12 h photoperiod, day temperature fluctuated between 4-25 °C and 15-35 °C for minimum and maximum temperature, respectively. Relative humidity ranged from 15% to 47% and from 74-90% for minimum and maximum relative humidity, respectively.

Fennel nurslings, seven weeks old were transplanted on October 15^{th} and October 29^{th} 2013 for 2012 and 2013 seasons, respectively. Nitrogen fertilizer levels were added at four equal doses 3, 6, 9 and 12 weeks after transplanting. Each plant received a total of 4.5 or 6.75 g ammonium nitrate or 7.5 or 11.25 g ammonium sulphate (60 and 90 k N/fad.) in both seasons. Mixture of micronutrients applied foliarly four times during growing seasons and added in the same time of nitrogen fertilizer addition. The soil moisture content was kept at an appropriate (50–75%) of field capacity for sandy soil as described by Klocke and Fischbach (1984) and Miles and Broner (1998). Recommended practices for disease and insect pests control were followed.

Data collection and analysis

Plant biomass

Leaf and bulb fresh weights of five plants for each replicate were determined using gravimetric method. Dry weight of leaves and bulbs were determined after oven drying at 70°C up to constant weight.

Yield

At marketable stage (after three and half months), all sweet fennel plants from each sub sub-plot were harvested to record total foliage yield expressed as ton/fad. Bulbs were excised by cutting 5 cm above the bulb using a sharp stainless steel knife. Also, roots were excised and the outer-leaf removed for obtaining clean bulbs for each sub sub-plot to record total bulb yield expressed as ton/fad.

Analysis of macro and micro-nutrients

0.5 g of powdered materials (leaves and bulbs) was digested separately for each plants (three samples per replicate) using a mixture of sulfuric acid and hydrogen peroxide and then brought to a final volume of 50 ml with distilled water. Total nitrogen was estimated using semi-micro-kjeldahl method as described by Ling (1963). Phosphorus was analyzed by a vanadate-molybdate method at 660 nm using a Spectro 22 spectrophotometer (Chapman and Pratt, 1982). Potassium was determined using a Perkin-elmer, Flame photometer (Page, 1982). Fe, Mn and Zn were determined using the Atomic Absorption Spectrophotometer (Perkin-Elmer 100B).

Statistical analysis:

The results were evaluated using descriptive statistics and analysis of variance (ANOVA). Using two-way ANOVA, the effect of nitrogen sources, nitrogen levels and micronutrients foliar application as well as their interactions were evaluated by Fisher's F-test, followed by Duncan's multiple range test for comparing the main effects means and the eight NS x NR x MX combinations. All tests were performed at a significance level α of 0.05. Calculations were carried out using the software package Statistica™ for Windows version 6.1 (Statsoft Inc., 2001, Tulsa, Oklahoma, USA).

RESULTS

The main effects of nitrogen source, nitrogen rates, application of micronutrients as well as their triple interaction on leaf fresh weight, bulb fresh weight and total foliage fresh weight of fennel plants cv. Florence are presented in Table (1). The obtained results indicate that the fennel plants fertilized with ammonium sulphate had, in most cases, the highest leaf fresh weight, bulb fresh weight and total foliage fresh weight of fennel plants in both seasons. Regarding to the main effect of nitrogen level, the results prove that the leaf fresh weight, bulb fresh weight and total foliage fresh weight of fennel plants were significantly increased by increasing nitrogen level from 60 kg/fad to 90 kg/fad. a rate of 90 kg/fad. or ammonium sulphate at both tested levels (60 or 90 kg/fad.) combined with sprayed or non-sprayed plants with micronutrients in the first season. However, in the second season the higher bulb fresh weight were found in plants treated with ammonium nitrate at the high level (90 kg/fad.) or ammonium sulphate at both tested levels Mostly, spraying fennel plants with mixture of micronutrients significantly improved leaf, bulb and total plant fresh weight (Table 1).

Regarding to the triple interaction effects, results show that the highest leaf fresh weight in fennel plants was observed when plants fertilized with ammonium sulphate at higher level (90 kg/fad.) and sprayed with the mixture of micronutrients with no significant difference when compared with those fertilized with 90 kg N/fad. ammonium nitrate combined with micronutrients mixture in both seasons. The higher bulb fresh weight were found in plants supplied with ammonium nitrate at (60 or 90 kg/fad.) combined with spraying with micronutrients (Table 1). Regarding to total plant fresh weight, the results showed that fennel plants cv. Florence fertilized with ammonium sulphate as N-source at high level (90 kg/fad) and micronutrients gave higher total plant fresh weight in both seasons. It is clear also that, the most favorable interaction treatments for increasing total plant fresh weight were fertilizing fennel plants with 90 kg N/fad from either A-nitrate or A-sulphate combined with micronutrients with no significant differences between them in both seasons of study (Table 1).

The results of the main effects of nitrogen source, nitrogen rate and spying with micronutrients showed that fennel plants fertilized with ammonium sulphate, higher N rate (90 kg/fad.) and sprayed with mixture of micronutrients significantly recorded the highest values of leaf, bulb and total plant dry weight in comparison with ammonium nitrate as nitrogen source (Table 2).The results of the triple interaction effect reveal that the fennel plants fertilized with the highest added rate of ammonium sulphate (90 kg N/fad.) and supplemented with the mixture of micronutrients gave the significant highest leaf, bulb and total plant dry weight, followed by ammonium sulphate at 90 kg N/fad. without micronutrients then 60 kg N/fad. ammonium sulphate with micronutrients. These last two treatments did not differ significantly when compared with 60 kg N/fad. as ammonium nitrate regarding leaf dry weight and total dry weight of fennel plants (Table 2).

The main effect of nitrogen source affected significantly the yield parameters, in most cases, whereas ammonium sulfate improved significantly leaf yield, bulb yield and total plant yield in comparison with ammonium nitrate as N-source, except leaf yield and total yield per fad. in the second season which did not show any significantly differences between both nitrogen source (Table 3). Regarding the effect of nitrogen rate, the results indicate that the leaf, bulb and total plant yield increased markedly with increasing nitrogen rate from 60 to 90 kg/fad in both seasons (Table 3). Generally, the data concerning the main effect of spraying of plants with micronutrient reveal that the fennel plants received mixture of micronutrients produced the highest leaf, bulb and total yield of fennel and this effect was significant in both seasons, except bulb and total yield in the first season which did not significantly differed (Table 3).

The results regarding triple interaction among ammonium sulphate, high level of nitrogen (90 kg N/fad.) and the foliar spraying with mixture of micronutrients (Fe, Mn and Zn) gave non-significant highest yield components of fennel plants cv. Florence (Table 3). The results showed also that this favorable effect of the previous interaction was not differed significantly when ammonium nitrate was used instead of ammonium sulfate (Table 3) as N-source in combination with high nitrogen level and spraying with micronutrients.

Results of the influence of nitrogen source and rate in addition to foliar application of micronutrients as well as their interactions on the uptake of macro (N, P and K) and micro-nutrients (Fe, Mn and Zn) by fennel cv. Florence were evident in Tables (4 and 5). The results of the main effect of nitrogen source and rate showed that fennel plants fertilized with ammonium sulphate and higher nitrogen rate (90 kg/fad.) significantly increased, in most cases, the uptake of macro and micro-nutrients in different plant parts (leaf and bulb) in comparison with ammonium nitrate as nitrogen source. Also, the fennel plants sprayed with mixture of micronutrients (Fe, Mn and Zn) had the significant higher macro and micro-nutrients uptake by different fennel plant parts (Table 4 and 5). The results of triple interaction revealed that the fennel plants fertilized with high level of ammonium sulphate and sprayed with the micronutrients mixtures gave the significant highest nitrogen, phosphorus and potassium uptake (mg/plant), except only ammonium nitrate at low level (60 kg N/fad.) and spraying plants with micronutrients mixtures gave the significant highest bulb nitrogen uptake (Table 4). Also, in the same direction, the fennel fertilized-plants with high level of ammonium sulphate and sprayed with the micronutrients mixtures gave the significant highest iron, manganese and zinc uptake (mg/plant) as presented in Table (5).

DISCUSSION

Nitrogen source, N-rate, application of micronutrients and their interactions significantly influenced plant growth (Table 1 and 2), yield (Table 3) and elements uptake (Tables 4 and 5) of fennel plants cv. Florence. Mostly, the highest plant growth, yield and elements uptake were associated with the fennel plants fertilized with ammonium sulphate in comparison with ammonium nitrate as N-source. These results were supported by the previous results of Elwan and Abd El-Hamed (2011) who found that ammonium sulphate produced higher plant growth and yield of broccoli in comparison with other N-sources such as ammonium nitrate and urea. The positive effect of ammonium sulphate (contain 24% sulfur) on yield may be explained by the fact that ammonium sulphate as N-form decrease soil pH, which might favor the elements availability and uptake by plants in slightly alkaline soils (Guelser, 2005; Fageria *et al.,* 2010). From our results of this investigation, the results presented in Tables (4 and 5) showed that the uptake of macronutrients (N, P and K) and micronutrients (Fe, Mn and Zn) were significantly higher in fennel plants fertilized with ammonium sulphate compared to ammonium nitrate. These results confirmed the fact that ammonium sulphate as N-source decrease soil pH and increase the elements availability and uptake in slightly alkaline soils as in our study where the experimental soil pH was 8.27.

Table (1): Main and triple interaction effects of nitrogen source and levels in addition to foliar application of micronutrients on fresh weight of vegetative growth, bulb and total plant of fennel cv. "Florence" during 2012/2013 and 2013/2014 seasons.

N-Source	N-Rate (Kg/fad)	Micronutr. Mix.	Leaf FW (g/plant)		Bulb FW (g/plant)		Total Plant FW (g/plant)	
			2012-2013	2013-2014	2012-2013	2013-2014	2012-2013	2013-2014
A-Nitr.			141.40 b*	316.46 a	43.80 b	95.05 b	185.20 b	411.51 a
A-Sulf.			158.90 a	306.31 a	50.92 a	116.77 a	209.82 a	423.08 a
	60		125.01 b	288.23 b	41.68 b	97.40 b	166.69 b	385.63 b
	90		175.29 a	334.55 a	53.04 a	114.41 a	228.33 a	448.96 a
		-	142.27 b	276.43 b	47.21 a	93.62 b	189.47 a	370.06 b
		+	158.03 a	346.34 a	47.52 a	118.19 a	205.55 a	464.53 a
A-Nitr.	60	-	104.83 d	247.88 bc	31.60 b	88.93 d	136.43 d	336.82 cd
		+	104.11 d	365.08 a	35.40 b	97.02 cd	139.51 d	462.10 ab
	90	-	177.18 ab	299.90 b	56.95 a	86.17 d	234.13 ab	386.07 bc
		+	179.48 ab	389.50a	51.24 a	121.10 ab	230.72 abc	510.60 a
A-Sulf.	60	-	138.09 c	224.83 c	53.11 a	75.50 d	191.20 c	300.33 d
		+	153.00 bc	283.42 b	46.61 a	117.20 ab	199.61 bc	400.62 bc
	90	-	148.97 bc	307.32 b	47.16 a	114.83 bc	196.13 bc	422.15 b
		+	195.54 a	368.95 a	56.81 a	138.90 a	252.35 a	507.85 a

*Values followed by the same letter within a column are not significantly different at the 0.05% level of probability according to Duncan's multiple range test. A. Nitr.=Ammonium nitrate; A. Sulf.= Ammonium Sulfate; Micronutr. Mix.= Micronutrients Mixture

Table (2): Main and triple interaction effects of nitrogen source and levels in addition to foliar application of micronutrients on dry weight of vegetative growth, bulb and total plant in fennel cv. "Florence" during 2013/2014 season.

N-Source	N-Rate (Kg/fad)	Micronutr. Mix.	Leaf DW (g/plant)	Bulb DW (g/plant)	Total Plant DW (g/plant)
A-Nitr.			37.95 b*	10.28 b	48.21 b
A-Sulf.			42.26 a	13.86 a	56.11 a
	60		38.63 b	11.01 b	49.64 b
	90		41.56 a	13.13 a	54.69 a
		-	35.59 b	10.90 b	46.48 b
		+	44.61 a	13.24 a	57.85 a
A-Nitr.	**60**	-	31.95 d	10.00 cd	41.95 e
		+	45.88 ab	10.50 c	56.38 b
	90	-	36.02 cd	9.93 cd	45.95 de
		+	37.83 c	11.10 c	48.93 cd
A-Sulf.	**60**	-	30.87 d	8.23 d	39.10 e
		+	41.95 bc	13.92 b	55.87 bc
	90	-	41.15 bc	14.08 b	55.23 bc
		+	49.37 a	16.38 a	65.75 a

*Values followed by the same letter within a column are not significantly different at the 0.05% level of probability according to Duncan's multiple range test. A. Nitr.=Ammonium nitrate; A. Sulf.= Ammonium Sulfate; Micronutr. Mix.= Micronutrients Mixture

Table (3): Main and triple interaction effects of nitrogen source and levels in addition to foliar application of micronutrients on yield of fennel cv. "Florence" during 2012/2013 and 2013/2014 seasons.

N-Source	N-Rate (Kg/fad)	Micronutr. Mix.	Foliage Yield (ton/fad.)		Bulb Yield (ton/fad.)		Total Yield (ton/fad.)	
			2012-2013	**2013-2014**	**2012-2013**	**2013-2014**	**2012-2013**	**2013-2014**
A-Nitr.			1.98 b*	4.43 a	0.613 b	1.33 b	2.59 b	5.76 a
A-Sulf.			2.22 a	4.29 a	0.713 a	1.63 a	2.94 a	5.92 a
	60		1.75 b	4.04 b	0.584 b	1.36 b	2.33 b	5.40 b
	90		2.45 a	4.68 a	0.743 a	1.60 a	3.20 a	6.29 a
		-	1.99 b	3.87 b	0.661 a	1.31 b	2.65 a	5.18 b
		+	2.21 a	4.85 a	0.665 a	1.65 a	2.88 a	6.50 a
A-Nitr.	**60**	-	1.47 d	3.47 c	0.442 b	1.25 c	1.91 d	4.72 cd
		+	1.46 d	5.12 a	0.496 b	1.35 c	1.95 d	6.47 ab
	90	-	2.48 ab	4.20 b	0.796 a	1.21 cd	3.28 ab	5.45 bcd
		+	2.51ab	5.45 a	0.717 a	1.70 b	3.23 abc	7.15 a
A-Sulf.	**60**	-	1.93 c	3.15 c	0.744 a	1.06 d	2.68 c	4.20 d
		+	2.14 bc	3.97 b	0.652 a	1.64 b	2.79 bc	5.61 bc
	90	-	2.09 bc	4.30 b	0.660 a	1.61 b	2.75 bc	5.91 ab
		+	2.74 a	5.16 a	0.795 a	1.95 a	3.53 a	7.11 a

*Values followed by the same letter within a column are not significantly different at the 0.05% level of probability according to Duncan's multiple range test. A. Nitr.=Ammonium nitrate; A. Sulf.= Ammonium Sulfate; Micronutr. Mix.= Micronutrients Mixture

Table (4): Main and triple interaction effects of nitrogen source and levels in addition to foliar application of micronutrients on the uptake of nitrogen, phosphorus and potassium of fennel cv. "Florence" during 2013/2014 season.

N-Source	N-Rate (Kg/fad)	Micronutr. Mix.	N uptake mg plant^{-1}			P uptake mg plant^{-1}			K uptake mg plant^{-1}		
			Leaf	Bulb	Plant	Leaf	Bulb	Plant	Leaf	Bulb	Plant
A-Nitr.			600.65 b*	83.53 a	684.18 b	131.95 b	21.10 b	153.05 b	1878.9 a	590.16 b	2469.1 b
A-Sulf.			1040.0 a	88.57 a	1128.5 a	158.66 a	26.66 a	185.32 a	1883.0 a	749.67 a	2632.7 a
	60		652.9 b	88.97 a	741.87 b	136.38 b	22.19 b	158.97 b	1855.2 b	591.60 b	2446.8 b
	90		987.72 a	83.13 a	1070.9 a	154.22 a	25.19 a	179.41 a	1906.7 a	748.23 a	2655.0 a
		-	758.64 b	73.09 b	831.73 b	131.47 b	20.62 b	152.09 b	1512.9 b	610.40 b	2123.3 b
		+	881.99 a	99.01 a	981.00 a	159.15 a	27.13 a	186.28 a	2249.1 a	729.43 a	2978.8 a
A-Nitr.	60	-	552.74 g	80.00 c	632.74 f	108.63 e	22.33 e	130.96 e	1460.1 e	540.00 e	2000.1 g
		+	293.63 h	120.75 a	414.38 g	157.52 b	23.80 d	181.32 b	2284.8 b	549.15 e	2834.0 c
	90	-	799.64 d	64.55 de	864.19 d	138.08 c	17.54 g	155.62 c	1822.6 d	626.58 d	2449.2 e
		+	756.60 e	68.82 cd	825.42 d	123.58 d	20.72 f	144.30 cd	1948.2 c	644.91 c	2593.2 d
A-Sulf.	60	-	645.18 f	53.50 e	698.68 e	121.42 d	13.99 h	135.41 de	1410.8 f	492.15 f	1902.9 h
		+	1120.1 b	101.62 b	1221.7 b	158.01 b	30.16 b	188.17 b	2265.3 b	785.09 b	3050.4 b
	90	-	1037.00 c	94.34 b	1131.3 c	157.74 b	28.63 c	186.37 b	1358.0 g	782.85 b	2140.8 f
		+	1357.7 a	104.83 b	1462.5 a	197.48 a	33.85 a	198.00 a	2498.1 a	938.57 a	3436.7 a

*Values followed by the same letter within a column are not significantly different at the 0.05% level of probability according to Duncan's multiple range test. A. Nitr.=Ammonium nitrate; A. Sulf.= Ammonium Sulfate; Micronutr. Mix.= Micronutrients Mixture

Table (5): Main and triple interaction effects of nitrogen source and levels in addition to foliar application of micronutrients on the content of iron, manganese and zinc of fennel cv. "Florence" during 2013/2014 season.

N-Source	N-Rate (Kg/fad)	Micronutr. Mix.	Fe uptake mg plant^{-1}			Mn uptake mg plant^{-1}			Zn uptake mg plant^{-1}		
			Leaf	Bulb	Plant	Leaf	Bulb	Plant	Leaf	Bulb	Plant
A-Nitr.			3.86 b*	0.689 b	4.55 b	3.71 b	0.537 b	4.25 b	4.04 b	0.939 b	4.98 b
A-Sulf.			4.56 a	0.810 a	5.37 a	4.16 a	0.643 a	4.81 a	4.30 a	1.250 a	5.55 a
	60		3.96 b	0.735 b	4.70 b	3.59 b	0.538 b	4.13 b	3.99 b	0.998 b	4.99 b
	90		4.46 a	0.764 a	5.22 a	4.28 a	0.643 a	4.93 a	4.35 a	1.195 a	5.55 a
		-	3.78 b	0.614b	4.39 b	3.59 b	0.537 b	4.12 b	3.81 b	1.025 b	4.83 b
		+	4.64 a	0.885 a	4.53 a	4.29 a	0.643 a	4.93 a	4.53 a	1.168 a	5.70 a
A-Nitr.	60	-	2.85 g	0.675f	3.52 g	3.23 e	0.500 e	3.73 e	3.75 e	1.013 d	4.77 d
		+	4.83 c	0.964 b	5.80 c	4.04 c	0.609 d	4.65 c	4.73 b	0.737 g	5.47 b
	90	-	4.18 d	0.697 d	4.88 e	3.53 d	0.516 e	4.05 d	3.68 e	1.033 d	4.71 d
		+	3.57 e	0.420 g	3.99 f	4.05 c	0.522 e	4.57 c	4.00 d	0.975 e	4.98 c
A-Sulf.	60	-	3.08 f	0.400 h	3.48 h	3.03 f	0.387 f	3.41 f	3.42 f	0.793 f	4.21 e
		+	5.10 a	0.902 c	6.00 b	4.07 c	0.654 c	4.72 c	4.07 d	1.448 b	5.51 b
	90	-	5.00 b	0.680 e	5.68 d	4.57 b	0.746 b	5.31 b	4.39 c	1.262 c	5.65 b
		+	5.07 a	1.250 a	6.32 a	4.99 a	0.786 a	5.77 a	5.33 a	1.512 a	6.84 a

*Values followed by the same letter within a column are not significantly different at the 0.05% level of probability according to Duncan's multiple range test. A. Nitr.=Ammonium nitrate; A. Sulf.= Ammonium Sulfate; Micronutr. Mix.= Micronutrients Mixture.

Generally, increasing nitrogen rate from 60 to 90 kg/fad. produced significant higher plant growth and yield of fennel cv. Florence. These results were in accordance with the previous results of Ehsanipoura *et al.* (2012) on fennel plants who reported that the highest seed and foliage essential oil contents and seed essential oil yield were produced at higher nitrogen level (160 kg per N ha^{-1}). In leafy vegetables such as lettuce, parsley and spinach, the yield increased with increasing nitrogen rate (Petropoulos *et al.,* 2008; Konstantopoulou *et al.,* 2010; Rop, 2012). Also, many investigators reported that increasing nitrogen levels application improved the plant growth and yield of some vegetable crops (Singer *et al.,* 2000; Saxena *et al.,* 2003; Hafez *et al*., 2004; Abdel-Mawgoud *et al*., 2005; Souza *et al*., 2008 and El-Bassiony *et al*., 2010). It is well known that nitrogen influences the structure and composition of photosynthetic apparatus. In crops, ribulose 1,5, bisphosphate carboxylase (rubisco) content increases linearly with leaf N accumulation (Kumar *et al*., 2002). Nitrogen fertilization management is important to optimize crop production. It is one of the most important nutrients in crop production that affect photosynthetic efficiency and leaf development, which leads to an increase in dry matter production (Dordas and Sioulas, 2008). Nitrogen is of vital importance for plant growth due to being a part of amino acid, protein, enzymes and chlorophyll molecule (Devlin and Witham, 1986).

The results of this work regarding the uptake of macro and micronutrients presented in Tables (4 and 5) showed that the uptake of macronutrients (N, P and K) and micronutrients (Fe, Mn and Zn) were at significant level in fad-fennel plants with higher nitrogen rate (90 kg N/fad.). These results were confirmed the fact reported by Malvi (2011) who reported that optimum supply of nitrogen ensures optimum uptake of potassium as well as phosphorus, magnesium, iron, manganese and zinc from the soils that called synergism effect.

Our results concerning the effect of foliar application of micronutrients reflected enhancement effect on plant growth, yield and uptake of macro and micronutrients of fennel plants cv. Florence. In this investigation we decided to use foliar application of micronutrients instead of soil supplementation because of antagonistic effects among cations and anions may occur when fertilizers supplied together to the soil, especially in the case of alkaline soil. For example, a deficiency of Zn in crops is dependent on high soil pH (Alloway, 2008). The advantages of foliar fertilization are low application rates, uniform distribution and quick plant responses to applied nutrients (Umer *et al.,* 1999; Mengel, 2002). Also, foliar application is a short term approach which provides more efficient utilization of nutrients and permits remediation of observed deficiencies in less time than would be done by soil application (Fageria *et al.,* 2009). The positive effects of foliar application of micronutrients on fennel plants may be due to that the measured concentrations of Fe, Mn and Zn in the tested soil were less than critical threshold, whereas the critical threshold for Fe, Mn and Zn are 2.5-4.5, 1.2-1.4 and 0.5-1.0 mg kg^{-1} soil.

The results in this investigation were in harmony with the results of Bhati and Srivastava (2005), Narimani *et al.* (2010), El-Fouly *et al.* (2011), Anees *et al.* (2011) and Yadav *et al.* (2013) who found that foliar application of micronutrients mixtures improved the yield and elements uptake in tomato, wheat, durum wheat, mango and peach, respectively. Iron (Fe) is a cofactor for approximately 140 enzymes that catalyze unique biochemical reactions (Brittenham, 1994). Hence, iron fills many essential roles in plant growth and development, including chlorophyll synthesis, thylakoid synthesis and chloroplast development (Miller *et al.,* 1995). Iron is required at several steps in the biosynthetic pathways. Foliar application of iron increased plant growth, yield and the elements uptake in dry bean (Moosavi and Ronaghi, 2010), maize (Çelik *et al*., 2010) and *Glycine max* var. Pershing (Pooladvand *et al.,* 2013). Zinc (Zn), an essential micronutrient, plays a vital role in various processes such as carbohydrate, auxin and nucleic acid metabolism, protein synthesis (Cakmak *et al.,* 1989), membrane stabilization and in the detoxification of highly active superoxide radicals. Zinc plays an important role as cofactors by defining the three-dimensional structure and function of many proteins as it is able to bridge many amino acid residues (Broadley *et al.,* 2007). About 40% of the Zn binding proteins are thought to be transcription factors which are needed for proper gene regulation during reproductive stage development like, flower initiation (Colasanti *et al.,* 2006), floral development (Takatsuji *et al.,* 1992), male and female gametogenesis (Payne *et al.,* 2004) fertilization and development and viability of seed (Sagasser *et al.,* 2002). The previous reports dealing with foliar application of zinc to onion and mung bean plants proved that plant growth, yield and elements uptake were increased by such treatment (Trivedi and Dhumal, 2013) Manganese is involved in the oxygen-evolving step of photosynthesis and membrane function, as well as serving as an important activator of numerous enzymes in the cell (Wiedenhoeft, 2006). Previous report regarding to foliar application of manganese showed that the yield of sweet orange increased significantly by Mn application (Tariq *et al.,* 2007).

It is clear from our results that the first season of cultivation produced less yield components in comparison with the second season, this may be due to the high air temperature (from 26-32°C) prevailing during earlier plant stage which affected negatively on the yield of fennel in the first season. However in the second season, the air temperature was from 8 to 11°C which was more suitable for normal growth of fennel plants.

In conclusion, a greater fennel plant biomass was observed when N fertilizer as ammonium sulphate with high rate was used. Foliar application of micronutrients mixtures improved markedly plant growth, yield and macro- and micro-nutrients uptake by different fennel plant parts. Also, results showed an evident synergism effect due to nitrogen sources x nitrogen rates x micronutrients mixtures, since the addition of micronutrients mixtures boosted plant biomass, yield and the elements uptake as N fertilizer rates increased and ammonium sulphate as nitrogen source was used.

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تحسين النمو والمحصول في نبات الفينوكيا باستخدام مصادر ومستويات من الأسمدة النيتروجينية والرش بمخلوط العناصر الصغرى

سمير كامل الصيقى – محمود عبد المحسن حسن - محمد وصفى محمد علوان– علا جودة حجاج
قسم البساتين – كلية الزراعة – جامعة قناة السويس

أجريت هذه الدراسة بهدف إعطاء بعض المعلومات والتي من الممكن أن تحسن من الحالة الغذائية وإنتاجية الفينوكيا. حيث تم دراسة تأثير مصادر النيتروجين (نترات الامونيوم و سلفات الامونيوم) و مستويين من السماد النيتروجينى (٦٠ و ٩٠ كيلوجرام نيتروجين) بالإضافة إلى مستويين من الرش بالعناصر الصغرى (بدون رش وبالرش بمخلوط العناصر المكون من الحديد والمنجنيز والزنك المخلبى) وذلك على النمو والمحصول وامتصاص العناصر المعدنية (نيتروجين – فوسفور – بوتاسيوم – حديد – منجنيز - زنك) في صنف الفينوكيا فلورنس. أظهرت النتائج أن سلفات الامونيوم عند المستوى الأعلى من السماد النيتروجينى (٩٠ كجم للفدان) أعطت أعلى نمو نباتي ووزن جاف بالإضافة إلى تحسين مكونات المحصول (الأخضر – الأبصال - الكلى). كما أوضحت النتائج أن الحالة الغذائية لنباتات الفينوكيا تحسنت حيث أن النباتات التي سمدت بسلفات الامونيوم عند المستوى الأعلى (٩٠ كجم للفدان) والتي تم رشها بمخلوط العناصر الصغرى قد زادت امتصاص العناصر الكبرى (نيتروجين – فوسفور – بوتاسيوم) والعناصر الصغرى (حديد – منجنيز – زنك)٠ و تقترح هذه الدراسة أن الرش بمخلوط العناصر الصغرى من الممكن أن تكون إستراتيجية مؤثرة في قوة نباتات الفينوكيا التي تحتوى على الحديد والمنجنيز والزنك والتي تؤدى إلى إنتاج محصول ذو جودة غذائية عالية.