The Effect of Balanced Nutrition and Soil Amendments on Productivity of Chickpea (*Cicer arietinum* L.)

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ABSTRACT

The growing process is a series of complex chemical and plant interactions. The right nutrient source applied at the right rate, at the right time, and in the right place is critical to managing soil fertility and optimizing plant growth and health. Soils of Mediterranean semi-arid regions generally have high pH, and low organic matter that negatively affect the availability of micronutrients and cause their deficiencies. For evaluating the influence of simultaneous utilization of various level of sulfur fertilizer and micronutrient fertilizers (Zn, Fe, Mn) on agronomic traits and yield components of chickpea, an experiment was carried out at highland semi-arid region. Assessment of agronomic characteristics revealed that sulfur application resulted in a significant increase in efficiency of micronutrient. Integrated application of Zn +30 kg S considerably elongated the vegetative growth and delayed the maturity. Application of high level of sulfur induced the canopy growth and ground cover. Finding revealed that application of Zn can substantially improve seed number per plant and seed weight when compared with Fe and Mn. Findings showed that economically integrated utilization of 15 kg ha^{-1} sulfur and Zn or Fe can be effective method to increase productivity of chickpea system. Balanced utilization of elemental sulfur as a soil amendment and essential micronutrient should be considered as a proficient agronomic management option in studied region. These results indicate that a substantial chickpea yield increase to S application is possible when soil conditions are conducive to low S supply and severe S deficiency exists.

Keywords: Iron, semi-arid region, vegetative growth, yield component, zinc

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INTRODUCTION

In semi-arid region the moisture supplied to the soil from rain is offset by evaporation; the latter is enhanced by low air humidity, high solar radiation and high air temperature (Verheye, 2009; Pasandi *et al*., 2014). The result is a limited dissolution of soluble primary minerals and the development of only a shallow, skeletal soil with a weak profile differentiation. Soils of these regions generally have free $CaCO_3$, high pH, and low organic matter, which reduce the availability of some essential elements andcause their deficiencies. Sulfur and micronutrient deficiencies have been reported in intensive, irrigated production systems globally and in semi-arid soils these deficiencies are reported as the main causes for yield plateau or declining yield levels (Srinivasarao *et al*., 2008). While, much attention has been paid to correcting S and micronutrient deficiencies separately, little attention has been devoted to diagnose interaction of sulfur and micronutrients in semi-arid region of Iran. It is well recognized that productivity of semi-arid soils is low due to water shortage. However, apart from water shortages, low soil fertility also constraints crop productivity in the semi-arid regions (Rego *et al*., 2007). Moreover, due to low crop productivity in the semi-arid regions, it is assumed that mining of secondary and micronutrients is much less as compared to irrigated agriculture (Rego *et al.*, 2007).

Micronutrients are important to world agriculture and has fundamental role in human health. Between the micronutrients, the deficiencies of zinc (Zn), iron (Fe) and manganese (Mn) have become the most distinguished yield-limiting factors in semi-arid Mediterranean highland areas and are partly responsible for low food nutrition (Ryan, 2008). However, the availability of micronutrients is greatly depends on soil pH so that high pH ties up trace elements such as iron, manganese, zinc, and others, leading to micronutrient deficiencies (Plaster, 2013). It seems that sulfur application can be suitable option for longer lasting pH reduction. By application of sulfur fertilizer, oxidizing bacteria particularly *Thiobacillus* spp would accelerate the oxidation process and convert the sulfur to sulfuric acid which significantly reduce soil pH (Mohammady Aria *et al.,* 2010). The availability of trace elements will be affected by sulfuric acid. Therefore, sulfur is an essential element for plant development and it can affect the plant growth both directly and indirectly. Although it is classified as a secondary element, it has become more important as a limiting nutrient in crop production in recent years (Jez, 2008). Sulfur plays some critical rules in plants and it is used in the formation of amino acids, proteins, and oils. Sulfur is necessary for chlorophyll formation, promotes nodulation in legumes, helps develop and activate certain enzymes and vitamins, and is a structural component of amino acids cysteine and histidine (Marschner, 2011). However, information regarding the effects of integrated application of S fertilizers and micronutrients especially zinc (Zn), iron (Fe) and manganese (Mn) on chickpea growth and yield plants is very scarce. Therefore present field survey was conducted to study the effect of S fertilizer and micronutrients on chickpea performance in semi-arid region in North West of Iran.

MATERIAL AND METHODS

A field experiment was carried out during 2014−2015 growing season in semi-arid highland region of Takab (47°70’ E; 36°23’ N with an altitude of 1765 m) in northwest of Iran. Seed were obtained from Seed and Plant Certification and Registration Institute (SPII) and during the first year seed were propagated in isolated fields under full irrigated condition, according to Sabaghnia *et al*. (2015). The geographical position of studied region are displayed in Figure 1.The experiment was established on a sandy loam soil (23% clay, 51% silt and 26% sand). The previous crop in the experimental field was safflower. Takab is representative of highland semi-arid zone and has a mean annual temperature of 12.3°C and annual rainfall of 340 mm. The total rainfall for during growing season was 120.5 mm. In this region irrigation is necessary because the rains were low and poorly distributed throughout the season. Physic-chemical properties of soil has been shown in Table 1.

Figure 1 The geographical position of Takab district on map of Iran

Table 1 Some important physicochemical characteristics of the soil

Depth (cm)	pH	EC dS. m^{-1}	T.N.V %	T.N%	O.C%	P mg. kg^{-1}	K	Fe*	Mn	Zn
0−30	7.8	0.79	11.88	0.044	0.42	4.34	227	7.41	5.26	0.75

T.N.V: Total Neutralizing Value, T.N: total nitrogen, O.C: organic carbon, * Extracted in DTPA solution

The experimental fields were ploughed once in early fall and harrowed twice to bring the soil to fine one week before planting. The recommended dose of fertiliser (30 kg N and 75 kg $P_2O_5ha^{-1}$) was applied in the form of urea and triple superphosphate at the time of seed bed preparation. The trial was laid out in randomized complete block design with three replications in split plot arrangement (plot size of 2 × 2 m^2) keeping sulfur in main plots and micronutrients in sub plots. Micronutrient fertilizers were including M_1: zinc, M_2: iron, N_3: manganese, and sulfur with three levels (S_1: no application, S_2: 15 K gha^{-1}, S_3: 30 Kg ha^{-1} were mixed with top soil. Micronutrients fertilizers were applied at rate of 1 kg ha^{-1} through incorporating within the irrigation water by the drip system 30 and 60 days after sowing date.

Chickpea was sown manually in the third week of April. In each plot, seeds were sown into 10 rows, at 20 cm row-to-row spacing and 8 cm plant-to-plant spacing. Two seeds were sown per hill and after germination, the plants were thinned to one seedling per hill. There was no incidence of pest or disease on plants during the experiment. Weeds were controlled by frequent hand weeding. The field was immediately irrigated after planting to ensure uniform germination and four times of irrigation applied during growth period. Phenological growth phases were monitored at 1–2 day intervals throughout the season and days to 50% flowering, vegetative growth period and day to maturity was recorded for each treatments. Canopy width was calculated by measuring length and breadth of canopy surface for each plant from which mean canopy width assuming the shape of the canopy as rectangle was computed and expressed in centimeters. Chickpea plants were harvested at ground level by hand from late June to early July.

Plant fresh and weight, biological yield per plant, Seed yield as well as harvest index were measured from a 2.0 m^2 harvest area from the central four rows of each plot when the crop reached physiological maturity. Ten plants from each treatment were selected at random in the harvested 2.0 m^2 sample and traits like as plant height (cm), canopy spread (cm), pods per plant, seeds per pod, seed per plant, umber of filled and unfilled pods, 100 seed weight (g), number of primary and secondary branches per plant were measured. Harvest index (HI) of each plot was calculated according to the following formula: HI = (grain yield/biological yield) ×100. Data were analyzed using analysis of variance procedures with the statistical program SPSS 15.0 and LSD test applied for comparison of means.

RESULT AND DISCUSSION

Results showed that application of sulfur and micronutrients has significant effect on plant height so that the lowest height was recorded for control plants (Table 2, 3). The tallest plants was recorded under application of 30 kg S ha^{-1} along with Zn fertilizer and the shortest plant was recorded under no application of sulfur. Number of the primary braches significantly affected by sulfur application, Such that utilization of 30 kg S ha^{-1} leads to 25% increase in number of the primary braches. However, application of 15 kg ha^{-1} had no significant effect on this trait. Analysis of variance showed that both factors noticeably affected the number of the secondary braches and interaction of sulfur and micronutrient had significant effect ($P < 0.05$) on this trait. Means comparison revealed that the highest number of secondary braches obtained by application of 30 kg ha^{-1} sulfur and Zn fertilizer, while the lowest number recorded for control condition (no application of sulfur) with Mn fertilizer utilization (Table 4). However, treatments could not affect the first pod height (Table 2).

Table 2 Effect of balanced utilization of elemental sulfur as a soil amendment and essential micronutrient on agronomic characteristics of chickpea

	DF	CW	DM	PH	FPH	PBP	SBP	VGP
Micronutrient (M)	**	**	**	**	NS	NS	**	NS
Zn	64.17	34.44	113.44	37.17	12.45	3.99	15.23	56.67
Fe	63.55	31.72	111.77	33.88	11.56	3.70	13.34	56.10
Mn	62.11	30.00	110.33	31.88	12.11	3.79	12.80	56.04
Sulfur (S)	**	*	**	**	NS	**	**	**
0	62.22	30.44	108.33	30.23	11.59	3.37	12.00	53.36
15	63.00	31.77	112.88	32.92	12.16	3.89	13.92	58.26
30	65.22	33.94	114.33	39.69	12.47	4.23	15.45	57.25
LSD	1.54	2.11	2.42	3.71	2.04	0.87	1.60	4.07
S×N	NS	NS	*	*	NS	NS	*	**
CV%	1.41	7.91	1.25	6.26	9.79	13.15	6.73	3.96

PH = plant height (cm), FBH = first pod height (cm), PBP = primary branch per plants, SBP = secondary branch per plant, CW = canopy width (cm), VGP = vegetative growth period (day), DF = days to flowering, DM = days to maturity. If the difference between two treatment means is greater than the LSD, then those treatment means are significantly different at the 95% level of confidence. *: statistically significant with 95% confidence level and **: statistically significant with 99% confidence level, respectively

Table 3 The effect of integrated application of elemental sulfur and micronutrients on yield components of chickpea

	EPP	STY	NPP	BY	NSP	HI	SY	HSW
Micronutrient (M)	**	**	**	**	NS	NS	**	NS
Zn	2.88	2925.65	23.19	4185.65	23.59	30.09	1260.00	16.38
Fe	3.43	2743.17	23.63	3960.68	23.52	30.77	1217.50	15.62
Mn	2.92	2725.20	22.30	3920.20	23.30	30.50	1195.00	15.77
Sulfur (S)	NS	**	*	**	*	NS	**	**
0	3.28	2651.69	21.62	3850.02	22.91	31.16	1198.33	15.26
15	3.09	2804.43	23.63	4024.43	23.75	30.33	1220.00	15.88
30	2.86	2937.90	23.86	4192.07	23.80	29.87	1254.16	16.63
LSD	0.39	202.2	2.02	217.37	0.71	1.66	50.42	0.67
S×N	*	NS	NS	NS	NS	NS	*	*
CV %	4.67	4.18	8.59	3.12	6.19	5.06	5.21	2.43

NPP = number of pods per plant, EPP = number of empty pod per plant, NSP = number of seeds per plant, HSW = 100-seed weigh (g), SY = Seed yield (kg ha^{-1}), BY=biological yield (kg ha^{-1}), STY = straw yield (kg ha^{-1}), HI = harvest index, *: statistically significant with 95% confidence level and **: statistically significant with 99% confidence level, respectively.

Canopy width significantly affected by both sulfur ($P < 0.05$) and micronutrient application ($P < 0.01$). Means comparisons between the different sulfur application levels showed that application of 30 kg ha^{-1} increased canopy width by 11% over the control condition. On the other hand the largest canopy width was recorded for chickpea plants grown by Zn fertilizer (Table 2). Assessment of phenological traits showed that application of sulfur fertilizer noticeably affected both vegetative and floral development. Sulfur application increased the vegetative growth period and partially delayed beginning of flowering stage, compared to control treatment. However, the earliest maturity observed for plants grown by Mn and Fe fertilizer under no application of sulfur. Evaluation of seed yield components showed that all traits, except the number of empty pod per plant affected by sulfur application (Table 3). Unlikely, the micronutrients only influenced number of empty pod and seed weight. Means compression of pod number between different sulfur levels showed that application of 15 kg ha^{-1} increased this component by 9% over the control.However, no difference was observed between 15 and 30 kg S ha^{-1}. A similar statue observed for number of the seed per plant (Table 3). Also application of Zn fertilizer significantly delayed flowering stage in comparison with other micronutrients (Table 2). The interaction effect of sulfur and micronutrients was statistically significant ($P < 0.05$) for days to maturity and the maximum number of the days to maturity was recorded for plant grown with 30 kg S ha^{-1} and Zn fertilizer that followed by 15 kg S ha^{-1} + Zn and with 30 kg S ha^{-1} + Fe (Table 4).

The seed weight was most responsive component to treatment. Assessments of 100-seed weight between combined treatments showed that the heaviest seeds obtained by application of 30 kg S ha^{-1} + Zn. However, the lightest seeds was related to plants grown under no-sulfur applied condition (Table 4). Interaction effect of sulfur and micronutrient was significant for number of empty pod per plant. Mean comparison of this trait showed that the lowest number of empty pod obtained by application of 30 kg S ha^{-1} + Zn while the highest number of empty pods was recorded for plants grown by Fe fertilizer. Overall, application 30 kg S ha^{-1} decreased the number of empty pods by 13% over control (Table 4). Also the highest seed yield obtained by application of 30 kg ha^{-1} sulfur + Zn (Table 4). The interesting thing is that under high sulfur consumption condition (30 kg ha^{-1}), the difference between micronutrients was more prominent and the best performance was related to Zn fertilizer. Assessment of biological yield and straw yield revealed that sulfur application significantly improves these traits; however, there was no significant difference between the 15 and 30 kg ha^{-1}. The effect of micronutrient also was significant on this traits and the highest value was recorded for plants grown by Zn fertilizer (Table 3).

Table 4 The integrated application of elemental sulfur and micronutrients on growth and yield components of chickpea

Micronutrients	Sulfur	PH	SBP	VGP	DM	EPP	HSW	SY
Zn	0	32.40^{abc}	13.06^{bcde}	54.52^{e}	110.50^{bc}	3.00^{bc}	15.30^{de}	4042.1^{abc}
	15	39.41^{abc}	14.67^{abc}	59.71^{ab}	115.00^{a}	2.39^{d}	16.35^{abc}	4084.2^{abc}
	30	43.01^{a}	16.94^{a}	56.46^{d}	116.50^{a}	2.47^{d}	15.20^{de}	4455.8^{a}
Fe	0	29.03^{c}	11.88^{de}	51.92^{f}	107.00^{de}	3.01^{bc}	14.90^{e}	3784.2^{c}
	15	29.95^{bc}	12.78^{cde}	58.41^{bc}	113.50^{ab}	3.54^{a}	15.55^{cde}	4022.7^{abc}
	30	40.55^{ab}	15.22^{ab}	59.71^{ab}	115.00^{a}	3.40^{ab}	16.00^{bcd}	4285.8^{ab}
Mn	0	29.01^{c}	10.99^{e}	51.92^{f}	106.50^{e}	2.79^{cd}	15.20^{de}	3735.8^{c}
	15	31.01^{bc}	14.05^{bcd}	57.11^{cd}	110.00^{cd}	2.83^{cd}	15.30^{de}	4066.2^{abc}
	30	38.02^{abc}	13.69^{bcd}	61.01^{a}	114.00^{a}	2.93^{c}	16.64^{ab}	3846.1^{bc}

PH = plant height (cm), SBP = number of secondary plant per plant, VGP = vegetative plant growth period (day), DM = days to maturity, EPP = number of empty pod per plant, HSW = 100-seed weigh (g), SY = Seed yield (kg ha^{-1}), Means sharing the same superscript are not significantly different from each other (LSD, $P < 0.05$)

Mean comparison of different traits between sulfur levels revealed that the highest number of branches, pod number per plant and seed number per plant had been obtained by application of 30 kg ha^{-1} sulfur. However, the lowest values of grain yield and biological yield were found in control plots. This finding corroborates the findings of Singh *et al.* (2003), who reported that the best performance of chickpea was obtained from 40 kg S ha^{-1} application. However, the sulfur requirement of crop depends on very different factors of which balance between S and other nutrient elements is important in view of a possible synergistic or antagonistic effects (Abdin *et al.,* 2003). This result may be explained by the fact that application of high level of sulfur fertilizer decrease pH in calcareous and alkaline soils increase the intake of the other nutritional elements and thus facilitate the enhancement of productivity and yield. Our finding revealed the combined application of micronutrient and high level of sulfur improved both growth traits and yield components. The findings of the current study are consistent with those of Islam (2012) who found that availability of soil zinc and copper increased with sulfur application and improved of chickpea yield in semi-arid region. This suggests that probably due to unfavorable soil conditions of in semi-arid region soil fertilization for micronutrients is problematic; hence it seems application of soil amendments, foliar feeding or breeding for tolerance remains the possible solutions (Rashid and Ryan, 2004). This also accords with our earlier observations, which showed that integrated application of zinc and macronutrients increased both vegetative and grain yield of chickpea in a semi-arid highland region (Janmohammadi *et al.*, 2014). Finding showed that application sulfur or micronutrient fertilizer significantly affected the phonological trend, so that plant grown with utilization of high level of sulfur the along with Zn considerably prolonged the period of vegetative and reproductive growth over to other treatments. These results support previous research into this brain area which showed a significant increase of phenological periods in chickpea by a precise nutrient managements (Namvar and Sharifi, 2011). The time available for chickpea crops to produce adequate vegetative structures and then yield components is often restricted by unfavorable environmental condition such as terminal drought stress and nutrients deficiencies. It seems the optimal nutritional conditions can considerably elongate plant development and at the same time increase the growth indices like as total dry matter, leaf area index, crop growth rate, relative growth rate and net assimilation rate (Namvar *et al*., 2011).

Although some studies have examined the interaction of sulfur and conventional micronutrients fertilizers (Abdin *et al.,* 2003; Islam, 2012), the innovative aspect of this study was the use of nano-struchered micronutrient fertilizers. Application of micronutrient has recently received considerable attention and has been attempted to enable the targeted delivery of nutrient (Rai *et al.,* 2015).It has been suggested that absorption and transport of nano-fertilizers is much higher than conventional types (Naderi and Danesh-Shahraki, 2013; Mastronardi *et al.,* 2015). Cell wall of the plant roots is very permeable on the nanometer scale. Pores on the order of one to a few tens of nanometers in diameter, essential for ionic and molecular transport process, have been observed in roots. Nano-sized micronutrients may then experience enhanced adsorption through these pores, or uptake could be improved by chemical complexing with molecular transporters or root exudates, through the creation of new pores, or by exploitation of endocytosis or ion channels (Rico *et al.,* 2011; Mastronardi *et al.,* 2015). Solubility, mobilizationand release of micronutrients from conventional fertilizers are highly dependent on the soil moisture content (Imtiaz *et al.,* 2010). Current results showed that in chickpea plants noticeably responded to application of Zn fertilizer. This probably refers to severe deficiency of this element in soil. Considering the local conditions, zinc deficiency may be due to the calcareous nature of soil, high pH, low organic matter, salt stress, continuous drought, high bicarbonate content in irrigation water and imbalanced application of fertilizers. The processes involved in the uptake of nutrients are affected by alterations in soil pH, apart from the effects on nutrient availability in soils. Generally, cation uptake is declined with decreasing pH, whereas anion uptake is inhibited when the external pH increases. This may be attributed to (1) competition of H^+ and OH^- (HCO_3) with other cations or anions, respectively, (2) external pH effects on the electrochemical potential gradient which provides the driving force for nutrient uptake and (3) pH-induced alterations of root metabolism and function (Marschner, 2011). Taken together, in soils with relatively high pH, the acidity caused by the addition of many fertilizers or from small quantities of elemental sulfur to a portion of the root zone can often provide adequate micronutrients to plants. It seems technology applied in nano-fertilizers provided a possibility for synchronizing the nutrient release from fertilizer according to crop demand during the growing season. Despite all the advantages of nano-structured fertilizers, some nano-particles such as sulfate, silicon dioxide and titanium oxide can be added to them during the synthesis. These material due to reducing the soil pH, stimulating the defense system and photocatalytic characteristic can improve the plant's resistance to stress and thus increases the crop yield (Derose *et al.,* 2010; Kumar and Pandey, 2014). However, the positive effects of combined application of Zn fertilizer and sulfur are directly related to some alternations in cellular process, and thus to be evaluated in depth. This would accelerate the recognition of nutritional behavior of micronutrients fertilizer with sulfur application, and may provide guidelines for producing suitable nano structured fertilizers in order to optimize chickpea yield in Mediterranean semi-arid areas. Sulfur-based fertilizers decrease the pH of soil and thus increase the uptake of other plant nutrients, which contributes to increased yields. The results of our study are in agreement with that of Sullivan *et al.* (2001), Sutaliya *et al.* (2003) and El-Desuki *et al.* (2006). Smatanová *et al.* (2004) reported that the application of S as $(NH4)_2SO_4$ had positive effects on yields and quality of the vegetables.

CONCLUSION

1. Applications of higher level of sulfur along with Zn increase total biological yield and seed yield, primarily due to an increase in the seed weight and number of filled pods per plant.

2. Lowest growth and seed yield of chickpea was recorded for plant grown by Mn under no-sulfur application condition.

3. The number of the empty pod significantly affected by micronutrient and sulfur application. This suggests the unavailability of micronutrients in slightly alkaline soils can influence abortion of reproductive structures was influenced by reducing seed formation.

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