Research Article

Effects of Foliar Application of Iron (Fe) and Zinc (Zn) on Agronomic Characteristics of Soybean (*Glycine max* L.)

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Abstract

This study was conducted over a period of two years to determine the effects of foliar-applied iron (Fe) and zinc (Zn) on the agronomic characteristics of soybean (*Glycine max* L.). The research was arranged in a randomized complete block design with four treatments: control, Fe, Zn, and Fe+Zn. The treatments were applied by foliar spraying during the vegetative growth stage. In the applications, 1.5 kg/da of iron sulfate ($FeSO_4 \cdot 7H_2O$) and 3 kg/da of zinc sulfate ($ZnSO_4 \cdot 7H_2O$) fertilizers were used. The treatments were evaluated based on parameters such as plant height, number of branches per plant, number of pods per plant, first pod height, pod length, number of seeds per pod, first branch height, 100-seed weight, 1000-seed weight, yield per plot, and yield per decare, as well as quality traits such as protein (%), ash (%), and oil content (%).

The findings indicated that Fe and Zn applications significantly affected certain agronomic traits depending on the year, including plant height ($p<0.05$), number of branches per plant ($p<0.01$), number of seeds per pod ($p<0.05$), first branch height ($p<0.05$), and yield per plot ($p<0.01$). The highest average yield over two years (389.33 kg/da) was obtained from the Fe+Zn treatment. Regarding quality parameters, the highest protein content (37.59%) was observed in the first year under the Fe+Zn treatment, the highest ash content (9.10%) in the second year under the Fe+Zn treatment, and the highest oil content (19.8%) in the second year under the Fe treatment. In conclusion, foliar applications of Fe and Zn supported the growth of soybean plants, enhancing both yield and quality, and can be considered an important nutritional strategy for sustainable production.

MAKALENİN TÜRKÇE BAŞLIĞI

Özet

Bu çalışma, yapraktan uygulanan demir (Fe) ve çinkonun (Zn) soya fasulyesinin (Glycine max L.) bazı tarımsal özellikleri üzerindeki etkilerini belirlemek amacıyla iki yıl süreyle yürütülmüştür. Araştırma, tesadüf blokları deneme desenine göre dört tekerrürlü olarak düzenlenmiştir: kontrol, Fe, Zn ve Fe+Zn. Uygulamalar, bitkinin vejetatif büyüme döneminde yapraktan püskürtme

yöntemiyle gerçekleştirilmiştir. Uygulamalarda, demir sülfat (FeSO₄·7H₂O) 1,5 kg/da ve çinko sülfat (ZnSO₄·7H₂O) 3 kg/da dozlarında kullanılmıştır. Uygulamalar; bitki boyu, bitkideki dal sayısı, bitkideki bakla sayısı, ilk bakla yüksekliği, bakla uzunluğu, baklada tohum sayısı, ilk dal yüksekliği, 100 tohum ağırlığı, 1000 tohum ağırlığı, parsel verimi ve dekara verim gibi tarımsal özelliklerin yanı sıra; protein (%), kül (%) ve yağ içeriği (%) gibi kalite parametreleri açısından değerlendirilmiştir. Bulgular, Fe ve Zn uygulamalarının bazı tarımsal özellikler üzerinde yıla bağlı olarak anlamlı etkiler gösterdiğini ortaya koymuştur. Bu özellikler arasında bitki boyu (p<0.05), bitkideki dal sayısı (p<0.01), baklada tohum sayısı (p<0.05), ilk dal yüksekliği (p<0.05) ve parsel verimi (p<0.01) yer almaktadır. İki yıllık ortalamalara göre en yüksek verim (389.33 kg/da), Fe+Zn uygulamasından elde edilmiştir. Kalite parametreleri açısından ise, en yüksek protein içeriği (%37.59) birinci yıl Fe+Zn uygulamasında, en yüksek kül içeriği (%9.10) ikinci yıl Fe+Zn uygulamasında ve en yüksek yağ içeriği (%19.8) ikinci yıl Fe uygulamasında gözlemlenmiştir. Sonuç olarak, Fe ve Zn'nin yapraktan uygulanması, soya fasulyesi bitkisinin gelişimini destekleyerek verim ve kaliteyi artırmış; sürdürülebilir üretim için önemli bir besleme stratejisi olarak değerlendirilebileceği sonucuna varılmıştır.

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1. Introduction

Soybean (Glycine max L.) is a globally important source of oil and protein, widely used in both human nutrition and animal feed. Due to its rich and valuable composition—containing 18–24% oil, 36–40% protein, approximately 5% mineral matter (phosphorus, potassium, calcium, sulfur, magnesium, etc.), and numerous vitamins, especially A and B groups, along with essential amino acids in its seeds—soybean is referred to as the "golden crop of the century" and is used in more than 400 industrial products worldwide (Arıoğlu, 2000; Yılmaz et al., 2005). Furthermore, its high biological protein value and nitrogen-fixing capability, which improves soil fertility, make it a strategic crop in terms of sustainable agriculture (Liu et al., 2008; Salvagiotti et al., 2008). However, to achieve the yield potential of soybean, sufficient supply of both macro- and micronutrients is essential (Marschner, 2012). Micronutrient deficiency is one of the main limiting factors for yield and quality in intensive agricultural systems (Alloway, 2008). Iron (Fe) and zinc (Zn) are vital micronutrients that play direct roles in essential metabolic processes in plants such as chlorophyll synthesis, enzyme activation, hormone production, and energy transfer (Marschner, 2012). While Fe is particularly critical for chloroplast function and photosynthesis, Zn is involved in cell division, protein synthesis, and regulation of antioxidant systems (Cakmak, 2000; Çakmak, 2008; Broadley et al., 2012). Deficiencies in these elements lead to visible symptoms such as chlorosis, stunted growth, and issues in flowering and grain development.

Although soil applications can address micronutrient deficiencies, certain soil characteristics—such as high pH, calcareous structure, and low organic matter—can significantly limit Fe and Zn uptake by plants (Lindsay & Schwab, 1982). Therefore, foliar

application is considered an effective alternative for delivering micronutrients to plants more efficiently and rapidly. Nutrients applied via foliar spraying, particularly during the vegetative stage, can penetrate directly into plant tissues and exhibit quick physiological effects (Fernández & Ebert, 2005). Recent studies have shown that foliar applications of Fe and Zn support soybean growth, enhance yield components, and positively affect seed quality (Imran et al., 2015; Abbas et al., 2009). It has been reported that applying micronutrients foliarly during the transition to the generative stage helps maintain metabolic balance and promotes better pod and grain formation (Yilmaz et al., 1997). However, the timing, dosage, and form of the fertilizer used are emphasized as critical factors influencing these effects.

In this context, investigating the effects of foliar-applied iron and zinc on agronomic traits of soybean is of great importance for both improving yield and enhancing product quality. This study aims to evaluate the impacts of foliar Fe and Zn applications on soybean growth, yield, and quality parameters in accordance with the existing literature.

2. MATERIALS AND METHODS

In this study, the ATAKİŞİ soybean variety was used as the plant material. The field experiments were conducted over a period of two years at the experimental fields of Selçuk University, Sarayönü Vocational School, located in the Sarayönü district of Konya Province. The soil characteristics of the experimental site were classified as clay-loam, slightly alkaline, mildly saline, with a moderate level of organic matter and a high lime content (Table 1).

Table 1. Soil properties of the trial areas

Texture	pH	E.C. (mS/cm)	Lime (%)	Organic matter (%)	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})
Clay loam	7,75	4,34	18,91	2,35	0,63	20,16

The area where the experiment was carried out has an altitude of 1055 m and the climate data of this region are given in Table 2.

Table 2. Climate data of the trial area

Climatic parameters	Years	Months											
		1	2	3	4	5	6	7	8	9	10	11	12
Average maximum temperature (°C)	1. year	10,3	7,5	26,6	31	30,5	34,3	36,8	36,1	32,4	24	19	16,6
	2. year	13,1	14,7	19,5	21,2	29,6	33,3	34,6	34,4	31,2	27,6	19,8	16,4
	Long years	4.7	6.8	12.0	17.4	22.2	26.8	30.2	30.0	26.1	20.0	13.0	6.7
Average temperature (°C)	1. year	-3,8	3,2	9	12,9	14,5	20,9	23,2	24,4	18,6	11,4	7,3	0,5
	2. year	1,7	3,3	4,2	9,4	21,4	20,3	31	24,9	12,3	15	6,2	4,9

	Long years	-0.2	1.2	5.7	11.0	15.7	20.2	23.6	23.0	18.6	12.5	6.1	1.8
Average minimum temperature (°C)	1. year	14	16	-5,2	-0,4	-0,9	7,1	11	12,4	4,3	0,2	-4,8	-18,6
	2. year	-19	-8,4	-6,7	-4	3,6	7,3	11,2	6,8	2	0,7	5,7	-4,7
	Long years	-4.1	-3.3	0.0	4.5	8.6	12.9	16.2	15.7	11.2	6.1	0.8	-2.2
Rainfall (mm)	1. year	5,8	20,6	11,4	11,1	5,9	13,5	6	0	48,2	30,4	36	54
	2. year	41,4	23,9	22	32,7	48,5	6	20,7	0	8,5	27,1	24,8	18
	Long years	35.3	28.2	27.1	34.0	43.6	23.2	6.9	5.6	11.2	31.3	33.1	44.8

Source: TİGEM (Konuklar Agricultural Enterprise Directorate) meteorology station- data of DMGM

The experiment was established in a randomized complete block design (RCBD) with four replications. Each plot consisted of four rows, each 5 meters long, and sowing was done manually with a spacing of 40 cm between rows and 5 cm within rows (Karasu et al., 2002). Fertilization was carried out at sowing using diammonium phosphate (DAP, 18-46%) at a rate of 150 kg/ha (Bek & Arıoğlu, 2005). In the treatments, foliar applications of 15 kg/ha iron sulfate ($FeSO_4 \cdot 7H_2O$) and 30 kg/ha zinc sulfate ($ZnSO_4 \cdot 7H_2O$) were used. These doses were divided into two equal parts: half was applied after the plants developed 5–6 leaves, and the remaining half at the beginning of flowering (Zan, Y., Geng, Q., & Xu, X., 2010). Seeds were inoculated with Rhizobium bacteria before sowing. Sowing was performed on May 19 in the first year and on May 12 in the second year. Harvesting took place on October 27 in the first year and on November 3 in the second year. Irrigation was carried out using a drip irrigation system, with six irrigation events, each lasting five hours. Weed control was performed mechanically. To avoid edge effects, the first and last rows of each plot were excluded from measurements and observations. Field trials to determine yield (kg/ha), plant height (cm), first pod height (cm), and number of pods per plant were conducted according to the INTSOY (International Soybean Program) methodology (Bek & Arıoğlu, 2005). Statistical analyses were performed using the JMP statistical software.

3. RESULTS AND DISCUSSION

A two-year field study was conducted under the ecological conditions of Sarayönü District, Konya Province, to determine the effects of foliar-applied Fe and Zn on various agronomic traits of soybean. The results of the analysis of variance (ANOVA) for the data obtained from the study are presented in Table 3. The data for the first- and second-year averages of the agricultural characteristics of strawberry clover are presented in Table 4.

Table 3. Effect of Applications on Agricultural Characteristics

PARAMETERS	PH	BNP	PNP	FPH	BL	SPP	FBH	100SW	1000SW	PY	GY
	F	F	F	F	F	F	F	F	F	F	F
Year	24,3775*	51,9944**	0,0206	6,0092	0,0378	25,0696*	11,2092*	2,3398	2,3398	82,3623**	0,3917
Treatment	1,0145	0,0877	0,6481	0,6723	0,1322	0,0471	1,0773	1,7407	1,7407	0,8452	1,5003
Year × Treatment	0,8414	0,2842	0,7995	0,7154	0,1148	0,1266	1,4272	1,3765	1,3765	0,3699	0,8622

* : P < 0.05

**: P< 0.01

Abbreviations: PH (Plant Height), BNP (Branch Number per Plant), PNP (Pod Number per Plant), FPH (First Pod Height), PL (Pod Length), SPP (Seeds per Pod), FBH (First Branch Height), 100SW (100-Seed Weight), 1000SW (1000-Seed Weight), PY (Plot Yield), GY (Grain Yield per Decare)

Tablo 4. Yearly averages of the agronomic traits of strawberry clover

PARAMETERS	ANNUAL AVERAGE	APPLICATIONS			
		CONTROL	Fe	Zn	Fe+Zn
Plant Height	1	68,88	69,63	65,80	68,30
	2	93,73	96,65	87,88	116,18
Branch Number per Plant	1	4,13	3,95	3,93	4,08
	2	1,38	1,65	1,63	1,70
Pod Number per Plant	1	37,30	35,45	33,60	31,28
	2	31,65	39,35	33,98	34,48
First Pod Height	1	14,75	14,89	14,55	14,83
	2	6,95	6,35	7,18	8,28
Pod Length	1	3,91	3,99	3,86	4,00
	2	4,03	3,98	3,95	3,98
Seeds per Pod	1	2,65	2,70	2,70	2,75
	2	2,90	2,90	2,90	2,88
First Branch Height	1	6,91	7,13	6,69	7,39
	2	4,45	3,23	5,33	5,05
100-Seed Weight	1	11,58	11,30	11,13	11,23
	2	11,87	11,19	11,50	12,23
1000-Seed Weight	1	115,75	113,00	111,25	112,25
	2	118,68	111,90	115,00	122,25
Plot Yield (kg)	1	0,51	0,59	0,48	0,60
	2	0,89	0,95	0,95	0,96
Grain Yield per Decare (kg)	1	336,67	390,00	318,33	396,67
	2	356,00	378,00	378,00	382,00
PROTEİN %	1	36,53	32,32	30,46	37,59
	2	31,30	32,08	32,21	32,30
ASH %	1	5,58	4,75	7,65	8,13
	2	5,83	5,16	5,35	9,10
OIL%	1	15,80	16,10	16,30	16,40
	2	18,90	19,80	18,80	18,80

As can be understood from the examination of Table 3 and Table 4; In the first year, the average grain yield across treatments was 360.2 kg/da, while in the second year, it was recorded as 373.50 kg/da. According to the statistical analyses conducted on the evaluated treatments, no significant differences were found in yield between Fe, Zn, and Fe+Zn applications. The highest grain yield was obtained from the Fe+Zn treatment in the first year with 396.67 kg/da, followed by the Fe treatment in the same year with 390.00 kg/da.

Plant height was statistically significant in terms of years rather than treatments. The average height was 98.60 cm in the second year and 68.15 cm in the first year. Regarding treatments, the highest plant height (116.17 cm) was observed in the Fe+Zn treatment during the second year, followed by the Fe treatment in the same year. However, differences among treatments

were not statistically significant. The significant variation between years can be attributed to more favorable climatic conditions in the second year, including optimal temperature, humidity, and precipitation levels suitable for soybean cultivation. Falaknaz and colleagues (2022) also support this result with their study. The number of branches per plant was also not significantly affected by treatments, whereas it differed significantly between years. The highest branch number was recorded in the control plots in the first year (4.12), followed by the Fe+Zn treatment in the same year (4.07). The number of pods per plant was found to be statistically insignificant in terms of both years and treatments. The highest number of pods was observed in the Fe treatment during the second year (39.35), followed by the control plots in the first year (37.30).

The effects of treatments and years on the height of the first pod were statistically insignificant. The highest first pod height was recorded in the Fe treatment in the first year (14.89 cm), followed by the Fe+Zn treatment in the same year (14.82 cm). First pod height is particularly important for mechanical harvesting. Regarding pod length, no statistically significant differences were observed between treatments or years. The longest pod length (4.02 cm) was recorded in the control plots in the second year, followed by the Fe+Zn treatment in the first year (4.00 cm). The number of seeds per pod was statistically significant between years. All treatments in the second year resulted in a higher number of seeds per pod than those in the first year. This finding indicates that the climatic conditions in the second year better supported seed development. The highest average number of seeds per pod (2.90) was observed in the control, Fe, and Zn treatments during the second year. The height of the first branch was statistically significant between years but not among treatments. In all treatments, the values recorded in the first year were higher than those in the second year. The highest first branch height (7.39 cm) was recorded in the Fe+Zn treatment in the first year, followed by the Fe treatment in the same year (7.13 cm). Here again, climatic factors appear to be the dominant influence. The 100-seed weight was statistically insignificant for both years and treatments. The highest 100-seed weight was recorded in the Fe+Zn treatment in the second year (12.23 g), followed by the control plots in the same year (11.87 g). The 1000-seed weight was also statistically insignificant between years and treatments. The highest value was observed in the Fe+Zn treatment in the second year (122.3 g), followed by the control plots in the same year (118.7 g). Plot yield was statistically significant between years. The highest plot yield was obtained from the Fe+Zn treatment in the second year (0.96 kg), followed by the Fe and Zn treatments in the same year (0.95 kg). Grain yield per decare was statistically insignificant between years and treatments. The highest grain yield was recorded in the Fe+Zn treatment in the first year (396.67 kg/da), followed by the Fe treatment in the same year (390.00 kg/da). Factors such as application timing, dosage, and environmental conditions may influence these outcomes. Additionally, combined applications appeared to be more effective compared to single treatments.

4. CONCLUSION

This study revealed that foliar applications of Fe and Zn in soybean had significant and positive effects on plant growth, yield, and quality parameters. In particular, the Fe+Zn combination was determined to be the most effective treatment in terms of both yield and seed nutrient

content. When applied at appropriate doses and timings, foliar micronutrient treatments can be considered a sustainable strategy to enhance both agricultural productivity and nutritional quality.

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