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Combined Effect of Arsenic and Phosphorus on Mineral Element Concentrations of Sunflower

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This study was undertaken to examine the combined effect of soil-applied phosphorus (P) and arsenic (As) on P, As, potassium (K), calcium (Ca), magnesium (Mg), silicon (Si), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), titanium (Ti), rubidium (Rb), strontium (Sr), barium (Ba), lantanium (La), and cerium (Ce) concentrations of sunflower plants under glasshouse conditions determined by polarized-energy-dispersive x-ray fluorescence (PEDXRF). Three levels of As (0, 30, and 60 mg kg^{-1}) and four levels of P (50, 100, 200, and 400 mg kg^{-1}) were applied to soil-grown plants. Increasing levels of both As and P significantly increased As concentrations in the plants. Plant growth was significantly reduced with increased As supply regardless of applied P levels. Arsenic toxicity caused significant increases in the concentrations of Mn, La and Ce, but it decreased K, Ca, Mg, Si, Fe, Zn, Cu, Rb, and Sr concentrations. Applied P increased the concentrations of Ti, Sr, and Ba and decreased Zn and Cu. In conclusion, the use of P fertilizers in As-contaminated soils should be carefully considered in respect to increased As, Ti, Sr, and Ba availability and reduced Zn and Cu availability.

Keywords Arsenic, mineral elements, phosphorus, sunflower

Introduction

Knowledge of arsenate and phosphate interactions are important to better understand their uptake and accumulation by plants, because of their similarities in chemical behavior (Tu and Ma 2003). Arsenic (As), a nonessential element for plants and animals, occurs naturally in the environment through geological activities. The element is most commonly found in the oxidized states arsenite [As(III)] and arsenate [As(V)]. Arsenic contamination is widespread because of anthropogenic activities such as smelting operations, fossil fuel combustion (Nriagu and Pacyna 1988; Ochiai 1995), As-based agrochemicals and fertilizers, and disposal of municipal and industrial wastes (Requejo and Tena 2006). Arsenic-enriched soils are major sources of contamination in the food chain and

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water supplies, and this is of great environmental concern because As is known to be a carcinogen and mutagen (Fayiga and Ma 2006). Studies on As toxicity have focused mainly on arsenate because it is the dominant form in aerobic soils and plants take up As mainly as arsenate. Arsenic is analogous to phosphorus (P); both have similar electron configurations and chemical properties and compete for the same uptake carriers in the root plasmalemma (Ullrich-Eberius, Sanz, and Novacky 1989; Meharg and MacNair 1992; Meharg and Hartley-Whitaker 2002). In soil, arsenate and phosphate compete with each other for soil sorption sites, and this competition results in a reduction in their sorption by soil and an increase in solution concentrations (Gao and Mucci 2001; Smith, Naidu, and Alston 2002). Knowledge of arsenate and phosphate interactions is important for a better understanding of their uptake and accumulation by plants because of the similarities in chemical behaviors of the two ions. Tu and Ma (2003) have reported competitive effects between arsenate and phosphate in Chinese brake fern. They observed that phosphate substantially increased plant biomass and arsenate accumulation by alleviating arsenate phytotoxicity at high arsenate levels. They also reported that high doses of As decreased phosphate concentrations of the plants. However, phosphate has also been shown to increase As availability in soil, leading to increased plant uptake (Peryea 1991; Fayiga and Ma 2006).

The use of x-ray fluorescence (XRF) to measure As is a quick and unobtrusive technique. The XRF method allows samples to be measured in situ with sensitivity to the level of parts per million and is oxidation-state-specific (Parsons, Aldrich, and Gardea-Torresdey 2002). Polarized-energy-dispersive x-ray fluorescence (PEDXRF) analysis is important in studying As because it reveals the most probable chemical state and atom arrangement (Smith et al. 2005; Smith, Koch, and Reimer 2008). X-ray techniques have been used to characterize As uptake within plants by many researchers (Pickering et al. 2000; Castillo-Michel et al. 2007; Smith, Koch, and Reimer 2008); XRF spectroscopy is one of the primary applications in x-ray science and has been used as an analytical tool for plant analysis (Ivanova, Djingova, and Kuleff 1999; Hodson and Sangster 2002; Anjos et al. 2002; Chuparina and Gunicheva 2003). It is normally used to determine the concentrations of different elements in a sample and has the advantages of good sensitivity, nondestructiveness, and simple relations to the fundamental physics of atom-radiation interaction (Anjos et al. 2002).

Previous studies have mainly expanded on the toxicology and uptake of As in As hyperaccumulator plants such as ferns (Tu et al. 2004; Tu and Ma 2003; 2004; Srivastava et al. 2005); less is known about As toxicity mechanisms in relation to interactions with P in field crops. Therefore, this study was designed to investigate the effect of As and P interactions on sunflower growth and on concentrations of As and P. In addition to this, understanding the relationships between As and other elements within the plants will help us better manage plant growth strategies under the conditions of As contamination, so we also determined the concentrations of essential and nonessential elements in relation to As and P interaction. In addition, the human body needs mineral elements to maintain healthy life. Therefore, it is essential to determine the concentration of both essential and nonessential elements in plants for their nutritive value.

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Materials and Methods

Growth Conditions and Treatments

Sunflower (*Helianthus annus* L. cv. 'Meric 2002') plants were grown from 8 May 2007 to 28 June 2007 in a naturally lighted glasshouse at the Faculty of Agriculture, Ankara University (39° 57′ 44.51″ N; 32° 51′ 46.95″ E). Some characteristics of the soil were as follows: water-holding capacity (WHC) 240 g kg^{-1}, texture clay loam, calcium carbonate ($CaCO_3$) 57.3 g kg^{-1}, pH (1:2.5 water) 7.98, electrical conductivity (EC) 0.44 dS m^{-1}, organic matter 7.60 g kg^{-1}, and total nitrogen (N) 0.92 g kg^{-1}. The concentrations of ammonium acetate (NH_4OAc)–extractable potassium (K), calcium (Ca), and sodium (Na) were as follows (mg kg^{-1}): 470, 2566, and 64, respectively. The level of sodium bicarbonate ($NaHCO_3$)–available P was 8.54 mg kg^{-1}, and levels of diethylenetriaminepentaacetic acid (DTPA)–extractable zinc (Zn), iron (Fe), copper (Cu), and manganese (Mn) were as follows (mg kg^{-1}): 0.72, 6.36, 1.01, and 24, respectively. Water-soluble As was 2.14 mg kg^{-1}. Detailed description of the experimental soil is given in Table 1. Plastic pots lined with polyethylene were filled with 3 kg of air-dried soil. Treatments, with three replicates, consisted of four levels of P [50, 100, 200, and 400 mg P kg^{-1} soil (as monopotassium phosphate (KH_2PO_4))], and three As rates [0, 30, and 60 mg As kg^{-1} (as sodium arsenate; $NaAsO_2$)]. All these treatments were applied and incorporated into the soil before seed sowing. Potassium concentrations were balanced with potassium sulfate (K_2SO_4). Sunflower seeds were sown at the rate of eight seeds to each pot. After a good stand of plants developed, they were thinned to four plants per pot. For the basal N fertilization, 150 mg kg^{-1} of N was applied as ammonium nitrate (NH_4NO_3) before sowing. During the experiment, soil was kept at approximately 70% of WHC by watering with tap water. At the end of the experiment, plants were harvested. Shoots were washed once with tap water and twice in deionized water. They were then dried in a forced-air oven at 60 °C until they reached constant mass.

Elemental Analysis

After determination of dry weights, all samples were ground into fine powder in an agate mortar. They were then sieved to pass through 200-μm mesh. Sieved 2.0-g subsamples were mixed with 0.4 g of wax. Pellets were then produced by pressing a 32-mm pellet at a pressure of 15 tons. Leaf standards (K04-BCR-61 and K04-BCR-62, European Community Bureau of Reference) and USGS sediment standards GBW-7109 and GBW-7309 (U.S. Geological Survey, Washington, D.C.) were similarly pressed into pellets and used for quality assurance.

Mineral element concentration was determined by PEDXRF. The spectrometer used in this study was a Spectro XLAB 2000 PEDXRF spectrometer, which was equipped with a rhodium (Rh) anode x-ray tube and 0.5-mm beryllium (Be) side window. The detector of the spectrometer is Si (Li) cooled by liquid N_2 with a resolution of $<$150eV at Mn Kα, 5000 cps. The spectrometer configures d as source beam, scattered beam, and fluorescent beam, all at mutually orthogonal angles (Ivanova, Djingova, and Kuleff 1999; Chuparina and Gunicheva 2003).

The sample measurements by PEDXRF were mainly ordered by three types of targets. The first target is suitable for the light elements with $Z > 22$, and this target is named the Barkla target. The second target is an oriented crystal target suitable for light elements up to $Z = 22$, and is named the Bragg target. The third target is a pure

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Table 1. Some physical and chemical properties of the experimental soil

Properties (method)	Amount/quantification
WHC	240 g kg^{-1}
Texture	Clay loam
$CaCO_3$ (Scheibler)	57.3 g kg^{-1}
pH (1:2.5 water)	7.98
EC (1:2.5 water)	0.44 dS m^{-1}
Organic matter (W.black)	7.60 g kg^{-1}
Total N (Kjeldahl)	0.92 g kg^{-1}
K (NH_4OAc-extractable)	0.47 g kg^{-1}
Total K (X-RF)	14.7 g kg^{-1}
Ca (NH_4OAc-extractable)	2.56 g kg^{-1}
Total Ca (X-RF)	33.8 g kg^{-1}
Na (NH_4OAc-extractable)	64.0 mg kg^{-1}
Total Na (X-RF)	0.29 g kg^{-1}
P ($NaHCO_3$-available)	8.54 mg kg^{-1}
Total P (X-RF)	0.76 g kg^{-1}
Zn (DTPA-extractable)	0.72 mg kg^{-1}
Total Zn (X-RF)	77.2 mg kg^{-1}
Fe (DTPA-extractable)	6.36 mg kg^{-1}
Total Fe (X-RF)	38.9 g kg^{-1}
Cu (DTPA-extractable)	1.01 mg kg^{-1}
Total Cu (X-RF)	33.7 mg kg^{-1}
Mn (DTPA-extractable)	24 mg kg^{-1}
Total Mn (X-RF)	0.76 g kg^{-1}
Total S (X-RF)	0.46 g kg^{-1}
Total Mo (X-RF)	4.40 mg kg^{-1}
Total Mg (X-RF)	11.5 g kg^{-1}
Total Al (X-RF)	51.8 g kg^{-1}
Total Si (X-RF)	178.1 g kg^{-1}
Total Cl (X-RF)	0.58 g kg^{-1}
Total Ti (X-RF)	4.53 g kg^{-1}
Total V (X-RF)	0.12 g kg^{-1}
Total Cr (X-RF)	0.15 g kg^{-1}
Total Ni (X-RF)	63.9 mg kg^{-1}
Total Co (X-RF)	28.0 mg kg^{-1}
Total Ga (X-RF)	15.7 mg kg^{-1}
Water-soluble As	2.14 mg kg^{-1}
Total As (X-RF)	19.1 mg kg^{-1}
Total Br (X-RF)	4.20 mg kg^{-1}
Total Rb (X-RF)	65.8 mg kg^{-1}
Total Sr (X-RF)	272.7 mg kg^{-1}
Total Zr (X-RF)	191 mg kg^{-1}
Total U (X-RF)	6.60 mg kg^{-1}
Total Th (X-RF)	8.70 mg kg^{-1}
Total Ba (X-RF)	458.7 mg kg^{-1}
Total La (X-RF)	29.3 mg kg^{-1}
Total Ce (X-RF)	66.0 mg kg^{-1}

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metal target suitable for specific elements or small groups of adjacent elements. Additionally, this target is useful for generating Compton scatter peaks, which can be used for matrix correction (Ivanova, Djingova, and Kuleff 1999; Chuparina and Gunicheva 2003).

Statistical Analysis

The experiments were set up in a completely randomized design with three replicate pots. Analysis of variance was performed on the data, and significant differences among treatment means were compared by descriptive statistics ($\pm$ SE) and by Duncan's multiple range tests.

Results

Plant Growth, As, and P Concentrations

The interaction between P and As and the effect of P treatment on the dry weight of sunflower plants were not significant, whereas increasing levels of As significantly reduced dry weights of the plants (Figure 1).

As expectedly, P concentration of the sunflower plants was increased by increasing levels of applied P, and the greatest levels of applied As ($60\,mg\,kg^{-1}$) significantly reduced P concentration of the plants. Arsenic concentration in the plants was also significantly increased by increased levels of applied As and P. The greatest As concentration was observed in the highest P and As treatment as $62.5\,mg\,kg^{-1}$ (Table 2).

Concentration of K, Ca, Mg, and Si

The interaction between P and As and the P treatments had no significant effect on the concentrations of K, Ca, Mg, and Si. However, application of As caused decreased K, Ca, magnesium (Mg), and silicon (Si) concentrations (Table 2).

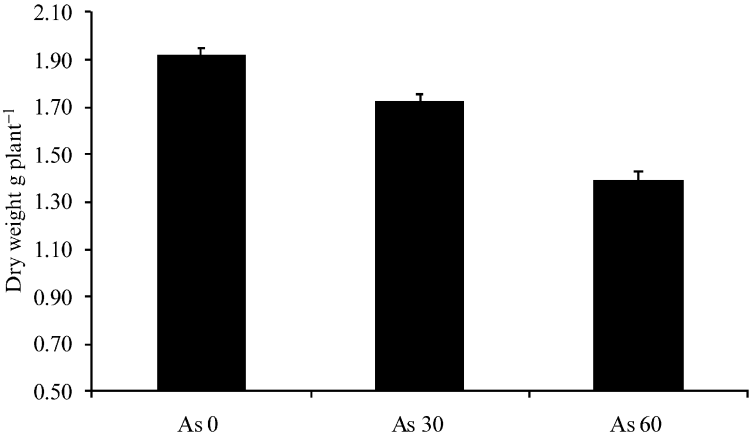


Figure 1. Effect of increasing levels of As on the dry weight of sunflower plants. The values are means of three replicates $\pm$ standard error (SE).

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Table 2. Interactive effect of soil-applied P and As on P, As, K, Ca, Mg, and Si concentrations of sunflower

P treatments ($mg\,kg^{-1}$)	As treatments ($mg\,kg^{-1}$)	P ($g\,kg^{-1}$)	As ($mg\,kg^{-1}$)	K ($g\,kg^{-1}$)	Ca ($g\,kg^{-1}$)	Mg ($g\,kg^{-1}$)	Si ($g\,kg^{-1}$)
50	0	2.21	0.50 f	96.4	21.1	4.32	4.50
	30	1.78	24.2 e	87.4	20.4	3.95	3.97
	60	1.40	38.3 cd	74.1	17.0	3.56	2.94
100	0	2.87	0.60 f	92.5	21.5	4.20	4.95
	30	2.87	29.5 e	87.2	22.1	4.27	3.81
	60	2.16	43.6 bc	79.1	19.1	4.03	2.76
200	0	4.66	0.83 f	92.7	22.1	4.31	4.55
	30	4.60	31.6 de	87.6	20.5	4.64	3.88
	60	3.69	50.8 b	83.3	19.5	4.13	3.11
400	0	7.95	0.50 f	108	24.5	6.05	7.39
	30	6.19	28.9 e	88.0	21.5	4.49	3.87
	60	5.41	62.5 a	76.3	19.7	3.64	2.84
LSD, $p < 0.05$		—	7.75	—	—	—	—
50		1.80 d	21.0 c	86.0	19.5	3.95	3.80
100		2.64 c	24.6 bc	86.3	20.9	4.17	3.88
200		4.32 b	27.8 ab	87.9	20.7	4.36	3.85
400		6.52 a	30.6 a	90.8	21.9	4.72	4.70
LSD, $p < 0.05$		0.78	4.47	—	—	—	—
	0	4.42 a	0.61 c	97.4 a	22.4 a	4.72 a	5.35 a
	30	3.86 a	28.6 b	87.5 b	21.2 a	4.34 ab	3.91 b
	60	3.17 b	48.8 a	78.2 b	18.8 b	3.84 b	2.91 c
LSD, $p < 0.05$		0.68	3.88	9.77	1.57	0.71	0.86
F values	P × As int.	1.13^{ns}	4.76**	0.61^{ns}	0.72^{ns}	1.33^{ns}	1.97^{ns}
	P treatment	60.2**	7.28**	0.32^{ns}	2.45^{ns}	1.39^{ns}	1.59^{ns}
	As treatment	7.29**	331**	8.21**	10.8**	3.31*	17.3**

*$P < 0.05$.
**$P < 0.01$.
Ns, nonsignificant.
Notes. The values are means of three replicates. Means for P treatments and As treatments are shown under the P × As interaction means. F values for the P × As interaction, P treatment, and As treatment are shown. Different letters in each column for P × As interaction, P treatment, and As treatment separately represent significant difference at the $P < 0.05$ level based on Duncan's multiple range tests.

Concentration of Fe, Mn, Zn, and Cu

Phosphorus × As interaction had no significant effect on the concentrations of Fe, Mn, Zn, and Cu (Table 3). Phosphorus treatments also had no significant effect on the concentrations of both Fe and Mn, and increasing levels of As reduced Fe but increased Mn concentrations (Table 3).

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Table 3. Interactive effect of soil-applied P and As on Fe, Mn, Zn, and Cu concentrations of sunflower

P treatments ($mg\,kg^{-1}$)	As treatments ($mg\,kg^{-1}$)	Fe ($mg\,kg^{-1}$)	Mn ($mg\,kg^{-1}$)	Zn ($mg\,kg^{-1}$)	Cu ($mg\,kg^{-1}$)
50	0	75.2	69.9	15.7	12.2
	30	64.0	90.0	14.9	11.2
	60	52.6	93.0	11.2	8.83
100	0	72.9	62.8	12.2	11.4
	30	52.1	87.4	11.6	11.6
	60	50.3	89.3	9.17	9.67
200	0	61.6	63.9	10.6	11.1
	30	54.9	78.3	10.3	11.6
	60	54.6	80.3	9.77	9.67
400	0	51.3	68.3	10.8	10.5
	30	56.9	79.7	9.33	11.1
	60	53.6	80.9	8.20	7.80
LSD, $p < 0.05$		—	—	—	—
50		63.9	84.3	13.9 a	10.8 a
100		58.4	79.9	11.0 b	10.9 a
200		57.0	74.2	10.2 bc	10.8 a
400		53.9	76.3	9.44 c	9.79 b
LSD, $p < 0.05$		—	—	1.23	0.85
	0	65.2 a	66.2 b	12.34 a	11.31 a
	30	57.0 ab	83.8 a	11.53 a	11.39 a
	60	52.8 b	85.9 a	9.58 b	8.99 b
LSD, $p < 0.05$		8.50	6.85	1.07	0.74
F values	As × P Int.	1.46^{ns}	0.57^{ns}	1.39^{ns}	1.16^{ns}
	P treatment	1.54^{ns}	2.67^{ns}	21.5**	3.20*
	As treatment	4.76**	21.2**	14.9**	29.2**

*$P < 0.05$.
**$P < 0.01$.
Ns, nonsignificant.
Notes. The values are means of three replicates. Means for P treatments and As treatments are shown under the P × As interaction means. F values for the P × As interaction, P treatment, and As treatment are shown. Different letters in each column for P × As interaction, P treatment, and As treatment separately represent significant difference at the $P < 0.05$ level based on Duncan's multiple range tests.

Zinc concentration of sunflower plants was significantly reduced by the increasing levels of P treatments. Copper concentration of the plants was also significantly reduced at the greatest P level. However, there was a decrease in concentration of Zn and Cu with increase in As, although this was only clear in the $60\,mg\,kg^{-1}$ As treatment (Table 3).

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Concentrations of Ti, Rb, Sr, Ba, La, and Ce

The concentrations of Ti, Rb, Sr, Ba, and rare-earth elements (REEs) of La and Ce of sunflower plants grown with different levels of P and As are presented in Table 4.

Table 4. Interactive effect of soil-applied P and As on Ti, Rb, Sr, Ba, La, and Ce concentration of sunflower.

P treatments ($mg\,kg^{-1}$)	As treatments ($mg\,kg^{-1}$)	Ti ($mg\,kg^{-1}$)	Rb ($mg\,kg^{-1}$)	Sr ($mg\,kg^{-1}$)	Ba ($mg\,kg^{-1}$)	La ($g\,kg^{-1}$)	Ce ($mg\,kg^{-1}$)
50	0	7.10	7.17	103	37.8	25.0	31.3
	30	10.5	6.30	101	37.3	17.6	30.5
	60	7.57	5.77	91	34.2	32.7	36.4
100	0	7.40	7.57	105	37.5	16.2	17.7
	30	5.57	7.00	108	44.3	43.8	55.3
	60	6.67	6.17	98	51.0	53.3	78.4
200	0	15.8	7.63	112	43.6	22.3	35.1
	30	8.80	7.07	106	51.4	41.1	63.7
	60	4.77	6.77	104	48.1	45.4	53.4
400	0	17.9	7.40	128	57.5	30.2	28.4
	30	19.9	6.90	117	58.1	27.9	27.9
	60	16.7	5.83	112	70.3	50.9	73.1
LSD, $p < 0.05$		—	—	—	—	—	—
50		8.39 b	6.41	98 c	36.4 c	25.1	32.7
100		6.54 b	6.91	103 bc	44.3 bc	37.8	50.5
200		9.80 b	7.16	107 b	47.7 b	36.3	50.8
400		18.2 a	6.71	119 a	61.9 a	36.3	43.1
LSD, $p < 0.05$		5.48	—	7.39	8.26	—	—
	0	12.1	7.44 a	112 a	44.1	23.4 b	28.1 b
	30	11.2	6.82 b	108 a	47.8	32.6 b	44.4 ab
	60	8.93	6.13 c	101 b	50.9	45.6 a	60.3 a
LSD, $p < 0.05$		—	0.52	6.40	—	12.02	16.90
F values	As × P Int.	0.87^{ns}	0.31^{ns}	0.50^{ns}	0.98^{ns}	1.20^{ns}	1.98^{ns}
	P treatment.	7.51**	2.35^{ns}	11.71**	14.21**	1.53^{ns}	1.60^{ns}
	As treatment	0.99^{ns}	13.50**	6.50**	1.93^{ns}	7.30**	7.74**

*$P < 0.05$.
**$P < 0.01$.
Ns, nonsignificant.
Notes. The values are means of three replicates. Means for P treatments and As treatments are shown under the P × As interaction means. F values for the P × As interaction, P treatment, and As treatment are shown. Different letters in each column for P × As interaction, P treatment, and As treatment separately represent significant difference at the $P < 0.05$ level based on Duncan's multiple range tests.

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Phosphorus × As interaction had no significant effect on Ti, Rb, Sr, Ba, La, and Ce concentrations of the plants. Increased levels of applied P increased Ti, Sr, and Ba concentrations of the plants. At the greatest P treatments, these increases were more pronounced. Applied As significantly decreased Rb and Sr while increasing REEs of La and Ce (Table 4).

Discussion

Arsenate and phosphate are chemical analogs and are taken up by plants by the same uptake system. However, according to previous reports, the effects of each ion on the other can be either positive or negative depending on growing conditions (Tu and Ma 2004). In hydroponic systems with As hyperaccumulating plants, phosphate has long been reported to suppress plant As uptake (Tu and Ma 2003). In soil, however, the influence of phosphate on As phytotoxicity is variable, because soil properties affect the availability of phosphate and arsenate (Tu and Ma 2003). Such As–P interactions in soil-grown crops need further investigation, and to the best of our knowledge, this is the first report that comprehensively describes the effects of As–P interactions on ionic imbalances in sunflower grown in calcareous soil.

In the present study, increasing levels of applied As significantly reduced sunflower growth regardless of applied P levels. Phytotoxicity of As has been previously reported for As-hyperaccumulating ferns (Tu and Ma 2003, 2004) and also bean (Stoeva, Berova, and Zlatev 2005), turnip (Carbonell-Barrachina et al. 1999), and maize (Requejo and Tena 2006). Even though applied P levels had no significant effect on As phytotoxicity, As concentration of sunflower plants was significantly increased by P application. This result is the opposite of the findings of Meharg and Macnair (1994): that because phosphate and arsenate compete for the high-affinity phosphate transporter and phosphate binds to it more efficiently than arsenate, the high phosphate concentration in the soil favors uptake of phosphate rather than arsenate. However, the result is in good agreement with our previous work with chickpea plants, in which we reported that increased As concentration in response to increasing level of P treatments (Gunes et al. 2008), and the findings of Tu and Ma (2003), who reported increasing soluble As in soil solution in response to increasing P additions to the soil. Tu and Ma (2003) suggested that applying more P fertilizers enhanced total As accumulation by Chinese brake fern because of the displacement of sorbed arsenate from the soil by phosphate. In the present study, we used calcareous soil with a high pH and therefore a high P-fixation capacity. It seems likely that increasing levels of applied P increased the soluble As concentration in the soil solution and consequently As concentration in the sunflower plants. Other studies on arsenate–P interaction in soils have also shown changes in concentrations in soil solution through competition for sorption sites (Gao and Mucci 2001; Smith, Naidu, and Alston 2002).

In the present work, P concentration of the sunflower plants was decreased by the increased As levels. This can be explained with competition for uptake between arsenate and phosphate; it might be expected that high As concentrations in the tissues caused lower P concentrations. Previously, reduced P concentration in As hyperaccumulator *Pteris vittata* L. tissues by As was also well documented by Tu and Ma (2003, 2004).

Arsenic-induced ionic imbalances have not been widely studied. However, Fayiga, Ma, and Rathinasabapathi (2007) published a work describing effects of Ca,

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K, P, NH_4, and Cl on As accumulation in *Pteris vittata* L., and Hartley and Lepp (2008) studied the effect of Fe oxide on the As uptake of spinach and tomato. In these works, Ca, K, P, NH_4, Cl, and Fe oxides were found to reduce As uptake of plants. In the present study, we determined the effect of As–P interaction on mineral imbalances in sunflower plants. Application of As gave increased concentrations of Mn and REEs of La and Ce in the sunflower plants. These increases can be attributed to the concentration effect in the plants because of growth reduction caused by As. In contrast to this, As reduced K, Ca, Mg, Si, Fe, Zn, Cu, Rb, and Sr concentration of the sunflower plants. Interaction between As, Fe, and Zn was previously reported by Hartley and Lepp (2008) and Das, Sur, and Das (2008). They suggested that the As contamination in soils may be reduced by applying Fe oxides and Zn sulfates to the soil. Applied Fe and Zn might cause fixation of As as Zn and Fe-arsenate, unavailable to plants. However, it is more difficult to postulate how the presence of As could influence uptake of K, Ca, Mg, Si, Cu, Rb, and Sr from the soil.

Mineral element concentration of plants is important for human and animal nutrition. Essential and nonessential element concentrations of sunflower plants presented in this study are similar to the data published elsewhere (Gunes et al. 2008; Inal et al. 2009). Increasing levels of applied P significantly increased Ti, Sr, and Ba concentrations, and Zn and also Cu concentrations were negatively affected by P. High levels of available P in soil or high application rates of phosphate are known to induce Zn deficiency in plants grown on soils with low available Zn (Gianquinto et al. 2000; Srinivasarao et al. 2006). The interaction of P and Zn, called P-induced Zn deficiency, has been well established in chickpea cultivars (Srinivasarao et al. 2006), bean (Singh, Karumanos, and Stewart 1988), and wheat cultivars (Imtiaz et al. 2006).

Conclusion

Applied P significantly increased As concentration of sunflower plants, probably by making As in the soil more available. Exposure to As resulted in lowered growth and mineral imbalances, which increased Mn, La, and Ce but decreased K, Ca, Mg, Si, Fe, Zn, Cu, Rb, and Sr concentrations of the sunflower plants. The use of P fertilizers in As-contaminated soils should be carefully considered in respect to increased As and Ti, Sr, and Ba availability and reduced Zn and Cu availability. It was hoped that this study provides a basis for developing strategies for reducing the risk associated with elemental toxicity, including As, and essential and nonessential element composition. The data obtained from this study will supply a database for further work on how to maintain sustainable and healthy plant production.

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