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Heavy Metal and Phosphorus Contents of Jew's Mallow (*Corchorus olitorius* L.) Plants Grown on Soil Amended with Phosphate, Bio and Organic Fertilizers

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors designed the study, wrote the protocol. Both author managed the experimental process, performed the chemical analysis, and wrote the first draft of the manuscript. Also, both author performed the statistical analysis, managed the literature searches and read and approved the final manuscript.

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ABSTRACT

This study was conducted to assess the impact of different chemical, organic and bio fertilizers on growth, phosphorus and heavy metal (Zn, Cd, Co, Cu and Ni) contents of Jew's mallow (*Corchorus olitorius* L.) plants. Pot and field experiments were carried out in the screen house and experimental farm, Faculty of Agriculture, South Valley University, Egypt in the summer season of 2013 and 2014, respectively. The experimental treatments included rock phosphate, superphosphate and triple superphosphate fertilizers singly or in combination with phosphate dissolving bacteria (PDB) and/or filter mud cake (FMC) as biological and organic amendment to the soil. They had a completely randomized design and complete block randomized design with three replications for pot and field experiment, respectively.
The results of both experiments showed that, although the second and third cuts gave greater plant growth than that of the first cut, only the first cut of the plants received rock phosphate fertilizer

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either alone or in a combination with PDB and FMC or their mixture contained the lowest level of heavy metals. The results indicated that, only in the first cut with plants receiving rock phosphate fertilizer either alone or combined with PDB, FMC and PDB+FMC recorded the lowest Zn content values of 45.0, 56.0, 64.0 and 94.0 mg / kg, respectively which were below permissible limit, while the second and third cut Zn concentration in plants with different combination treatments was higher than the permissible levels. Also, rock phosphate treatment alone or with PDB in the first cut showed lowest plant Ni content (10 mg/kg) which on the border of the permissible level. The cobalt level in *C. olitorius* plants that received all phosphate fertilizer types (ranged from 7.0 to 16 mg/Kg) were below the permissible limit. The Cu level in investigated plants received all phosphate fertilizer types with different combination treatments with the three cuts were within the acceptable range. Also the results showed that plants grown on the soil amended with natural rock phosphate alone or in combination with phosphate dissolving bacteria recorded lowest Cd values. It is recommended to use the natural rock phosphate in combination with phosphate dissolving bacteria for growing Jew's mallow plants instead of chemical phosphate fertilizers and the plants should be harvested by pulling the whole plant including roots from the soil after 40 days from planting to avoid high heavy metal uptake by the plants of the second and third cuts which had a possible health impacts.

Keywords: Heavy metals; phosphate fertilizer; rock phosphate; phosphate dissolving bacteria.

1. INTRODUCTION

The entry of different heavy metals into human food chain *via* various agricultural products has been given increased attention in recent years due to their possible health impacts.

Applications of phosphate fertilizers are required for optimum crop growth and adequate production of food and fiber. Tropical soils are often low in the available phosphorus and therefore require different inputs of phosphorus (P) for optimum plant growth, especially for rapid growing of crops such as leafy vegetables [1]. Phosphate fertilizers are widely used in the agricultural activities in Egypt to supply crops with adequate amounts of P for growth and development.

These phosphate fertilizers are produced from phosphate rocks which contain apatite minerals [2]. All Phosphate rocks contain hazardous elements including heavy metals, such as cadmium (Cd), chromium (Cr), mercury (Hg) and lead (Pb) that are considered to be toxic to human and animal health [3, 4]. The amounts of these hazardous elements vary widely among phosphate rock sources [5]. Isil et al. [6] reported that the main source of most heavy metals in produced phosphate fertilizers is attributed to the impurities in phosphate rock. Also, Chen et al. [7] reported that phosphate fertilization is a significant contributor of trace elements, especially Cd, in cropland soils. Low levels of these elements naturally occur in soils and some of them are essential for plants or animals. However, these essential trace elements are toxic if their levels are high in the environment [8]. Accumulation of heavy metals in some vegetables after phosphate fertilization application was studied by Oyedel et al. [9] who showed that the Cd, Pb and Hg contents of the soils were significantly increased by 14 to 60% over the control soil with phosphate fertilization. Leafy vegetables absorb more Cd than grasses [10]. Top dressing pastures with TSP also increased Cd content of pasture species, especially that of subterranean clover *Trifolium subterraneum* L. [11].

Jew's mallow (*Corchorus olitorius*) is one of the most common plants that grows well in the tropical and sub-tropical region including Middle East, Asia and Africa. The plant is used as a food ingredient, herb, and vegetable, and contains acidic polysaccharides, proteins, calcium, thiamin, riboflavin, and dietary fibers [12, 13]. It is an important green leafy vegetable in many countries including Egypt, Sudan, India, Bangladesh, Malaysia, Japan, the Caribbean and Cyprus [14].

The objective of this study was to evaluate soil application effects of different mineral phosphate fertilizers as well as natural rock phosphate in the presence or absence of phosphate dissolving bacteria and/or an organic amendment on growth, yield, phosphorus and heavy metal uptake and by Jew's mallow plants.

2. MATERIALS AND METHODS

Pot and field experiments were conducted in the screen house and experimental farm, respectively, Faculty of Agriculture, South Valley

University, Egypt in the summer season of 2013 and 2014, respectively, to evaluate application impact of different mineral sources of phosphate fertilization (Rock phosphate, superphosphate and triple superphosphate) in the presence or absence of phosphate dissolving bacteria (PDB) and/or filter mud cake (FMC) as an organic amendment to the soil on the growth, phosphorus and heavy metal (Zn, Cd, Co, Cu and Ni) contents of Jew's mallow (*Corchorus olitorius*) plants. All types of phosphate fertilizers that are present in the market and used as soil applications in Egypt were investigated in these experiments. The contribution of these phosphate fertilizers to heavy metal contents of growing plants was also assessed. Twenty four different substrate treatments were set up as shown in Table 1.

2.1 Pot Experiment

Plastic pots of 30 cm in diameter and 35 cm in height were arranged in a completely randomized design. Pre composted filter mud cake (FMC) was used at a level of 4 ton/fed. (47.62 g/pot). The investigated phosphate fertilizers were added at a level of 7.75 unit P_2O_5 which matched (0.33, 0.6, 0.77, 0.77 and 0.20 g/pot) for RP, T.P.F, S.P.F1, S.P.F2 and S.P.F3, respectively. Six kg of the soil/pot were thoroughly mixed with each investigated treatments and then 0.071 g of Jew's mallow (*Corchorus olitorius*) seeds were sown in each pot. 20 ml of a phosphate dissolving bacteria (PDB) containing $4x10^7$ cells ml^{-1} were diluted in 1 liter of water. With respect to PDB treatment, 8.5 ml of diluted inoculum were applied to each pot of this treatment and then, pots were directly irrigated. The control treatment was set up without applying any addition and each treatment was replicated three times. Soil moisture content in all pots was kept at field capacity during the experiment. Some chemical and physical properties of soil used in the experiment are presented in Table 2. The chemical analysis of the filter mud cake (FMC) applied in the previous treatments are shown in Table 3. Also, the heavy metal contents of the different used phosphate fertilizers are found in Table 4.

2.2 A field Experiment

Field experiment was layout in Randomized Complete Block Design (RCBD) consisting of the same treatments as the pot experiment including the control with 3 replications. Each plot had an area of 6 m^2 (2 X 3 meter).

Filter mud cake (FMC) was used at a level of 4 ton/fed. (5.71 kg/ plot) and phosphate fertilizers were applied at a level of 7.75 unit P_2O_5 that (39.5, 71.4, 92.3, 92.3 and 24.1 g/plot) for RP, TPF1, SPF1, SPF2 and SPF3, respectively. Each investigated amendment for each plot was thoroughly mixed with the soil. Then 8.6 g of Jew's mallow seeds/ plot were planted by broadcast cultivation method. 20 ml of PDB liquid inoculant ($4x10^7$ cells ml^{-1}) was diluted in 1 liter of water and spread over each plot of PDB inoculation treatments.

Table 1. Experimental treatments

No.	Treatments	No.	Treatments
T1	Control soil	T13	Soil + SPF1
T2	Soil + PDB	T14	Soil + SPF1 + PDB
T3	Soil + OM	T15	Soil + SPF1 + OM
T4	Soil +OM+PDB	T16	Soil + SPF1 + PDB+ OM
T5	Soil + RP	T17	Soil + SPF1
T6	Soil + RP + PDB	T18	Soil + SPF1 + PDB
T7	Soil + RP + OM	T19	Soil + SPF1 + OM
T8	Soil + RP + PDB + OM	T20	Soil + SPF1 + PDB+ OM.
T9	Soil + TPF	T21	Soil + SPF1
T10	Soil + TPF + PDB	T22	Soil + SPF1 + PDB
T11	Soil + TPF + OM	T23	Soil + SPF1 + OM
T12	Soil + TPF + PDB+ OM	T24	Soil + SPF1 + PDB + OM

RP = Rock phosphate, 28% P_2O_5 (Sebeya phosphate mine –Aswan Governorate, Egypt).
T.P.F= Triple Superphosphate granule fertilizer 46% P_2O_5 Abu-Zaable factory).
S.P.F1= Superphosphate granule fertilizer 15.5% P_2O_5 (El-Nasser factory)
S.P.F2= Superphosphate fine fertilizer 12% P_2O_5 (Assuite factory, Egypt).
S.P.F3= Superphosphate granule fertilizer 12% P_2O_5 (Assuite factory, Egypt).
P.D.B = Phosphate Dissolving Bacteria (Paenibacillus polymyxa; previously Bacillus polymyxa) locally isolated from Sebeya phosphate mine, Aswan governorate, Egypt in a previous study [15].
FMC = Filter mud cake (Qous sugar cane factory, Egypt).

Table 2. Some physical and chemical characteristics of the studied soil

Property	Value
Particle-size distribution:	
Clay (%)	12.0
Silt (%)	10.0
Sand (%)	78.0
Texture	Sandy loam
pH (1:1)	8.0
EC (dSm^{-1})	0.60
Organic matter (%)	0.15
Available P ($mg\ kg^{-1}$)	10.0
Total heavy metals ($mg\ kg^{-1}$)	
Zn	9.3
Cd	2.0
Cu	7.3
Co	1.0
Ni	20.3

Table 3. Some chemical characteristics of the filter mud cake (FMC) used as a source of organic matter in the experiment

Property	Value
pH (1:10)	6.7
EC (1:10) (dS/m)	5.6
Organic carbon (%)	37.94
Total nitrogen (%)	2.31
C/N ratio	16.40
Total P (P_2O_5%)	2.51
Total heavy metal content ($mgkg^{-1}$)	
Zn	43.2
Cd	0.0
Cu	36.1
Co	0.0
Ni	0.0

Jew's mallow plant samples were cut after 40, 70 and 100 days from planting and growth parameters were estimated. The samples were washed with de-ionized water, separated into shoots and roots, oven dried at 70ºC for three days, then grinding and kept for chemical analysis.

2.3 Chemical Analysis

2.3.1 Plant samples analysis

0.5 gram of ground Jew's mallow plant sample was digested in 10 ml of H_2SO_4 acid and 2 ml of perchloric acid in a conical flask as it is described by Chapman and Pratt [16]. The digests were used for the following determination:

- Total phosphorus which was determined spectrophotometrically using the chlorostannus-phosphomolybdic acid method in a sulfuric acid system [17].
- Zinc, Cd, Cu, Co and Ni contents were determined using inductively Coupled Plasma-Mass Spectrometry (ICP-MS).

2.3.2 Soil and fertilizers samples analysis

- Particle size distribution was determined using the pipette method [17].
- The electric conductivity (EC) was determined in a 1: 2.5 ratio soil to water extract using a conductivity meter according to [17].
- Soil pH was measured in a 1: 1 ratio of soil to water suspension using Beckman pH meter as it was reported by McLean [18].
- Organic carbon content was determined according to Walkely and Black's wet oxidation method [17].
- Total P and heavy metals of the soil and phosphate fertilizers were obtained using the method described by Knudsen et al. [19]. The heavy metal contents of these fertilizers were determined using inductively coupled plasma optical-emission spectrometry ICP-OES.
- Available phosphorus was extracted according to Olsen et al. [20] using 0.5 M Na HCO_3 at pH 8.5. The extractable P was measured colorimetrically using chlorostannus phosphomolybdic-sulfuric acid method as it was described by Jackson [17].

Table 4. Concentrations of heavy metals in the natural and chemical phosphate fertilizers used in the experiments

Fertilizers type	Total metals (mg/kg)				
	Zn	Ni	Cu	Co	Cd
RP = Rock phosphate, 28% P2O5 (Sebeya phosphate mine –Aswan Governorate, Egypt).	111.6	6.9	6.0	0.0	2.5
Triple Superphosphate granule fertilizer 46% P2O5 Abu-Zaable factory). (T.P.F)	148.6	0.0	9.0	0.0	1.1
S.P.F1= Superphosphate granule fertilizer 15.5% P2O5 (El-Nasser factory)	66.8	0.0	5.5	0.0	1.8
S.P.F2= Superphosphate fine fertilizer 12% P2O5 (Assuite factory, Egypt).	48.4	0.0	5.9	0.0	0.9
S.P.F3= Superphosphate granule fertilizer 12% P2O5 (Assuite factory, Egypt).	51.4	0.0	5.6	0.0	1.0

2.4 Statistical Analyses

All data obtained were analyzed using MSTAT-C [21] and one-way analysis of variance was applied. The differences between means of the different treatments were compared using the least significant difference (L.S.D.) at 5% and 1% probability.

3. RESULTS AND DISCUSSION

3.1 Growth Parameters of *Corchorus olitorius* Plants

Selected growth parameters of three cuttings of *Corchorus olitorius* plants grown in the soil (pot and field experiments) amended with rock phosphate or different mineral phosphate fertilizers either alone or in a combination with filter mud cake (FMC) with or without phosphate dissolving bacteria (PDB) are shown in Tables 5 and 6.

3.1.1 Shoot fresh and dry weights

The results showed that the first and third cuts of Jew's mallow plants grown in the pot had lowest shoot fresh and dry weight values while the second one showed the highest values for all treatments, (Table 5). On the other hand, in the field, the first cut gave the lowest shoot fresh weight values while the third cut exhibit the highest values for all treatments (Table 5).

In the pot experiment, the application of all phosphate fertilizers including rock phosphate (RP) recorded shoot fresh weight values significantly higher than the control treatment particularly when the filter mud cake(FMC) was added with or without phosphate dissolving bacteria (PDB) (Table 5). Moreover, the highest values of shoot fresh weight were obtained from Jew's mallow plants that received phosphate fertilizers with FMC plus PDB. The shoot fresh weight in the second cut was 16.13, 65.52, 35.97, 45.03, 58.57 and 71.5 g/ plant for T4, T8, T12, T16, T20 and T24 treatments, respectively. The results generally exhibited that the highest shoot fresh weight (71.5 g/plant) accrued with applying SPF3+PDB+FMC (T24).

In the field, the sole application of all phosphate fertilizers including rock phosphate did not record any significant increase in the shoot fresh weight of the first cut except with T13, which recorded highly significant increase reached to 278.7% compared to the untreated control treatment (T1). However, high significant increases were found when PDB was applied with all phosphate fertilizers. These increases reached 649.2, 373.8 and 262.3% compared to the control, for T6, T14, T18 and T22 treatments, respectively. Maximum increases in the shoot fresh weight of the first cut of 260.7, 462.8, 1042.6, 1059.0 and 1466.7% for T8, T12, T16, T20 and T24 treatments compared to the untreated control, respectively. These increases occurred with applying phosphate + PDB + FMC.

In the second cut a similar trend was obtained as in the first cut, which the shoot fresh weight increase for T8, T12, T16, T20 and T24 treatments was 323.7, 594.4, 300.9, 213.6 and 322.8 %, compared to the untreated control, respectively. Application of PDB plus FMC to phosphate fertilizer treatments led to a high significant increase in the shoot fresh weight in the third cut of 1234.1, 1436.5, 1165.9, 1137.7 and 1154.1 % for T8, T12, T16, T20 and T24 treatments compared to the untreated control, respectively. Therefore, application of filter mud cake (FMC) with rock phosphate (RP) or other phosphate fertilizers treated with PDB showed the highest effect on the shoot fresh weight in the three cuttings of Jew's mallow plants. This may have been due to the role of organic material as a source of different nutrients which activate the phosphate dissolving bacteria.

3.1.1.1 Plant dry weight

Similar trends in the shoot dry weight of Jew's mallow plants grown in the pots or field were obtained as in the shoot fresh weight. Application of PDB and FMC with RP, TPF, SPF1, SPF2 and SPF3 had highest significant increases in the shoot dry weight. The increases of the field experiment were 320.3, 661.8, 926.8, 965.0 and 1629.3% in the first cut, 367.3, 560.4, 245.5, 351.5 and 405.0 in the second cut and 1166.3, 1662.5, 1108.7, 1007.6 and 1264.1% in the third cut and with using T8, T12, T16, T20 and T24 treatments compared to the untreated control, respectively. Also, positive effect of PDB applied in a combination with the different sources of phosphorus fertilizers and organic material was greater than that of the same treatments without applying PDB.

3.1.2 Root fresh and dry weights

The root fresh weights varied among the investigated treatments of fertilizer types and different cuts of Jew's mallow plants grown in the pots (Table 5). In the first cut all phosphate fertilizer treatments gave significant increases in the root fresh weight. The highest root fresh weight values were recorded for the fertilizer treatments that received PDB plus FMC. Application of rock phosphate (RP) exhibited significant increases only when an organic matter source (FMC) was applied in combination with PDB. The root fresh weight had the highest values with using T8, T12, T16, T20 and T24 treatments of 0.981, 0.428, 0.960, 1.043 and 1.189 g / plant in the first cut, 13.6, 7.68, 5.70, 10.6 and 10.97 g / plant in the second cut, and 1.073, 1.76, 1.15, 4.02 and 4.61 g/plant in the third cut, respectively. The root dry weight showed an almost similar trend to that obtained for the root fresh weight in all three cuts (Table 6).

As it was previously mentioned in the pots, the root fresh and dry weights of the plant grown in the field varied among different treatments and cuts (Table 6). In the first cut all single fertilizer treatments did not show significant increases in the root fresh and dry weights, while applying PDB with these phosphate fertilizers, except rock phosphate (RP) treatment had highly significant increases compared to the control treatment. Adding both (FMC) and PDB with the phosphate fertilizer (T8, T12, T16, T20 and T24) exhibited highly significant increases of 251.8, 438.5, 893.8, 770,8 and 1393.8% compared to the control, respectively for the root fresh weight, and 385.7, 592.9, 978.6, 1092.9 and 1942.9% of the control, respectively for the root dry weight. In the second and third cuts the results showed that all treatments recorded highly significant increases of root fresh and dry weight compared to the control.

In this respect, the highest increases of the root fresh weight in the second cut were 1350.0, 2272.2, 983.3, 1266.7 and 1122.2% compared to the control treatment and those of the third cut were 2793.8, 1041.7, 3135.4,1358.3 and 1535.4%, compared to the control for T8, T12, T16, T20 and T24 treatments, respectively. Also, the increases in the root dry weight of the second cut were 2081.6, 2997.4, 1097.4, 1813.2 and 1607.9% compared to the control for the previously respective treatments, respectively. In addition, the root dry weight of the third cut revealed increases of 2494.1, 788.2, 2029.1, 1117.6 and 1300.0%, compared to control for the respective treatments.

3.2 Phosphorus Content of *Corchorus olitorius* plants

3.2.1 Pot experiment

The Phosphorus content of *C. olitorius* plants is taken as an indicator for levels of the supplying power of phosphorus in the soil under applying different types of phosphate fertilizers (Tables 7). In the pot experiment, significant increases occurred in the P content of the plant shoots as a result of using different types of phosphate fertilizers in the first and second cuts compared to the untreated control (Table 7). Adding phosphate dissolving bacteria (PDB) or filter mud cake (FMC) and their mixture to the amended phosphate fertilizers increased the P content of plant shoots. The highest P content of the shoots of the first cut was 0.21, 0.13, 0.133, 0.179 and 0.147% for T8, T12, T16, T20 and T24 treatments, respectively compared to the control which recorded P content of 0.05%. However, the P content of the second cut was 0.23, 0.2, 0.21, 0.26 and 0.24% for the previously respective treatments compared to the untreated control that recorded plant P content of 0.08%. The maximum values of the plant P content were obtained for T8 and T16 treatments in all three cuts. The relative increases of P content due to these respective two treatments were 320 and 258 % of the control, respectively in first cut, 187.5 and 225.0% in the second cut and 233.3 and 230.0% in the third cut.

The P content of plant shoots varied among fertilizer types and cuts in the field. In the first cut all single fertilizer treatments gave the lowest values of the plant P content. The application of PDB with these fertilizers including rock phosphate showed higher P plant content in all three cuts than without applying PDB. In the first cut, adding the organic material (FMC) alone or in combination with PDB to all types of fertilizer treatment exhibited highly significant increases in the plant P content particularly the treatments that received FMC plus PDB. These increases recorded 130.0,130.0, 130.0, 130.0 and 170.0% over the control for T8, T12, T16, T20 and T 24 treatments, respectively. Moreover, the highest increases of the plant P content of 2000, 2900, 2900, 3100 and 2130% over the control in the second cut and 1700, 5300, 2000, 2200 and 2500% over the control in the third cut, for the previously respective treatments.

Table 5. Effect of natural and manufactured phosphate fertilizers with and without addition of FMC and/or phosphate dissolving bacteria on plant shoot fresh and dry weights

No.	Treatment	Pot experiment						Field experiment					
		Plant fresh weight (g/plant)			Plant dry weight (g/plant)			Plant fresh weight (g/plant)			Plant dry weight (g/plant)		
		Cut 1	Cut 2	Cut 3	Cut 1	Cut 2	Cut 3	Cut 1	Cut 2	Cut 3	Cut 1	Cut 2	Cut 3
T1	Control soil	0.44	2.720	1.650	0.039	0.560	0.450	0.610	5.31	8.5	0.123	1.01	1.84
T2	Soil + PDB	0.66	3.490	1.870	0.058	0.620	0.530	0.653	6.83	11.2	0.130	1.13	2.50
T3	Soil + FMC	1.71	4.410	2.010	0.193	1.090	0.590	1.700	7.91	32.7	0.380	1.68	7.21
T4	Soil + FMC +PDB	7.70	16.13	4.240	0.744	1.220	1.310	2.590	10.50	44.1	0.443	2.38	9.96
T5	Soil + RP	1.50	3.947	1.70	0.338	1.020	0.510	0.763	5.45	17.3	0.170	1.16	3.97
T6	Soil + RP + PDB	2.00	16.18	2.040	0.483	3.560	0.530	0.950	7.33	23.4	0.253	1.54	5.60
T7	Soil + RP + FMC	3.15	55.35	6.600	0.590	3.613	1.700	1.443	12.78	85.5	0.363	2.66	17.55
T8	Soil + RP + PDB + FMC	8.73	65.52	7.853	0.759	14.050	2.037	2.200	22.50	113.4	0.517	4.72	23.30
T9	Soil + TPF1	1.40	28.81	2.200	0.483	6.493	0.450	0.867	7.19	25.2	0.173	1.53	5.37
T10	Soil + TPF1 + PDB	1.95	32.13	2.750	0.725	6.863	0.520	0.910	10.56	34.9	0.250	1.59	7.77
T11	Soil + TPF1 + FMC	3.39	35.73	2.850	0.918	9.570	0.677	1.353	14.09	123.6	0.367	2.59	27.03
T12	Soil + TPF1 + PDB+ FMC	8.39	35.97	3.010	1.010	20.130	0.850	3.433	36.87	130.6	0.937	6.67	32.43
T13	Soil + SPF1	6.00	11.680	2.910	0.967	2.680	0.657	2.310	11.49	15.2	0.330	1.86	3.68
T14	Soil + SPF1 + PDB	9.00	28.15	3.050	1.112	6.297	0.760	4.570	14.92	26.8	0.473	1.92	5.60
T15	Soil + SPF1 + FMC	11.90	36.46	3.573	1.266	7.677	1.033	6.720	17.18	74.6	0.890	2.88	16.22
T16	Soil + SPF1 + PDB+ FMC	15.33	45.03	4.950	1.837	8.177	1.237	6.970	21.29	107.6	1.263	3.49	22.24
T17	Soil + SPF1	7.50	18.25	3.510	0.870	4.987	0.980	1.047	6.46	15.3	0.243	1.74	3.53
T18	Soil + SPF1 + PDB	10.48	19.97	7.510	1.392	6.753	1.000	2.890	6.91	14.0	0.523	3.50	4.40
T19	Soil + SPF1 + FMC	10.05	38.64	9.540	1.663	8.447	2.317	5.970	13.23	75.1	1.220	3.66	15.70
T20	Soil + SPF1 + PDB+ FMC	12.20	58.57	12.700	2.146	14.18	2.950	7.070	16.65	105.2	1.310	4.56	20.38
T21	Soil + SPF1	2.79	28.39	3.170	0.638	5.470	0.507	0.853	8.85	16.1	0.217	1.95	3.58
T22	Soil + SPF1 + PDB	4.7	42.53	6.430	0.974	9.010	0.590	2.210	13.56	21.9	0.487	3.28	4.87
T23	Soil + SPF1 + FMC	5.69	60.04	8.410	1.276	11.100	1.993	4.433	18.41	82.7	1.133	3.76	19.49
T24	Soil + SPF1 + PDB + FMC	10.61	71.50	8.350	2.379	10.200	2.600	9.557	22.45	106.6	2.127	5.10	25.10
LSD0.05		0.945	8.634	2.226	0.214	1.896	0.5896	0.644	2.46	4.6	0.127	0.50	1.26
LSD 0.01		1.26	11.52	2.970	0.286	2.529	0.7866	0.859	3.27	6.1	0.170	0.66	1.68

Table 6. Effect of natural and manufactured phosphate fertilizers with and without additions of FMC and/or phosphate dissolving bacteria on root fresh and dry weights

No.	Treatment	Pot experiment						Field experiment					
		Root fresh weight (g/plant)			Root dry weight (g/plant)			Root fresh weight (g/plant)			Root dry weight (g/plant)		
		Cut 1	Cut 2	Cut 3	Cut 1	Cut 2	Cut 3	Cut1	Cut 2	Cut 3	Cut 1	Cut 2	Cut 3
T1	Control soil	0.031	0.320	0.250	0.006	0.066	0.150	0.065	0.18	0.48	0.014	0.038	0.17
T2	Soil + PDB	0.052	0.583	0.373	0.012	0.113	0.160	0.082	0.25	2.44	0.019	0.078	0.44
T3	Soil + FMC	0.273	0.670	0.380	0.028	0.176	0.170	0.234	1.02	7.06	0.025	0.177	1.60
T4	Soil + FMC +PDB	1.805	1.19	1.360	0.167	0.310	0.360	0.280	1.09	8.30	0.027	0.293	1.97
T5	Soil + RP	0.157	0.620	0.140	0.023	0.140	0.160	0.069	0.36	2.48	0.015	0.084	0.48
T6	Soil + RP + PDB	0.104	9.960	0.330	0.033	0.193	0.290	0.085	0.43	3.86	0.020	0.088	0.89
T7	Soil + RP + FMC	0.323	13.600	0.680	0.088	1.015	0.367	0.166	2.10	12.28	0.047	0.638	3.73
T8	Soil + RP + PDB + FMC	0.981	3.443	1.073	0.280	4.190	0.440	0.229	2.61	13.89	0.068	0.829	4.41
T9	Soil + TPF	0.219	6.630	0.800	0.051	1.167	0.160	0.066	0.76	3.41	0.017	0.192	0.85
T10	Soil + TPF + PDB	0.219	7.940	0.910	0.054	1.539	0.160	0.174	1.17	3.93	0.042	0.280	0.99
T11	Soil + TPF + FMC	0.303	4.763	0.687	0.070	1.850	0.207	0.205	2.09	4.50	0.049	0.502	1.08
T12	Soil + TPF + PDB+ FMC	0.428	7.677	1.760	0.114	2.053	0.860	0.350	4.27	5.48	0.097	1.177	1.51
T13	Soil + SPF1	0.344	3.140	0.510	0.121	0.795	0.200	0.066	1.21	2.36	0.032	0.316	0.62
T14	Soil + SPF1 + PDB	0.438	5.200	0.600	0.161	1.448	0.260	0.237	1.69	8.38	0.068	0.485	2.40
T15	Soil + SPF1 + FMC	0.866	5.153	0.810	0.215	1.399	0.277	0.393	1.89	12.18	0.108	0.519	3.34
T16	Soil + SPF1 + PDB+ FMC	0.960	5.697	1.153	0.228	1.289	0.640	0.646	1.95	15.53	0.151	0.455	3.62
T17	Soil + SPF1	0.282	3.873	0.560	0.081	0.915	0.210	0.107	0.66	1.87	0.032	0.198	0.52
T18	Soil + SPF1 + PDB	0.866	10.600	3.380	0.198	0.902	0.280	0.286	1.37	2.37	0.068	0.329	0.60
T19	Soil + SPF1 + FMC	0.908	4.423	4.020	0.206	1.017	0.830	0.529	2.43	3.29	0.125	0.576	0.76
T20	Soil + SPF1 + PDB+ FMC	1.043	3.143	5.670	0.295	3.039	1.340	0.566	2.46	7.00	0.167	0.727	2.07
T21	Soil + SPF1	0.188	3.500	0.290	0.049	0.893	0.450	0.114	1.19	3.25	0.031	0.313	0.86
T22	Soil + SPF1 + PDB	0.282	10.970	0.330	0.072	1.871	0.470	0.247	1.76	4.24	0.066	0.474	1.14
T23	Soil + SPF1 + FMC	0.876	7.880	3.267	0.245	2.131	1.100	0.519	1.84	6.50	0.151	0.513	2.01
T24	Soil + SPF1 + PDB + FMC	1.189	7.163	4.610	0.336	3.139	1.407	0.971	2.20	7.85	0.286	0.649	2.38
LSD0.05		0.1038	1.302	0.5370	0.027	0.2698	0.344	0.052	0.29	1.11	0.0167	0.073	0.31
LSD 0.01		0.1385	1.737	0.7164	0.036	0.3599	0.459	0.096	0.39	1.48	0.0223	0.098	0.41

Table 7. Phosphorus contents (%) of Jew's mallow plant shoots using the different investigated treatments

No.	Treatment	Pots experiment			Field experiment		
		Cut 1	Cut 2	Cut 3	Cut 1	Cut 2	Cut 3
T1	Control soil	0.05	0.08	0.06	0.1	0.01	0.01
T2	Soil + PDB	0.801	0.101	0.09	0.12	0.03	0.01
T3	Soil + FMC	0.101	0.14	0.11	0.13	0.12	0.12
T4	Soil + FMC +PDB	0.11	0.18	0.12	0.13	0.12	0.12
T5	Soil + RP	0.11	0.16	0.12	0.12	0.02	0.09
T6	Soil + RP + PDB	0.13	0.18	0.16	0.19	0.16	0.13
T7	Soil + RP + FMC	0.17	0.22	0.19	0.21	0.2	0.17
T8	Soil + RP + PDB + FMC	0.21	0.23	0.2	0.23	0.21	0.18
T9	Soil + TPF	0.101	0.16	0.112	0.12	0.22	0.19
T10	Soil + TPF + PDB	0.11	0.18	0.121	0.16	0.25	0.21
T11	Soil + TPF + FMC	0.127	0.2	0.14	0.18	0.29	0.34
T12	Soil + TPF + PDB+ FMC	0.13	0.2	0.144	0.23	0.3	0.54
T13	Soil + SPF1	0.113	0.16	0.121	0.13	0.18	0.11
T14	Soil + SPF1 + PDB	0.116	0.16	0.126	0.14	0.22	0.15
T15	Soil + SPF1 + FMC	0.121	0.18	0.133	0.19	0.26	0.17
T16	Soil + SPF1 + PDB+ FMC	0.133	0.21	0.143	0.23	0.3	0.21
T17	Soil + SPF1	0.124	0.18	0.127	0.15	0.16	0.14
T18	Soil + SPF1 + PDB	0.13	0.2	0.138	0.16	0.17	0.15
T19	Soil + SPF1 + FMC	0.137	0.22	0.147	0.21	0.21	0.21
T20	Soil + SPF1 + PDB+ FMC	0.179	0.26	0.198	0.23	0.32	0.23
T21	Soil + SPF1	0.11	0.157	0.118	0.21	0.16	0.16
T22	Soil + SPF1 + PDB	0.114	0.177	0.124	0.22	0.18	0.17
T23	Soil + SPF1 + FMC	0.122	0.22	0.134	0.24	0.21	0.24
T24	Soil + SPF1 + PDB + FMC	0.147	0.24	0.16	0.27	0.223	0.26
LSD0.05		0.0279	0.0309	0.1798	0.0298	0.0335	0.0367
LSD 0.01		0.0447	0.0412	0.2399	0.0398	0.0447	0.0490

3.3 Heavy Metal Contents of *Corchorus olitorius* Plants

Contents of heavy metals in *C. olitorius* plants were taken as an indicator of these metals in the rock phosphate or chemical phosphate fertilizers that were added to the soil.

3.3.1 Pots Experiment

Significant increases in the heavy metals contents of Jew's mallow plants grown in the pots in all cuts occurred as a result of applying the different treatments compared to the untreated control (Table 8). However, the lowest metal contents were obtained in the first cut of the plants that were grown in the pots treated with rock phosphate compared to those treated with chemical phosphate fertilizers.

3.3.1.1 Zinc (Zn)

In the first cut all chemical phosphate fertilizers added either alone or in combined with biological (PDB) or organic (FMC) additives caused highly significant increases in Zn-content of Jew's mallow plants compared to the untreated control treatment (Table 8). However, the lowest Zn contents of the investigated plants of 6.9, 7.9, 12.3 and 21.2 mg/kg were obtained with rock phosphate (RP) alone, (RP) plus phosphate dissolving bacteria (PDB), RP + filter mud cake (FMC) and RP+PDB+FMC treatments, respectively. Other chemical fertilizers treatments recorded Zn content values ranged from 20 to 41.6mg/kg. Also, Zinc contents of the plants of the second and third cuts where higher for all treatments compared to the first cut. Moreover, the application of all phosphate fertilizers combined with FMC or FMC+ PDB showed a higher Zn content than that of fertilizers without these additives.

3.3.1.2 Nickel (Ni)

In all cuts, Ni content of Jew's mallow plant increased under conditions of applying all treatments comparing to untreated control (Table 8). However, it showed lowest values of 6.3, 6.4, 7.1 and 7.1 mg/kg with the application of RP, RP+PDB, RP+FMC and RP+PDB+FMC in the first cut. However, higher Ni content values of

7.3, 7.78, 8.21 and 8.25 mg/kg were obtained in the second season for the respective treatments and 8.0, 7.8, 8.3 and 8.61 mg/kg in the third cut for the respective treatments.

3.3.1.3 Cupper (Cu)

It is clear from Table 8 that Jew's mallow plants had the highest Cu values in all three cut with applying all types of phosphate fertilizers plus FMC and PDB. The first showed Cu contents of 3.4, 2.80, 2.19, 2.88 and 3.64 mg/kg for T8, T12, T16, T20 and T24 treatments, respectively. In the second cut they were 3.9, 3.9, 3.49, 4.36 and 6.20 mg/ kg, while in the third cut they were 3.50, 5.50, 5.20, 6.90 and 8.60, for the respective treatments.

3.3.1.3.1 Cobalt content (Co)

As it was shown for the previous metals, the investigated plants exhibited the low Co contents with adding RP alone or combined with FMC or PDB or their mixture (Table 8). These lowest Co content values were 2.50, 2.80, 3.10 and 3.21 for T5, T6, T7 and T8 treatments, respectively. However, the highest content values of Co in Jew's mallow were found with the application of the chemicals fertilizers either alone or combined with PDB or FMC or their mixture. Moreover, it was found that the Co content in the three cuts of these plants decreased in the order of third cut > second cut > first cut.

3.3.1.3.2 Cadmium (Cd)

The plant Cd content due to the application of chemical fertilizers alone or with their PDB and FMC combinations ranged from 0.174 to 0.370 mg/kg, 0.418 to 0.479 mg/kg and 0.487 to 0.505 mg/kg for the first, second and third cuts, respectively (Table 8). However, the rock phosphate added alone or with the PDB and FMC combination recorded lowest values of plant cadmium content in the first, second and third cuts which ranged from 0.087 to 0.170 mg/kg, 0.091 to 0.174 mg/kg and 0.483 to 0.513 mg/ kg, respectively.

3.3.2 Field experiment

Generally, significant increases occurred in tested heavy metal contents of Jew's mallow plants in all three cuts as a result of applying different types of phosphate fertilizers compared to the untreated control (Table 9). However, the lowest values of these metal contents were obtained in the first cut and with applying the rock phosphate.

3.3.2.1 Zinc (Zn)

Both the natural rock P and chemical P addition as fertilizers significantly increased the Zn-content of *C. olitorius* compared to the untreated control treatment (Table 9 and Fig.1). Moreover, in the first cut the natural rock phosphate treatments showed the lowest Zn content values of Jew's mallow plants compared to the chemical fertilizers.

The plants of the first cut receiving rock phosphate fertilizer either alone or combined with PDB, FMC and PDB+FMC recorded the lowest Zn content values of 45.00, 56.00, 64.00 and 94.00 mg / kg for T5, T6, T7 andT8, respectively.

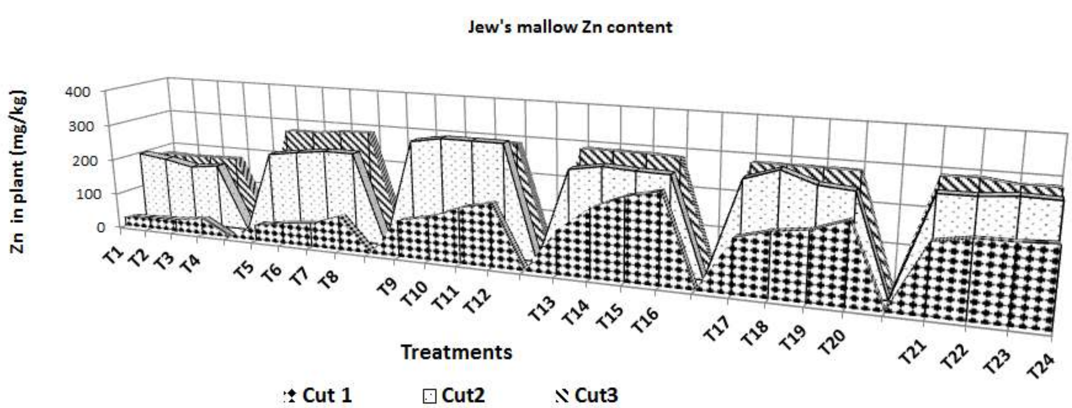

Fig. 1. Zinc content of *Corchorus olitorius* plants (mg/kg) in the first, second and third cuts using different investigated treatments

Table 8. Heavy metal (Zn, Cd, Co, Cu and Ni) contents of Jew's mallow plants (mg/kg) using the investigated treatments in the pot experiment

T. No.	Treatments	Zn			Ni			Cu			Co			Cd		
		Cut 1	**Cut 2**	**Cut 3**	**Cut 1**	**Cut 2**	**Cut 3**	**Cut 1**	**Cut 2**	**Cut 3**	**Cut 1**	**Cut 2**	**Cut 3**	**Cut 1**	**Cut 2**	**Cut 3**
T1	Control soil	18.00	36.90	31.00	4.80	4.80	4.90	1.20	2.40	2.50	1.50	1.7	2.00	0.074	0.037	0.030
T2	Soil + PDB	20.30	38.24	75.00	4.80	4.80	4.90	1.50	2.80	2.90	1.60	1.74	2.00	0.078	0.039	0.035
T3	Soil + FMC	22.90	42.80	80.00	4.90	4.90	5.00	3.00	3.10	3.10	1.90	1.92	2.10	0.087	0.039	0.048
T4	Soil + FMC +PDB	28.80	45.39	86.00	4.90	4.90	5.00	3.10	3.10	3.30	1.95	1.95	2.10	0.091	0.039	0.052
T5	Soil + RP	24.90	39.00	105.00	6.30	7.30	8.00	1.30	2.90	2.50	2.50	2.9	3.40	0.087	0.091	0.483
T6	Soil + RP + PDB	25.90	66.00	114.00	6.40	7.78	7.80	1.70	2.90	3.30	2.80	3.2	3.67	0.113	0.126	0.492
T7	Soil + RP + FMC	30.30	93.00	128.10	7.10	8.21	8.30	3.30	3.90	3.40	3.10	3.4	3.74	0.135	0.135	0.509
T8	Soil + RP + PDB + FMC	39.20	95.00	167.60	7.10	8.25	8.61	3.40	3.90	3.50	3.21	3.51	3.90	0.170	0.174	0.513
T9	Soil + TPF	47.00	66.00	79.00	9.00	9.00	9.00	1.30	2.50	2.70	6.07	6.84	7.38	0.174	0.418	0.487
T10	Soil + TPF + PDB	51.3.	69.00	86.90	9.44	9.00	9.00	1.50	2.50	3.10	6.18	6.6	7.68	0.209	0.431	0.492
T11	Soil + TPF + FMC	58.00	71.00	101.00	9.50	9.50	10.00	2.70	3.60	5.40	6.74	7.6	8.70	0.231	0.444	0.505
T12	Soil + TPF + PDB+ FMC	58.00	73.90	149.00	9.50	9.60	10.00	2.80	3.90	5.50	7.14	8.63	9.50	0.265	0.435	0.500
T13	Soil + SPF1	38.00	44.00	48.00	8.90	8.90	10.70	1.30	2.40	2.70	3.97	4.59	4.69	0.218	0.444	0.496
T14	Soil + SPF1 + PDB	40.30	46.30	50.00	9.10	9.10	10.81	1.41	2.40	3.10	4.20	4.77	5.30	0.252	0.452	0.500
T15	Soil + SPF1 + FMC	44.70	48.40	71.00	9.80	10.90	10.90	2.10	2.98	4.80	4.70	5.3	5.83	0.257	0.457	0.496
T16	Soil + SPF1 + PDB+ FMC	45.20	48.90	107.00	10.00	10.79	10.99	2.19	3.49	5.20	4.94	5.55	5.97	0.265	0.457	0.500
T17	Soil + SPF1	46.00	69.00	73.00	8.80	9.70	11.20	1.24	2.40	2.80	4.95	5.515	6.68	0.278	0.479	0.479
T18	Soil + SPF1 + PDB	51.90	69.30	100.00	9.72	10.00	11.43	1.62	2.40	3.60	5.52	5.875	7.12	0.313	0.470	0.483
T19	Soil + SPF1 + FMC	54.60	69.80	104.00	10.34	11.60	11.44	2.76	3.89	5.90	5.91	6.57	7.8	0.322	0.479	0.492
T20	Soil + SPF1 + PDB+ FMC	59.60	69.80	104.00	10.79	11.80	11.54	2.88	4.36	6.90	6.16	7.02	7.98	0.313	0.479	0.544
T21	Soil + SPF1	44.00	61.00	44.00	8.99	9.43	9.93	1.25	2.40	2.70	5.93	6.44	8.66	0.339	0.465	0.492
T22	Soil + SPF1 + PDB	45.10	68.00	63.00	10.33	10.11	10.13	1.81	2.80	3.30	6.84	6.98	8.93	0.352	0.474	0.492
T23	Soil + SPF1 + FMC	48.10	99.00	79.00	10.49	10.23	10.33	2.80	4.60	4.70	7.12	7.84	9.77	0.361	0.479	0.492
T24	Soil + SPF1 + PDB + FMC	49.70	112.00	92.00	10.52	10.55	10.65	3.64	6.20	8.60	7.38	8.49	9.99	0.370	0.479	0.492
L.S.D0.05		12.65	11.18	15.50	1.42	1.50	1.55	0.568	0.535	1.01	0.818	1.47	1.15	0.052	0.073	0.073
L.S.D 0.01		16.87	14.91	20.68	1.89	2.01	2.07	0.757	0.713	1.35	1.09	1.96	1.55	0.069	0.979	0.098

Table 9. Heavy metal (Zn, Cd, Co, Cu and Ni) contents of Jew's mallow plants (mg/kg) using the investigated treatments in the field

No.	Treatments	Zn			Ni			Cu			Co			Cd		
		Cut 1	**Cut 2**	**Cut 3**	**Cut 1**	**Cut 2**	**Cut 3**	**Cut 1**	**Cut 2**	**Cut 3**	**Cut 1**	**Cut 2**	**Cut 3**	**Cut 1**	**Cut 2**	**Cut 3**
T1	Control soil	26	196	180	8	8	9	3	3	3	7	9	8	0.17	0.085	0.07
T2	Soil + PDB	30	186	178	8	8	9	3	3	3	7	9	8	0.18	0.09	0.08
T3	Soil + FMC	33	170	179	9	9	10	3	4	4	9	10	9	0.20	0.09	0.11
T4	Soil + FMC +PDB	44	180	181	9	9	10	4	4	4	9.5	10	9	0.21	0.09	0.12
T5	Soil + RP	45	227	278	10	12	13	3.6	7.1	7.3	9	12	14	0.20	0.21	1.13
T6	Soil + RP + PDB	56	239	278	10	13	13	4.1	7.1	7.3	10	12	14	0.20	0.29	1.11
T7	Soil + RP + FMC	64	249	287	11	13	13	6	9.2	9.3	10	11	15	0.31	0.31	1.17
T8	Soil + RP + PDB + FMC	94	249	289	11	13	14	7	9.2	9.3	10	11	15	0.39	0.40	1.18
T9	Soil + TPF	100	296	288	11	16	15	4	11	17	11	11	15	0.40	0.96	1.12
T10	Soil + TPF + PDB	116	310	289	12	15	15	4	10	13	11	11	13	0.48	0.99	1.13
T11	Soil + TPF + FMC	150	310	290	14	14	14	4	10	11	11	10	14	0.53	1.02	1.16
T12	Soil + TPF + PDB+ FMC	170	310	291	13	14	14	5	10	11	11	12	16	0.61	1.00	1.15
T13	Soil + SPF1	118	255	291	11	10	13	11	8.1	9	12	12	15	0.50	1.02	1.14
T14	Soil + SPF1 + PDB	183	270	291	12	12	14	12	9	9	12	12	14	0.58	1.04	1.15
T15	Soil + SPF1 + FMC	220	265	290	13	10	14	13	10.8	12	11	13	15	0.59	1.05	1.14
T16	Soil + SPF1 + PDB+ FMC	240	263	286	13	10	15	15	11	16	11	12	15	0.61	1.05	1.15
T17	Soil + SPF1	142	267	288	11	11	15	6	9	7	11	12	14	0.64	1.10	1.10
T18	Soil + SPF1 + PDB	166	297	288	12	12	14	6	9	7	11	12	15	0.72	1.08	1.11
T19	Soil + SPF1 + FMC	178	267	288	12	12	14	7	10	9	11	11	15	0.74	1.10	1.13
T20	Soil + SPF1 + PDB+ FMC	210	260	288	13	12	14	8	10	11	10	10	15	0.72	1.10	1.25
T21	Soil + SPF1	178	270	290	12	13	14	6	9.9	7	10	13	15	0.78	1.07	1.13
T22	Soil + SPF1 + PDB	194	271	293	13	13	13	7	13	7	11	13	16	0.81	1.09	1.13
T23	Soil + SPF1 + FMC	195	279	283	14	13	14	8	14	9	11	13	16	0.83	1.10	1.13
T24	Soil + SPF1 + PDB + FMC	200	277	285	14	14	15	10	15	10	12	14	16	0.85	1.10	1.13
L.S.D0.05		2.42	4.20	4.83	0.127	0.201	0.220	0.127	0.156	0.156	0.164	0.187	0.244	0.016	0.020	0.017
L.S.D 0.01		3.23	5.60	6.44	0.170	0.268	0.294	0.170	0.208	0.208	0.219	0.250	0.325	0.014	0.021	0.022
Permissible levels		99.4 mg/kg			10-100 mg/kg			73.3 mg/kg			50 mg/kg			0.2 mg/kg		

In the second and third cuts, all treatments included rock phosphate recorded higher Zn contents of the plants compared to the first cut. Lowest values of Zn content in the plants were 227 and 278 mg/kg for T5 (RP) treatment in the second and third cuts, respectively.

Adding an organic material (FMC) and phosphate dissolving bacteria (PDB) or both to phosphate fertilizers mostly caused more Zn contents of *C. olitorius* plants than applying these fertilizers alone. In this respect, the highest Zn content were 296.0, 310.0, 310.0 and 310.0 mg/kg for T9, T10, T11 and T12, respectively, in the second cut. The third cut showed results near those of the second one. The high results of adding FMC and PDB to the sole phosphate treatments attributed to the effects of organic acids released during organic matter decomposition and the acids produced by PDB.

3.3.2.2 Nickel (Ni)

The plant Ni content increased with applying all treatments compared to control (Table 9 and Fig. 2). The rock phosphate application caused highest Ni contents in both the second and third cuts compared to the first one that had 10, 10, 11, 11 mg/kg for the plants receiving T5, T6, T7 and T8 treatments, respectively.

Also, in first cut, the addition of chemical phosphate fertilizer significantly increased the Ni content of the investigated plants compared to the untreated control or the RP treatment which may be due to the solubility of Ni initially present in the soil under conditions of these treatments. Moreover, increases in the plants Ni content were generally attained with adding the organic material (FMC) the presence or absence of PDB. The second and third cuts scored the higher values of the plant Ni content for all treatments compared to the first one.

3.3.2.3 Copper (Cu)

In all different cuts, the plants amended with all types of phosphate fertilizers plus FMC in the presence and absence of PDB showed higher Cu contents than those singly added (Table 9 and Fig. 3). It is clear that the highest Cu values in all three cuts were obtained in all treatments that included FMC and PDB. The Cu values were 7, 5, 15, 8 and 10 mg/kg in the first cut, 9.2, 10, 11, 10 and 15 mg/ kg in the second cut and 9.3,11, 16, 11 and 10 mg/ kg in the third cut for T8, T12, T16, T20 and T24 treatments, respectively.

3.3.2.4 Cobalt (Co)

All treatments exhibited highly significant increases in the Co content of *C. olitorius* compared with the control (Table 9 and Fig. 4.). However, the highest content values of Co in the investigated plants were found with applying the different treatments either alone or combined with FMC and PDB. The result show that plant Co contents in the three cuts followed the order of the third cut > second cut > first cut.

3.3.2.5 Cadmium (Cd)

The addition of P fertilizers including RP significantly increased the plant Cd-content in the three cuts compared to the control (Table 9 and Fig. 5). The first cut recorded the lowest Cd content followed by the second and then the third cut which showed the highest values particularly, with adding PDB and FMC. Also the results showed that plants grown on the soil amended with natural rock phosphate alone recorded lowest Cd values.

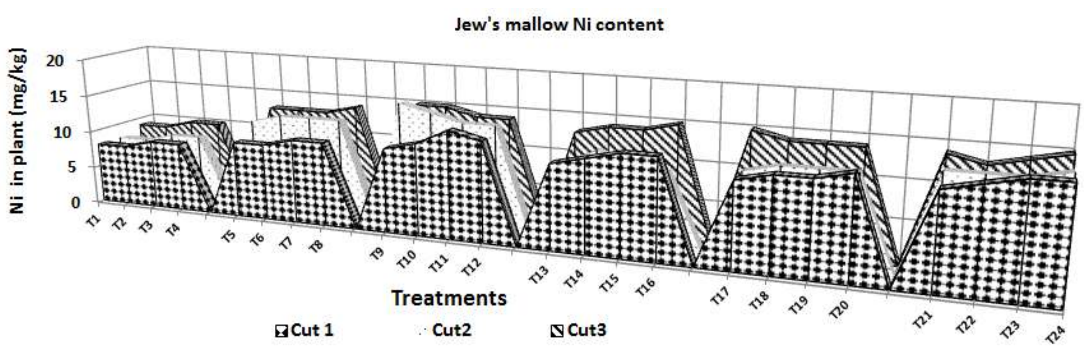

Fig. 2. Nickel content of *Corchorus olitorius* plants (mg/kg) in the first, second and third cuts using different investigated treatments

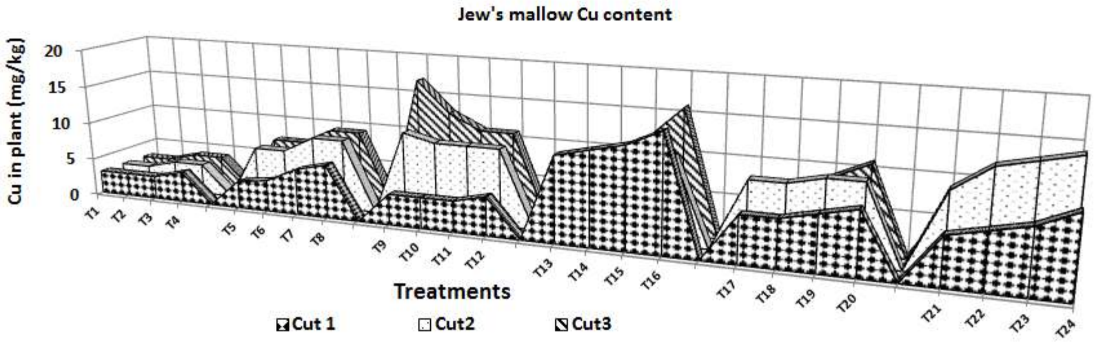

Fig. 3. Copper content of *Corchorus olitorius* plants (mg/kg) in the first, second and third cuts using different investigated treatments

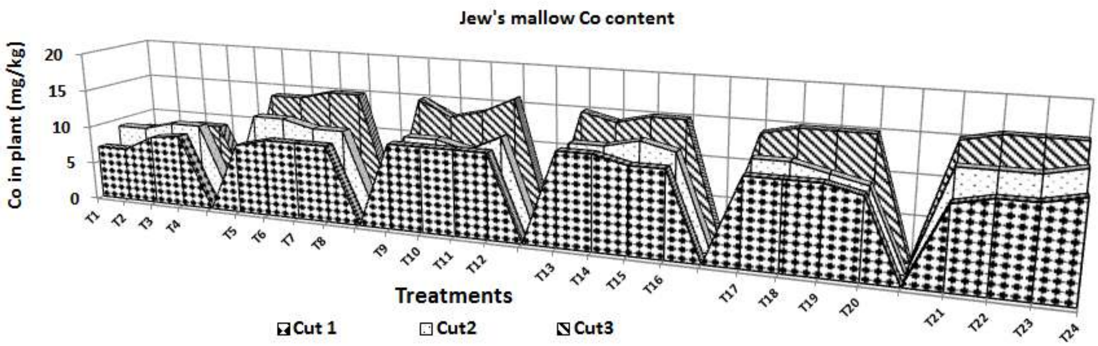

Fig. 4. Cobalt content of *Corchorus olitorius* plants (mg/kg) in the first, second and third cuts using different investigated treatments

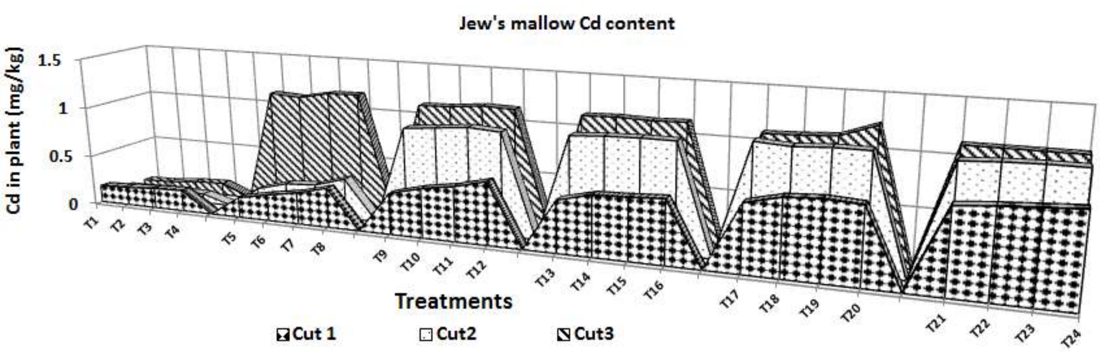

Fig. 5. Cadmium content of *Corchorus olitorius* plants (mg/kg) in the first, second and third cuts using different investigated treatments

4. DISCUSSION AND CONCLUSIONS

Results of selected growth parameters proved that, positive effects were found for the biological and /or organic additives to the soil in a combination with different types of natural and chemical phosphate fertilizers. Application of filter mud cake (FMC) with rock phosphate (RP) or other phosphate fertilizers showed the highest positive effect on the fresh and dry weight of shoots and roots in the three cuts. This may be due to the role of organic material as a source for different nutrients and an activator for phosphate dissolving bacteria.

The application of filter mud cake alone or with phosphate dissolving bacteria increased the soil fertility and in turn the number of such microorganisms that accelerate the microbial activity in the rhizosphere of the inoculated soil. This agrees with the results obtained by Heikal [22] who reported that, the most effective increase of herb fresh weights was obtained by the application of chicken manure with yeast bio-fertilizers on thyme plants. It may be also explained on the basis of the beneficial effects of these applied bacteria which convert the insoluble phosphate compounds such as rock phosphate into a soluble form through producing organic acids and increasing the nutrients availability which in turn stimulate the plant growth. The combined application of rock phosphate containing minerals with these bacteria provides the growing plants with a continuous supply of phosphorus and potassium for best plant growth rate [23]. The present results of plant growth are comparable with those reported by Han and Lee [23] in an inoculation study of phosphate solubilizing bacteria (PSB) which resulted in a high amount of NPK uptake leading to high plant growth. Also, maize yield significantly increased and soil properties such as organic content improved due to co-inoculation with potassium solubilizing bacteria (KSB) and PSB [24].

The present results are also comparable with those of [25, 26] who indicated that seed inoculation with phosphate dissolving bacteria (PDB) caused remarkable increases in most growth parameters of mung bean plants.

Nitrogen, phosphorus and potassium uptakes by hot pepper (*Capsicum annuum* L.) plants were improved as a result of combined application of rock phosphate and potassium feldspar with the inoculation of phosphate and potassium solubilizing bacteria which increased plant photosynthesis by 16% and leaf area by 35% compared to control plants [27]. In this respect, Sikander [28] reported that addition of organic materials promote the metabolic activity inside the plant and enhance the movement of the metabolites through the roots and stems toward the leaves; so the nutrient content of the plants may increase. The application of yeast bio-fertilizers with chicken manure to the soil gave the most effective increases in the plant height and number of branches/plant of thyme plants [22].

Also, broad bean plants grown on soil amended with a mixture of rock phosphate, sulphur, and organic manure exhibited higher N, P and K contents than those obtained from adding each amendment separately [29]. In addition, the application of K and P solubilizing bacterium inoculants with humic substances as organic additions maximizes the favorable effect on the growth and yield of canola plants than applying each inoculant separately [28]. Moreover, these results are in agreement with those obtained by Brahmachari and Mondal [30] who found that the maximum nutrients uptake (N, P and K) were obtained when Jew's mallow received both organic and inorganic sources of nutrients types.

Application of PDB with different type of fertilizers including rock phosphate fertilizer treatment recorded higher P contents than those obtained with these treatments without applying PDB. In this regard, the combined soil inoculation with potassium solubilizing bacteria (KSB) and phosphate solubilizing bacteria (PSB) as well as adding humic acid showed greater growth and yield as well as higher available phosphorus and potassium levels in the soil compared to those of the control and the sole inoculation treatment with KSB or PDB [31].

Heavy metals present in soils can easily accumulate in plant tissues. With regard to the contents of heavy metals in different phosphate fertilizers used in this study, the analysis proved that T.P.F, S.P.F1, S.P.F2 and S.P.F3 fertilizers contained 148.6, 66.8, 484, and 51.4 mg/kg of Zn respectively, 9.0, 5.5, 5.9 and 5.6 mg/kg of Cu respectively, and 1.1, 1.8, 0.9 and 1.0 mg/kg of Cd, respectively. These previous chemical fertilizers did not contain cobalt or Nickel. However, rock phosphate showed Zn, Ni, Cu, and Cd concentrations of 111.6, 6.9, 6.0 and 2.g mg/kg, respectively and it did not include Cobalt. Also, the analysis indicated that filter mud cake (FMC) only comprised Zn (43.2 mg/kg) and Cu (36.1 mg /kg). The soil of this study contained total contents of Zn, Ni, Cu, Co and Cd of 9.3, 20.3, 7.3, 1.0 and 2.0 mg/kg respectively. Adding FMC alone or with PDB resulted in Zn and Cu content of *C. olitorious* which increased with using fertilizer treatments.

The chemical fertilizers and FMC did not exhibit Ni levels, while soil and rock phosphate had 20.3 and 6.9 mg/kg, respectively. So, the Ni content of *C. olitorious* was mainly due to the native soil content or rock phosphate while, the Cobalt in *C. olitorious* was attributed only to the soil. Morover, soil, chemical fertiizers and rock phosphate were the sources of cadmium up take by *C. olitorious* plants.

The relative increases in heavy metal contents (Zn, Cu and Cd) in *C. olitorious* plants under this study were due to the application of rock phosphate and chemical manufactured phosphate fertilizers which had a significant contributor of the heavy metals as shown in chemical analysis of tested fertilizers. Nabulo et al. [32] found that metal uptake by the tropical vegetable plants was modeled as a function of the total soil metal concentration and soil solution concentration. Our findings are in agreement with those of Chen *et al*. 2007 [7]. Also, Tabatabai [33] reported that rock phosphate contains heavy metals such as cadmium, chromium, mercury and lead. Mortvedt and Sikora [3] and Isil et al. [6] found that the main source of heavy metals in the manufactured phosphate fertilizers was related to the phosphate rock. In addition, van Kauwenbergh [34] reported that phosphate rocks and fertilizers contain hazardous elements such as Cd, As, Cr, Hg, Pb, Se, U and V^5. Moreover, Guzman et al. [35] found that the contamination of corn with heavy metals was due to intensive fertilizer application. Oyedel et al. [9] studied the accumulation of heavy metals in vegetables fertilized with phosphate fertilizer. They reported that the addition of fertilizer significantly increased Cd, Pb and Hg contents of the soils by 14-60% over the control soil and increased heavy metal contents in plants. The application of triple supper phosphate (T.S.P) containing Cd to the soil resulted in increased Cd concentrations in both cereal grains and the edible portions of vegetables [10].

The application of FMC as a source of organic matter with or without application PDB in combination with all fertilizers resulted in a higher increase in Zn, Cd, Co, Cu and Ni content of the investigated plants. Such effects were recorded with all investigated treatments in all three cuttings. The increased solubility of these metals in the soil amended with FMC could be due to the decrease in soil pH [36]. That the addition of organic material (sewage sludge) to the soil increased the percentages of available Ni, Zn, and Cd [37]. Usman et al. [38] found that the mobility of heavy metals can be increased by the addition of sewage sludge. Temminghoff et al. [39] reported that the mobility of heavy metals increased with soluble organics.

The cobalt level in *C. olitorious* plants that received all phosphate fertilizers types were below the permissible limit (50.0 mg/Kg) recommended by FAO/WHO [40] which the cobalt levels in the investigated plants ranged from 7.0 to 16 mg/Kg.

From the above discussion it seems that the concentration of Zn in the plants received rock phosphate (RP) either alone or in combination with phosphate dissolving bacteria (PDB), Filter mud cake (FMC) or with PDB+FMC were lower in the first cut only and were below permissible limit according to Kabata-Pendias and Pendias [41] (27-100 mg /kg) , while in the second and third cuts the concentration of Zn under this treatment exceeded the permissible limits while the concentration of Zn in plants fertilized with chemical manufactured phosphate fertilizers with different combination treatments was higher than that of RP treatments but higher than the permissible levels.

The Ni content of *C. olitorius* plants in the three cuts treatments except RP alone or with PDB in the first cut was higher than the maximum allowable level of Ni [42] which was 10.0 mg/kg. The rock phosphate (RP) treatment alone or with PDB in the first cut showed a plant Ni content on the border of the permissible level (10 mg/kg) set by WHO [42].

The concentration of Cd in *Corchorus olitorius* plants grown on the soil amended with different types of phosphorus chemical fertilizers is higher than the allowable level of Cd as set by the FAO/WHO-Codex alimentarious commission [40] which was 0.2 mg/kg for leafy vegetables.

The obtained results showed that studied heavy metals in *C. olitorious* plants fertilized with different phosphate fertilizers varied from one cut to another. The plants of the first cut gave generally lower heavy metals contents than the two other cuttings. This was true for all treatments and may be due to that the development occurred in growth of plant roots of the second and third cuts which increase the capacity to absorb nutrients.

The obtained results are in agreement with that of [43,44,45] who indicated that both the organic source and bio fertilizer promote the growth of plant roots and hence increase the capacity to absorb nutrients.

The results also indicated that *C. olitorius* heavy metal contents at second and third cuts for the control treatment were higher than in the first cut. On the other hand, the results of Cu level in the investigated plants received all phosphate fertilizers types with different combination treatments below permissible limit set by FAO/WHO [40] which was 73.3 mg/kg.

Therefore, the concentrations of plant Cu in this study were within the acceptable range.

It can be concluded that although each of the second and third cuts gave greater growth than that of the first cut, only first cut of the plants which received rock phosphate either alone or in combination with PDB, FMC or their mixture is considered safe. So, natural rock phosphate fertilization for Jew's mallow instead of the use of phosphate manufactured chemical fertilizer for Jew's mallow that should be harvest by pulling the whole plants with their roots from the soil after 40 days from planting is recommended to avoid the high heavy metals contents in Jew's mallow which occur in the second and third cuts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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