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Effect of Foliar Iron Applications at Different Growth Stages on Iron and Some Nutrient Concentrations in Strawberry Cultivars

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Abstract: This study was conducted to investigate the effect of foliar Fe applications on leaf Fe and some nutrient (P, Ca, Mg, K, Mn and Zn) concentrations in strawberry (*Fragaria vesca* L.) cultivars. For this purpose, 2 forms of Fe solutions ($FeSO_4$. 7 H_2O and Fe-EDTA) containing 0.28% Fe were sprayed onto the strawberry leaves at 3 growth stages (before blooming, first blooming, full blooming). Depending on the Fe sources, Fe concentration increased after each application. Before blooming, leaf Fe concentration increased from 60 mg kg^{-1} (control) to 127 and 105 mg kg^{-1} with Fe-EDTA and $FeSO_4$. 7 H_2O, respectively. During the first blooming, leaf Fe concentration continued to increase to 139 mg kg^{-1} with both Fe sources. While Fe concentration was 87 mg kg^{-1} with the control treatment, it reached 184 mg kg^{-1} with Fe-EDTA and 238 mg kg^{-1} with $FeSO_4$. 7 H_2O application after the full blooming. While the leaf Fe and Zn concentrations increased with foliar Fe applications, leaf P, Mg and K concentrations were not affected, but Ca and Mn concentrations decreased. This indicated that the leaf Fe concentration of strawberry increased continuously with repeated foliar Fe application from both sources. Regarding leaf Fe concentrations, it was seen that the effect of $FeSO_4$. 7 H_2O on leaf Fe concentrations was higher than that of Fe-EDTA.

Key Words: Foliar fertilization, Fe, nutrient contents, strawberry, plant

Farklı Dönemlerde Yapraktan Demir Uygulamasının Çilek Çeşitlerinin Demir ve Bazı Besin Maddesi İçeriklerine Etkisi

Özet: Bu çalışma, yapraktan Fe uygulamasının, çilek çeşitlerindeki (*Fragaria vesca* L.) Fe ve bazı (P, Ca, Mg, K, Mn ve Zn) besin elementi konsantrasyonlarına etkisini araştırmak için yapılmıştır. Bu nedenle, çilek yapraklarına % 0.28 Fe içeren iki Fe formu ($FeSO_4$. 7 H_2O ve Fe-EDTA) 3 farklı dönemde (çiçeklenme öncesi, ilk çiçeklenme, tam çiçeklenme) uygulanmıştır. Demir uygulamalarına bağlı olarak yaprak Fe konsantrasyonları artmıştır. Çiçeklenme öncesi yaprak Fe konsantrasyonu Fe- EDTA ve $FeSO_4$. 7 H_2O ile 60 mg kg^{-1} dan 127 ve 105 mg kg^{-1}'a yükselmiştir. Ilk çiçeklenmede yaprak Fe konsantrasyonu artmaya devam etmiş ve 139 mg kg^{-1}'a ulaşmıştır. En yüksek Fe konsantrasyonu tam çiçeklenme döneminde elde edilmiş ve kontrol uygulamasında 87 mg kg^{-1} olan Fe konsantrasyonu Fe- EDTA ve $FeSO_4$. 7 H_2O uygulamaları ile 184 ve 238 mg kg^{-1}'a ulaşmıştır. Demir uygulamaları ile yaprak Fe ve Zn içerikleri artarken P, Mg and K içerikleri değişmemiş buna karşılık Ca ve Mn içerikleri azalmıştır. Elde edilen sonuçlara göre çilek yapraklarının Fe içerikleri tekrarlayan yaprak uygulamaları ile her iki Fe kaynağında da sürekli bir artış göstermiştir. Elde edilen artış oranlarına göre $FeSO_4$. 7 H_2O uygulamasının Fe-EDTA ya göre daha etkili olduğu belirlenmiştir.

Anahtar Sözcükler: Yapraktan gübreleme, Fe, besin elementi içeriği, çilek, bitki

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Introduction

The foliar application of mineral nutrients by means of sprays offers a method of supplying nutrients to higher plants more efficiently than methods involving root application when soil conditions are not suitable for Fe availability. In calcareous soils, for example, Fe availability is usually very low and Fe deficiency widespread. Foliar spraying under these conditions could be much more efficient than any other applications of Fe to the soil (Horesh and Levy, 1981).

In a study conducted by Türemiş et al. (1997), strawberry cultivars showed different responses to various doses and application types of sequestrene Fe-138. Some varieties responded negatively to the Fe fertilization, and the yield decreased compared to the control (no Fe application). Almaliotis et al. (2002) found that there was a significant linear relationship between Fe concentration and yield. Similarly, Karp et al. (2002) indicated that strawberry fruit quality increased with foliar Fe fertilization. In another study, amino-acid-chelated Fe applied to a pear cultivar by foliar spraying ameliorated Fe deficiency symptoms and increased total yield by 47% and Fe concentration of leaves by 120% (Köksal et al., 1999).

Interactions between mineral elements in soil are one of the most important factors affecting plant nutrient balance. It is known that there is certain competition between some nutrients, and an excess of a nutrient can affect the availability, uptake by plants and distribution in plant tissue; thus plant growth is affected negatively (Bergman, 1992; Marschner, 1995). If plant available Zn is low in soils, it is affected negatively by N, P, K, Ca, Mg, Na, Fe, Cu and Mn (Loneragan and Micheal, 1993). A study of Erdal et al. (2003) showed that the Fe, Cu, Mn, N, P, K, Ca and Mg concentrations of maize plants decreased with Zn fertilization from soil. In another study, conducted by Karaman et al. (1997), the application of different Fe sources increased bean Fe concentration but decreased P, Zn, Cu and Mn concentrations. Başar and Özgümüş (1999) found a negative correlation between the total Fe concentration and Cu, Zn and Mn concentrations of peach trees, and Fe concentration in leaves increased with sequestrene 138 Fe and Fe-sulfate applications.

The chlorosis associated with Fe deficiency is not usually a direct consequence of an absolute lack of this element as in the case of other micronutrient elements, but rather a secondary effect resulting from the complex interactions of Fe with other elements and various soil and environmental factors. Fe deficiency can occur in plants grown on alkaline soils that are rich in Ca and Mg. Fe deficiency is also possible in soils with high concentrations of Cu, Mn and Zn and in soils with low organic matter. Excess concentrations of Cu, Mn and Zn in soil solution cause Fe deficiency. Similarly, high levels of Fe in soil can reduce plant uptake of Cu, Mn and Zn. Excessive Ca leads to deficiencies of Fe, B, Mn and Mg. Similarly, excessive phosphate anions can prevent Fe uptake and use by plants (Havlin et al., 1999). In a study conducted by Wikoff and Moraghan (1986), increasing levels of Fe application to the soil for eliminating Fe deficiency under unfavorable conditions for Fe availability resulted in Mn deficiency. In another study, the Fe uptake and concentration of rice plants decreased with increasing levels of Zn in the soil (Alpaslan and Taban, 1996).

The objective of this study was to examine the response of strawberry varieties to organic and inorganic source of foliar Fe fertilisation at different plant growth stages and to investigate the variations of some nutrient concentrations in relation to foliar Fe applications.

Materials and Methods

Plant materials

Addie, Dorit, Camarosa, (Fe sensitive), Selva (Fe semi-sensitive) and Delmarval (Fe resistant) strawberry cultivars were used in the present study.

Preparing Fe solutions

Two different Fe sources (Fe-EDTA and $FeSO_4 . 7 H_2O$) were sprayed onto the leaves. Solutions of foliar applications were prepared as follows (Hewitt, 1966):

Fe-EDTA: 89.0 g of free EDTA was dissolved in 1 N NaOH and 83.4 g of $FeSO_4 .7 H_2O$ was dissolved in 1 l of pure water. EDTA solution was added to Fe solution and aerated in a darkened vessel until dark brown. The last volume was brought up to 6 l with pure water.

$FeSO_4 . 7 H_2O$: 83.4 g of $FeSO_4 .7 H_2O$ was dissolved in 6 l of pure water.

The final Fe concentration of both solutions was 2.8 g l^{-1}.

Application

The study was conducted under field conditions. Fe solutions (Fe-EDTA and $FeSO_4$. 7 H_2O) were sprayed onto the leaves at 3 growth stages [before blooming (second week of April) , first blooming (first week of May) and full blooming (last week of May)] as 3 replicates of field block per Fe source (field blocks were randomly treated). For the control treatment, pure water was sprayed onto the leaves. During spraying, the soil surface and plants were covered with plastic to prevent any Fe contamination.

Plant analysis

In order to determine Fe variations related to growth stages, leaf samples were collected after each application (just before the other spraying). To determine the effect of applied Fe on other nutrient concentrations, another sampling was performed in the middle of the harvest. Leaf samples were collected as described by Cline (1962) and washed thoroughly with dilute acid (0.2 N HCl) and pure water to remove surface Fe and other residues. The samples were dried at 65 ^{0}C and then wet digested in a HNO_3 and $HClO_4$ acid (4/1, v/v) mixture (Kacar, 1972). Fe, Mn and Zn concentrations were determined by atomic absorption spectrophotometer; Ca, Mg and K concentrations were determined by flamephotometer and P was determined as described by Jackson (1967) using a spectrophotometer.

Soil properties

Some physical and chemical characteristics of the field soil were as follows: texture clay loam; $CaCO_3$ 15%; pH (1/2.5 H_2O) 8.0; EC 0.5 dS m^{-1}; organic matter 1.7%, NH_4OA_c-extractable K 1.49 me 100 g^{-1}; exchangable Ca 11.0 me 100 g^{-1}; Mg 5 me 100 g^{-1}; total N 0.23%; $NaHCO_3$- extractable P 25.6 mg kg^{-1} and DTPA-extractable Fe, Cu, Zn and Mn as 4.4, 1.5, 0.64 and 16.8 mg kg^{-1}, respectively. Chemical soil analysis was conducted as described in Kacar, 1994.

Statistical analysis

The experiment was designed in completely randomized blocks with 3 replications. The experimental data were analyzed by ANOVA and differences between the treatment means were separated by Duncan's multiple range test.

Results

Variations in leaf Fe concentrations depending on growth stages

Leaf Fe concentrations before blooming significantly differed with Fe applications, varieties and variety x Fe interactions (Table 1). Of the Fe sources, the highest Fe value (127 mg kg^{-1}) was obtained from Fe-EDTA followed by $FeSO_4$. 7 H_2O (105 mg kg^{-1}). The lowest Fe value (60 mg kg^{-1}) was obtained from the control treatment. The changes in leaf Fe concentrations between varieties by control, Fe-EDTA and $FeSO_4$. 7 H_2O treatments ranged from 50 to 70, 83 to 162 and 80 to 116 mg kg^{-1}, respectively. When the means of leaf Fe concentration are considered, the 2 Fe sources increased the leaf Fe concentration at first blooming to a similar extent. Since leaf Fe concentration was 52 mg kg^{-1} in the control and 139 mg kg^{-1} in both Fe treatments, the percentage of increase was equal. With Fe-EDTA and $FeSO_4$. 7 H_2O treatments, the leaf Fe concentrations of the varieties were 207 and 120 mg kg^{-1} for Addie, 112 and 190 mg kg^{-1} for Dorit, 83 and 176 mg kg^{-1} for Camarosa, 150 and 95 mg kg^{-1} for Selva and 144 and 115 mg kg^{-1} for Delmarval, respectively (Table 2). The effects of Fe applications and varieties were significantly different on leaf Fe concentration at full blooming (Table 1). The mean leaf Fe concentrations were 87, 184 and 238 mg kg^{-1} in control, Fe-EDTA and $FeSO_4$. 7 H_2O treatmebts respectively. In comparison to the control treatment, leaf Fe concentration significantly increased with Fe-EDTA and $FeSO_4$. 7 H_2O. Mean values of leaf Fe concentrations of Addie, Dorit, Camarosa, Selva and Delmarval were 157, 160, 150, 197 and 183 mg kg^{-1} respectively. The response of varieties to Fe sources greatly differed. Thus the mean leaf Fe concentrations of Addie, Dorit, Camarosa, Selva and Delmarval with Fe-EDTA and $FeSO_4$. 7 H_2O were 154 and 247 mg kg^{-1}, 187 and 227 mg kg^{-1}, 154 and 208 mg kg^{-1}, 233 and 267 mg kg^{-1} and 191 and 242 mg kg^{-1}, respectively (Table 2).

Effect of leaf Fe concentration on P, Ca, Mg, Mn and Zn concentrations

Leaf Fe concentrations at harvest decreased in all varieties generally. Leaf Fe concentrations of Addie, Dorit, Camarosa, Selva and Delmarval at harvest were 50, 65, 48, 46, and 62 mg kg^{-1} in the control treatment respectively. Leaf Fe concentrations in the Fe-EDTA and $FeSO_4$. 7 H_2O applied plots were 109-125, 187-227, 99-

Table 1. Degree of freedom (DF) and F values from ANOVA on independent variables.

		Growth stages		
		Before blooming	First blooming	Full blooming
Sources	DF	F values		
Varieties (A)	4	6.7***	3.8*	6.5***
Applications (B)	2	70.7***	173.0***	169***
AxB	8	4.2**	25***	Ns
Error	30			

*P < 0.05; **P < 0.01; ***P < 0.001; Ns: not significant

Table 2. Changes in leaf Fe concentrations depending on variety and Fe sources at different growth stages of strawberry.

Varieties	Control	Fe-EDTA	$FeSO_4 . 7 H_2O$	Mean	% increase in Fe	
					Fe-EDTA	$FeSO_4 . 7 H_2O$
	Fe concentrations before blooming (mg kg^{-1})					
Addie	70	151	115	112 a*	157	64
Dorit	50	127	99	92 ab	154	98
Camarosa	60	83	113	85 b	38	88
Selva	56	162	116	113 a	189	107
Delmarval	62	113	80	86 b	82	29
Mean	60 c	127 a	105 b			
	Fe concentrations at the first blooming (mg kg^{-1})					
Addie	37	207	120	121 a*	459	224
Dorit	50	112	190	117 ab	124	280
Camarosa	40	83	176	100 ab	107	304
Selva	64	150	95	103 ab	134	48
Delmarval	69	144	115	109 ab	108	67
Mean	52 b	139 a	139 a			
	Fe concentrations at the full blooming (mg kg^{-1})					
Addie	72	154	247	157 b	114	243
Dorit	65	187	227	160 b	188	249
Camarosa	89	154	208	150 c	73	134
Selva	90	233	267	197 a	158	196
Delmarval	117	191	242	183 ab	63	106
Mean	87 c	184 b	238 a			

*Values with the same letter are not statistically significant

108, 116-130 and 81-82 mg kg^{-1} in Addie, Dorit, Camarosa, Selva and Delmarval, respectivelly. Foliar Fe applications did not significantly affect leaf P, K or Mg concentrations but leaf Ca and Mn concentrations were negatively affected by foliar Fe applications generally (Table 3). In the control treatment, leaf Ca concentrations were 2.1%, 1.92%, 1.66%, 1.92% and 1.87% in Addie, Dorit, Camarosa, Selva and Delmarval but these values decreased to 0.39% and 0.40%, 0.61% and 0.56%, 0.36% and 0.38%, 0.54% and 0.41% and 0.54% and 0.41% with $FeSO_4$. 7 H_2O and Fe-EDTA applications, respectively (Table 3).

Foliar Fe application from both sources resulted in significiant increases in leaf Zn concentration generally (except for in Dorit). While leaf Fe concentrations in the control treatment were 30, 29, 23, 22 and 26 mg kg^{-1} in Addie, Dorit, Camarosa, Selva and Delmarval, leaf Fe concentrations were 24 and 39, 22 and 37, 29 and 35, 34 and 36 and 35 and 26 with Fe-EDTA and $FeSO_4$. 7 H_2O, respectively (Table 3).

Discussion

Fe treatments increased foliar Fe concentrations in all varieties but the Fe concentrations varied between the varieties. From a detailed examination of leaf Fe concentration for the control treatment, sensitive and semi-sensitive varieties contained less Fe (except for Addie before the first blooming) compared to the resistant variety. These Fe concentrations were just over the optimal sufficient level (Bergman, 1992) or under the optimal concentration (May and Prits, 1990; Jones et al., 1991). On the other hand, after Fe treatments, leaf Fe concentrations increased and reached optimal levels in all varieties. The percentage increase in leaf Fe concentrations differed between varieties. This can be explained by the variations between varieties in their response to the treatments (Türemiş et al., 1997). The difference in leaf Fe concentrations among the varieties may be caused by different Fe absorption capacities through the leaves and roots (Römheld and Kramer, 1983; Marschner et al., 1986a; Marschner at al., 1986b;

Table 3. Effect of Fe applications on leaf nutrient concentrations of strawberry cultivars.

		Leaf nutrient concentrations						
Cultivars	Applications	Fe (mg kg^{-1})	P (%)	Ca (%)	Mg (%)	K (%)	Mn (mg kg^{-1})	Zn (mg kg^{-1})
	Control (-Fe)	50	0.31	2.10	0.68	1.50	192	30
Addie	$FeSO_4$. 7 H_2O	109	0.30	0.39	0.56	1.32	154	24
	Fe-EDTA	125	0.30	0.40	0.61	1.55	148	39
	Control (-Fe)	65	0.30	1.92	0.60	1.48	184	29
Dorit	$FeSO_4$. 7 H_2O	187	0.29	0.61	0.54	1.40	147	22
	Fe-EDTA	227	0.30	0.56	0.58	1.37	129	27
	Control (-Fe)	48	0.33	1.66	0.60	1.38	148	23
Camarosa	$FeSO_4$. 7 H_2O	99	0.31	0.36	0.58	1.41	140	29
	Fe-EDTA	108	0.33	0.38	0.61	1.41	144	35
	Control (-Fe)	46	0.29	1.92	0.56	1.59	211	22
Selva	$FeSO_4$. 7 H_2O	116	0.28	0.54	0.63	1.46	169	36
	Fe-EDTA	130	0.28	0.41	0.60	1.48	189	34
	Control (-Fe)	62	0.26	1.87	0.56	1.60	138	26
Delmarwal	$FeSO_4$. 7 H_2O	81	0.25	0.54	0.61	1.50	113	35
	Fe-EDTA	82	0.26	0.41	0.59	1.55	137	26
LSD Fe applications (A)		36	Ns	0.14	Ns	Ns	11	5.3
LSD variety (B)		12	0.03	Ns	Ns	0.13	14	Ns
LSD: AxB	21	Ns	Ns	Ns	Ns	10.4	4.7	

* means in the same column with different letters are significantly different

*P < 0.05; **P < 0.01; ***P < 0.001; Ns: not significant

Table 4. Degree of freedom (DF), F values and signifiance levels from ANOVA on independent variables.

Source	DF	F values						
		Fe	P	Ca	Mg	K	Mn	Zn
Varieties (A)	4	8.5***	5.5**	Ns	Ns	9.6***	77***	Ns
Fe applications (B)	2	98***	Ns	540***	Ns	Ns	69**	14.4***
AxB	8	4.9***	Ns	Ns	Ns	Ns	4**	4.7**
Error	30							
Total	44							

**P < 0.01; ***P < 0.001; Ns: not significant

Marschner et al.1987). If the Fe sensitivity of the varieties is evaluated on the basis of leaf Fe concentrations, the varieties may be grouped as sensitive, semi-sensitive and tolerant. However, considering the changes in Fe concentration after the applications, Camarosa, which is graded as sensitive depending on visual symptoms, showed the lowest reaction towards Fe applications among the sensitive varieties. This may be interpreted to mean that although the total leaf Fe concentration is high, it may not be used metabolically (Marschner, 1995; Erdal et al., 1998). In experiments conducted under uncontrolled conditions in calcareous soils, it was found that the concentration of Fe in chlorotic leaves might be similar to or even higher than that in green leaves. These situations are partly related to the localization and binding properties of Fe in leaves. A portion of Fe might be precipitated in the apoplasm of leaves and not be physiologically active (Mengel and Geurtzen, 1988). These findings showed an agreement with the present results. Our results also showed differences in the physiological utilization of total plant Fe among strawberry varieties. Another important result is the differing response of varieties. This is also consistent with the results of many experiments.

Our results indicated that leaf Fe concentrations decreased at harvest generally, and that plants fertilized with $FeSO_4$. 7 H_2O contained less Fe when compared to Fe-EDTA at harvest. This may be due to the faster utilization and transfer of Fe from $FeSO_4$. 7 H_2O to the fruit. The results also showed that the plant used more Fe from Fe-EDTA at early stages, but with progressing stages, Fe usage from $FeSO_4$. $7H_2O$ increased.

The increase in leaf Zn concentration with Fe sprayings may be due to increasing plant growth and metabolism. The influence of foliar Fe on leaf Ca and Mn concentrations is quite strange. The Ca and Mn uptake mechanism of the roots might be affected by increasing levels of Fe in plant tissue in different ways. It is known that the nutrient uptake of roots depends on different mechanisms and these mechanisms are controlled by different factors (Mohr and Schopfer, 1994).

The results suggest that foliar Fe application is an effective way to increase Fe concentrations in strawberry cultivars (Horesh and Levy, 1981; Loneragan and Web, 1993; Karaman et al., 1997; Başar and Özgümüş, 1999; Erdal, 2003) because the leaf Fe concentration of strawberry increased continuously with repeating foliar Fe applications. It is necessary for optimal Fe concentration in the leaves to spray Fe solutions at different growth stages. Furthermore, $FeSO_4$. 7 H_2O, which is cheaper than other Fe sources can be used in foliar fertilization. Finally, further detailed experiments must be conducted to investigate the negative impact of foliar Fe application on leaf Mn and especially Ca concentration and the mechanism of this response.

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