Effects of Phosphorus Fertilizer Type and Rate on Plant Growth and Heavy Metal Content in Lettuce (*Lactuca sativa* L.) Grown on Calcareous Soil

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ABSTRACT

A field experiment was carried out to investigate effects of phosphorus (P) fertilizer type and rate on plant growth and toxic heavy metals contents (Cd, Pb and As) in head lettuce plant on calcareous soil. Four P fertilizer types {single super phosphate (SSP), di ammonium phosphate (DAP), mono ammonium phosphate (MAP) and a local phosphate rock (PR)} were applied as main plot treatments and five rates of each fertilizer (0, 125, 250, 375, and 500 kg P_2O_5/ha) as subplot treatments. P fertilizer type, rate and their interaction showed a significant effect on the fresh plant yield and dry matter production. Both P fertilizer type and rate didn't induce significant differences in heavy metals contents of the plant and soil, as they were within tolerable limits. The examined P fertilizers constitute no potential risks for heavy metals accumulation in the soil-plant system over short-term.

Keywords: *Lactuca sativa*, phosphorus, fertilizers, heavy metals, calcareous soil, transfer coefficient.

INTRODUCTION

Phosphorous (P) is highly needed to establish and maintain crops especially in calcareous soils, where its natural availability is very low (Siam et al., 2008). It is considered an essential nutrient for plant growth and development and its deficiency is representing a major constraint to crop production worldwide (George and Richardson, 2008).

Therefore, farmers use P fertilizers to increase growth and productivity. However, soils in arid and semi arid regions are considered alkaline; they are in most cases calcareous (Mohammad and Rawajfih, 1997). Under these conditions, P availability becomes limited due to the precipitation and sorption reactions of P, which compel farmers to apply P fertilizers annually at high rates (Mohammad and Malkawi, 2004).

Cadmium (Cd), lead (Pb) and arsenic (As) have been reported to be available in P fertilizers as the most important heavy metals of health concern (Minnesota Department of Health, 1999). These metals are considered toxic (Wolnik, et, al., 1983; Minnesota Department of Health, 1999). Cadmium and Pb have a tendency to accumulate in plants and animals as well (Wolnik, et, al., 1983). While As, Pb and Cd are classified as carcinogenic (Minnesota Department of Health, 1999; Mensah, et al., 2009). Therefore, attention has been given to the long-term application of P fertilizers and their potential to build up heavy metals in soil, and, subsequently in plants which pose a threat to the human health and environment (Huang, et al., 2004; Thomas et al., 2012).

Low levels of As, Cd and Pb are usually detected in

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soils, but fertilizers application for long period can increase soil levels of these metals (Chen et al., 2008). Agricultural soils used for vegetables are highly fertilized and the accumulation of heavy metals is more probable (Chen, et al., 2008). According to Alfaiyz, et al., (2007), if heavy metal concentration is 2-3 times higher than the natural, the soil can be regarded as contaminated soil. They found that Cd content in the leaves of lettuce affected by P fertilizer application as its level increased from 0.07 ppm (control treatment) to 0.13 ppm at 720 kg P_2O_5/ha. Williams and David (1976) indicated that P fertilizers application increased the Cd contents of some agricultural soils 10 times more than the background values and caused an appreciable increase in Cd concentrations of grown plants subsequently. He and Singh (1994), also, reported that, under greenhouse conditions, application of phosphorus fertilizers containing Cd tended to increase Cd contents in fertilized crops including lettuce. Moreover, Zarcinas et al. (2004) indicated that P fertilizers application at high rates was associated with increases in Cd contents of agricultural soils. Furthermore, Osztoics et al. (2005) reported that the application of either SSP (0.9 ppm Cd content) or PR (18.3 ppm Cd content) increased the available Cd levels of the investigated acidic soils. Additionally, Ghrefat et al. (2012) pointed out that fertilizers used in agricultural production are responsible for the high average levels of Cd (4.6 ppm) and Pb (58.4 ppm) in soils along the Zerqa river in Jordan.

Some of P fertilizers applied in Jordan including phosphate rocks have been found to contain heavy metals like Cd, Pb and As. Javied, et al. (2009) indicated that Jordan phosphate rock used primarily in P fertilizers production contains some of heavy metals like Cd (10.9 ppm) and Pb (32.5 ppm). Therefore, agricultural soils in Jordan might be subjected to the contamination with such toxic heavy metals as a result of continuous use of P fertilizers.

Lettuce (*Lactuca sativa* L.), a leafy vegetable, demonstrated a high capacity to absorb Cd from the soil and accumulate it in its tissues (Smical, et al., 2008; Yargholi et al., 2008). Therefore, lettuce was used as a test plant in this study.

The objectives of this study were to determine effects of application of four types of P fertilizers at different rates on plant growth and heavy metals contents of Cd, Pb and As in lettuce grown on calcareous soil.

MATERIALS AND METHODS

Experimental Site

A field experiment was conducted during the growing season 2011/2012 at The Deir Alla Station of the National Center for Agricultural Research and Extension (NCARE), that is located at 32^o 11.559' North and 35^o 37.216' East, and 226.8 m below sea level.

The experimental site history indicated it was of low agricultural activity compared with other sites in the station, and cultivated with vegetables and field crops as trials. The texture of the soil is clay (13.9% sand, 31.9% silt, and 54.2% clay). Climatic data collected from the meteorological station of Deir-Alla indicated that the minimum and maximum temperatures during the growing season were 8.5 and 32.0 ^oC, respectively. Meanwhile, the minimum and maximum relative humidity values recorded were 15.0 and 98.0 %, respectively.

Plant Material

Seedlings of iceberg lettuce (*Lactuca sativa* L. cv. Robinson) were used as test crop. These seedlings were 27-days-old, which obtained from a commercial nursery.

Irrigation Water and Fertilizer Analysis

Chemical analysis for the irrigation water used in the field experiment was conducted to determine pH, electrical conductivity (EC), major cations and anions according to Chapman and Pratt (1982). Heavy metals

(Cd, Pb and As) were, also, measured using Atomic Absorption Spectrophotometer (Model Varian, Spectr. AA-200, Australia), with instrument detection limits for Cd, Pb and As as 0.002 ppm, 0.01 ppm and 0.2 ppb, respectively.

Nitrogen, P, K and heavy metals (Cd, Pb, and As) contents in the four types of P fertilizers used in this study were determined according to Horwitz and Latimer (2005). Heavy metals were, also, determined using Atomic Absorption Spectrophotometer.

Cultural Practices and Treatments

The soil of the experimental site (9 m x 41 m = 369 m^2) was plowed, rotivated, leveled and divided into subplots with dimensions of 1.5 x 1.5 m. Each subplot consisted of three planting rows spaced at 50 cm, while spacing within a row was 20 cm with 7 plants per row. Four P fertilizers types were assigned to main plots: Single super phosphate (SSP), Di ammonium phosphate (DAP), Mono ammonium phosphate (MAP) and a local phosphate rock (PR) in a finely ground form (powder) obtained from a local phosphate mine (Rusaifa). Meanwhile, five fertilizer rates of each fertilizer were assigned to subplots: R1 = 0, R2 = 125, R3 = 250, R4 = 375, and R5 = 500 kg P_2O_5/ha.

Phosphorus fertilizers were applied during soil preparation and mixed thoroughly with the soil up to a depth of about 5 cm for each subplot according to specified treatments. Urea was used as a source of N which was applied at a rate of 200 Kg N/ha. One-fourth of the N fertilizer was mixed with P fertilizers before transplanting. Meanwhile, 50 and 100 kg N of the N fertilizer were applied 3 and 6 weeks after transplanting, respectively. Subplots were covered with black plastic mulch after installing a drip irrigation system of 16 mm lateral lines and on line drippers at 20 cm spacing of 4 lh^{-1} discharge rate. Three lateral lines were located at each subplot spaced at 50 cm.

Twenty tensiometers were installed at 15, 30, and 45 cm depths and distributed over the four replicates in the field to monitor soil moisture tension. Irrigation was applied just before transplanting which was carried out on October 23 2011. Irrigation henceforth was applied just before soil moisture tension reached 40 cbar (30-35 cbar) according to Hanson, et al. (2000). The total amount of water received by the crop from both irrigation and rainfall was 394.6 mm.

Soil Chemical and Physical Analysis

Composite soil samples at 0-20 and at 20-40 cm depths were collected from the experimental site for chemical analysis. Collection was performed just after soil preparation and before transplanting. The samples were air dried, crushed and passed through a 2 mm sieve. Paste extract were subjected to the analysis of soil pH and salinity according to Bower and Wilcox (1965), CEC according to Chapman (1965), organic matter according to Allison (1965), calcium carbonate (calcimeter method) according to Allison and Moodie (1965), total N (Kjeldhal method) according to Bremner (1965), available P (using spectrophotometer) according to Olsen and Dean (1965), available K (using flame photometer) according to Pratt (1965) and soil texture (hydrometer method) according to Day (1965). Soil 0.005 M diethylenetriaminepentaacetic acid (DTPA)-extractable Cd and Pb, and 0.5 M $NaHCO_3$-extractable As were determined according to methods described by Lindsay and Norvell (1978) and Shiowatana et al. (2001), respectively.

At the end of the growing season and for each replicate, composite soil samples at the two depths (0-20 and 20-40 cm) had been collected from the mid line of each subplot from which the three plants were taken. These samples were air dried, crushed and passed through a 2 mm sieve for heavy metals analysis as mentioned before.

Some chemical and physical properties of the soil of the experimental site at the start of the growing season at the 0-20 and 20-40 cm depths are listed in **Table 1.**

Total heavy metals contents for composite soil samples from the experimental site using acid digestion (HNO_3 then HCl) method were determined according to Kimbrough and Wakakuwa (1989). The results are also shown in **Table 1**.

Table 1. The average values of some chemical and physical properties of the soil in the experimental site (0-20 and 20-40 cm depths) before the beginning of the growing season 2011/2012.

Soil characteristic	**Soil depth (cm)**	
	0-20	**20-40**
pH (Paste extract)	7.8±0.1	7.8±0.1
EC (Paste extract)	3.38±0.42	3.30±0.81
$CaCO_3$ (%)	20.07±3.65	20.38±4.25
Organic Matter (%)	1.42±0.37	1.28±0.50
CEC (meq/100 g)	47.13±0.70	47.14±0.88
Texture	Clay	Clay
Total N (%)	0.112±0.008	0.118±0.011
Available P (ppm)	25.8±2.3	22.0±2.9
Available K	749.7±29.0	704.7±46.3
DTPA-Extractable Cd	0.063±0.019	0.055±0.017
DTPA-Extractable Pb	1.68±0.14	1.64±0.14
$NaHCO_3$-extractable As	4.40±1.63	3.91±1.84
Total Cd▪ (ppm)	7.8	7.4
Total Pb▪ (ppm)	40.1	30.1
Total As▪ (ppm)	25.3	23.5

▪:The maximum permissible levels for Cd, Pb and As in agricultural soils are 3, 300 and 50 ppm, respectively (Warren et al., 2003).

Plant Harvesting and yield

Harvesting was started 56 days after transplanting. The three mid plants from the middle line of each subplot were cut above the soil surface after reaching the marketable size. Fresh weight of the three plants sample (leaves and stems) per treatment was recorded and then rinsed with tap and distilled water and dried in an oven at 65 ^{0}C for 72 hrs and their dry matters weight was determined. The head fresh and dry weights were averaged over the three plants. The average plant yield (kg/m^2) was calculated by dividing the average plant fresh weight by the plant spacing (0.20 m x 0.50 m = 0.10 m^2). After that, the dried materials of the three plants were ground by stainless steel grinder to pass a 1 mm stainless steel sieve for chemical analysis. The water content of the plant on the average was found to be 96 %; the dry matter was 4 %.

Plant Heavy Metals Analysis

Each plant sample of 1.0 g weight was transferred into a silica crucible and placed in a muffle furnace at 500 ^{0}C for 4 hrs in a dry-ashing process. The crucible was left to cool and then 5 ml of 6 N HCl was added. After that, the crucible was placed on a hot plate and digested to obtain a clear solution. The residue was dissolved in 0.1 N HNO_3 and transferred to a 50 ml volumetric flask and completed to the mark with deionized water. Standard solutions of the heavy metals (Cd, Pb, and As) were prepared from the stock solutions (1000 ppm) by dilution with 0.1 N HNO_3 for linearity inspection. Heavy metals contents were determined using Atomic Absorption Spectrophotometer. Measurements for heavy metals were taken in triplicate and averaged.

Transfer Coefficient

Transfer coefficients (TC) of the heavy metals were determined according to Huang et al., (2003). It equals the ratio of the metal concentration in the plant (dry mass basis) to the DTPA extractable metal (Cd and Pb) in the soil (dry mass basis).

Experimental Design and Statistical Analysis

The design of the field experiment was a split-plot arrangement in a randomized complete block design (RCBD) with four replicates. Analysis of variance (ANOVA) and mean separation according to least significant difference (LSD) at the 5% level of probability were conducted for the results using SAS version 9.0 for Windows (SAS Institute Inc., 2002).

RESULTS AND DISCUSSION

Irrigation Water and Phosphorous Fertilizers

The levels of the heavy metals (Cd, Pb and As) in the irrigation water were below the instrument detection limits. However, the pH and salinity of the irrigation water were 8.1 and 2.4 dS/m, respectively. Major cations and anions concentrations were as follows: Ca^{2+}, 5.8; Mg^{2+}, 5.0; Na^{+}, 12.5; K^{+}, 0.86; Cl^{-}, 14.1; HCO_3^{-}, 0.95 meq/l; P, 2.7; NO_3^{-}, 48.2 ppm. Generally, the levels of the heavy metals in the P fertilizers used in the current trial (**Table 2**) are considered below the critical limits (20, 500 and 75 ppm for Cd, Pb and As, respectively), according to the Canadian Standards (Heckman, 2006) and other countries like Australia, Austria, Belgium, Japan and Sweden (Chen et al., 2008; Molina et al., 2009).

Table 2. Chemical analysis of the P fertilizers used in the field experiment.

Phosphorous Fertilizer	Nutrients			Heavy metals		
	N	P_2O_5	K_2O	Cd	Pb	As
	%			(ppm)		
DAP	18.2	44.0	0	7.9	2.1	2.8
MAP	12.3	61.1	0	0.5	1.8	43.0
SSP	0	17.4	0	6.1	2.2	5.5
PR	0	29.5	0	9.2	1.2	15.7

Effect of P Fertilizers on Plant Growth and Yield

The lettuce plant grown on the calcareous soil of the experimental site was responsive to P application. Fresh weight (g/head), yield (kg/m^2) and dry matter production (g/m^2) of the plant were significantly affected by the P fertilizer type, rate and their interaction. MAP fertilizer was superior to the other water soluble P fertilizers; meanwhile PR was the lowest in the effectiveness rank: MAP>DAP=SSP>PR. The application rates of 500 and 350 kg P_2O_5/ha of MAP significantly induced higher values of growth parameters than those of the other treatments (**Table 3**). However there were no significant increments in the fresh weight and yield when applying P beyond 350 kg P_2O_5/ha rate of MAP. At the moment of using lower P rates to reduce the costs of P application and conserve the natural reserves of phosphate without compromising the plant yield, positive environmental consequences through minimizing pollution could also be attained (Boutraa, 2009).

The results agree with the findings of many researchers (Shrivastava et al., 2007; Csatho et al., 2009) which indicated that the effectiveness of PR was less than those of the other kinds of water soluble P fertilizers.

Table 3. Effect of P fertilizer type and rate interaction on the fresh weight (g/head), yield (kg/m^2) and dry matter (g/m^2) of lettuce head.

Fertilizer type	Fertilizer Rate	Fresh weight	Yield	Dry matter
	(kg P_2O_5/ha)	(g/head)	kg/m^2	g/m^2
DAP	0	576.28 e	5.76 e	230.51 e
	125	730.93 cd	7.31 cd	292.37 cd
	250	774.13 c	7.74 c	309.64 c
	375	854.78 b	8.54 b	341.89 b
	500	878.03 b	8.78 b	351.21b
SSP	0	585.48 e	5.85 e	234.19 e
	125	717.50 d	7.17 d	287.00 d
	250	730.33 cd	7.30 cd	292.14 cd
	375	834.68 b	8.34 b	333.87 b
	500	851.35 b	8.51 b	340.52 b
MAP	0	556.38 e	5.56 e	222.55 e
	125	842.55 b	8.42 b	337.03 b
	250	859.33 b	8.59 b	343.73 b
	375	983.25 a	9.83 a	393.30 a
	500	1005.88 a	10.05 a	402.34 a
PR	0	552.00 e	5.52 e	220.80 e
	125	545.58 e	5.45 e	218.23 e
	250	578.10 e	5.78 e	231.23 e
	375	573.78 e	5.73 e	229.50 e
	500	577.00 e	5.77 e	230.80 e
$LSD_{0.05}$		55.90	0.56	22.36

Within each column, means with different letter(s) are significantly different according to LSD test at 0.05 level of probability.

Effect of P Fertilizers on the Soil and Plant Contents of Heavy Metals

In comparison with the maximum permissible levels for the heavy metals in agricultural soils, the total Cd level in the soil of the experimental site (**Table 1**) exceeded the standard levels (Warren et al., 2003; Heckman, 2006). Whereas the total Pb and total As are within the accepted standards (Warren et al., 2003).

On the other hand, P fertilizer type and rate demonstrated no significant effects on soil DTPA-extractable Cd and Pb, and soil $NaHCO_3$-extractable As at both soil depths (**Table 4**). The respective average values at the surface and subsurface soil depths for Cd were 0.059 and 0.060 ppm, for Pb were 0.741 and 0.827 ppm, and for As were 13.55 and 12.41 ppm. This could be attributed to the small amounts of added heavy metals from the applied P fertilizers in a single growing season relative to what originally exist in the soil.

The results were confirmed by the findings of other researchers (Mohammad and Athamneh, 2004; Rusan and Athamneh, 2009) which indicated that there were no detected increments in soil DTPA-extractable Cd and Pb concentrations by DAP application (80 kg P_2O_5 ha^{-1} rate) to calcareous soils.

However, the potential sources of the heavy metals other than P fertilizers might be pesticides application (Warren et al., 2003; Intawongse and Dean, 2006; Ghrefat et al., 2012). Heavy metals from polluted air and leaded fuel, also, could be considered responsible for the soil contamination with heavy metals (Jaradat and Momani, 1999; Kachenko and Singh, 2006).

Table 4. Effect of P fertilizer type and rate on the soil DTPA-extractable Cd, Pb and $NaHCO_3$- extractable As at the end of the growing season (2011/2012).

Fertilizer type	Cd		Pb		As	
	(ppm)					
	Soil depth (cm)					
	0-20	20-40	0-20	20-40	0-20	20-40
DAP	0.062 ab	0.058a	0.720 a	0.845 ab	15.06 a	12.50 ab
SSP	0.055 b	0.063 a	0.715 a	0.865 a	14.59 ab	12.25 bc
MAP	0.063 a	0.061 a	0.792 a	0.844 ab	12.28 b	12.15 c
PR	0.056 ab	0.059 a	0.735 a	0.754 b	12.25 b	12.75 a
Mean	0.059	0.060	0.741	0.827	13.55	12.41
LSD $_{0.05}$	0.007	0.005	0.160	0.102	2.65	0.33
Fertilizer rate (kg P_2O_5/ha)						
0	0.056 a	0.057 b	0.831 a	0.830 ab	13.42 a	12.19 a
125	0.062 a	0.058 ab	0.719 a	0.820 ab	13.85 a	12.51 a
250	0.057 a	0.061 ab	0.719 a	0.745 b	13.45 a	12.41 a
375	0.057 a	0.063 a	0.680 a	0.908 a	13.35 a	12.54 a
500	0.062 a	0.063 a	0.754 a	0.831 ab	13.66 a	12.40 a
Mean	0.059	0.060	0.741	0.827	13.55	12.41
LSD $_{0.05}$	0.008	0.005	0.179	0.114	2.96	0.37

Significance level						
Fertilizer type	Ns	Ns	Ns	Ns	Ns	Ns
Fertilizer rate	Ns	Ns	Ns	Ns	Ns	Ns
Fertilizer type x rate	Ns	Ns	Ns	Ns	Ns	Ns

Ns : Not significant;

Within each column, means with different letter(s) are significantly different according to LSD test at 0.05 level of probability.

Similarly, P fertilizer type and rate didn't induce significant variation in Cd and Pb contents in the plant. The plant As level, however, was not detected. The average concentrations of Cd and Pb in the plant (on the dry mass basis) were 1.58 and 7.56 ppm, respectively. On the other hand, the average concentrations of Cd (0.063 ppm) and Pb (0.302 ppm) in the plant tissue (on fresh mass basis) were within the tolerable levels of 0.2 and 0.3 mg kg^{-1} fresh weight for leafy vegetables (EC, 2006), as shown in **Table 5**. Meanwhile, the plant is safe with respect to the As as it was not detected, and given that the acceptable level of As is 1 mg kg^{-1} fresh weight (Warren et al., 2003).

Actually, high soil pH of the experimental site induces immobilization of the heavy metals and limits their bioavailability to the plant (Bolan et al., 2003, a; Castro et al., 2009). Such conditions enhance formation of strongly bound metal complexes and precipitation of metal hydroxides. The concentration of the heavy metals in the immobile and less available organic and inorganic fractions, in turn, increases (Bolan et al., 2003, b). Furthermore, the huge variability presented in the field might produce difficulty to detect significant differences among P fertilizers treatments regarding soil heavy metals content (Warren et al., 2003).

It can be concluded that the P fertilizers investigated in this study didn't affect negatively the quality of the lettuce head plant with respect to heavy metal contents, namely, Cd, Pb and As.

Table 5. Effect of P fertilizer type and rate on the lettuce head plant contents of Cd, Pb and As (on fresh mass basis).

Fertilizer type	Cd•	Pb•	As•
	(ppm)		
DAP	0.061 a	0.264 a	▪<I.D.L.
SSP	0.065 a	0.312 a	<I.D.L.
MAP	0.066 a	0.313 a	<I.D.L.
PR	0.061 a	0.321 a	<I.D.L.
Mean	0.063	0.302	<I.D.L.
LSD $_{0.05}$	0.006	0.058	
Fertilizer rate (kg P_2O_5/ha)			
0	0.061 b	0.318 a	<I.D.L.
125	0.064 ab	0.267 a	<I.D.L.
250	0.068 a	0.316 a	<I.D.L.
375	0.063 ab	0.332 a	<I.D.L.
500	0.061 ab	0.279 a	<I.D.L.
Mean	0.063	0.302	<I.D.L.
LSD $_{0.05}$	0.007	0.065	
Significance level			
Fertilizer type	Ns	Ns	Ns
Fertilizer rate	Ns	Ns	Ns
Fertilizer type x rate	Ns	Ns	Ns

Ns: Not significant;

▪: Below instrument detection limit (I.D.L.): The instrument detection limits for Cd, Pb and As are 0.002 ppm, 0.01 ppm and 0.2 ppb, respectively.

Within each column, means with different letter(s) are significantly different according to LSD test at 0.05 level of probability;

•: The tolerable levels for Cd, Pb and As in leafy vegetables on fresh mass basis are 0.2, 0.3 and 1 $mgkg^{-1}$, respectively.

Transfer Coefficient for the Heavy Metals in the Plant

Fertilizer type and rate did not induce any significant variations among transfer coefficient (TC) values of Cd and Pb in the lettuce head plant, as indicated in **Table 6**. As expected, the average Cd TC (27.89) was relatively higher than that of Pb (12.03). The high mobility of Cd in the soil-plant system compared with that of Pb might be responsible for this discrepancy (Adelekan and Abegunde, 2011). This actually implies that Cd is more bioavailable to the plant than Pb (Intawongse and Dean, 2006). Thus, the potential risk of human exposure to Cd is much higher than that to Pb (Huang, et al., 2004).

Table 6. Effect of P fertilizer type and rate on the lettuce head plant transfer coefficient for Cd, Pb and As at the end of the growing season (2011/2012).

Fertilizer type	Cd	Pb	As
	Transfer coefficient		
DAP	25.16 b	10.79 a	▪N.D.
SSP	30.66 a	11.98 a	N.D.
MAP	27.22 ab	12.39 a	N.D.
PR	28.54 ab	12.96 a	N.D.
Mean	27.89	12.03	N.D.
LSD $_{0.05}$	4.22	4.57	
Fertilizer rate (kg P_2O_5/ha)			
0	27.44 a	10.11 a	N.D.
125	26.52 a	10.23 a	N.D.
250	30.62 a	13.55 a	N.D.
375	28.91 a	14.43 a	N.D.
500	25.97 a	11.82 a	N.D.
Mean	27.89	12.03	N.D.
LSD $_{0.05}$	4.72	5.11	
Significance level			
Fertilizer type	Ns	Ns	
Fertilizer rate	Ns	Ns	
Fertilizer type x rate	Ns	Ns	

▪ : Not determined (N.D.);
Ns: Not significant;
Within each column, means with different letter(s) are significantly different according to LSD test at 0.05 level of probability.

CONCLUSIONS

The investigated P fertilizers in this study contained heavy metals impurities of Cd, Pb and As, but still within acceptable limits. The lettuce head plant grown at the experimental site was responsive to P fertilizers additions. Yield parameters (fresh weight and dry matter production) of the plant were influenced significantly by the P fertilizer type x rate interaction. However, heavy metals contents of the plant were within the permissible levels; the quality of the plant with respect to the heavy metals content was not affected by the investigated fertilizers. Thus, these P fertilizers can be used with no potential risks of heavy metals accumulation in the soil-plant system over the short-term. However, such accumulation over the long-term and under continuous and high rates of P fertilizers application is expected. This implies that environmental pollution and health risk, through entering the heavy metals into the food chain, in the future, are likely.

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تأثير استعمال الأسمدة الفوسفاتية على نمو ومحتوى العناصر الثقيلة في نبات الخس المزروع بالتربة القلوية

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ملخــص

أجريت تجربة حقلية لدراسة تأثير الأسمدة الفوسفاتية على نمو ومحتوى محصول الخس من العناصر الثقيلة (Cd، Pb و As) في تربة قلوية. تم استعمال أربعة أنواع من الأسمدة الفوسفاتية (سوبر فوسفات أحادي، امونيوم فوسفات ثنائي، امونيوم فوسفات أحادي، و صخر فوسفاتي محلي) كمعاملات رئيسة وخمسة مستويات من الفوسفور (0 ,125, 250, 375 و 500 كغم P_2O_5/هكتار) كمعاملات فرعية. كان لنوع السماد ومستوى التسميد والتفاعل بينهما تأثيرا معنويا على الإنتاج و المادة الجافة للنبات. في حين لم يكن هناك تأثيرا معنويا لنوع السماد ومستوى التسميد على محتوى النبات والتربة من العناصر الثقيلة، حيث كان تركيزها ضمن الحدود المقبولة والآمنة في التربة والنبات. كذلك لا تشكل الأسمدة الفوسفاتية المدروسة خطورة بالنسبة لتراكم العناصر الثقيلة في التربة والنبات جراء استعمال هذه الأسمدة على المدى القصير.

الكلمات الدالة: الخس، الفوسفور، الأسمدة، المعادن الثقيلة، معامل الانتقال.

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