Yuzuncu Yil University
Journal of Agricultural Sciences
(Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi)
https://dergipark.org.tr/en/pub/yyutbd
ISSN: 1308-7576
e-ISSN: 1308-7584

Research Article

Relationship Between Chemical Properties of Soils Cultivated with Safflower (*Carthamus tinctorius* L.) and Base Cation Saturation Ratios (BCSR)

Ahu Alev ABACI BAYAR*[1], Ömer Faruk DEMİR[2]

[1]Soil Science and Plant Nutrition Department, Faculty of Agriculture, Kirsehir Ahi Evran University, 40100, Kirsehir, Türkiye
[2]Soil Science and Plant Nutrition Department, Faculty of Agriculture, Kahramanmaras Sutcu Imam University, Kahramanmaras, Türkiye

[1]https://orcid.org/0000-0002-4467-7676, [2]https://orcid.org/0000-0002-0636-5225

*Corresponding author e-mail: ahu.abaci@ahievran.edu.tr

Article Info

Received: 26.02.2025
Accepted: 07.07.2025
Online published: 15.09.2025
DOI: 10.29133/yyutbd.1642934

Keywords

Base cation saturation ratios,
Plant nutrients,
Safflower,
Soil analysis

Abstract: This research was conducted to determine the fertility status of lands used for safflower cultivation in the Kırşehir province. For this purpose, the physical and chemical properties, as well as the nutrient concentrations of soils sampled from safflower cultivation areas, were analyzed. The results revealed that the soils generally exhibited slightly to moderately alkaline reactions and had very high lime content. The Ca/K (calcium/potassium) and Ca/Mg (calcium/magnesium) ratios were determined to have risen significantly, averaging 55.60 and 16.90, respectively. These findings indicate that the cation ratios are far above the ideal levels. While deficiencies in microelements such as manganese (Mn) and copper (Cu) were not observed, it was found that 80% of the soils were deficient in iron (Fe) and 60% were deficient in zinc (Zn). Regarding macroelements, no significant deficiencies were identified in the majority of soils. The high lime content of the soils appears to lead to elevated calcium (Ca) levels, which in turn causes deviations from the ideal cation ratios. Moreover, it should be noted that excess calcium in the region may have an antagonistic effect on potassium (K) and magnesium (Mg). Therefore, fertilizer management should be carefully tailored to address this issue. Additionally, due to the high pH and lime content in the region, challenges in the uptake of microelements may arise. Incorporating Fe and Zn, which are frequently deficient in the soils, into fertilization programs is recommended. Furthermore, foliar fertilizers are considered a potential alternative for microelement supplementation.

To Cite: Abacı Bayar, A A, Demir, Ö F, 2025. Relationship Between Chemical Properties of Soils Cultivated with Safflower (*Carthamus tinctorius* L.) and Base Cation Saturation Ratios (BCSR). *Yuzuncu Yil University Journal of Agricultural Sciences*, 35(3): 463-474.
DOI: https://doi.org/10.29133/yyutbd.1642934

1. Introduction

The safflower (*Carthamus tinctorius* L.), known as "aspir" in Türkiye, is an annual oilseed plant belonging to the Compositae (*Asteraceae*) family (Santos et al., 2018). The plant can typically reach a height of 80–120 cm and has thorny and non-thorny forms. In fully developed safflower plants grown in adequately deep soils, the taproots can extend 2-3 meters deep, accompanied by numerous fine horizontal lateral roots. This root system enables the plant to absorb moisture and nutrients, enhancing its survival in regions with limited surface moisture (Dajue and Mündel, 1996). Due to its taproot system, the plant is capable of penetrating deep layers in search of water. It suppresses weeds, softens soil structure, prevents erosion, and yields better than other crops on sloped, poor soils and dry lands, making it a valuable alternative crop for fallow fields (Yılmazlar, 2008). Its drought and salinity tolerance allow safflower to be grown efficiently across almost every region of Türkiye, particularly in areas unsuitable for economically important crops or where land remains unused. This makes safflower an alternative crop, especially in the Central Anatolia and Transitional Zones, where it is cultivated relying solely on rainfall and in areas where wheat-fallow-wheat rotations dominate (Bayramin and Kaya, 2009; Keleş and Öztürk, 2012). Additionally, its adaptability to dry farming, suitability for both summer and winter cultivation in coastal areas, and low soil selectivity further increase its importance (Baydar and Erbaş, 2014).

In terms of soil requirements, the safflower (*Carthamus tinctorius* L.) plant is not soil selective. However, it shows successful growth in well-drained, deep-profile, loamy, and clay-loamy soils, where it yields the highest yield (Weiss, 2000). In terms of soil reaction (pH), it generally tolerates a range of 6.0–8.0, but neutral or slightly alkaline soils are preferred for optimal growth (Knowles, 1989). In contrast, acidic soils (pH< 7.0) increase the incidence of root rot disease. In terms of soil fertility, sunflowers can achieve high yield potential in environments where base cations such as Ca^{2+}, Mg^{2+}, and K^{+} are balanced. In this context, base cation saturation ratio (BCSR) is an important soil chemical property for sunflower cultivation. The literature indicates that the optimal Ca saturation for sunflowers should be between 65–80%, Mg between 10–15%, and K between 3–5% (Troeh and Thompson, 2005). Excessive Na^{+} accumulation, on the other hand, both disrupts soil structure and negatively affects plant growth due to sunflower's salt sensitivity (Rengasamy, 2006). Therefore, it is recommended to monitor BCSR ratios through soil analyses in areas where sunflower cultivation is planned and, if necessary, optimize this ratio using soil conditioners.

The ability of safflower to be grown in different ecological conditions with proper planting times, its compatibility with grain mechanization, its potential to bring fallow fields into cultivation, and its significant role in reducing the national deficit in oil production are the main reasons for its growing attention (Kütük Dinçel, 2024). Globally, the area planted with safflower in 2020 was 652 780 ha, with a production of 590 869 tons and an average yield of 90 kg da^{-1} (Anonymous, 2022). In Türkiye, the Central Anatolia, Inner Aegean, suitable altitudes of the Eastern Anatolia region, the entire Southeastern Anatolia region, Thrace, South Marmara, and the Central Black Sea region are appropriate for safflower cultivation (Babaoğlu, 2012). Since the early 2000s, production has increased with the introduction of the biofuel program, reaching 18 000 tons in 2011 (Anonymous, 2012). In 2022, the Central Anatolia region accounted for 89% of the total safflower cultivation area in Türkiye. Table 1 presents the top six provinces in the region based on safflower production. According to the data, Ankara has the largest cultivation area at 38 296 da, while Kırşehir ranks first in yield with 169 kg da^{-1}. The plant's high tolerance to drought, cold, and salinity, along with its strong adaptability, highlights the importance of safflower farming in Kırşehir.

Table 1. Safflower production areas

Province	Cultivated Area (da)	Harvested Area (da)	Yield (kg da^{-1})	Production (tone)
Ankara	38 296	38 296	109	4 185
Konya	29 675	29 675	121	3 598
Aksaray	17 741	17 741	126	2 232
Kayseri	17 457	17 457	126	2 201
Nevşehir	1 086	11 086	79	877
Kırşehir	10 524	10 524	169	1 776

Turkish Statistical Institute (TÜİK), Agricultural Production Statistics (Anonymous, 2023).

Research on safflower, both globally and in Türkiye, has predominantly concentrated on product-specific characteristics such as oil content, seed quality, and grain weight. However, the lack of scientific studies aimed at determining the soil properties of safflower fields in Kırşehir, despite the plant's increasing importance due to its drought resistance and minimal ecological requirements, makes this research unique. In this study, soil samples from safflower fields in Kırşehir were analyzed to determine their physical and chemical properties, mineral nutrient content, and base cation saturation ratios. The results were compared with reference values to contribute to improving productivity.

2. Material and Methods

Safflower cultivation areas in Kırşehir province were identified through the Provincial Directorate of Agriculture and Forestry. A total of 30 disturbed soil samples were collected from depths of 0-30 cm using a GPS (Global Positioning System) device for the purpose of displaying them on a map of Türkiye. The study was conducted according to a methodology involving field identification, soil sampling, and laboratory analysis.

2.1. Soil sampling and preparation for analysis

Following the method described by Kaçar (1995), at least 10 points were selected in a zigzag pattern from each field, excluding central and marginal areas. Soil samples were collected from 0–30 cm depths for annual crops, mixed in a bucket, and labeled. The soil samples were allowed to dry naturally in laboratory conditions, crushed with a wooden mallet, sieved through a 2 mm sieve, and prepared for analysis. The map of the soil samples collected from the fields is shown in Figure 1**.**

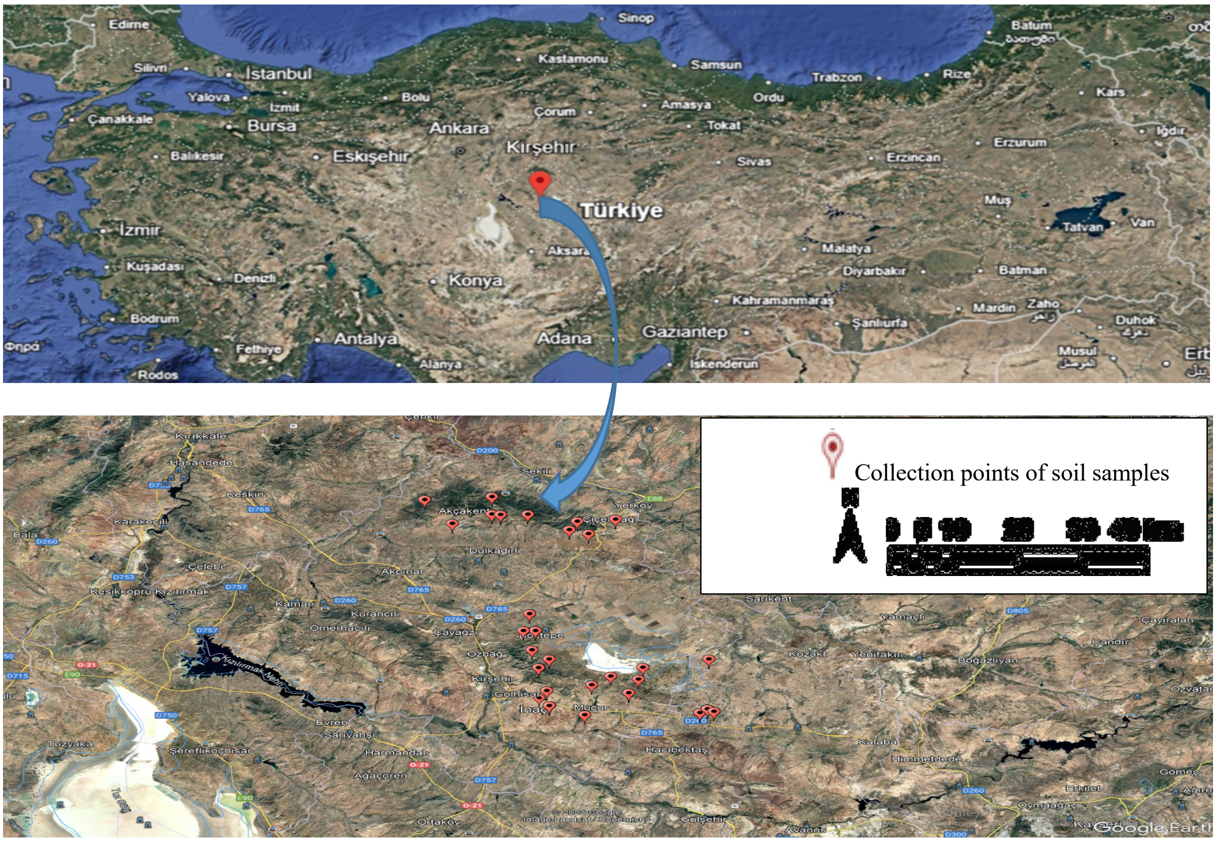

Figure 1. Collection points of soil samples.

2.2. Methods of analysis of soil samples

In the soil samples prepared for analysis, texture was determined by hydrometer method (Bouyoucos, 1951), organic matter was determined by modified Walkley Black method (Nelson and Sommers, 1996), total N was determined by Kjeldahl method (Bremner, 1996), available Fe, Mn, Cu and Zn were determined by DTPA extraction method as reported by Lindsay and Norvell (1978). In addition, pH (Thomas, 1996), total salt (Rhoades, 1996), lime were analyzed by Scheibler calcimeter (Loeppert and Suarez, 1996), available phosphorus by extraction with 0.5 M sodium bicarbonate (pH: 8.5) (Kuo, 1996), exchangeable cations (K, Ca, Mg, Na) by extraction with 1 N ammonium acetate (Helmke and Sparks, 1996). Basic cation saturation ratio (Ca/Mg, Ca/K, and Mg/K) data were obtained by calculating the relative proportions of individual cation concentrations based on cmolc kg^{-1} as described by McLean (1977).

2.3. Statistical analysis

Statistical analyses were performed using simple descriptive statistics using SPSS software (version 15.0). The relationships among selected soil parameters, macro-elements, base cation ratios, and micro-elements were examined through correlation analyses conducted using the JMP 17 statistical software package.

3. Results and Discussion

The soil pH values analyzed in the study ranged from 7.44 to 8.10, classifying them as moderately alkaline (Table 2). Çolakoğlu and Çiçekli (2015) reported that the optimum soil pH for safflower is in the range of 6.0 to 7.0. Soil pH directly or indirectly affects many physical, chemical, and biological processes occurring in the soil. Additionally, the pH level plays an important role in the availability of plant nutrients in the soil. At high pH levels, the uptake of micronutrients such as zinc, iron, and copper is hindered. Soil pH is often used as an indicator of the chemical fertility of the soil, with the optimum pH ranges for the availability of macro and micronutrients known to be in slightly acidic conditions. On a global scale, there is a relationship between soil pH and climate. High pH soils are typically common in arid regions, while acidic soils are more prevalent in humid and semi-humid regions (Hartemink and Barrow, 2023). Small changes in water balance can lead to sharp transitions from alkaline soils to acidic soils along climate gradients worldwide (Slessarev et al., 2016). The Kırşehir region, according to the Thornthwaite climate classification, has been determined to be in the semi-arid, mesothermal climate group with little to no water surplus (Anonymous, 2024). White (2006) linked the most important process controlling soil pH to the leaching of basic cations from the profile along with precipitation, with H^+ and Al^{+3} being the dominant cations. As indicated by the climate data, the region's semi-arid climate means that precipitation is insufficient to leach basic cations from the profile. As a result, the soils in this region generally have high pH levels.

Table 2. Some characteristic properties of safflower soils

Parameter	Min.	Max.	Mean	SD
pH	7.44	8.10	7.88	0.147
EC (dS m^{-1})	40.80	137.91	93.66	27.78
OM (%)	0.97	4.39	2.94	0.86
Lime (%)	0.71	55.57	27.92	15.02
Clay (%)	6.2	19.10	11.09	3.78
Silt (%)	8.60	21.20	16.15	3.91
Sand (%)	65.70	83.00	72.77	5.34

Min:Minumum, Max:Maksimum, SD: standard deviation.

When the salinity status of the areas where soil samples were taken is evaluated, it was determined that soil EC values ranged from 40.80 to 137.90 µS cm^{-1}, and as seen in Table 2, there was no salinity problem in the sampled fields. In Table 3, the pH, EC, lime, and OM values of the soils, along with their corresponding threshold values, are provided and interpreted. In a study conducted by Ismayil-Zada (2018), where safflower varieties were used as material, it was determined that the soil properties included a pH of 7.50, a lime content of 2.15%, an EC value of 150 µS cm^{-1}, an OM content of 0.95%, a phosphorus (P) content of 6.13 kg da^{-1}, and a potassium (K) content of 90.66 kg da^{-1}. Yolci and Tunçtürk (2022) conducted a study to determine the effects of biofertilizer applications and inorganic fertilization on certain quality and biochemical characteristics of the safflower plant. They determined that the trial area soils were calcareous, slightly alkaline, salt-free, sufficient in potassium, low in phosphorus, and poor in organic matter. They reported that petal yield and crude oil yield increased with increasing NP doses, while crude oil content and total phenolic content were unaffected. Weiss (2000) reported that safflower, being more drought and salt-tolerant than some other oilseed crops, is suitable for areas where cultivating other oilseeds is challenging. Çelik and Karakurt (2022) reported that aspir seeds are relatively resistant to 100, 150, and 200 mM NaCl salt concentrations and that germination continues. They also reported that the increase in salt-affected soils has made the growth of aspir cultivation increasingly important. Bonfim-Silva et al. (2015) stated that although safflower is adapted to grow under adverse conditions and is tolerant to salinity and water scarcity, its productivity increases when grown in regions with more water and under fertilized conditions. Safflower is an important crop that can be grown in both dryland farming areas, due to its resistance to extreme conditions such as drought, heat, and cold, and in irrigated farming areas due to its tolerance to salinity and weeds (Dajue and Mündel, 1996; Santos et al., 2018). It performs well in low-yield soils, under water stress, and even in frost or high-temperature conditions (Omidi et al., 2012). The plant, with its deep taproot system, has the ability to access deeper soil layers to extract water and nutrients that are not available to most other crops (Bagheri and Sam-Dailiri, 2011).

Table 3. Soil pH, EC, Lime and OM values and corresponding limit values

pH	**>4.5**	**4.5-5.5**	**5.5-6.5**	**6.6-7.3**	**7.4-7.8**	**7.9-8.5 >8.5**	**References**
Class	Strong acid	Medium acid	Mild acid	Neutral	Light alkaline	Medium Sodic alkaline	Richards, 1954
EC dS m^{-1}	**0-2**	**2-4**	**4-8**	**8-16**	**>16**		**References**
Class	Low	Medium	High	Extreme	Very Extreme		Maas, 1986
Lime%	**<1**	**1-5**	**5-15**	**15-25**	**>25**		**References**
Class	Low lime	Lime	Medium lime	Highly lime	Too much lime		Ülgen and Yurtsever, 1974
OM %	**<1**	**1-2**	**2-3**	**3-4**	**>4**		**References**
Class	Very little	Less	Middle	Good	High		Ülgen and Yurtsever, 1974

In 80% of the soils, lime content was found to be high according to the threshold values specified in Table 3. It is known that safflower is highly tolerant to soil lime, demonstrates good growth, and does not suffer from yield loss (Çolakoğlu, 1985). However, it shows optimal growth in soils with moderate lime content (Hartmann and Lilleland, 1966; Llamas, 1984; Mengel and Kirkby, 2001). Excess calcium (Ca) ions in the soil are known to exhibit an antagonistic effect with soil phosphorus (P), reducing P availability. Additionally, excessive lime can hinder the uptake of micronutrients such as iron (Fe) and zinc (Zn) by plants (Kacar and Katkat, 2009).

The analyses revealed that the organic matter (OM) content of the soils ranged from 0.97% to 4.39%. These results indicate that 33.3% of the safflower fields in the region had moderate OM levels, while 46.7% had good OM levels (Table 2). Doran et al. (1991) emphasized the critical importance of organic matter in enhancing soil fertility, noting that the efficiency of chemical fertilization depends, among other factors, on the organic matter content of the soil. Çolakoğlu and Çiçekli (2015) stated that safflower prefers soils that are well-drained, have high water-holding capacity, and are rich in organic matter. A linear relationship is expected between soil organic matter and mineralizable nitrogen. Furthermore, the quality of organic matter also plays a role in the pool of mineralizable nitrogen in soils (Sahrawat, 2004). De Neve et al. (1996) calculated nitrogen mineralization rates of 0.18-0.79 kg N da^{-1} week^{-1}, Clivot et al. (2017) 0.013-1.10 kg da^{-1} day^{-1}, Jarvis et al. (1996) 0.020-0.23 kg da^{-1} day^{-1}, and Hatch et al. (2000) 0.05-0.15 kg da^{-1} day^{-1}. Moreover, N15 isotope studies have shown that nitrogen mineralized from soil organic matter accounts for more than 50% of the nitrogen assimilated by maize during a growing season, even with high nitrogen fertilizer applications (Stevens et al., 2005; Gardner and Drinkwater, 2009). Therefore, the amount of organic matter is one of the most critical parameters to consider for productivity. Considering the moderate OM levels of the region's soils, it is suggested that organic matter applications are necessary to ensure the sustainability of these soils.

When the average texture class of the field soils was examined, it was found to be sandy loam. Sandy loam soils drain well due to their high sand content, which prevents aspirin from being damaged by excessive moisture. In addition, the small amount of silt and clay it contains prevents the soil from completely losing its nutrient and water retention capacity, thus supporting root development (Weiss, 2000). According to the literature, aspirin can be successfully cultivated in soils ranging from loamy to sandy loam; however, yields decrease in heavy clay or highly water-retaining, compacted soils (Li and Mündel, 1996).

In Table 4, the concentrations of macro-nutrients in the soil of safflower are shown. The available P content in the soils where safflower is grown ranged from 5.03 mg kg^{-1} to 29.01 mg kg^{-1} (Table 4). The analyses showed that 6.7% of the soils had excessive P, 13.3% had insufficient P, and 80% had adequate P levels. According to the threshold values provided by Olsen and Sommers (1982), there was no significant P deficiency in the region (Table 5). Eyüpoğlu (1999) reported that plant-available P was insufficient in soils of the Central Anatolia region, with approximately 59% of the soils having low P levels. Although no severe P deficiency was detected in this study, it should be noted that the high pH and lime levels of the soils could negatively affect the availability of P. The K content of the soils ranged from 81 mg kg^{-1} to 689 mg kg^{-1}, and it was determined that 6.7% of the research soils had low K levels, while 93.3% had levels above the sufficiency threshold. Additionally, it was reported that 84.7% of the soils in Türkiye and 94.9% of the soils in the Central Anatolia region had high K content (>132 mg kg^{-1}) (Eyüpoğlu, 1999). The Mg content of the soils varied between 125 mg kg^{-1} and 710 mg kg^{-1}, with 6.7% being high, 13.3% low, and 80% having sufficient Mg content. The Ca levels of the soil samples ranged from 3275 mg kg^{-1} to 9950 mg kg^{-1}, and it was determined that 6.7% of these soils had adequate levels, while 93.3% had an excess of this nutrient. Based on these values, it was concluded that the soils from which safflower samples were taken were sufficient in K, Ca, and Mg.

Table 4. Macronutrient concentrations in safflower soils (mg kg^{-1})

Elements	Min.	Max.	Mean	SD
P	5.03	29.01	15.246	5.997
K	81.00	689.00	306.700	129.437
Mg	125.00	710.00	286.00	137.665
Ca	3 275	9 950	6 890.83	1 554.647
Na	28.60	109.40	49.86	23.647

Min:Minumum, Max:Maksimum, SD: Standard deviation.

Table 5 provides the threshold values used to evaluate the macronutrient elements in safflower soils.

Table 5. Limit values used for macronutrient assessment in soil

Macronutrient element classes (mg kg^{-1})						
Class	Very Low	Sufficient	Moderate	High	High Very	References
P	<2.5	2.5-8	8-25	25-80	>80	Olsen and Sommers, 1982
K	<50	50-140	140-370	370-1 000	>1 000	Sumner and Miller, 1996
Ca	<380	380-1 150	1 150-3 500	3500-10 000	>10 000	Sumner and Miller, 1996
Mg	<50	50-160	160-480	480-1 500	>1 500	Sumner and Miller, 1996

One of the most important aspects to consider for healthy plant nutrition is the cation ratios in the soil. The base cation saturation ratio (BCSR) approach is a soil management strategy that targets the ideal ratios of exchangeable cations (Chaganti et al., 2021). BCSR suggests that there is a balance among the essential cations for the cation exchange capacity (CEC) of the soil, and that plant growth will be impaired in soils lacking these cations in the specified proportions (McLean, 1977). Kopittke and Menzies (2007) stated that the ideal cation proportions in soil should be 65% Ca, 10% Mg, 5% K, and 20% H. Based on this, Havlin et al. (2016) noted that the Ca/K ratio should be 13, the Ca/Mg ratio should be 6.5, and the Mg/K ratio should be 2. Upon examining the soils of the study area, it was found that the calcium levels were quite high. Therefore, as mentioned earlier, it was determined that the concentration of Ca was excessive in the area. This results in high Ca/K (55.60), Ca/Mg (16.90) and Mg/K (3.90) ratios (Table 6). In these conditions, it is important to pay attention to the K and Mg concentrations when growing safflower. Various studies have indicated that interactions among nutrient ions—particularly between potassium (K), calcium (Ca), and magnesium (Mg) are common, and such interactions may result in nutrient imbalances or deficiencies in plants (Fageria, 2001). Given the elevated calcium (Ca) concentrations in the soils of the study area, there is a risk of potassium (K) and magnesium (Mg) deficiencies resulting from cationic competition. This highlights the importance of incorporating cation balance considerations into fertilization strategies.

Table 6. Base cation saturation ratios (BCSR) in safflower soils (cmolc kg^{-1})

Class	Min.	Max.	Mean
Ca/Mg	6.00	46.70	16.90
Ca/K	9.30	88.60	55.60
Mg/K	0.90	6.80	3.90

Min:Minumum, Max:Maksimum.

When examining the relationships between selected key soil parameters and macronutrient levels as well as base cation ratios, a noticeable negative correlation was observed between soil pH and available phosphorus (P) (Figure 2). Furthermore, the Ca/Mg ratio exhibited a positive correlation with calcium (Ca) (r = 0.31), but negative correlations with potassium (K) and magnesium (Mg) (r = –0.80 and –0.22, respectively). This pattern can be attributed to the high calcite content of the regional soils (Ekincioğlu et al., 2022), which leads to elevated levels of available Ca. However, an increase in lime ($CaCO_3$) content was found to be associated with a decline in available K and Mg (r = –0.17 and –0.29, respectively). Consequently, negative correlations were observed between the Ca/K ratio and available K and Mg (r = –0.32 and –0.87), as well as between the Ca/Mg ratio and available Mg and K (r = –0.22 and –0.81, respectively).

Correlations

	pH	EC	OM	Lime	P	Ca	Mg	K	Ca/Mg	Ca/K	Mg/K
pH	1,0000	-0,4029	-0,4797	0,1283	-0,4066	0,0878	-0,2468	-0,1637	0,3219	0,1226	0,0197
EC	-0,4029	1,0000	0,6220	0,1082	0,2915	0,5948	-0,3644	0,0303	0,0255	0,3682	0,1746
OM	-0,4797	0,6220	1,0000	-0,0902	0,1234	0,4097	-0,1324	-0,0267	-0,1759	0,2787	0,0891
Lime	0,1283	0,1082	-0,0902	1,0000	0,3577	0,3681	-0,2912	-0,1738	0,5212	0,0856	-0,1160
P	-0,4066	0,2915	0,1234	0,3577	1,0000	0,0602	0,1150	-0,0971	0,1034	0,0580	-0,1961
Ca	0,0878	0,5948	0,4097	0,3681	0,0602	1,0000	-0,4174	-0,0126	0,3120	0,4340	0,0323
Mg	-0,2468	-0,3644	-0,1324	-0,2912	0,1150	-0,4174	1,0000	0,2440	-0,2254	-0,8869	-0,5596
K	-0,1637	0,0303	-0,0267	-0,1738	-0,0971	-0,0126	0,2440	1,0000	-0,8033	-0,3270	0,5732
Ca/Mg	0,3219	0,0255	-0,1759	0,5212	0,1034	0,3120	-0,2254	-0,8033	1,0000	0,2003	-0,6003
Ca/K	0,1226	0,3682	0,2787	0,0856	0,0580	0,4340	-0,8869	-0,3270	0,2003	1,0000	0,4710
Mg/K	0,0197	0,1746	0,0891	-0,1160	-0,1961	0,0323	-0,5596	0,5732	-0,6003	0,4710	1,0000

Figure 2. Correlations of selected soil parameters, macro nutriens, and cation ratios.

As a result of the study, the available Cu contents in the soils for plant uptake ranged from 0.95 mg kg^{-1} to 2.08 mg kg^{-1}, Mn contents ranged from 1.38 mg kg^{-1} to 11.16 mg kg^{-1}, Fe contents ranged from 1.76 mg kg^{-1} to 5.20 mg kg^{-1}, and Zn contents ranged from 0.34 mg kg^{-1} to 1.74 mg kg^{-1} (Table 7).

Table 7. Micronutrient concentrations of safflower soils (mg kg^{-1})

Micro element	**Min.**	**Max.**	**Mean**	**SD**
Fe	1.76	5.20	3.80	0.938
Zn	0.34	1.74	0.75	0.371
Mn	1.38	11.15	4.58	2.482
Cu	0.94	2.08	1.53	0.367

Min:Minumum, Max:Maksimum, SD: Standard deviation.

An examination of the relationships between selected soil properties and the concentrations of available micronutrients revealed that soil pH was negatively correlated with iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu), with correlation coefficients of –0.50, –0.71, –0.63, and –0.64, respectively (Figure 3). These findings suggest that elevated soil pH levels may reduce the bioavailability of these micronutrients. Moreover, positive correlations among all four micronutrients indicate that their availability is likely governed by similar soil-related factors. This pattern may be explained by common mechanisms influencing micronutrient solubility and mobility, such as pH-dependent precipitation, complexation with organic matter, and redox-related transformation.

It was found that in all of the research soils, the available Cu and Mn content for plants were sufficient, while the Fe content was deficient in 80% of the cases according to Table 7. It was also determined that the available Zn content in the aspir fields was insufficient by 60%. Due to the high lime levels and pH values in the soil of the working area, micro nutrient deficiencies are likely to occur in the safflower plant. In a study conducted by Gürsoy (2020) under greenhouse conditions, different doses of micronutrient elements (Fe, Mn, Zn) were applied to safflower plants (control-0, 5, 10 mg kg^{-1}). It is thought that micronutrient fertilizers play an important role in increasing resistance to adverse environmental conditions, promoting leaf formation in plants, and encouraging the plants to develop thicker stems and stronger structures. Additionally, higher results were obtained in the characteristics examined (seedling height, number of leaves on the plant, stem diameter, seedling dry weight, number of roots, root dry weight, and root length) when micronutrient fertilizers were applied compared to the control. In a study by Gülmezoğlu and Aytaç (2016), which investigated the effect of different Zn applications on the Zn uptake of safflower plants, it was reported that the highest stem and leaf dry weight during the flowering period was achieved by applying $ZnSO_4$ fertilizer to the soil, and the contibution of root feeding with $ZnSO_4$ during the vegetative period was also significant.

Correlations

	pH	EC	OM	Lime	Fe	Zn	Mn	Cu
pH	1,0000	-0,4026	-0,4720	0,1125	-0,5001	-0,7066	-0,6367	-0,6498
EC	-0,4026	1,0000	0,6171	0,1077	0,3445	0,5530	0,4825	0,1347
OM	-0,4720	0,6171	1,0000	-0,0886	0,5502	0,3975	0,5107	0,5064
Lime	0,1125	0,1077	-0,0886	1,0000	-0,1210	0,0570	0,1434	-0,0671
Fe	-0,5001	0,3445	0,5502	-0,1210	1,0000	0,4580	0,6578	0,5955
Zn	-0,7066	0,5530	0,3975	0,0570	0,4580	1,0000	0,6852	0,5704
Mn	-0,6367	0,4825	0,5107	0,1434	0,6578	0,6852	1,0000	0,5773
Cu	-0,6498	0,1347	0,5064	-0,0671	0,5955	0,5704	0,5773	1,0000

Figure 3. Correlations of selected soil parameters and micro nutriens.

Table 8. Limit values used in the classification of microelements*

Class	Fe	Zn	Cu	Mn
Qualification Limit	4.5	0.76	0.20	1.20

*Lindsay and Norvell (1978).

Conclusion

As a result of the research, it was found that the soils of the fields where the safflower was planted had sufficient concentrations of macroelements, but were significantly deficient in microelements, particularly Fe and Zn. This is further understood when considering the high lime content and pH conditions of the soils. Due to the high lime content in the soils, the Ca concentrations are quite high, leading to elevated Ca/K and Ca/Mg ratios. Under these conditions, attention must be given to K and Mg concentrations in the safflower plants. In terms of healthy plant cultivation in the area, it is essential to consider these high pH and lime conditions. Firstly, the soil pH should be reduced to optimal levels using appropriate pH-reducing agents such as elemental sulfur. Since safflower does not show soil selectivity and has high adaptability, it is believed that it would be more suitable as an alternative crop in these areas if grown with proper soil management practices, ensuring healthier cultivation. Micro-nutrient elements are reported to have a positive impact on plant development.

Ethical Statement

Ethical approval was not required for this study as there was no specific type of research involving humans or animals.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Funding Statement

This research was funded by Kırşehir Ahi Evran University Scientific Research Projects Coordination Unit for financial support with project number ZRT.A4.24.001.

Author Contributions

The first author determined the scope of the research, conducted the research, generated the findings, analyzed the data, prepared the draft article, and developed the article. The second author contributed to the presentation of the findings by generating the research data and developed the article. All authors read and approved the final version of the article.

Acknowledgments

Financial support provided by Kırşehir Ahi Evran University Research Fund (Project No: ZRT.A4.24.001) is gratefully acknowledged and appreciated.

References

Anonymous, (2022). Food and Agriculture Organization of the United Nations. Faosatat organization. Access date: 31.12.2024 https://www.fao.org/statistics/en

Anonymous, (2023). Turkish Statistical Institute. (TÜİK), Agricultural Production Statistics Access date: 20.09.2024

Anonymous, (2024). General Directorate of Meteorology, Access date: 20.09.2024 https://www.mgm.gov.tr/il=Kirsehir

Babaoğlu, M. (2012). The Safflower Plant and the Future of Safflower in Turkish Agriculture. https://www.researchgate.net/publication/339447749.

Bagheri, B., & Sam-Dailiri, M. (2011). Effect of water stress on agronomic traits of safflower spring (Carthamus tinctorius L.). *Aust J Basic Appl Sci*, *5*(12), 2621-2624. ISSN 1991-8178. http://ajbasweb.com/old/ajbas

Baydar, H., & Erbaş, S. (2014). Oil Plant Science and Technology. Süleyman Demirel University Publication No: 97. ISBN: 978-9944-452-75-5,ss:313.

Bayramin, S., & Kaya, M. D. (2009). Recent developments in sunflower and rapeseed production in our country. *Journal of the Field Crops Research Institute*, *18*(1-2), 43-47.

Bonfim-Silva, E. M., Anicésio, E. C. A., Oliveira, J. R., Freitas Sousa, H. H., & Silva, T. J. A. (2015). Soil water availabilities in the content and accumulation of nitrogen and chlorophyll index in the safflower. *American Journal of Plant Sciences*, *6,* 2280-2286. http://www.scirp.org/journal/ajps http://dx.doi.org/10.4236/ajps.2015.614231

Bouyocous, G. L. (1951). A recalibration of hydrometer method for making mechanical analysis of soils. *Agronomy Journal*, *43*, 434-438.

Bremner, J. M. (1996). Nitrogen Total. In D.L. Sparks (Eds) Methods of Soil Analysis, Part 3, Chemical Methods, SSSA Book Series Number 5, SSSA., Madison,WI, s. 1085–1112.

Chaganti, V. N., Culman, S.W., Herms, C., Sprunger, C.D., Brock, C., Leiva Soto, A., & Doohan, D. (2021). Base cation saturation ratios, soil health, and yield in organic field crops. *Agronomy Journal*, *113*(5), 4190-4200. https://doi.org/10.1002/agj2.20785.

Clivot, H., Mary, B., Valé, M., Cohan, J. P., Champolivier, L., Piraux, F., ... & Justes, E. (2017). Quantifying in situ and modeling net nitrogen mineralization from soil organic matter in arable cropping systems. *Soil Biology and Biochemistry*, *111*, 44-59.

Çelik, C., & Karakurt, Y. (2022). Determination of the Effect of Salt Stress on Germination, Biochemical and Antioxident Enzyme Activities in Linas Safflower Seeds. *Yuzuncu Yil University Journal of Agricultural Sciences*, Volume: 32, Issue:4,(682-691) DOI: 10.29133/yyutbd.1105636.

Çolakoğlu, H. (1985). Fertilizer and Fertilization. Ege University, *Faculty of Agriculture*. Teksir No: 17- 1. Bornova, İzmir.

Çolakoğlu, H., & Çiçekli, M. (2015). Fertilization Guide. Toros Agriculture.

Dajue, L., & Mündel, H. H. (1996). *Safflower Carthamus tinctorius L., promoting the conservation and use of underutilized and neglected crops*. 7. Institute of Plant Genetics and Crop Plant Research, Gatersleben/International Plant Genetic Resources Institute, Rome, Italy (ISBN92-9043-297-7). 85 pp. International Plant Genetic Resources Institute, IPGRI Via delle Sette Chiese 142 00145 Rome Italy.

De Neve, S., Pannier, J., & Hofman, G. (1996). Temperature effects on C-and N-mineralization from vegetable crop residues. *Plant and Soil*, *181*, 25-30.

Doran, İ., Aydın, R., Çakır, İ., Güler, S., Sofuoğlu, Ş., & Pişirgen, T. (1991). Project to determine the nutritional status of olive groves in the İçel Region. Alata Horticultural Research Institute Directorate, Mersin.

Ekincioğlu, G., Başıbüyük, Z., Büyükbayrak, F., & Akbudak, İ. K. (2022). Investigation of the usability of marble from the Kırşehir region as micronized calcium carbonate. *Aksaray University Journal of Science and Engineering*, *6*(2), 178-191.

Eyyüpoğlu, F. (1999). Fertility Status of Turkish Soils. Soil Fertilizer Research Institute General Publications No: 220, Ankara

Fageria, V. D. (2001). Nutrient interactions in crop plants. *Journal of Plant Nutrition*, *24*, 1269-1290.https://doi.org/10.1081/PLN-100106981.

Gardner, J. B., & Drinkwater, L. E. (2009). The fate of nitrogen in grain cropping systems: a meta-analysis of 15N field experiments. *Ecological applications*, *19*(8), 2167-2184.

Gülmezoğlu, N., & Aytaç, Z. (2016). The effect of different zinc applications on the yield and zinc uptake of the aspir plant. *Soil Water Journal*, *5*(2), 11-17.

Gürsoy, M. (2020). Determination of the effects of microelement fertilization applied to safflower (*Carthamus tinctorius* L.) varieties on germination and seedling stages. *Garden, 49*(Special Issue 1: II. International Agriculture Congress (Utak 2019)): 105-111 (2020) ISSN 1300-8943.

Hartemink, A. E., & Barrow, N. J. (2023). Soil pH-nutrient relationships: the diagram. *Plant and Soil, 486*(1), 209-215.

Hartmann, H. T., & Lilleland, O. (1966). Olive Nutrition Temperateto Tropical Fruit Nutrition (Ed:N.F. Childers) Horticulture Publication Rutgers, Chapter X. The State University of New Jersey

Havlin, J. L., Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (2016). Soil fertility and fertilizers. Pearson Education India, pp. 529.

Helmke, P. A., & Sparks, D. L. (1996). Lithium, Sodium, Potassium, Rubidium, and Calcium. In Sparks, D.L., (Ed) Methods of Soil Analysis, Part 3, Chemical Methods, SSSA Book Series Number 5, SSSA., Madison, WI, s. 551-574.

Ismayil-Zada, L. (2018). The effect of different planting norms on the yield and some quality characteristics of safflower (*Carthamus tinctorius* L.). Tekirdağ Namık Kemal University Institute of Science. Field Crops Department Master's Thesis. pp: 36.

Jarvis, S. C., Stockdale, E. A., Shepherd, M. A., & Powlson, D. S. (1996). Nitrogen mineralization in temperate agricultural soils: processes and measurement. *Advances in Agronomy, 57*, 187-235.

Kaçar, B. (1995). Soil Analyses. Chemical Analyses of Plants and Soil: III. Ankara University Faculty of Agriculture Education Research and Development Foundation Publications, No: 3, Ankara, 705pp.

Kaçar, B., & Katkat, A. V. (2009). *Fertilizers and Fertilization Techniques*, ISBN, 978-9944-77159-7, Nobel Publishing Distribution, Ankara, 17-62.

Keleş, R., & Öztürk, Ö. (2012). The effects of different planting times on yield and quality in some aspir varieties. *Journal of Agricultural Sciences Research*, *5*(1), 112-117.

Knowles, P. F. (1989). Safflower. In: *Oil Crops of the World*, Robbelen, G., Downey, R. K., & Ashri, A. (Eds.). McGraw-Hill.

Kopittke, P. M., & Menzies, N. W. (2007). A review of the use of the basic cation saturation ratio and the “ideal” soil. *Soil Science Society of America Journal*, *71*(2), 259-265.

Kuo, S. (1996). Phosphorus in D.L. Sparks (Ed) Methods of Soil Analysis, Part 3, Chemical Methods, SSSA Book Series Number 5, SSSA., Madison, WI, s. 869–921.

Kütük Dinçel, N. G. (2024). A Valuable Alternative Among Oil Plants: Safflower (*Carthamus tinctorius* L.) *Bilecik Şeyh Edebali University Journal of Science Journal of Science/BSEU Journal of Science*, *11*(1), 195-203DOİ:10.35193/bseufbd.1165220e-ISSN:2458-7575.

Li, D., & Mündel, H. H. (1996). *Safflower (Carthamus tinctorius L.)*. International Plant Genetic Resources Institute (IPGRI), Rome, Italy.

Lindsay, W. L., & Norvell W. A. (1978). Development of A DTPA Soil Test for Zinc, Iron, Manganese and Copper. *Soil Science Society of American Proceeding*, *42*, 421-428.

Llamas, J. F. (1984). Basis of Fertilization in Olive Cultivation on the Olive Trees Vegetative Cycle and Nutrition Needs. International Course on Fertilization and Intensitication of Olive Cultivation. UNDP-FAO. CodobaSpain.

Loeppert, R. H., & Suarez, D. L. (1996). Carbonate and gypsum. *Methods of Soil Analysis: Part 3 Chemical Methods, 5,* 437-474.

McLean, E. O. (1977). Contrasting concepts in soil test interpretation: Sufficiency levels of available nutrients versus basic cation saturation ratios. Soil testing: Correlating and interpreting the analytical results. ASA Spec. Publ. 29. ASA, CSSA, and SSSA, Madison, WI. In T.R. Peck et al. (ed.) pp. 39-54.

Mengel, K. & Kirkby, E. A. (2001). Principles of plant nutrition. 5th edition. Kluwer Academic Publishers. Isbn: 1-4020-008-1, Dordrecht, 5th edition, 849 p, The Netherlands

Nelson, D. W., & Sommers, L. E. (1996). Total Carbon, Organic Carbon, and Organic Matter. In D.L. Sparks (Ed) Methods of Soil Analysis, Part 3. Chemical Methods, SSSA Book Series Number 5, SSSA., Madison,WI, s. 961-1011.

Olsen, S. R., & Sommers, L. E. (1982). Phosphorus, In: Methods of Soil Analysis Chemical and Microbiological Properties (Eds. Page A.L., Miller R.H., Keeney D.R.), Second Edition Agronomy No: 9 American Society of Agronomy Inc, Soil Science Society of America Inc. 403-429.

Omidi, A. H., Khazaei, H., Monneveux, P., & Stoddard, F. (2012). Effect of cultivar and water regime on yield and yield components in safflower (Carthamus tinctorius L.). Turk J Field Crops, 17(1), 10-15.

Rengasamy, P. (2006). World salinization with emphasis on Australia. *Journal of Experimental Botany*, *57*(5), 1017–1023.

Rhoades, J. D. (1996). Salinity: Electrical conductivity and total dissolved solids. Methods of soil analysis: Part 3 Chemical methods, *5*, 417-435.

Richard, L. A. (1954). Diagnosis and Improvement of Saline and Alkali Soils. Agriculture Handbook, No:60, U.S. Department of Agriculture. U.S. Government Printing Office, Washington D.C., 166s.

Sahrawat, K. L. (2004). Organic matter accumulation in submerged soils. *Advances in Agronomy, 81,* 169-201.

Santos, R. F., Bassegio, D., Sartori, M. M. P., Zannoto, M. D., & Silva, M. A. (2018). Safflower (*Carthamus tinctorius* L.) yield as affected by nitrogen fertilization and different water regimes. *Ecofisiología Vegetal y Producción de Cultivos / Plant Ecophysiology and Crop Production. Acta Agron,* *67*(2), 264-269, ISSN 0120-2812, e-ISSN 2323-0118. https://doi.org/10.15446/acag.v67n2.60896

Slessarev, E. W., Lin, Y., Bingham, N. L., Johnson, J. E., Dai, Y., Schimel, J. P., & Chadwick, O. A. (2016). Water balance creates a threshold in soil pH at the global scale. *Nature*, *540*(7634), 567–569.

Stevens, W. B., Hoeft, R. G., & Mulvaney, R. L. (2005). Fate of nitrogen-15 in a long-term nitrogen rate study: II. Nitrogen uptake efficiency. *Agronomy Journal*, *97*(4), 1046-1053.

Thomas, G.W. (1996). Soil pH and soil acidity. *Methods of Soil Snalysis: Part 3 Chemical Methods, 5,* 475- 490.

Troeh, F. R., & Thompson, L.M. (2005). *Soils and Soil Fertility*, 6th Edition. Blackwell Publishing.

Ülgen, N., & Yurtsever, N. (1974). Türkiye Fertilizer and Fertilization Guide. Soil and Fertilizer Research Institute Technical Publication No. 28, Ankara.

Weiss, E. A. (2000). Safflower. In: Oilseed Crops, Blackwell Sci. Ltd., Victoria, Australia, 93-129 pp.

White, R. E. (2006). Principles and Practice of Soil Science:Soil as a Natural Resource, Blackwell Publishing, Oxford, UK.

Yılmazlar, B. (2008). *The effect of different sowing times on important agricultural characteristics and yield in some varieties of sunflower under Konya conditions*. Doctoral Thesis, Ankara University Institute of Science, Department of Field Crops, Ankara.

Yolci, M.S., & Tunçtürk, R. (2022). The Effect of Inorganic Fertilizer and Biofertilizer Applications on Some Quality and Biochemical Properties of Safflower (Carthamus tinctorius L.). Yuzuncu Yil University Journal of Agricultural Sciences, Volume: 32, Issue: 4, 8740-753), DOI: 10.29133/yyutbd.1136973, e-ISSN: 1308-7584.