Effect of Soil Water Stress and Nickel Application on Micronutrient Status of Canola Grown on Two Calcareous Soils

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Abstract: Recently, application of sewage sludge /effluents to soils as an alternative source of organic matter in arid / semi-arid regions and as a practical approach to remove its sanitary adverse effects in urban and industrial regions is gaining increased attention. This may lead to high levels of nickel (Ni) in soil and plants. On the other hand, in these regions water shortage is a major constraint of plant productivity. To determine the combined effects of Ni and water stress on the nutritional status of canola, we studied the effect of five Ni levels (0, 0.05, 0.1, 0.5 and 1 mg Ni kg⁻¹ soil as Ni(NO₃)₂) and two levels of water status (field capacity, FC, and 0.6 FC) on the contents of iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) in canola (Brassica napus L.) on two loamy and sandy clay calcareous soils in greenhouse conditions. Shoot /root dry matter yield (SDMY / RDMY), their Fe, Zn and Mn content decreased under 0.6 FC conditions; whereas, their concentrations increased. Shoot /root Cu concentration /content decreased in water-stressed plants. Application of > 0.05 mg Ni kg⁻¹ to loamy soil increased SDMY, however Ni did not affect SDMY positively or even decreased it in sandy clay soil. Application of 0.01 ~ 0.5 mg Ni increased RDMY in loamy soil under FC conditions; whereas, higher levels of Ni decreased it. Nickel decreased RDMY in sandy clay soil, whereas did not affect micronutrient concentrations in the root. The concentration and content of Mn in the shoot followed different patterns in response to applied Ni. Although the highest level of applied Ni increased shoot Zn content. Application of 0.05 and 1 mg Ni decreased the Cu concentration in the shoot on loamy and sandy clay soils, respectively. However, Ni did not affect the Cu content of shoot. Nickel had different impacts on the content of each micronutrient and was not effective in mitigating the adverse effects of drought stress.

Key words: Calcareous soil, Drought stress, Iron, Manganese, Zinc, Copper.

Normal growth of living plants depends on a number of basic factors e.g., air, light, water, temperature, nutrient elements, soil and physical conditions (Mengel and Kirkby, 2001). Soil properties e.g., texture is one of the factors affecting the plants growth via the control of water and nutrient supply to roots. Most nutrients are taken up through the root system. Therefore, nutrient absorption by plant roots is strongly influenced by the soil moisture (Marschner, 1995). In moisture-stressed canola, roots account for 25% of plant dry matter at the stem elongation stage, compared with 20% in unstressed plants. Moisture stress during the early vegetative stages reduces the ability of stomata to conduct CO₂ and therefore reduces photosynthesis and dry matter, and limits the growth of roots and nutrient content (Edwards and Hertel, 2011).

To achieve the optimum growth and maximum yield, plants need macro and micro nutrients (Mengel and Kirkby, 2001). As an essential element, plants need small amounts of Ni²⁺ (Marschner, 1995), whereas much larger amounts of Fe, Zn, Mn and Cu are required. In higher plants, urease is the only known Ni-containing enzyme. Other roles of Ni include Fe absorption, seed viability, N fixation and reproductive growth. Uptake of Ni by root, likely follows similar patterns to other micronutrients and it appears to be readily mobile in both xylem and phloem (Marschner, 1995). Nickel deficiency in field-grown crops has not been reported. However, human activities e.g. metal processing, land application of sludge and use of certain fertilizers can lead to an accumulation of Ni at potentially toxic levels (Kabata Pendias and Pendias, 2010). Kopittke et al. (2007) revealed that Ni caused a reduction in fresh mass of cowpea shoot. There are plenty of elements that can interfere with the absorption and transport of other nutrients in plants; therefore, there
must be a balance between different nutrients (Mengel and Kirkby, 2001). Ghasemi et al. (2009) determined the effects of excessive Ni on Cu and Fe homeostasis in the Ni hyper-accumulator plant. They stated that Ni interferes with Cu regulation and root to shoot Fe translocation. Rabie et al. (1992) showed that in cereal and legume plants, with increasing the foliar applied Ni, the shoot Ni and Fe content increased, whereas the Zn and Mn content decreased. The amount of absorbed essential nutrients, their concentrations and partitioning between underground and aboveground parts of plants may vary with the soil moisture status. In addition, some nutrients may mitigate the adverse effects of water stress on the plant growth. For instance, Kachenko (2008) showed that shoot Ni concentration (SNC) in H. floribundus decreased under water-deficient conditions but root Ni concentration (RNC) increased. However, values were not significantly changed by increasing levels of water stress. In contrast, Bhatia et al. (2005) observed a significant increase in SNC under decreased soil moisture levels in S. tryonii plants. They suggested that Ni had a positive osmoregulatory role.

Canola is an important industrial crop with seeds of high oil and protein content (Grassano et al., 2011). Its cultivation area in 2010–2011 in Iran was about 170000 ha which is > 20% of total land allocated to industrial crop production activities (Iran, Ministry of Agriculture Jihad, unpublished data, http://www.maj.ir). Nearly one half of the canola in Iran is produced by rain fed farming that is often under water-shortage conditions especially in the recent years of severe drought.

In arid/semi-arid regions, shortage of rainfall and high evaporation are major restriction imposed on plant growth, especially as global warming and anthropogenic activities have increased recently, the local environment becomes more and more rigorous and some of these areas have degraded severely (Wu et al., 2009). Among various abiotic stresses, water stress is a major constraint in arid/semi-arid regions that limit the growth and productivity of plant (Araus et al., 2002; Moosavi et al., 2014). Besides, nowadays increased sewage sludge and effluents application for overcoming the water shortage especially in these regions may result in a high Ni concentration in plants. There are no quantitative studies about the effects of simultaneous Ni application and water stress on the nutritional status of canola, therefore, the objective of this study was to investigate the combined effects of water stress and Ni on micronutrients status of canola grown on two different textured calcareous soils.

**Materials and Methods**

1. **Soil collection and pre planting analysis**

Samples were collected from 0 – 30 cm depth of two calcareous soil series of Kooye Asatid (Fluventic Xerorthents with sandy clay texture) and Chitgar (Typic Calcixerepts with loamy texture) located in Bajgah (College of Agriculture, Shiraz University) and Sarvesten, Shiraz, Iran, respectively. Soils were air dried, sieved through a 2 mm sieve, and analyzed for common physico-chemical properties. The soil series of Kooye Asatid and Chitgar consist of 130 and 250 g kg⁻¹ clay, 470 and 470 g kg⁻¹ silt, and 400 and 280 g kg⁻¹ sand, respectively. The gravimetric FC water in the soils were 160 and 200 g kg⁻¹, respectively, and the soils had electrical conductivities of 0.28 and 0.58 dS m⁻¹, pH of 7.61 and 7.46, organic matter of 6.8 and 13.6 g kg⁻¹, calcium carbonate equivalent of 550 and 610 g kg⁻¹, NaHCO₃ extractable P of 8 and 13 mg kg⁻¹, DTPA extractable Fe, Mn, Zn and Cu of 2.3 and 4.1, 3.6 and 6.3, 2.5 and 3.6, and 1.7 and 2.5 mg kg⁻¹ soil, respectively. DTPA extractable Ni could not be detected by atomic absorption spectrophotometer.

2. **Experimental design**

The experiment was conducted according to a completely randomized 2 × 2 × 5 factorial design with 3 replicates. Treatments consisted of 2 moisture levels of FC and 0.6 FC, 2 soil textures of loam and sandy clay, and 5Ni levels of 0, 0.01, 0.05, 0.5 and 1 mg Ni kg⁻¹ soil as Ni(NO₃)₂.

3. **Preparation of soil and canola planting**

Each plastic pot contained 3 kg soil. Each pot received 450 mg nitrogen (N) as NH₄NO₃ (one half was added at planting and the other half 3 weeks after emergence). 90 mg P as Ca(H₂PO₄)₂H₂O, 15 mg Cu, and 30 mg Zn, Mn and Fe from aqueous Cu, Zn and Mn sulfates and Fe EDDHA, respectively. Eight canola (Brassica napus L. cv. Talayeh) seeds were planted at a depth of 2~3 cm and were thinned to 4 uniform stands pot⁻¹ 10 days after emergence. The pots were maintained in greenhouse condition (at 15 – 35°C temperature and 60 – 75% humidity) and were irrigated with distilled water to the defined moisture status (FC or 0.6 FC). The soil moisture was maintained at the mentioned levels by adding water every other day during the experiment.

4. **Plant harvesting and determination of yield and nutrient contents**

After ripening, shoots were harvested and roots were separated from soil. Both parts were rinsed with distilled water, dried at 65°C for 48 h, weighed, ground, and dry ashed at 550°C. The ash was dissolved in 2N HCl. Iron, Mn, Zn, and Cu concentrations were determined by atomic absorption spectrophotometer and their contents were calculated by multiplying dry matter yield (DMY) by their concentrations. Shoot and root DMY, nutrient concentrations and contents were used as plant responses.

5. **Statistical analysis**

The normality of errors and existence of outlier data
Results and Discussion

1. Shoot dry matter yield (SDMY)

(1) Influence of Ni

Nickel did not affect SDMY, significantly (Fig. 1). Other researchers also reported an insignificant increase in SDMY of plants (Rabie et al., 1992 for faba bean, wheat and sorghum in response to 15–60 ppm foliar applied Ni) or even significant decrease in fresh/dry matter yield (Eleiwa and Naguib, 1987 for soybean in response to application of $10^{-5} - 10^{-4}$ M Ni). Abdel Latif et al. (1988) also reported findings similar to Rabie et al. (1992). The maximum SDMY was obtained by adding 0.05 and 0.01 mg Ni in loamy and sandy clay soils, respectively; however, the maximum SDMY was not statistically different ($P > 0.05$) from that in controls. Nickel could not reduce the adverse effect of water stress on canola growth.

(2) Influence of soil moisture

The SDMY was reduced by 1.57 and 1.38 fold as moisture status changed from FC to 0.6 FC in loamy and sandy clay soils, respectively. The maximum SDMY were obtained under FC conditions indicating that this variety of canola is relatively sensitive to water stress. The results were in agreement with the findings of Muhammad et al. (2007), Ahmadi and Bahrani (2009), Khalili et al. (2012) and Moosavi et al. (2014) who reported the reduced yield of canola subjected to water stress and with that of Kachenko (2008) who showed that the shoot biomass of *H. floribundus* decreased with increasing drought stress. A reduction in shoot biomass is considered a typical adaptive response of plants to water-deficient conditions (Whiting et al., 2003). Presumably, a decline in canola shoot biomass eventuated from suppressed cell expansion and cell growth arising from low turgor pressure (Mengel and Kirkby, 2001). The results are in contrast to the findings of Bhatia et al. (2005) who stated that the growth of *Stackhousia tryoni* Bailey plant was adversely affected by FC conditions in a clay soil due to the poor porosity and root anaerobiosis.

(3) Influence of soil texture

The canola SDMY on loamy soil was significantly (23%) higher than in sandy clay soil. It may relate to the higher capacity of loamy soil to rectify water/nutrients requirement. Mirzashahi et al. (2010) also stated that soil texture directly affects the yield response of canola to N fertilizer.

2. Root dry matter yield (RDMY)

(1) Influence of Ni

Application of 0.01, 0.05, and 0.5 mg Ni kg$^{-1}$ soil significantly increased RDMY in loamy soil under FC conditions by 41, 28, and 44%, respectively, whereas, application of 1 mg Ni, significantly decreased this trait by 26% (Fig. 1). Similar to loamy soil, application of 1 mg Ni to sandy clay soil decreased RDMY under 0.6 FC conditions ($P > 0.05$). In general, Ni decreased ($P < 0.05$) RDMY in sandy clay soil compared with the controls. In contrast, application of 0.5 and 1 mg Ni kg$^{-1}$ to sandy clay soil...
decreased RDMY under FC and 0.6 FC conditions, by 37 and 34%, respectively. The root of canola seems to be more sensitive than the shoot to high level of applied Ni. The results are in agreement with the findings of Yang et al. (1996) who reported that the root of maize and white clover was more sensitive to increasing Ni than was the shoot. However, results are not in accordance with those of Yang et al. (1996) for cabbage and ryegrass and Kopittke et al. (2007) for cowpea. Nishida et al. (2011) also showed that Ni decreased shoot and root fresh weight in Arabidopsis thaliana. The maximum RDMY was obtained by application of 0.5 mg Ni to loamy soil under FC conditions; whereas, the minimum RDMY was observed by application of 1 mg Ni to sandy clay soil. Seregin and Kozhevnikova (2006) stated that the toxicity of trace metals e.g., Ni varies with the plant species and the findings in canola may not be applicable to other plants.

(2) Influence of soil moisture status
In both of soils, RDMY decreased by 2 fold compared to controls as soil water status decreased from FC to 0.6 FC. Wedderburn et al. (2010) also reported that the growth of ryegrasses roots decreased under drought conditions.

(3) Influence of soil texture
The mean RDMY in loamy soil was higher (36%) than that in sandy clay soil, indicating that canola can develop its roots in loamy soil better than in sandy clay i.e. the loamy soil is preferred as a growth medium for canola roots, probably due to the easier penetration and root growth in loamy than sandy clay soils.

3. Iron (Fe) concentration and content
(1) Influence of Ni
Application of 0.05 mg Ni to loamy soil and 0.5 and 1
mg Ni to sandy clay soil significantly increased the shoot Fe concentration (SFC) at 0.6 FC conditions (Fig. 2). However, only application of 0.05 mg Ni increased shoot Fe content in loamy soil at FC conditions likely due to increased SFC. Increased SFC at 0.6 FC conditions in response to 0.05 mg Ni may correspond to the increased translocation of Fe from roots to shoots to maintain the nutritional balance or to the lower SDMY under this moisture conditions (Fig. 1). The maximum and minimum SFC was observed by application of 0.05 mg Ni in loamy soil under 0.6 FC and FC conditions, respectively. The results coincided with those obtained by Eleiwa and Naguib (1987) for soybean and with Rabie et al. (1992) for faba beans, sorghum and wheat plants. They reported that the increasing Ni content of shoot was proportional to the reduction in Fe content and concluded that Ni may disturb nutrient uptake pattern resulting in reduced uptake of some nutrients and increased uptake of some other nutrients. However, Abdel Latif et al. (1988) reported that excessive Ni interferes with the uptake and metabolism of Fe resulting in Fe deficiency. Also, Kopitke et al. (2007) stated that SFC in cowpea decreased at a high Ni concentration in nutrient solution.

Nickel did not affect root Fe concentration (RFC). However, application of 1 mg Ni increased RFC in sandy clay soil under 0.6 FC conditions by 22% (P > 0.05), probably due to the decreased RDMY or Ni toxicity in roots. Kopitke et al. (2007) reported the same results for cowpea. Iron accumulation in the roots has been attributed to a probable decrease in Fe translocation from root to shoot whilst the rate of Fe content by the roots was maintained (Yang et al., 1996). Nishida et al. (2011) showed that Fe accumulation in roots of Arabidopsis thaliana increased with increasing Ni, but in contrast SFC
decreased. They concluded that Ni inhibited Fe translocation from roots to shoots, resulting in an over accumulation of Fe in roots. Ghasemi et al. (2009) showed a reduced SFC and an increased RFC in Ni hyperaccumulator plants exposed to excess Ni. They suggested that a sub-toxic concentration of Ni may promote Fe release into the xylem, whereas a higher Ni concentration progressively increases with radial cell-to-cell movement of Fe in the root towards the vasculature bundle. Consequently, Ni appears to compete with Fe for translocation from root to shoot. Hell and Stephan (2003) stated that Fe$^{3+}$ is thought to form complexes with nicotiamine after taken up into the root symplasm, which also has a high affinity for Ni$^{2+}$. Application of 1 mg Ni resulted in a considerable but non significant decrease in root Fe content (Fig. 2) mainly due to the lower RDMY (Fig. 1). Generally, results indicated that the SFC and content were significantly lower than those in root by more than 10 and 20 fold, respectively.

(2) Influence of soil moisture

Water stress (0.6 FC) increased SFC by 38 and 16% in loamy and sandy clay soils, respectively (Fig. 2) due to the decreased SDMY. Shoot Fe content was significantly lower under FC conditions than under 0.6 FC only when 0.05 mg Ni was applied. This resulted from the increased SFC and larger Fe translocation from root to shoot. The mean RFC in loamy soil significantly increased (21%) by changing the moisture status from FC to 0.6 FC, whereas it decreased by 12% in sandy clay soil. However, the mean root Fe content was significantly decreased under 0.6 FC conditions due to reduced RDMY.

(3) Influence of soil texture

There was no significant difference between the mean
shoot and root Fe concentration/content values (Fig. 2). Availability of Fe to plants and its uptake by roots highly depends on soil pH (Hell and Stephan, 2003). Therefore, non-significant differences between Fe concentrations and contents in canola grown on the soils may correspond to their similar pH values (7.6 against 7.5).

4. Manganese (Mn) concentration and content

(1) Influence of Ni

The shoot Mn concentration (SMC) under FC conditions were influenced by applied Ni, being lowest at the middle level of applied Ni (0.05 mg Ni) and increasing on both sides (lower and higher levels) of Ni (Fig. 3). However, the reverse was the case under 0.6 FC conditions. This means that the SMC was higher at the middle level of applied Ni, although some of differences were not significant ($P < 0.05$). The pattern of changes in shoot Mn content in loamy soil under FC conditions was similar to that in SMC. However, the maximum and minimum values of shoot Mn contents on sandy clay soil under FC conditions were observed with application of 0.5 and 0 mg Ni, respectively. The findings showed that Ni may not interfere with Mn uptake content and the change in shoot Mn content in response to Ni may have resulted from the changes in SDMY and SMC (Figs. 1 and 3). However, the SMC was decreased by Ni in soybean (Eleiwa and Naguib, 1987), faba bean, wheat and sorghum (Rabie et al., 1992), white clover, ryegrass, and cabbage (Yang et al., 1996), fenugreek (Parida et al., 2003) and cowpea (Kopittke et al., 2007).

Nickel had no effect on root Mn concentration (RMC), except for 0.01 mg Ni that decreased RMC in sandy clay soil under 0.6 FC conditions, by 37% (Fig. 3). The results was not in accordance with the findings of Parida et al. (2003) for fenugreek and Kopittke et al. (2007) for
cowpea. Root Mn content was not influenced significantly by Ni, except for that of in loamy soil under FC conditions, where it was increased (76%) by application of 0.01 mg Ni and also that in sandy clay soil under FC conditions where it was decreased (46%) by application of 1 mg Ni. The minimum RMC and content were observed by application of 0.01 mg Ni in sandy clay soil under 0.6 FC conditions. In general, the results showed that shoot Mn concentrations/contents were lower than those of root by 2 and 3 fold, respectively.

(2) Influence of soil moisture
At 0.6 FC conditions SMC was significantly higher than that under FC conditions, by 32 and 30% in loamy and sandy clay soils, respectively. The reduced SDMY under water-deficient conditions has resulted in a significant increase in SMC; whereas, shoot Mn content did not influenced. Water-deficient conditions decreased root Mn content by 39 and 56% in loamy and sandy clay soils, respectively, i.e., the minimum root Mn content was observed under 0.6 FC conditions (Fig. 3).

(3) Influence of soil texture
The mean SMC in loamy soil was significantly lower (10%) than that in sandy clay soil probably due to that increased SDMY and the induced dilution effect; whereas, the mean root Mn content in loamy soil was significantly higher (31%) than that on the sandy clay soil probably due to the increased RDMY (Fig. 3).

5. Zinc (Zn) concentration and content
(1) Influence of Ni
Application of 0.01, 0.05, 0.5 and 1 mg Ni increased shoot Zn concentration (SZC) by 52, 40, 47 and 51%,
respectively, in loamy soil, whereas, Ni did not affect this trait on sandy clay soil, significantly (Fig. 4). The results may correspond to the larger amount of Zn in the loamy than in the sandy clay soil. However, only application of 1 mg Ni significantly increased shoot Zn content on loamy soil by 2 fold. The results were in agreement to those of Rabie et al. (1992) for faba bean, wheat and sorghum; whereas, not in accordance with the findings of Kopittke et al. (2007) for cowpea. High levels of applied Ni (0.5 and 1 mg Ni) generally decreased root Zn content except for application of 0.5 mg Ni that increased this trait in loamy soil under FC conditions. Application of a larger amount of Ni decreased the RDMY (Fig. 1) and consequently the Zn content of roots was adversely affected. Nickel interferences in Zn uptake from soil into plant roots or translocation from root to shoot. However, Kopittke et al. (2007) stated that Zn concentration in cowpea root decreased with increasing Ni due to unclear reasons.

2) Influence of soil moisture
The mean shoot Zn content decreased by 29 and 35% on loamy and sandy clay soils, respectively, under the 0.6 FC conditions compared with those under the FC conditions. The mean root Zn content also decreased by 23 and 58% as the moisture changed from FC to 0.6 FC in loamy and sandy clay soils, respectively (Fig. 4). The results demonstrated that the greater reduction in root Zn content in sandy clay soil compared with that of shoot (58 vs. 35%) in response to water-deficient conditions may result from the stronger adverse effect of these conditions on the root growth than the shoot growth.

3) Influence of soil texture
Shoot Zn content of canola grown on loamy soil was about 25% higher than that grown on sandy clay soil due to the increased SDMY on loamy soil. The mean value of root Zn concentration in sandy clay soil was about 26% higher than that in loamy soil. However, the root Zn content was about 15% higher in loamy soil than in sandy clay soil (Fig. 4). The higher Zn content of root in loamy soil in spite of its lower root Zn concentration may correspond to the increased RDMY (and induced dilution effect) in loamy soil compared with sandy clay soil (Fig. 1).

6. Copper (Cu) concentration and content
1) Influence of Ni
Application of 0.05 and 1 mg Ni significantly decreased shoot Cu concentration (SCC) on loamy and sandy clay soils, respectively (Fig. 5). Kopittke et al. (2007) reported similar findings for cowpea. The findings showed that Ni did not affect the root Cu content. However, application of 0.05 mg Ni increased root Cu content in loamy soil due to increased RDMY; while, Ghasemi et al. (2009) reported greater shoot/root Cu concentration of Alyssum inflatum in the presence of Ni. Results showed that the maximum root Cu concentration/content was observed by application of 0.05 mg Ni.

2) Influence of soil moisture
The SCC increased by 18 and 20% under 0.6 FC conditions in loamy and sandy clay soils, respectively (Fig. 5). However, the shoot Cu content decreased by 20 and 12% in these soils, respectively, due to decreased SDMY under 0.6 FC conditions. In contrast to the findings for the other micronutrients (Fe, Mn and Zn), under 0.6 FC conditions RCC was 33 and 14% lower than that under FC conditions in loamy and sandy clay soils, respectively. Furthermore, root Cu content under 0.6 FC conditions was 2.9 and 2.3 fold lower than under 0.6 FC conditions in these soils, respectively. It seems that moisture-deficient conditions may reduce Cu availability, as a consequence decrease root Cu uptake. Misra and Tyler (2000) stated that changes in moisture can regulate the nutrient availability via changing soil solution chemistry. Ponizovsky et al. (2006), however, reported that an increase in moisture decreased the soil Cu concentration, significantly.

3) Influence of soil texture
The shoot and root Cu content in loamy soil was significantly higher than those in sandy clay soil by 18 and 39%, respectively (Fig. 5) because of increased SDMY and RDMY on the loamy soil. The results revealed that 50 and 58% of Cu absorbed by roots was transported to shoots in loamy and sandy clay soils, respectively.

7. Nickel (Ni) concentration and content
1) Influence of Ni
Nickel had no significant effect on the shoot Ni concentration (SNC) and content (Fig. 6). However, Rabie et al. (1992) reported increased SNC of faba beans, wheat and sorghum with increasing the applied rate of Ni. Bybordi and Gheibi (2009) also reported the same results for canola. Nickel has been reported to be readily taken up by plants and the Ni content to be positively correlated with a certain external Ni concentration (Morrison et al., 1980). Application of 0.01 mg Ni decreased root Ni concentration (RNC) in loamy soil while application of 1 mg Ni increased it in the sandy clay soil. Kopittke et al. (2007) showed that SNC and RNC increased when the Ni activities in solution increased. The rate of increase in RNC was greater than that in shoot, so that the RNC were 3 to 10 times higher than SNC. Ghasemi et al. (2009) showed that application of Ni increased SNC/RNC in Alyssum inflatum. Nishida et al. (2011) also stated that in the hydroponic solution, SNC/RNC increased with increasing Ni concentration in the solution and Ni accumulation in roots was significantly higher than that of shoots.
**Influence of soil moisture**

In loamy soil, SNC and content increased by 48 and 22%, respectively, under 0.6 FC conditions (Fig. 6). The results were in agreement with the findings of Bhatia et al. (2008), who observed a significant increase in SNC in drought-stressed *S. tryonii* plants. They suggested the positive osmoregulatory role in Ni. However, our results were not in agreement with the findings of RNC bybordi, A. and Gheibi, M.N. 2009. Growth and chlorophyll content of canola plants supplied with urea and ammonium nitrate in response to various nickel levels. *Nat. Sci. Biol.* 1:53-58.

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**Conclusion**

Nickel had different impacts on canola micronutrient contents, especially under different soil moisture conditions and could not mitigate the adverse effect of drought stress on canola growth. The findings revealed that the studied variety of canola (*B. napus* L. cv. Talayeh) may be a relatively sensitive variety to drought stress and its planting is not suggested in arid regions, where water shortage is one of the major limiting factors. Findings confirmed that loamy soils can provide more suitable conditions for canola than coarser textured soils, especially in the regions where water is the limiting factor. Since water scarcity is a major constraint of plant productivity in the context of climate change, further research especially under field conditions needed to assess the actual effects of the studied factors on the growth and chemical composition of canola.

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