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# Evaluation of Arsenic and Nutrients Uptake of Tomato Plant at Various Arsenic Concentrations of Irrigation Waters

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**ABSTRACT**

Under various Arsenic (As) loads, growth of the tomato plant and changes in elemental uptake were investigated in this experimental study. Plants were transplanted into the As free soils and the loads of As were increased gradually with irrigation. The root and stem dry weights (DW) steadily increased with the increase of As concentration up to 1.5 mg $L^{-1}$, while the DW dropped to lower than the control plant's DW when the As concentration was higher than mg $L^{-1}$. Although the leaves DW variations for the studied As concentrations were negligible, As application to the tomato plants positively affected the biomass amount of leaf. Considering the decrease in root/shoot ratio, the root growth was more promoted at low As concentrations, while the effect of As on the production rate of aboveground biomass could be neglected. When the As concentration was increased from 0.5 mg $L^{-1}$ to 3.0 mg $L^{-1}$, average 90% of the total applied As to the plants was accumulated in the root and As content in the root was enhanced about four times. Significantly higher levels of N, K, Mg, and Ca in the aerial parts of tomato than in roots were determined while the level of P was about equal in the tissues. Among the tissues, the lowest microelements; Cu, Mn, Fe, and Zn concentrations were determined at the root of control plant. However, especially at high As loads, the increase in the amount of microelements in the root was considerably higher compared to the stem and leaf.

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Uptake; translocation; groundwaters; contamination

## Introduction

Because of the applications of untreated wastewaters, phosphate fertilizers, and contaminated watering practices to the agricultural areas, the agricultural soils and irrigation waters (IW) have been contaminated with heavy metals (Salem, Albanna, and Awwad 2016). Arsenic (As) is widely encountered in the environment as the geogenic and anthropogenic sources (Meharg, Naylor, and Macnair 1994) and causes soil and water source pollution which is a serious environmental problem (Caporale et al. 2013; Mohan and Pittman Jr. 2007; Smedley and Kinniburgh 2002). As mobility, bioavailability, and toxicity might be greatly affected by the nature of soil components, pH, presence of anions ($PO_4^{3-}$), and residence time in the medium (Violante and Pigna 2002). In some areas (Das et al. 2004; Kobya et al. 2011; Mutlu 2010), because As concentration in the groundwater has exceeded the recommended limit of 0.01 mg $L^{-1}$ (WHO 2001), it has received more attention due to its toxic effect on humans, plants, and animals (Stazi et al. 2016).

Groundwater mostly known as a clean source is widely consumed for drinking water as well as for the plant irrigation. Because the As-contaminated groundwater is extensively used for crop irrigation, the potential of high amount of As accumulations in the agronomic products is taken into account

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(Abedin et al. 2002). Exposure of human to As mainly occurs through As-contaminated drinking water and agricultural products (Rahman et al. 2008).

Although As is not an essential element for the plants (Marin et al. 1993), it is essential for the animal metabolism (Lepp 1981). As uptake of the plants depends on the plant species and habitats (Bergqvest and Greger 2012). As contents of plants in the As-contaminated areas are several times greater than the similar types of plants grown in the uncontaminated areas (Huq et al. 2006). The highest level of As was detected in the sea foods, meats, and grains, while its low level has been reported in some foods (Sushant and Ghosh 2010).

Most of the plants could tolerate the soil As amount up to 50 mg $kg^{-1}$, while higher levels negatively affect the plant growth. However, some of the plants have strategies to adapt to the unfavorable conditions (Madeira et al. 2012). As tolerance of some plants might be related to changes of the phosphorus uptake, due to As being taken up into the roots through the phosphate transporters (Carbonell-Barrachina, Burló-Carbonell, and Beneyto 1997a; Zhao, McGrath, and Meharg 2010). Because As is chemically similar to P, it is assumed that As is likely to take part in many cellular reactions. Phosphate and arsenate are taken into the plant roots by a common carrier, which has a much higher affinity for phosphate than arsenate. P is also reported as a highly efficient competitive inhibitor on the uptake of arsenate into the plant (Meharg and Macnair 1990).

Increase of As uptake by the plant increases phosphorus uptake also (Burló et al. 1999; Cao, Ma, and Shiralipour 2003). But uptake of As is restricted when the plant phosphorus requirement is met. The defense mechanism of plants to As toxicity may derive from the capacity to metabolize As to less toxic forms (reduction of arsenate (V) to arsenite (III)) which complexes with glutathione and phytochelatins (Madeira et al. 2012).

In Turkey, tomato one of the most cultivated food plants is about 40% of the total vegetable production. Tomato production was 10,624,862 tons between 2006 and 2016 in Turkey (TSI, 2017). The need of world total tomato production of about 7% is provided by Turkey, which ranks fourth (Bashimov 2016).

Effect of As on the tomato plant growth was widely studied in the As-contaminated soil and water mediums. In the previous experimental studies, As was added into the growth mediums at the beginning of experiment in order to investigate the effect on plant growth. However, when As is gradually added to the growth medium there is lack of knowledge on the tomato plant growth and changes of upward transportation of nutrients from the root to the aboveground biomass.

In the present research, various concentrations of As in the irrigation water (IW) were applied to the tomato plants, which cultivated in a laboratory condition. The plants were planted into the As free soils and the loads of As increased gradually by irrigation. The tomato plant growth under various As loads and changes of As and nutrients amounts in the tomato tissues were investigated.

## Materials and methods

### Experimental methodology

#### Soil sampling

Upper layer of the soil (0–30 cm) in the Campus Area of Sivas Cumhuriyet University was used as a growth medium. The soil was initially dried in an air environment and passed through from the 2 mm sieve. The principal physicochemical properties of soil before fertilization are presented in Table 1. Basic fertilization (500 mg $kg^{-1}$ N in $CaNO_3.4H_2O$ form; 100 mg $kg^{-1}$ P and 125 mg $kg^{-1}$ K in $KH_2PO_4$ form; 2.0 mg $kg^{-1}$ Zn in $ZnSO_4.7H_2O$ form; and 20 mg $kg^{-1}$ Fe in Fe-EDTA form) for each pot was carried out to the soils to ensure the growth of plants (Ozturk, Aslan, and Demirbas 2020).

**Table 1.** The principal physicochemical properties of soil.

| Soil property | values |
|---|---|
| pH | 7.28 |
| Lime | 19.6% |
| Salt | 0.033% |
| Organic matter | 1.7% |
| Texture | SiCL |
| Available (kg P $ha^{-1}$) | 34 |
| Available (kg K $ha^{-1}$) | 953.9 |
| Available (mg Fe $ha^{-1}$) | 3.99 |
| Available (mg Mn $ha^{-1}$) | 4.68 |
| Available (kg Zn $ha^{-1}$) | 0.42 |
| Available (kg Cu $ha^{-1}$) | 1.23 |
| Available (kg Fe $ha^{-1}$) | 3.99 |

### *Seed sowing and plant growth*

Pot experiments were conducted in the laboratory. Firstly, the tomato seeds (H–2274) were sowed into the viols having peat with high water-holding capacity and rich in the organic matters and nutrients. The seeds were grown at room temperature in viols and irrigated with the As free tap water. During this stage, in order to avoid negative effects of high temperature and sunlight on the seed germination, the viols were kept far away from the window.

Germination, which was the optimum time for transplanting to the pots, was observed approximately 25 days after seed sowing. After planting of the plants into the pots, which were 3 kg of soil capacity, they were placed in the closest position to sunlight. During the experiments, temperature was determined between 19°C and 25°C in the laboratory. To provide growth uniformity among the plants, the position of pots in the laboratory was routinely changed during the study. After planting in the pots, the plants were treated with the As-contaminated water. Arsenic concentrations 0.5, 1.0, 1.5, 2.0, 2.5, to 3.0 mg As $L^{-1}$ were prepared from a stock solution of 0.05 mol $L^{-1}$ $NaAsO_2$ (Merck). The ranges of As concentration in the IW were chosen considering widely encountered concentrations of As-contaminated groundwater in the world (Aslan 2018). Experimental study was conducted according to a completely randomized design factorial with three replicates. Harvesting was carried out in the period when 10% of all plants flowering.

The applied total As loads to the pots are calculated by using Equation 1 according to the volume of IW. In order to maintain 70% water-holding capacity of the pot, the pots were weighed before each watering.

$$As\ Loads\left(mg\ pot^{-1}\right) = volume\ of\ IWs\,(L) \times As\ concentrations\ in\ the\ IWs \tag{1}$$

All plants were irrigated with an equal amount of tap water. The As loads were varied, because of the different concentrations of As in waters. For irrigation, the total volume of 10.2 L water was applied and the total applied As loads to the pots ranged between 0 mg $pot^{-1}$ and 30.6 mg As $pot^{-1}$ (10.2 mg As $(kg\ soil)^{-1}$)

After the tomato plants are harvested before flowering, the aboveground biomass from the soil surface above 1–4 cm was cut and then its shoots and leaves were separated.

### *Sampling of plants and soils*

After harvesting, the root, stem and leaves were collected separately. The tissues were cleaned by using tap water and 0.1% HCl solution and then rinsed at least twice with deionized water to remove soil residues. To get a constant dry weight (DW), the plant tissues were dried in an oven for 48 hours at about 65°C (Demirbas et al. 2017). For the element analysis, the dried plant tissues were ground into powder by using grinding mill (HD–702 model, Simsekler Labortechnik).

### *Macro and micro nutrient analysis*

To determine As amounts, 0.2 g soil and powdered plant samples were digested by using 2 mL of 35% $H_2O_2$ and 5 mL of 65% $HNO_3$ in the microwave oven (Milestone Srl – ETHOS EASY). After digestion of samples, P concentration was calorimetrically determined at 882 nm by the spectrophotometer (Shimadzu UV–1800 model) (Murphy and Riley 1962) while As, K, Ca, Mg, Fe, Zn, Cu and Mn were analyzed by using a hydride generation atomic absorption spectrophotometer (Analytik Jena AG–contrAA 700 model) (Guzel et al. 1992; Kacar and Inal, 2008). The total N concentration of samples was measured by Kjeldahl method using the Kjeldahl distillation unit (VELP Scientifica marka UDK 139) (Bremner 1965). The precision was calculated on the three replications for the digestion procedures.

### *Statistical analysis*

The experimental data was subjected to ANOVA variance analysis with the use of SPSS23.0 for Windows packet for the statistical analysis (SPSS Inc, Chicago IL). The differences between the applications were determined in a way that they were lower than 0.05 ($P < 0.05$) with Tukey test.

## Results and discussion

### *Plant tissue dry weights*

Effects of As on the tomato plant growth and changes of elements contents in the tissues were evaluated by comparing with the control plants.

As can be seen from Figure 1, low concentrations of As (up to 2.0 mg $L^{-1}$) positively affected the tomato plant growth. Higher amount of DW at the As applied plants than the control plant was observed. The root and stem DW of control plant were 4.6 g and 15.7 g, respectively. Up to the concentration of 1.5 mgAs $L^{-1}$, the DW of root (6.08 g) and stem (18.7 g) increased, while the decrease of DWs was observed when the As load was further increased. It was determined that the root DW was lower than the control plant root DW when the As concentration was higher than 2.0 mg $L^{-1}$. The lowest root DW (4.3 g) was observed at the As concentration of 3.0 mg $L^{-1}$. Compared to the control plant, at the highest concentration of As, decrease in the plant root dry weight was negligible. Considering the previous study, which was reported that the root membrane of tomato was damaged at the As concentration of 10 mg $L^{-1}$ (Carbonell-Barrachina et al. 1998), it was thought that the roots were not damaged for the applied As concentrations.

The stem DW constituted the major portion (average %73) of the total biomass of tomato plant. The DW change of stems in the applied As concentrations was similar to the root DW changes. The stem DW of control plant was 15.7 g and increased steadily to about 18.9 g up to the As concentration

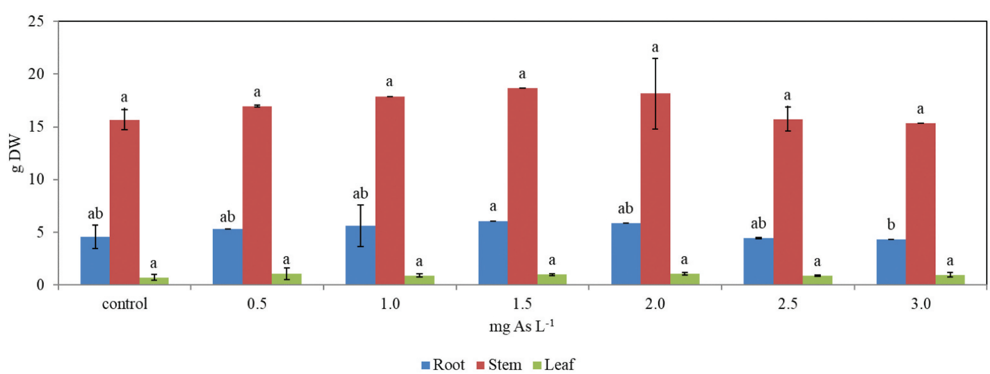


Figure 1. The dry weight change of tomato plant at various Arsenic concentrations.

of 2.0 mg $L^{-1}$. Although the stem DW decreased to the lower than 18.9 g at the concentration of 2.5 mgAs $L^{-1}$, it was higher than the stem of control plant. At the highest As concentration, the DW of stem dropped to 15.3 g approximately equal to the control plant.

The leaf DW of control plant was 0.7 g and it increased to about 1.1 g at the As concentration of 0.5 mg $L^{-1}$. Although significant leaf DW variations were not observed, the leaf DW of whole As applied plants were higher than the control plant.

While the root/shoot ratio of control was 0.28, the ratio increased to about 0.3 up to the As concentration of 2.0 mg $L^{-1}$ (Figure 2). Further increase of the As concentration caused the decrease in ratio to about 0.26. From the increase in root/shoot ratio, it could be concluded that the root growth is more promoted at low As concentrations and/or positive effect of As on the growth of aboveground biomass could be neglected. However, sharp drop of the root/shoot ratio at high As concentrations indicated that the root growth was inhibited more than the above-ground biomass.

The total dry biomass of plants is considered as a critical parameter in order to evaluate the effects of As on the tomato growth (Niazi et al. 2017). When the amount of biomass of the tomato plant is taken into account, experimental results indicate that the effects of applied As concentrations on the total DW of tomato were negligible. Compared to the control plant, at the As concentration of 3.0 mg $L^{-1}$, while the leaf biomass production increased about 33%, the root and shoot biomass productions were decreases about 5.9% and 2.1%, respectively. Although the experimental results are in agreement with the findings of Burló et al. (1999), who found that tomato plants treated with arsenite exhibited a higher DW than the controls, they were not consistent with the other studies (Carbonell–Barrachina et al. 1997b; Pigna et al. 2012). At the As concentration of 2.0 mg $L^{-1}$, decrease in the stem DW about 36.8% (Pigna et al. 2012) and 12.5% (Carbonell–Barrachina et al. 1997b) were reported, while about 17.5% increase was observed in this study.

The tissue dry weight difference of tomato plant was not observed by Stazi et al. (2016). It is believed that the As effect on plant growth is varied according to the experimental conditions (gradually adding of As, growth mediums like soil or hydroponic, etc.). In the literature, the subject of As accumulation in the plants was widely investigated in the contaminated soils and in the nutrients solution. However, As was gradually added into the soil with IW in this study. It is thought that the gradual addition of As positively affected the plant growth. Compared with the control plant, for the studied As concentrations, negligible DW decrease was determined and the plant survived, grew normally and the symptoms such as wilting were not observed. Although As has not been considered to be an essential nutrient for the plant, at low concentrations (≤2.0 mg $L^{-1}$), positively affect the growth of some plants such as tomato (Burló et al. 1999; Miteva 2002), *Spartina alterniflora* and *Spartina patens* (Carbonell–Barrachina, 1995; Carbonell-Barrachina et al. 1998; Marin, Masscheleyn, and Patrick 1992), onion

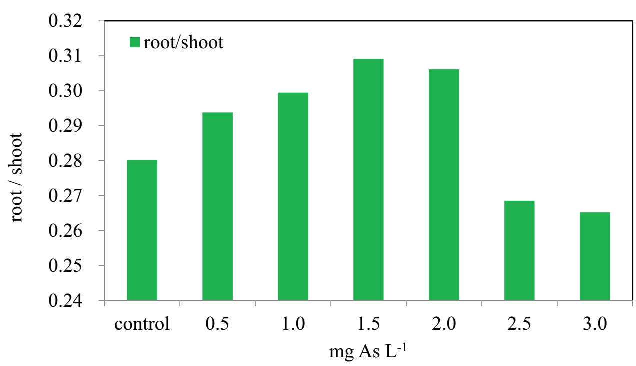


**Figure 2.** The root/shoot ratio under various As concentrations.

(Sushant and Ghosh 2010), red clower (Mascher et al. 2002), wheat (Li et al. 2007; Liu et al. 2005), *Baccharis dracunculifolia* (Gilberti et al. 2014), *P. vittata* (Singh and Ma 2006; Tu and Ma 2002, 2004), common vetch and alfalfa (Aslan 2018; Hamid 2019; Ozturk 2018) has been reported. However, its high concentration becomes toxic to all plants (Gulz, Gupta, and Schulin 2005).

### *As accumulation and transportation in the tissues*

The As level in fruit was reported as about 0.66% of the total level of tomato plant (Stazi et al. 2016). Experimental study carried out in the hydroponic growth medium contained 10 mgAs $L^{-1}$ indicated that the As level in the tomato fruits was not toxic or harmful to human consumption (Carbonell-Barrachina, Burlo, and Beneyto 1995). In this study, since the highest As concentration was 3.0 mg $L^{-1}$, the fruit As amount was not planned to study, and therefore the tomato plant was harvested at the flowering period of 10%.

Changes of As amount in the plant depend on the applied As compounds, and rate, time of plant harvest, and plant organ analyzed (Tlustoš et al. 2006). As reported in the literature (Pigna et al. 2012, 2009; Stazi et al. 2016; Tao et al. 2006), accumulation of As in the plant tissues steadily increased with the elevation of applied As concentration.

As levels in the root, shoot and leaf are presented in Figure 3. Up to the concentration of 1.5 mgAs $L^{-1}$, the As accumulation in stem was higher than the leaves. However, accumulation was lower in the stems than in the leaves when the As concentration was equal to 2.0 mg $L^{-1}$ and higher.

With the increase of As concentration in IW, As amounts in the roots and leaves steadily elevated and at the concentration of 3.0 mg $L^{-1}$, reached to about 129.3 and 7.7 mgAs $kg^{-1}$, respectively. The highest As accumulation in the stem was at the concentration of 2.0 mgAs $L^{-1}$ and accumulation decreased with further increase of As dose. However, the leaf As content steadily increased with the elevation of As dose. The transportation of As from the root to leaf was higher than the stem when the concentration was higher than 1.5 mgAs $L^{-1}$. Similar observation was also reported for all applied As doses by Carbonell-Barrachina, Burlo, and Beneyto (1995) and it is explained by the fact that the stems are the transition zone between the roots and leaves.

While the average 90% of the total applied As to plants was accumulated in the roots, remaining portion was transported to the aboveground biomass. Accumulation of As in the root enhanced about four times when the As concentration increased from 0.5 mg $L^{-1}$ to 3.0 mg $L^{-1}$. Because the tomato plant accumulates most of the applied As in its root, it could be characterized as the plant that avoiding

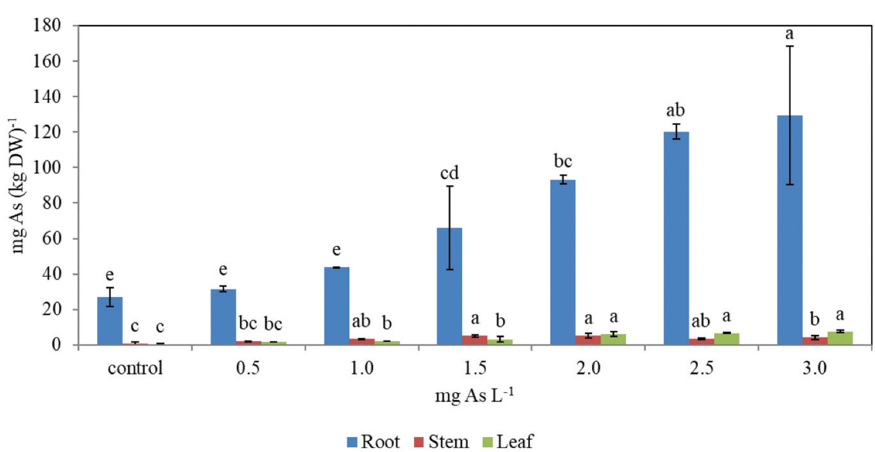


**Figure 3.** Arsenic accumulation in the tomato plant tissues.

As (Tlustoš et al. 2006). By considering the root growth and functions, the applied As loads on the tomato plant could not be considered as the toxic dose. It has been reported that most of the applied As was accumulated in the root of tomato, and regardless of the As compounds, accumulation followed in decreasing order by leaf, stem, and fruits (Tlustoš et al. 2006). As transport from the roots to the aboveground biomass was limited by its high toxicity to the radicular membranes (Carbonell-Barrachina, Burlo, and Beneyto 1995). When the As level in the root is low, As is upward transported and the As level in the aboveground biomass of plant increases with exposure time. High As levels damage the root cells and cause the disruptions of root function and even cellular death. When the toxic level of As in the plants is reached, upward transportation of As is restricted (Carbonell-Barrachina, Burlo, and Beneyto 1995). At the beginning of experiment, As level was too low and the level was steadily increased with irrigation. It is thought that As was upward transported from the root at low loads while high As loads achieved with watering caused the restriction of upward translocation and results in the accumulation of As in the root.

It has been reported that the rice (Lei et al. 2013), ferns (Feng et al. 2015), mangrove species (*Kandelia obovata* and *Aegiceras corniculatum L.*) (Liu et al. 2014; Wu, Hong, and Yan 2015), and common vetch (Aslan 2018) plants also accumulated more As in their root than the aboveground biomass.

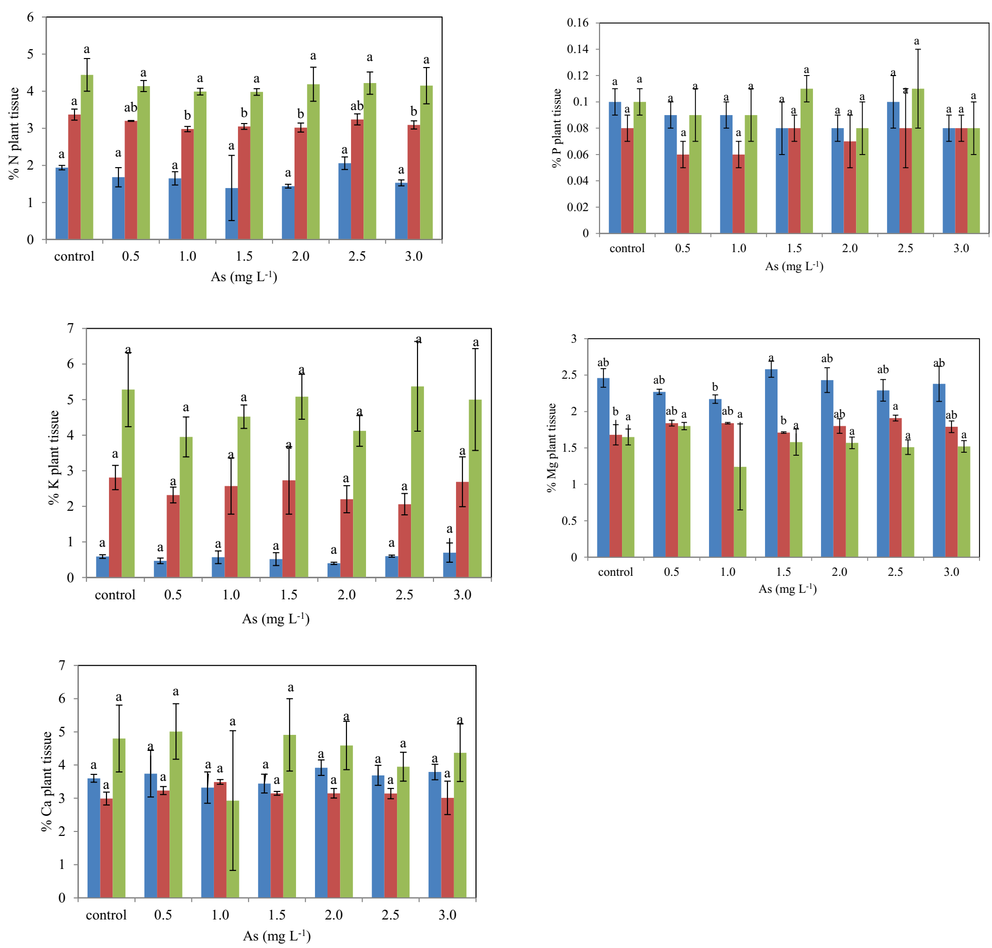


**Figure 4.** Effect of As concentrations on the macro element contents of tomato plant tissues (%).

### Amounts of macroelements in the plant tissues

The macro element compositions of plant tissues are presented in Figure 4. Comparison between the root and aboveground biomass element concentrations showed significantly higher levels of N, K, Mg, and Ca in the aerial parts than in the roots while the level of P was about equal in the tissues.

Concentration of N in the tissues of As applied plants was slightly lower than the tissues of control plant. The N amount in root was the lowest among the tissues and the most of N was transported from the growth medium to the leaves. The root N content of control plant was 1.94% and concentration steadily reduced with the increase of As load. The concentration of N dropped to its lowest level, which was about 1.5%, at the concentration of 3.0 mgAs $L^{-1}$.

Some competitive interactions in the absorption of anionic forms of As and N, which are taken up by the plants, have been reported (Carbonell-Barrachina, Burló-Carbonell, and Beneyto 1997a). According to this possibility, the root N uptake might reduce at high concentrations of As in the solution. Decrease in N uptake by the root of tomato plant was observed for the studied As concentrations in this study.

The N content in the tomato tissues decreased by the application of As-contaminated waters, but the biomass yields slightly increased. The biomass yield increase has been associated with the presence of other limiting factors (Carbonell–Barrachina et al. 1997b) and nutrients (Carbonell–Barrachina et al. 1997b; Klimek-Kopyra et al. 2015). It was reported that the plant yield decreases and produces excessive vegetation when the concentration of N in the plant is high (Carbonell-Barrachina, Burló-Carbonell, and Mataix-Beneyto 1994). Adding of As into the growth medium did not change the N transportation to the above ground biomass of tomato plant unlike for wheat (Quanji et al. 2008) and the common vetch plants (Aslan 2018). As caused the decrease of N content of some plants such as lentil (Ahmed et al., 2012) and *B. Dracunculifolia* (Gilberti et al. 2014), while causing the increase in the green and red *Amaranthus* plants (Roy, Parveen, and Huq 2012).

P content of control plant tissues was determined to be between 0.08 and 0.1 mg $kg^{-1}$. Experimental results indicated that the changes in P amount in tomato tissues were negligible for the applied As doses. Because As addition into the soil may cause phosphate displacement in the plant, positive effect on the plant growth is attributed to the increases of P bioavailability in the soil. The As accumulation at the root is related to the phosphorus due to affinity of As compounds to phosphate channels (Stazi et al. 2016). As in the growth medium affects the P concentration in the plant tissues. The P level reductions were 32% and 11% in the roots and shoots of tomato plant were observed, respectively (Stazi et al. 2016). It was determined that the concentration of P increased from 1.16 g $kg^{-1}$ (control plant non-fertilized with P) to 2.30 g $kg^{-1}$ (at the As concentration of 4.0 mg $L^{-1}$) and from 1.65 g $kg^{-1}$ (control plant with fertilized with P) to 3.40 g $kg^{-1}$, respectively (Pigna et al. 2012). Amounts of P in the tomato tissues are varied according to the As and plant species. For the Marmande cultivar of tomato, while the root P concentration of control plant was about 2.1 g $kg^{-1}$, at the concentrations of 5 mg $L^{-1}$ of As species namely arsenite, arsenate, methylarsonate, and dimethylarsinate, P amount increased to about 2.2 g $kg^{-1}$, 2.9 g $kg^{-1}$, and 3.6 g $kg^{-1}$, respectively (Burló et al. 1999).

Uptake of P by plants is controlled by a high-affinity carrier at low concentration of P in the medium, whereas it is controlled with a low affinity at high concentrations (Reed et al. 2015). At the beginning of the study, the soil P (100 mg $kg^{-1}$ P and 125 mg $kg^{-1}$ K (in $KH_2PO_4$ form)) and available P amounts (34 kg ha $^{-1}$) were very high while As concentration was negligible. The As amount increased gradually in the soil by the irrigation throughout the experiments. When the soil was free of As at the beginning of trial, it is estimated that more P was taken into the root cell and transported to the aboveground biomass, due to the element carriers of tomato have higher affinities to phosphorus than As.

Compared with the control plant, significant K contents variations in the As applied tomato plant tissues were not observed. However, the root K concentration was significantly lower than the leaf and stem. As is taken up by the plant as an anion while cation K is also transported to the plant in order to maintain electroneutrality or ionic balance (Carbonell-Barrachina et al. 1998). The soil Na content was provided by both the IW and the addition of As as the sodium salts. Increase of As load into the soil caused K depression in the root, because of the competition with Na (Carbonell-Barrachina et al. 1998; Marin, Masscheleyn, and Patrick 1992; Wallace, Mueller, and Wood 1980). Because of the low As content of soil at the beginning of experiment, without competing with As, K might be transported from the root to the aboveground biomass. With the increase of As content of soil, the plant K uptake could be restricted and caused the reduction of K amount in the root to lower than the aboveground biomass K contents.

Significant variations in Ca and Mg amounts under studied As loads were not observed. Mg level in the root was higher than the aboveground biomass. While the root Ca amount was higher than the stem, it was lower than the leaf. It has been reported that As caused the increase in Ca and Mg concentrations in the stems. It was assumed that increased Ca level in the tissues might be a protective behavior of plants to the toxicity of metal/loids (Mengel and Kirkby 1987). Increase of Ca concentration in the plants was observed, when the application of organic and/or inorganic As compounds to the plants, such as canola (Cox 1995), (Marin 1989), *spartina alterniflora* (Carbonell-Barrachina et al. 1998), common vetch, and alfalfa (Aslan 2018; Hamid 2019; Ozturk 2018).

Amount of contents (nutrients, protein, carbohydrates, etc.) in plants might vary with environmental conditions, plants species and cultivars, harvest years (Yucel et al. 2014) and planting time (Bingol et al. 2007). Effects of As on the plant growth may vary according to the plant species, level of contamination and toleration ability (Gilberti et al. 2014). As might influence the nutrient uptakes and distributions in the plants through competing directly with nutrients and/or altering metabolic processes and also affect the root and shoot development (Armendariz et al. 2016; Gilberti et al. 2014; Tu and Ma 2004).

### *Amounts of microelements in the tissues*

Among the tissues of tomato, the lowest microelements concentration was determined in the root of control plant (Figure 5). Microelements; Cu, Fe and Mn were predominantly transported to the leaf, except for Zn. However, especially at high As loads, the increase in the amount of microelements in the root was considerably higher compared to the stem and leaf. Mn and Fe amounts in the root

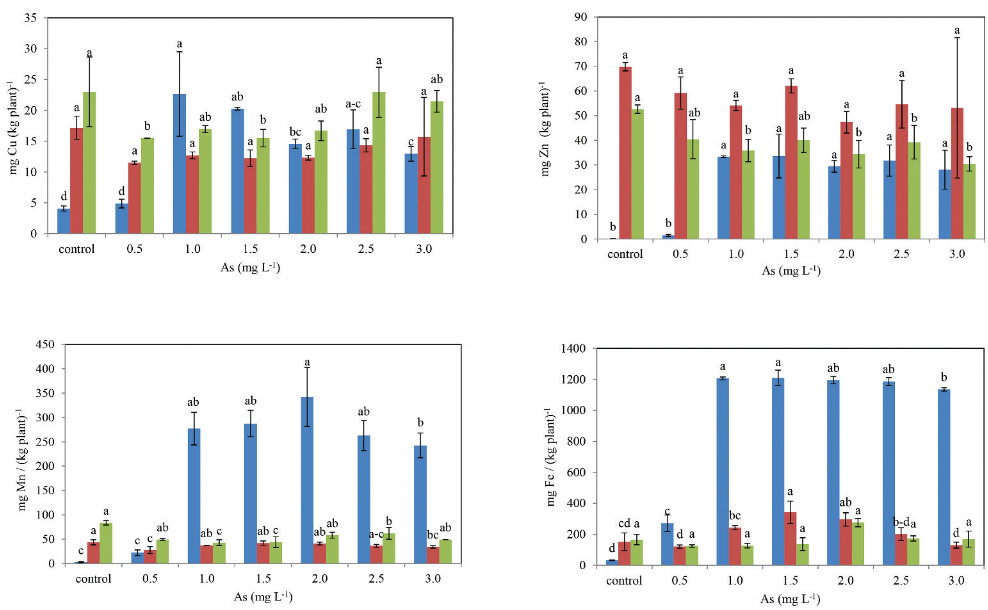


Figure 5. Effect of as concentrations on the micro element contents of tomato plant tissues (mg/kg).

significantly increased with the increase of As concentration and reached to the higher levels than the stem and leaf. Cu content of root was also higher than the stem and leaf for some As loads.

The microelements content of plant roots which were exposed to As was considerably higher than the root of control plant. Although the microelements amount decreased at the As concentration of 3.0 mg $L^{-1}$, they were significantly higher than the control plant root.

When the As concentration was higher than 0.5 mg $L^{-1}$, the microelement concentrations in the root sharply increased, while the stem and leaf concentrations were lower than the control. It was observed that the use of As-contaminated water for the plant growth caused the decrease in microelements concentration in the aboveground biomass.

For the applied As doses, meaningful changes in the microelement concentrations in tissues were not observed. When the tomato plant was grown with the As-contaminated waters, the transportation of microelements from the root to the aboveground biomass was restricted and most of elements taken from the growth medium were kept by the root. Instead of the aboveground biomass, higher accumulation of As or microelements at its root is defined as an exclusion strategy of plant (Wang et al. 2009; Zhang et al. 2002).

## Conclusion

The tomato plant survived and grew normally under the studied As concentrations. While As has not been considered to be an essential element for the plant growth, additions of As at low concentrations into the IW, positively affected the tomato plant growth and increased the biomass production. The stem DW constituted the major portion of the total biomass of tomato plant. Increase of the root/shoot ratio at low As concentrations indicated that the root growth is more than the aboveground biomass. However, at high As concentrations, the root growth inhibition was more compared to the aboveground biomass. Due to about 90% of applied As was accumulated in the root; the tomato could be characterized as the plant avoiding the As. Gradually adding of As to the growth medium with the IW caused the increase of As load to the tomato plant throughout the experimental study. It was determined that the plants grown with the As-contaminated water changed the amounts of elements carried from the root to the aboveground biomass. At the low As loads, more As was transferred from the root to the aboveground plant biomass, while the As transfer from the root was restricted when the high loads were reached. With the increase of As load, it was determined that there was also a change in the transfer of As, P and K from the root to the stem and leaf. Use of As-contaminated water in the tomato plant growth negatively affected the transportation of elements from the root to the aerial parts and it was observed that most of microelements accumulated in the root.

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## References

Abedin, M. J., M. S. Cresser, A. A. Meharg, J. Feldmann, and J. Cotter–Howells. 2002. Arsenic accumulation and metabolism in rice (*Oryza sativa L.*). *Environmental Science & Technology* 36 (5):962–68. doi:10.1021/es0101678.

Ahmed, F. S., I. J. Alexander, M. Mwinyihija, and K. Killham. 2012. Effect of arsenic contaminated irrigation water on *Lens culinaris L.* and toxicity assessment using lux marked biosensor. *Journal of Environmental Science* 24 (6):1106–16. doi:10.1016/S1001-0742(11)60898-X.

Armendariz, A. L., M. A. Talano, C. Travaglia, H. Reinoso, A. L. W. Oller, and E. Agostini. 2016. Arsenic toxicity in soybean seedlings and their attenuation mechanisms. *Plant Physiology and Biochemistry* 98:119–27. doi:10.1016/j.plaphy.2015.11.021.

Aslan, S., 2018. Accumulation of arsenic in alfalfa (*Medicago sativa L.*) and common vetch (*Vicia sativa L.*) plants from arsenic contaminated irrigation water and effects on plant growth, TÜBİTAK - the scientific and technological research council of Turkey, Final Report, 126 p. (in Turkish)

Bashimov, G. 2016. Türkiye'nin domates ihracat performansı ve rekabet gücü. *Alinteri Ziraat Bilimleri Dergisi* 31 (2):1–8. in Turkish. doi:10.28955/alinterizbd.319451.

Bergqvest, C., and M. Greger. 2012. Arsenic accumulation and speciation in plants from different habitats. *Applied Geochemistry* 27 (3):615–22. doi:10.1016/j.apgeochem.2011.12.009.

Bingol, N. T., M. A. Karslı, H. Yılmaz, and D. Bolat. 2007. The effects of planting time and combination on the nutrient composition and digestible dry matter yield of four mixtures of vetch varieties intercropped with barley. *Turkish Journal of Veterinary and Animal Sciences* 31 (5):297–302.

Bremner, J. M. 1965. *Method of soil analysis. part 2. chemical and microbiological methods*, Wise S–1149–1178. USA: American Society of Agronomy Inc. Madison.

Burló, F., I. Guijarro, A. A. Carbonell-Barrachina, D. Valero, and F. Martínez-Saínchez. 1999. Arsenic Species: Effects on and accumulation by tomato plants. *Journal of Agricultural Food Chemistry* 47 (3):1247–53. doi:10.1021/jf9806560.

Cao, X. D., L. Q. Ma, and A. Shiralipour. 2003. Effects of compost and phosphate amendments on arsenic mobility in soils and arsenic uptake by the hyperaccumulator, *Pteris vittata* L. *Environmental Pollution* 126 (2):157–67. doi:10.1016/S0269-7491(03)00208-2.

Caporale, A. G., M. Pigna, A. Sommella, J. J. Dynes, V. Cozzolino, and A. Violante. 2013. Influence of compost on the mobility of arsenic in soil and its uptake by bean plants (*Phaseolus Vulgaris L.*) irrigated with arsenite–contaminated water. *Journal of Environmental Management* 128:837–43. doi:10.1016/j.jenvman.2013.06.041.

Carbonell, A. A., M. A. Aarabi, R. D. DeLaune, R. P. Gambrell, and W. H. Patrick Jr. 1998. Bioavailability and uptake of arsenic by wetland vegetation: Effects on plant growth and nutrition. *Journal of Environmental Science and Health, Part A*.33 (1):45–66. 10.1080/10934529809376717

Carbonell-Barrachina, A., C. F. Burlo, and J. M. Beneyto. 1995. Arsenic uptake, distribution, and accumulation in tomato plants: Effect of arsenite on plant growth and yield. *Journal of Plant Nutrition* 18 (6):1237–50. doi:10.1080/01904169509364975.

Carbonell–Barrachina, A., F. Burlo, A. Burgos–Hernandez, E. Lopez, and J. M. Beneyto. 1997b. The influence of arsenite concentration on arsenic accumulation in tomato and bean plants. *Scientia Horticulturae* 71 (3–4):167–76. doi:10.1016/S0304-4238(97)00114-3.

Carbonell-Barrachina, A., F. Burló-Carbonell, and J. Mataix-Beneyto. 1994. Effect of arsenite on the concentrations of micronutrients in tomato plants grown in hydroponic culture. *Journal of Plant Nutrition* 17 (11):1887–903. doi:10.1080/01904169409364853.

Carbonell-Barrachina, A. A., F. Burló-Carbonell, and J. M. Beneyto. 1997a. Effect of sodium arsenite and sodium chloride on bean plant nutrition (macronutrients). *Journal of Plant Nutrition* 20 (11):1617–33. doi:10.1080/01904169709365361.

Carbonell-Barrachina, A. A., M. A. Aarabi, R. D. DeLaune, R. P. Gambrell, and W. H. Patrick Jr. 1998. The influence of arsenic chemical form and concentration on *Spartina patens* and *Spartina alterniflora* growth and tissue arsenic concentration. *Plant and Soil* 198 (1):33–43. doi:10.1023/A:1004285625998.

Cox, M. C. 1995. Arsenic characterization in soil and arsenic effects on canola growth. Ph.D. Thesis, Louisiana State University, Baton Rouge.

Das, H. K., A. K. Mitra, P. K. Sengupta, A. Hossain, F. Islam, and G. H. Rabbani. 2004. Arsenic concentrations in rice, vegetables, and fish in Bangladesh: A preliminary study. *Environment International* 30 (3):383–87. doi:10.1016/j.envint.2003.09.005.

Demirbas, A., T. Karakoy, H. Durukan, and H. Erdem. 2017. The impacts of the Biochar addition in different doses on yield and nutrient uptake of the chickpea plant (*Cicer Arietinum L.*) under the conditions with without incubation. *Fresenius Environmental Bulletin* 26 (12A):8328–36.

Feng, R. W., X. L. Wang, C. Y. Wei, and S. X. Tu. 2015. The accumulation and subcellular distribution of Arsenic and antimony in four fern plants. *International Journal of Phytoremediation* 17 (4):348–54. doi:10.1080/15226514.2013.773281.

Gilberti, L., A. Menezes, A. C. Rodrigues, G. W. Fernandes, R. L. L. Berbara, and H. B. Marota. 2014. Effects of arsenic on the growth, uptake and distribution of nutrients in the tropical species *Baccharis dracunculifolia DC((Asteraceae). European Journal of Toxicological Sciences* 1:1–27. doi:10.1.1.884.3913&rep=rep1&type=pdf.

Gulz, P. A., S. K. Gupta, and R. Schulin. 2005. Arsenic accumulation of common plants from contaminated soils. *Plant and Soil* 272 (1–2):337–47. doi:10.1007/s11104-004-5960-z.

Guzel, N., K. Y. Gulut, I. Ortas, and H. Ibrikci. 1992. *Toprakta verimlilik analiz yöntemleri laboratuvar el kitabı*, 117. in Turkish: Ziraat Fakültesi Yay.

Hamid, E. 2019. Effects of arsenic contaminated irrigation water on common vetch (*Vicia sativa*) plant growth with the presence of biochar, Master of Science Thesis, Sivas Cumhuriyet University, The Graduate School of Natural and Applied Sciences Department of Environmental Engineering, 75 p. (in Turkish)

Huq, S. I., J. C. Joardar, S. Parvin, R. Correll, and R. Naidu. 2006. Arsenic contamination in food–chain: Transfer of arsenic into food materials through groundwater irrigation. *Journal of Health, Population, and Nutrition* 24 (3):305–16.

Kacar, B., and A. Inal. 2008. Plant analysis. *Nobel Pres* 1241:891.

Klimek-Kopyra, A., A. Baran, T. Zajac, and B. Kuligi. 2015. Effects of heavy metals from polluted soils on the root and nodules formation. *Bulgarian Journal of Agricultural Science* 21 (2):295–99.

Kobya, M., U. Gebologlu, F. Ulu, S. Oncel, and E. Demirbaas. 2011. Removal of arsenic from drinking water by the electrocoagulation using Fe and Al electrodes. *Electrochimica Acta* 56 (14):5060–70. doi:10.1016/j.electacta.2011.03.086.

Lei, M., B. Q. Tie, M. Zeng, P. F. Qing, Z. G. Song, P. N. Williams, and Y. Z. Huang. 2013. An Arsenic-contaminated field trial to assess the uptake and translocation of arsenic by genotypes of rice. *Environmental Geochemistry and Health* 35 (3):379–90. doi:10.1007/s10653-012-9501-z.

Lepp, N. W. 1981. *Effect of heavy metal pollution on plants. Effects of trace metal on plant function*, Vol. 1. London, U.K: Applied Science Publishers.

Li, C. X., S. L. Feng, Y. Shao, L. N. Jiang, X. Y. Lu, and X. L. Hou. 2007. Effects of arsenic on seed germination and physiological activities of wheat seedlings. *Journal of Environmental Science* 19 (6):725–32. doi:10.1016/S1001-0742(07)60121-1.

Liu, C. W., Y. Y. Chen, Y. H. Kao, and S. K. Maji. 2014. Bioaccumulation and translocation of Arsenic in the ecosystem of the Guandu Wetland, Taiwan. *Wetlands* 34 (1):129–40. doi:10.1007/s13157-013-0491-0.

Liu, X., S. Zhang, X. Shan, and Y. G. Zhu. 2005. Toxicity of arsenate and arsenite on germinat ion, seedling growth and amylolytic activity of wheat. *Chemosphere* 61 (2):293–301. doi:10.1016/j.chemosphere.2005.01.088.

Madeira, A. C., A. Varennes, M. M. Abreu, C. Esteves, and M. C. F. Magalhães. 2012. Tomato and parsley growth, arsenic uptake and translocation in a contaminated amended soil. *Journal of Geochemical Exploration* 123:114–21. doi:10.1016/j.gexplo.2012.04.004.

Marin, A. R. 1989. Effect of applications of arsenic and zinc on straighthead disease in rice (*Oryza sativa L.*). M.Sc. Thesis, Louisiana State University, Baton Rouge.

Marin, A. R., P. H. Masscheleyn, and W. H. Patrick Jr. 1992. The influence of chemical form and concentration of arsenic on rice growth and tissue arsenic concentration. *Plant and Soil* 139 (2):175–83. doi:10.1007/BF00009308.

Marin, A. R., S. R. Pezeshki, P. H. Mascheleyn, and H. S. Choi. 1993. Effect of dimethylarsenic acid (DMAA) on growth, tissue arsenic, and photosynthesis of rice plants. *Journal of Plant Nutrition* 16 (865–880):865–80. doi:10.1080/01904169309364580.

Mascher, R., B. Lippmann, S. Holzinger, and H. Bergmann. 2002. Arsenate toxicity: Effects on oxidative stress response molecules and enzymes in red clover plants. *Plant Science* 163 (5):961–69. doi:10.1016/S0168-9452(02)00245-5.

Meharg, A. A., J. Naylor, and M. R. Macnair. 1994. Phosphorus nutrition of arsenate-tolerant and nontolerant phenotypes of velvetgrass. *Journal of Environmental Quality* 23 (2):234–38. doi:10.2134/jeq1994.00472425002300020003x.

Meharg, A. A., and M. R. Macnair. 1990. An altered phosphate uptake system in arsenate-tolerant *Holcus lanatus L. New Phytologist* 116 (1):29–35. doi:10.1111/j.1469-8137.1990.tb00507.x.

Mengel, K., and E. A. Kirkby. 1987. *Principles of plant nutrition*. Worblaufen-Bern, Switzerland: International Potasnich Institute.

Miteva, E. 2002. Accumulation and effect of arsenic on tomatoes. *Journal Communications in Soil Science and Plant Analysis* 33 (11–12):1917–26. doi:10.1081/CSS-120004832.

Mohan, D., and C. U. Pittman Jr. 2007. Arsenic removal from water/wastewater using adsorbents—A critical review. *Journal of Hazardous Materials* 142 (1–2):1–53. doi:10.1016/j.jhazmat.2007.01.006.

Murphy, J., and J. P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta* 27:31–36. doi:10.1016/S0003-2670(00)88444-5.

Mutlu, M. 2010. *Arsenic pollution and health risk assessment in the groundwater of Simav Plain, Kütahya*. İzmir: Graduate School of Natural and Applied Sciences Dokuz Eylül University.

Niazi, N. K., I. Bibi, A. Fatimah, M. Shahid, M. T. Javed, H. Wang, Y. S. Ok, S. Bashir, B. Murtaza, Z. A. Saqib, et al. 2017. Phosphate-assisted phytoremediation of arsenic by *Brassica napus* and *Brassica juncea*: Morphological and physiological response. *International Journal of Phytoremediation* 19(7):670–78. 3. doi:10.1080/15226514.2016.1278427.

Ozturk, M. 2018. Accumulation of arsenic in alfalfa (*Medicago sativa*) and vetch plants (*Vicia sativa*) and soil from arsenic contaminated irrigation water and its effect on plants growth, PhD Thesis, Department of Environmental Engineering, Sivas Cumhuriyet University, The Graduate School of Natural and Applied Sciences, 144p.

Ozturk, M., S. Aslan, and A. Demirbas. 2020. Effect of domestic wastewater sewage sludge applications on yield and nutrient uptake of tomato plant. *Turkish Journal of Agriculture - Food Science and Technology* 8 (7):1508–16.

Pigna, M., A. G. Caporale, V. Cozzolino, C. F. López, M. L. Mora, A. Sommella, and A. Violante. 2012. Influence of phosphorus on the arsenic uptake by tomato (*Solanum lycopersicum L*) irrigated with arsenic solutions at four different concentrations. *Journal of Soil Science and Plant Nutrition* 12 (4):775–84. doi:10.4067/S0718-95162012005000031.

Pigna, M., V. Cozzolino, A. Violante, and A. A. Meharg. 2009. Influence of phosphate on the arsenic uptake by wheat (*Triticum durum* L.) irrigated with arsenic solutions at three different concentrations. *Water, Air, and Soil Pollution* 197 (1–4):371–80. doi:10.1007/s11270-008-9818-5.

Quanji, L. I. U., H. U. Chengxiao, T. A. N. Qiling, S. U. N. Xuecheng, S. U. Jingjun, and Y. Liang. 2008. Effects of arsenic on arsenic uptake, speciation, and nutrient uptake by winter wheat (*Triticum aestivum L.*) under hydroponic conditions. *Journal of Environmental Science* 20 (3):326–31. doi:10.1016/S1001-0742(08)60051-0.

Rahman, M. A., H. Hasegawa, M. M. Rahman, M. A. Mazid Miah, and A. Tasmin. 2008. Arsenic accumulation in rice (*Oryza sativa L.*); Human exposure through food chain. *Ecotoxicology and Environmental Safety* 69 (2):317–24. doi:10.1016/j.ecoenv.2007.01.005.

Reed, S. T., T. Ayala–Silva, C. B. Dunn, and G. G. Gordon. 2015. Effects of Arsenic on nutrient accumulation and distribution in selected ornamental plants. *Agricultural Sciences* 6 (12):1513–31. doi:10.4236/as.2015.612145.

Roy, S., Z. Parveen, and S. I. Huq. 2012. Effect of arsenic on the nutrient uptake pattern of Amaranthus. *Dhaka University Journal of Biological Sciences* 21 (1):87–96. doi:10.3329/dujbs.v21i1.9748.

Salem, N. M., L. S. Albanna, and A. M. Awwad. 2016. Toxic heavy metal accumulation in tomato plant (*Solanum lycopersicum*). *ARPN Journal of Agricultural and Biological Science* 11 (10):399–404.

Singh, N., and L. Q. Ma. 2006. Arsenic speciation, and arsenic and phosphate distribution in arsenic hyperaccumulator *Pteris vittata L.* and non-hyperaccumulator Pteris ensiformis L. *Environmental Pollution* 141 (2):238–46. doi:10.1016/j.envpol.2005.08.050.

Smedley, P. L., and D. G. Kinniburgh. 2002. A review of the source, behaviour and distribution of arsenic in natural waters. *Applied Geochemistry* 17 (5):517–68. doi:10.1016/S0883-2927(02)00018-5.

Stazi, S. R., C. Cassaniti, R. Marabottini, F. Giuffrida, and C. Leonardi. 2016. Arsenic uptake and partitioning in grafted tomato plants. *Horticulture, Environment, and Biotechnology* 57 (3):241–47. doi:10.1007/s13580-016-0036-6.

Sushant, K. S., and A. K. Ghosh. 2010. Effect of arsenic on photosynthesis, growth and its accumulation in the tissues of *Allium cepa* (Onion). *International Journal of Environmental Engineering and Management* 1 (1):39–50. http://resolver.tudelft.nl/uuid:6c347854-340e-4a08-aa21-c2bff981eda5 .

Tao, Y., S. Zhang, W. J. Yuan, and X. Q. Shan. 2006. Effect of oxalate and phosphate on the release of arsenic from contaminated soils and arsenic accumulation in wheat. *Chemosphere* 65 (8):1281–87. doi:10.1016/j.chemosphere.2006.04.039.

Tlustoš, P., J. Száková, D. Pavlíková, and J. Balík. 2006. The response of tomato (*Lycopersicon esculentum*) to different concentrations of inorganic and organic compounds of arsenic. *Biologia, Bratislava* 61 (1):91–96. doi:10.2478/s11756-006-0013-0.

TSI, Turkish Statistic Institute. 2017. Crop production statistic, statistical tables and dynamic search vegetables cultivated for their fruits, http://www.turkstat.gov.tr .

Tu, C., and L. Q. Ma. 2002. Effects of arsenic concentrations and forms on arsenic uptake by the hyperaccumulator ladder brake. *Journal of Environmental Quality* 31 (2):641–47. doi:10.2134/jeq2002.6410.

Tu, S., and L. Q. Ma. 2004. Comparison of arsenic and phosphate uptake and distribution in arsenic hyperaccumulating and non-hyperaccumulating fern. *Journal of Plant Nutrition* 27 (7):1227–42. doi:10.1081/PLN-120038545.

Violante, A., and M. Pigna. 2002. Competitive sorption of arsenate and phosphate on different clay minerals and soils. *Soil Science Society of America Journal* 66 (6):1788–96. doi:10.2136/sssaj2002.1788.

Wallace, A., R. T. Mueller, and R. A. Wood. 1980. Arsenic phytotoxicity and interactions in bush bean plants grown in solution culture. *Journal of Plant Nutrition* 2 (1–2):111–13. doi:10.1080/01904168009362747.

Wang, S., Z. Nan, X. Liu, Y. Li, S. Qin, and H. Ding. 2009. Accumulation and bioavailability of copper and nickel in wheat plants grown in contaminated soils from the oasis, northwest China. *Geoderma* 152 (3–4):290–95. doi:10.1016/j.geoderma.2009.06.012.

WHO. 2001, http://www.who.int/inf-fs/en/fact210.html .

Wu, G.-R., H.-L. Hong, and C.-L. Yan. 2015. Arsenic accumulation and translocation in mangrove (*Aegiceras corniculatum L.*) grown in arsenic contaminated soils. *International Journal of Environmental Research and Public Health* 12 (7):244–7253. doi:10.3390/ijerph120707244.

Yucel, C., D. Yucel, M. R. Akkaya, and A. E. Anlarsal. 2014. Bazı ümitvar yaygın fiğ (*Vicia sativa L.*) genotiplerinde kalite özellikleri. *Kahramanmaras Sütçü Imam Üniversitesi Tarim Ve Doga Dergisi* 17 (1):8–14.

Zhang, W., Y. Cai, C. Tu, and L. Q. Ma. 2002. Arsenic speciation and distribution in an arsenic hyperaccumulating plant. *Science of the Total Environment* 300 (1–3):167–77. doi:10.1016/S0048-9697(02)00165-1.

Zhao, F. J., S. P. McGrath, and A. Meharg. 2010. Arsenic as a food chain contaminant: Mechanisms of plant uptake and metabolism and mitigation strategies. *Annual Review of Plant Biology* 61 (1):535–59. doi:10.1146/annurev-arplant-042809-112152.