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THE AGRONOMIC RESPONSE OF *CARTHAMUS TINCTORIUS* TO SULPHUR FERTILIZERS

SUMMARY

Sulphur fertilizer can be used as a soil amendment in semi-arid region. The current field trial aimed to study the effect of different levels of various sulphur fertilizers (control: no sulphur application, utilization of 25 or 50 kg S from single superphosphate: $P+S_{25}$ or $P+S_{50}$, 25 or 50 kg S from the elemental form: S_{25} or S_{50}, 25 or 50 kg S from zinc sulfate: $Zn+S_{25}$ or $Zn+S_{50}$) on growth and qualitative proprieties of safflower in west of Iran. The application of sulphur increased vegetative growth components such as plant height, first capitulum height, stem diameter, and the number of lateral branches. The highest rate of vegetative growth was obtained with the application of zinc sulfate. Chlorophyll content increased by 21-24% with zinc sulfate compared to the control. The widest canopy was recorded under the conditions of the use of $Zn+S_{50}$ and $P+S_{50}$ (a 53% increase). Regardless of the amount of consumption, the highest plant dry weight was obtained with the use of Zn+S and S. Utilization of the high level of zinc sulfate and elemental sulphur by increasing the number of capitula, number of achenes in capitulum and diameter of capitulum improved achene yield (by 17%). The highest amount of achene oil was achieved by S_{50} and the application of $P+S_{50}$ was in the second rank. However, consumption of all levels of S or Zn+S and $P+S_{50}$ caused a significant increase in achene protein content. The highest amount of oleic acid, stearic acid, and palmitic acid was obtained with the use of Zn+S. Altogether, under farmyard applied conditions, elemental sulphure and zinc sulphate significantly improved safflower performance due to its high S content, slow S releasing property and low leaching. Application of elemental sulphure and zinc sulphate in semi-arid areas should be seriously considered.

Keywords: achene protein content, number of achenes, single superphosphate, soil amendment, zinc sulfate

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INTRODUCTION

Safflower (*Carthamus tinctorius* L.) is a member of the Composite family with a very long history of cultivation and is domesticated in the semi-arid regions of West Asia. Safflower is a multi-purpose plant that has been cultivated to produce colored petals, medicinal uses, bird feed, forage, and for extracting oil from Achene (Emongor and Emongor 2023). Owing to the extensive root system and shoot anatomy, this plant has a relatively good tolerance against water scarcity and can be considered a crop option in areas with low water resources (Sarto *et al*., 2018). However, during the past decades, this plant has not had an acceptable place in crop rotations and has been less interested or concerned by farmers. However, the amount of safflower annual production in the world is about 996,000 t harvested from 1.2 million hectares of cultivated area. Most of its production is in Asia, North America, and South America. Despite the numerous potentials of safflower and its compatibility with semi-arid areas, it has remained a minor, underutilized, and neglected crop (Emongor 2010) so its cultivated area in Iran is very limited and estimated at 4,000 ha, and about 5,000 t of safflower seed is harvested from these areas (FAOSTAT, 2022). However, safflower compared to other oilseed crops has not fully achieved its rightful position and the potential of this plant can still be used to produce oil and protein. The absence of technical and scientific information about agronomic management, the weak promotion process regarding the introduction of this crop among the farmers, the lack of promoted cultivars, and the absence of a continuous breeding process for this crop are among the things that have caused the reduction of the cultivated area of safflower (Knowles 1955). The oil extracted from safflower achene has a balanced fatty acid profile, and with several monounsaturated and polyunsaturated fatty acids, is noteworthy in terms of oil quality and its effect on various aspects of health (Katkade *et al*., 2018).

The soils of semi-arid regions face serious restrictions such as low organic matter, high pH, and the unavailability of elements for the root system of plants due to special climatic conditions, low rainfall, and irregular distribution of precipitation (Roozitalab *et al*., 2018). Sulphur (S) as one of the essential elements and macronutrients ranks fourth after NPK according to the importance and amount required. Sulphur plays a key role in the structure and biosynthesis of proteinaceous amino acids such as cysteine, methionine, and chlorophyll, as well as in the structure of defense molecules such as glutathione, sulpholipids in the chloroplast membrane, some vitamins such as biotin and thiamine, coenzymes involved in the synthesis and oxidation of fatty acids and molecules involved in trans-sulphuration such as S-Adenosyl methionine (Narayan et al., 2023). However, sulphur deficiency is evident in sandy soils or soils that have little organic matter. In addition to providing plant needs, supplying sulphur fertilizer can play a role as a soil amendment. Sulphur application in calcareous soils can improve plant nutrition. Sulphur has the potential to reduce soil pH, at least on a small scale around its particles. Due to sulphur ability to oxidize and produce sulphuric acid, if sulphur fertilizer particles are present in the rhizosphere environment, it can be effective in dissolving insoluble food compounds and releasing essential nutrients (Sharma *et al*., 2024). In West Bengal, by supplying sulphur from single superphosphate, elemental sulphur and zinc sulphate (zero, 20, 40 and 60), it was determined that the consumption of 40 kg of sulphur through zinc sulphate resulted in the highest plant height, growth rate, accumulation of dry matter and also it resulted in the highest achene yield (Divya 2019). Therefore, it seems that the use of sulphur-containing fertilizers as acidifying substances can affect the ability to absorb other food elements. It should be noted that the biological oxidation of sulphur in the soil is mainly carried out by some bacteria, such as Thiobacillus, and the population of these bacteria is strongly influenced by the amount of organic matter in the soil, and to increase the effectiveness of sulphur, it is necessary to improve the organic matter of the soil (Malik *et al*., 2021). Therefore, it appears that using sulphur fertilizers on the soil surface, conjoining them with animal manure, incorporating them into the soil to the depth of root expansion, and then providing the moisture through irrigation can accelerate the action of sulphur oxidation by bacteria. In addition, the use of manure improves the permeability and water-holding capacity of the soil. The application of sulphur in the calcareous soils of Iran along with bio-sulphur (biological sulphur fertilizer) increased seed yield and oil percentage in *camelina sativa* (Rostami *et al*., 2022). Compared to other crops, oilseed crops require more sulphur due to the formation of oil bodies and the need for more acetyl-CoA and other sulphur-containing compounds and enzymes. In the nutritional management of oilseed crops, a special categorizer for sulphur application should be opened. Sulphur also plays a role in improving the effectiveness and efficiency of consumption of other food elements such as nitrogen, phosphorus, and micronutrients as well as has synergistic effects on some nutrients (Narayan *et al.*, 2023). The soils of semi-arid regions face many physical, moisture and chemical limitations. It appears that the biological oxidation of sulphur produces H_2SO_4 which decreases soil pH and solubilizes $CaCO_3$ in alkaline calcareous soils of semi-arid region and in addition to supplying the sulfur needed by the plant it may provide more advantageous conditions in rhizospher for plants growth (Sharma *et al*., 2024). However, there is no comprehensive information regarding the comparison of different sources of sulphur-containing fertilizers in mesic active Calcixerepts soil in semi-arid regions of Iran. The present experiment is designed to explore the impact of different sources of sulphur-containing fertilizers (single superphosphate, elemental sulphur and zinc sulphate) on the agronomic characteristics and oil quality of safflower grown in the west of Iran.

MATERIAL AND METHODS

Soil and climate characteristics

The achenes of safflower (*Carthamus tinctorius* L.) cv. “ZYS” was kindly provided by the Agricultural Research Station of Kurdistan Province. This variety has been genetically improved in China and has an acceptable range of compatibility with the semi-arid conditions of Iran, and its root system is relatively deep. To evaluate the effect of different sources of sulphur fertilizers on the growth and achene yield of safflower, a field trial was conducted in the northwestern region of Kurdistan province and near the Iraqi border during 2021-2022. The height of the experimental field was 1650 above sea level and the amount of precipitation during the growing season was 149 mm, the average annual temperature was 16.4 centigrade, the maximum annual average temperature was 29.4 centigrade and the minimum annual average temperature was 9.7 centigrade and the average and the annual relative humidity was 48%. The texture of the soil was sandy clay loam. The combined soils were sampled before crop sowing. Then some chemical properties and nutrient concentrations in the soil were evaluated. The amount of absorbable potassium estimated by the method with Ammonium acetate one normal (Stanford and English, 1949). The amount of phosphorus was calculated by Olsen's method (Olsen, 1954). The amount of organic carbon calculated by digestion method (Walkley and Black, 1934), and crude pH evaluated in 1:1 water to soil suspension (Mclean, 1982), electrical conductivity (EC) measured in 1:1 water to soil solution calcium carbonate evaluated by neutralization with acid and titration with soda (Richards, 1954). The amount of soil sulfate was measured by the monocalcium phosphate method (Singh *et al*., 1995). Overall soil properties were pH: 7.68, organic carbon: 0.51%, total nitrogen: 0.26%, $CaCo_3$: 17%, EC: 2.15 ds m^{-1}, SO_4^-: 3.42, P: 16.28 mg kg^{-1}, K: 625 mg kg^{-1}.

Treatments implement

The initial tillage of the field was done by moldboard plow in February 2021. Before plotting and dividing the land, 10 t ha^{-1} of cow manure was added to the land and integrated with the soil through the tandem disk. The plotting of the land was done in February 2021, and sulphur fertilizers were applied on the soil surface according to the dimensions of the plot and integrated with the soil through a shovel, and the field surface was prepared with a pattern of ridges and furrows. The 7 treatments examined in this research were 1) control: no sulphur application, 2, 3) utilization of 25 or 50 kg S from single superphosphate: $P+S_{25}$ or P+S50, 4, 5) application of 25 or 50 kg S from elemental form: S_{25} or S_{50}, 6, 7) use of 25 or 50 kg S from zinc sulfate: $Zn+S_{25}$ or $Zn+S_{50}$. The experimental plots with a size of 4 × 4 meters and with three replications were based on an arbitrary complete block design. Between the experimental plots, 0.5 m was considered as a margin or boundary to prevent the leakage or leaching of fertilizers to the adjacent plots. 50 cm inter-row spacing with 5 cm intra-row spacing was considered and planting was done manually on March 27, 2022. Watering was performed with the *irrigation drip tape* rolls and the water from the pool was delivered by polyethylene pipes to the *tapes* by a pressure pump. The first irrigation was done immediately after planting and the subsequent irrigations were done at intervals of 5-7 days according to climatic conditions and plant requirements. During the growing stages of saffron, weeds were manually weeded. Due to the absence of pests, pesticides and herbicides were not used.

Assessment of growth and achene yield

To evaluate the chlorophyll as the main photosynthetic pigment, a Soil Plant Analysis Development (SPAD) chlorophyll meter (502-PLUSE, Japan) was used at the stage of appearance of the capitulum in the main branch. At the end of the stages of capitula formation in the secondary branches, the width of the canopy was measured from the tip of the branches on the right side to the tip of the branches on the left side using a meter. In the physiological maturity stage, 10 plants were randomly selected and harvested from each plot, and growth characteristics and achene yield components such as stem diameter, height, number of capitulum per plant, the diameter of the capitulum, number of lateral branches, number of achenes per capitulum and percentage of wrinkled and unfilled achenes were calculated and counted. To calculate the achene yield per unit area, A quadrat ($1m^{-2}$) was randomly used to sample plants, the plants were cut from the surface of the ground and dried by placing them in an electric oven at a temperature of 60 °C for 24 h and by weighing them biological yield was obtained, then by threshing capitula, achene yield was acquired.

Oil Extraction

The harvested achene samples were desiccated at 45°C for 45 h under vacuum to reach the low moisture content (≤7%) and then pummeled to the ideal particle size by a mortar. The oil mining was done by Soxhlet extractor for 8 h using cold industrial hexane as a solvent, according to the AOCS method Ba 3-38 (AOCS 1993). For the assessment of fatty acids profiles, the gas chromatography methods were used. The preparation of methyl ester of fatty acids was done based on the instruction described by Ortega et al., (2004). Finally, the prepared samples were measured by a gas chromatography device (Agilent 6890N, USA), fortified with a FFAP-TC capillary column with a length of 30 meters, a diameter of 0.32 mm, and a thickness of the thin layer inside the tube (phase constant) of 0.25 μm was applied. Detector the FID type device was at 250 ˚C and the carrier gas was nitrogen.

For the statistical analysis of the data, the normality of the data was evaluated by SAS software before subjecting the data to the analysis of variance. Correlation and decomposition into main components were done with Minitab software. The comparison of average data was done using an LSD test at a 5% level. Box plots were drawn with Statistica software.

RESULTS

The results of the analysis of variance indicated that the application of sulphur had a significant effect on the diameter of the stem and regardless of the amount of application, the consumption of zinc sulfate and elemental sulphur increased this component by 4% and 26% compared to the control (Table 1). The thickest stems were recorded for plants grown under the application of $Zn+S_{50}$.

The number of lateral branches increased with the application of sulphur fertilizer. The highest number of branches was obtained with the application of high levels of single superphosphate, low levels of elemental sulphur and both levels of zinc sulfate (Table 1).

Table 1- The effect of application of different levels of sulphur fertilizers on the growth characteristics and yield components of safflower in the western region of Iran

Sulphur treatments	SD	SBN	CD	SNP	TSW	SS	CNP
control	7.33^{e}	7.00^{d}	28.64^{c}	32.22^{cd}	28.26^{c}	5.11^{c}	11.44^{c}
$P+S_{25}$	8.33^{d}	8.81^{c}	30.82^{ab}	32.89^{bcd}	29.57^{bc}	5.33^{ab}	12.88^{bc}
$P+S_{50}$	8.77^{cd}	9.71^{abc}	30.63^{ab}	34.44^{abcd}	31.37^{a}	5.88^{a}	15.00^{a}
S_{25}	9.40^{bc}	9.92^{ab}	32.07^{ab}	31.77^{d}	30.11^{ab}	4.55^{c}	14.55^{ab}
S_{50}	9.14^{cd}	9.37^{bc}	32.29^{a}	36.44^{ab}	31.57^{a}	5.33^{ab}	15.66^{a}
$Zn+S_{25}$	10.13^{ab}	10.14^{ab}	30.55^{b}	35.88^{abc}	31.13^{a}	5.66^{ab}	15.00^{a}
$Zn+S_{50}$	10.40^{a}	10.66^{a}	32.24^{a}	37.33^{a}	30.47^{ab}	5.22^{abc}	15.88^{a}
LSD	0.906	1.04	1.67	3.71	1.53	0.684	2.02
CV	5.61	6.28	9.03	16.83	7.09	12.24	8.34

Control: no-sulphur application, $P+S_{25}$: application of 25 kg ha^{-1} sulphur by utilization of single superphosphate, $P+S_{50}$: application of 50 kg ha^{-1} sulphur by utilization of single superphosphate, S_{25}: application of 25 kg ha^{-1} sulphur by utilization of elemental sulphur, S_{50}: application of 50 kg ha^{-1} sulphur by utilization of elemental sulphur, $Zn+S_{25}$: application of 25 kg ha^{-1} sulphur by utilization of zinc sulfate, $Zn+S_{50}$: application of 25 kg ha^{-1} sulphur by utilization of zinc sulfate. SD: stem diameter (mm), SBN: number of branches, CD: capitulum diameter (mm), SNP: achene number per plant, TSW: thousand achene weight (g), SS: unfilled and wrinkled achene (%), CNP: number of capitula per plant. LSD: least significant difference, CV: coefficient of variation. In each attribute, the means with the same letters do not have statistically significant differences.

The lowest effect of sulphur application on the number of branches was observed with low levels of single superphosphate (25%) and the highest effect was observed with the application of ZN (52%) compared to the control.

The diameter of the capitulum was greatly increased with the application of high levels of elemental sulphur and zinc sulfate, and the plants grown under the mentioned conditions had larger layers (13%) compared to the control (Table 1). The number of achenes in capitulum, as one of the important components of the achene yield, was affected by the level and type of sulphur fertilizer source at a statistical level of 5%. The application of high levels of single superphosphate and other sulphur sources could increase this component.

The highest number of achenes in the capitulum was recorded in the plants grown with the application of $Zn+S_{50}$, which was 15% higher than the control condition (no sulphur consumption

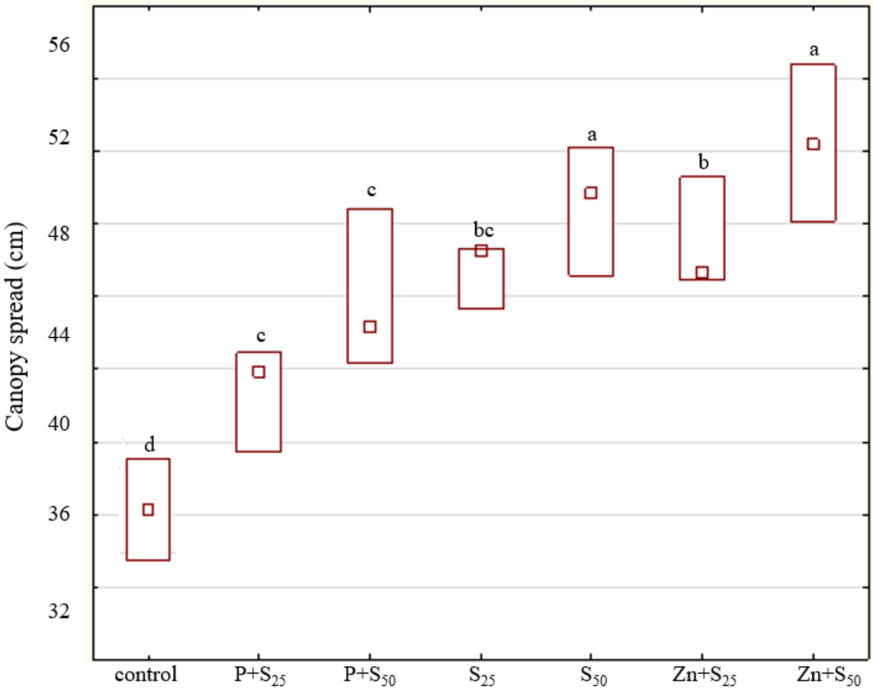

Figure 1. Investigating the effect of applying different levels of sulphur from different fertilizer sources on the growth and canopy size of safflower in the western region. Control: no-sulphur application, $P+S_{25}$: application of 25 kg ha^{-1} sulphur by utilization of single superphosphate, $P+S_{50}$: application of 50 kg ha^{-1} sulphur by utilization of single superphosphate, S_{25}: application of 25 kg ha^{-1} sulphur by utilization of elemental sulphur, S_{50}: application of 50 kg ha^{-1} sulphur by utilization of elemental sulphur, $Zn+S_{25}$: application of 25 kg ha^{-1} sulphur by utilization of zinc sulfate, $Zn+S_{50}$: application of 25 kg ha^{-1} sulphur by utilization of zinc sulfate. Boxes with different letters have a statistically significant difference at the 5% level.

The examination of the canopy spread indicated that the lateral growth and width of the canopy were strongly affected by the investigated treatments. The widest canopies were observed in plants grown using high levels of zinc sulfate and elemental sulphur (Figure 1). However, low levels of zinc sulfate and elemental sulphur improved canopy width by 34% and 27%.

Evaluation of chlorophyll content showed that the application of zinc sulfate at both levels of 25 and 50 kg ha^{-1} led to the highest chlorophyll content in the safflower leaves. The application of elemental sulphur was in the second position of influence on this component. Application of low and high levels of single superphosphate could increase the chlorophyll content by 5 and 11%, respectively (Figure 2).

The evaluation of the number of capitula in the plant indicated that this component increased with the application of sulphur-containing fertilizers.

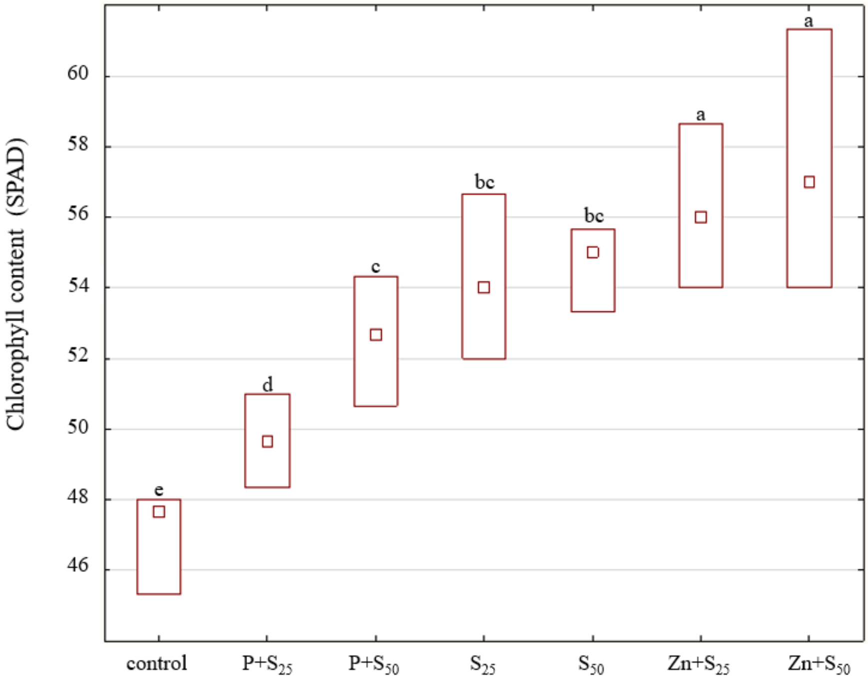

Figure 2- Comparison of chlorophyll content of upper leaves of safflower grown at different sulphur levels. Control: no-sulphur application, $P+S_{25}$: application of 25 kg ha^{-1} sulphur by utilization of single superphosphate, $P+S_{50}$: application of 50 kg ha^{-1} sulphur by utilization of single superphosphate, S_{25}: application of 25 kg ha^{-1} sulphur by utilization of elemental sulphur, S_{50}: application of 50 kg ha^{-1} sulphur by utilization of elemental sulphur, $Zn+S_{25}$: application of 25 kg ha^{-1} sulphur by utilization of zinc sulfate, $Zn+S_{50}$: application of 25 kg ha^{-1} sulphur by utilization of zinc sulfate. Boxes with different letters have a statistically significant difference at the 5% level.

Application of $P+S_{50}$ (31%), S_{50} (36%), $Zn+S_{25}$ (31%) and $Zn+S_{50}$ (38%), increased compared to the control. The consumption of $P+S_{25}$ did not have much effect on this important component of achene yield.

The application of sulphur at a statistical level of 1% affected the achene yield. The utilization of $P+S_{25}$ was associated with a slight increase in achene yield (82 kg ha^{-1}). However, the consumption of $Zn+S_{50}$ improved the achene yield by more than 200 kg ha^{-1}.

The use of $P+S_{50}$, S_{25}, $Zn+S_{25}$, and S_{50} $Zn+S_{50}$ fertilizers could increase the yield by 8%, 10%, 12% and 14%, respectively, compared to the no sulphur applied condition (Figure 3). The results indicated that high levels of zinc sulfate and elemental sulphur led to the highest achene yield.

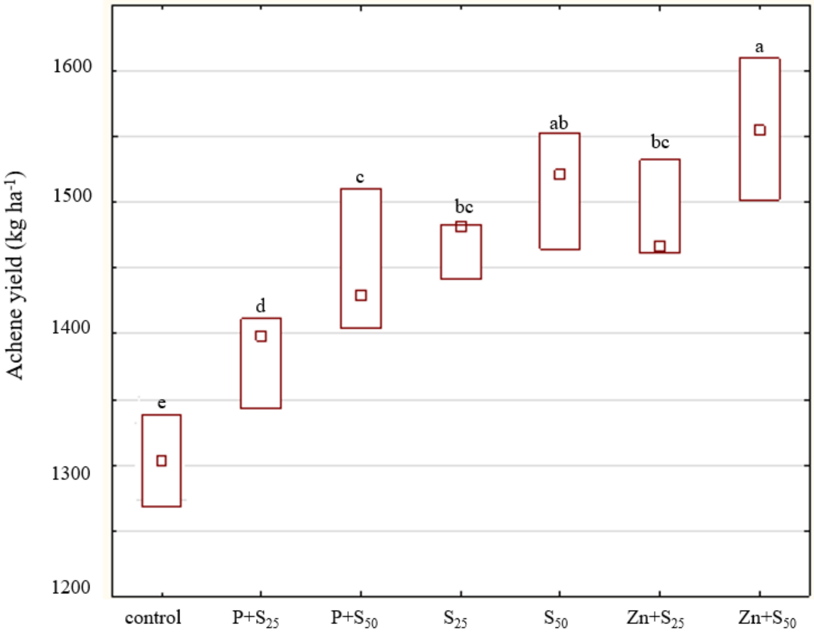

Figure 3- The effect of utilization of different levels of sulphur from different fertilizer sources on safflower achene yield grown in the western region. Control: no-sulphur application, P+S_{25}: application of 25 kg ha^{-1} sulphur by utilization of single superphosphate, P+S_{50}: application of 50 kg ha^{-1} sulphur by utilization of single superphosphate, S_{25}: application of 25 kg ha^{-1} sulphur by utilization of elemental sulphur, S_{50}: application of 50 kg ha^{-1} sulphur by utilization of elemental sulphur, Zn+S_{25}: application of 25 kg ha^{-1} sulphur by utilization of zinc sulfate, Zn+S_{50}: application of 25 kg ha^{-1} sulphur by utilization of zinc sulfate. Boxes with different letters have a statistically significant difference at the 5% level.

DISCUSSION

The obtained results showed that both vegetative growth characteristics, yield components, and oil quality were affected by sulfur treatments. The evaluations of the soil in the region indicated that the soil is facing serious limitations and soil amendment should be placed in the priorities of agronomic management. Although Organic fertilizers such as cow farm yard manure contain low levels of total sulfur, our results showed that the application of sulfur along with animal manure has a great effect on growth. Undoubtedly, the simultaneous application of animal manure and fertilizers containing sulfur leads to the acceleration of microbial oxidation and release of sulfuric acid in the rhizosphere environment, and at least on a small scale, they can cause chemical modification of the soil and improve the availability of nutrients (Salih, 2021). Among the examined fertilizers, the most improving effect was observed in zinc sulfate and elemental sulfur fertilizers. It seems that combined fertilizers containing micronutrients, while affecting the soil properties and modifying the chemical aspects of the soil, have been able to meet the need for this element by supplying sufficient amounts of zinc. Zinc plays a role in many key plant enzymes as a cofactor and is also essential for the activation of plant hormone biosynthesis pathways (Castillo-González et al., 2018). The application of sulfur along with organic fertilizer improves plant nutrition and can lead to an increase in soil fertility. Although all the sulfur-containing fertilizers increased the yield of achene, the greatest increase (20%) was obtained with the application of high levels of zinc sulfate. It appears that in the current experiment, the increase in vegetative growth with the application of sulfur caused a significant alteration in source-sink patterns with the increase in the size of the source and more supply of the photoassimilates. Consequently, high amounts of photosynthetic products can convert a larger number of reproductive primordia into achene yield components. With sulfur application, canopy width, chlorophyll content, plant height, and number of lateral branches increased, all of which indicate an increase in source size and activity. Evaluation of the achene yield components and quality characteristics of the extracted oil showed that the application of sulfur not only improves photoassimilate partitioning between different reproductive organs, but also changes the allocation of photoassimilates between different biochemical pathways such as fatty acid and protein biosynthesis. The use of zinc sulfate and elemental sulfur showed the highest fatty acids content, oil, and protein. Although one of the effects of sulfur application is increasing the solubilization of phosphorus in the soil and increasing its availability for the root system (Sugiura et al., 2021), in this experiment the application of composite phosphorus + sulfur had not prominent improving effects compared to other sulfur fertilizers, which can be attributed to the nature of the used composition or its slow phosphorus release.

Our findings confirmed the results of Kaya et al. (2020) as they reported that the simultaneous application of organic fertilizer and sulfur improved the yield of corn under phosphate deficiency conditions by improving vegetative growth components, relative water content, chlorophyll content, and antioxidant enzyme activity. The results obtained in this study showed that Sulfur-enriched soil amendments should be considered as one of the agricultural techniques in semi-arid areas. The evaluation of the quality characteristics of safflower oil showed that to improve the quantity and quality of the oil, it is necessary to use zinc sulfate or elemental sulfur in high amounts. Considering the low of oil production in the country and the high need of oilseed crops for sulfur, the consumption of sulfur, especially along with micronutrients such as zinc, should be an integral part of nutritional management. In addition to the roles that sulfur has in soil chemical modification, sulfur by forming disulfide bonds can play a role in fine regulation and activating and deactivating enzymes or modulating gene expression (Koprivova and Kopriva 2014). Continuous use of traditional chemical NPK fertilizers leads to soil acidification in the long term and reduces soil carbon content and soil fertility (Xun et al., 2016). The obtained results showed that according to the existing restrictions in the soils of the studied area, the use of sulfur along with other chemical or organic fertilizers will be very fruitful. The results of correlation between traits showed that under sulfur applied conditions, the number of capitula per plant, the number of achenes per capitulum, the content of linoleic acid, linolenic acid, the total oil content and the percentage of achene protein increased with the improvement of the canopy width, the increase of the leaf area and the supply of photoassimilates. Our finding revealed that sulphur deficiency is more prevalent in semi-arid region and safflower production system in west of Iran. Especially under farm yard applied condition elemental sulphur and zinc sulphate can affect both vegetative and qualitative characteristics of safflower. Sulphur deficiency is becoming more common in soil with low organic material and Promotion and incentive policies for farmers to use sulphur should be on the agenda.

CONCLUSIONS

This research is unique in terms of evaluating the effect of various sulphur fertilizer sources on the quantitative and qualitative characteristics of safflower. The soil of the investigated area was faced with severe deficiencies of organic matter and some nutrients. The obtained results showed that the use of all types and levels of sulphur-containing fertilizers caused a significant increase in vegetative growth compared to the control. However, the application of zinc sulfate and elemental sulphur had the best effect on reproductive growth components and achene yield. Our finding showed that application of zinc sulfate and elemental sulphur affected safflower oil. Fatty acide profile revealed that from qualitative prospect its oil has high nutritional value and has high potential to use oil in agro-food industries. However, the interaction of compound fertilizers containing other primary plant nutrients is not well known and needs further investigation. The obtained results showed that the application of zinc sulfate or elemental sulphur is one of the correct and necessary nutrient management options in pre-planting soil amendments. The use of sulphur could increase the release of elements from animal manure and improve their availability for the plant roots system and subsequently increase the amount of oil and protein in achenes. This eliminates the need to use high levels of other chemical fertilizers to a large extent. Providing subsidized sulphur fertilizers in semi-arid areas with small-scale farmers and those with low socioeconomic status can significantly improve safflower production. Studying the molecular aspects of the effect of sulphur can provide valuable information for safflower breeding processes.

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