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EFFECT OF MUNICIPAL SOLID WASTE COMPOST, GYPSUM AND MYCORRHIZA ON METALS CONTENT IN SOIL AND PEANUT GRAIN

*Maryam Janbazi Rudsari[1], Hamid Reza Doroudian[*1], Naser Mohammadian Roshan[1], Seyyed Mostafa Sadeghi[1], Majid Ashouri[1]*

[1]Department of Agronomy and Plant Breeding, Lahijan Branch, Islamic Azad University, Lahijan, Iran
**Corresponding author: agroecologist.hamid@gmail.com*

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ABSTRACT

Municipal solid waste compost (MSWC) is widely used as an organic soil amendment and fertilizer on agricultural land. However, applying MSWC can cause adverse effects due to the heavy metals contained. This study aimed to determine the heavy metal content of MSWCs in the presence of mycorrhizae and gypsum and their effects on soil and peanut grain. The field experiment was conducted using a split factorial design based on a Randomized Complete Block Design (RCBD) with three replications in Iran during 2018 and 2019. The main factor includes two levels of gypsum (0 and 150 kg ha^{-1}) and the sub-factors include the presence and absence of Arbuscular mycorrhizal fungi (AMF) and different levels of MSWC at five levels (0, 2, 4, 6, and 8 t ha^{-1}). The findings showed that MSWC significantly increased the concentrations of manganese (Mn), lead (Pb), nickel (Ni), zinc (Zn), cobalt (Co), chromium (Cr), cadmium (Cd), and boron (B) in soil and grains. In addition, Co, Ni, and Zn concentrations in grain increased and Pb, Mn, Ni, and Zn concentrations in soil decreased with AMF application. Gypsum treatment also had no significant effect on metals in both grain and soil. According to the obtained results, the use of 4 t ha^{-1} of MSWC along with mycorrhiza in peanut cultivation is suggested in order to reduce the environment risks of soil and plants cause by the use of compost, and also use the benefits of urban waste compost.

Keywords: Gypsum, Heavy metals, Human health, Mycorrhiza, Peanut.

INTRODUCTION

Over the past few years, the use of MSWCs in agricultural fields has increased. MSWC provides the organic compounds required by the soil. A number of studies have shown that the addition of MSWC improves the physico-chemical properties of the soil due to the high amount of organic matter it contains (Batool et al., 2015; Yuksel, 2015; Tepecik et al. 2022). Using MSWCs improves soil microbial characteristics and crop production (Meena et al., 2016). Furthermore, they improve crop yields and improve soil nutrition, soil structure, and soil buffers. MSWCs are high in nitrogen, and humic compounds which include humic and fluvial acids (Srivastava et al., 2016). However, there are also negative impacts associated with the use of MSWC. One of the main concerns of its use is its heavy metals, which increase their accumulation in the soil (Yuksel, 2015; Tepecik et al. 2023). Ayari et al. (2010) showed that the using MSWC increased increased soil concentrations of Cd, Cr, copper (Cu), Ni, Pb, and Zn compared to control.

Heavy metals are the main contaminants causing environmental and human health problems because they do not biodegrade. Therefore, soil and crop exposure to these pollutants shortens life (Gu et al., 2019). They are essential for plant growth but toxic to animals, and are also toxic to plants if their concentrations exceed tolerance levels. Studies show that heavy metals accumulate in the soil as a result of the weathering of soil minerals and the use of treated wastewater, sewage sludge, and fertilisers (Nouri et al., 2016; Ongun et al. 2023). Besides polluting soil, heavy metals also affect food production, quality and safety. Heavy metals can affect plant metabolism and physical and biochemical processes, leading to reduced growth, reduced biomass production, and reduced metal accumulation (Edelstein and Ben-Hur 2018; Nouri et al., 2016). Plant exposure to heavy metals causes oxidative stress, cellular damage, and disrupts cellular ion homeostasis (Yadav, 2010).

To cope with high concentrations of heavy metals, plants use a variety of strategies to prevent them from entering the roots one such strategy (Rousta et al., 2023). Heavy metals can be immobilised by mycorrhizae, by sequestration of the metal and by complexation with organic compounds secreted by the roots of the plant (Antosiewicz et al., 2014). In addition to the provision of essential minerals to the plant, mycorrhizae also improve the physico-chemical properties of the soil (Nouri et al., 2020) and it also act as filters (Wu et al., 2019). They block xenobiotics in their mycelium and immobilise heavy metals in the roots (Matinizadeh et al., 2022). The co-occurrence of mycorrhizal fungi with plant roots in areas of heavy metal contamination has already been reported (Riaz et al., 2021). The second strategy the tolerance mechanism for detoxification is activated if the plant cannot prevent heavy metals from entering the roots (Nouri et al., 2016). This mechanism includes the sequestration and compartmentalisation of metals in different intracellular compartments, the transport of metal ions, the binding of metals to the cell wall, the biosynthesis or accumulation of osmolytes and osmoprotectants (Emamverdian et al., 2015, Fryzova et al., 2018). Subsequent human intake can cause diseases including cancer, cardiovascular problems, depression, blood, gastrointestinal and renal failure, and osteoporosis (Edelstein and Ben-Hur, 2018).

Gypsum has been introduced as a soil remediation and fertilisation tool in many countries. Gypsum can meet soil sulphur requirements as a fertiliser. It provides a high level of exchangeable divalent cations and coagulates the colloids in the soil, particularly in temperate soils. It is also a source of calcium for clay flocculation in acidic and alkaline soils (Anikwe et al., 2016). Research shows that by altering water-holding capacity, soil structure, water infiltration rate and increasing water mobility in the soil, gypsum is involved in improving plant production, strengthening plant root systems, increasing nutrient availability and soil moisture (Batool et al., 2015). However, the extent of plant response and environmental improvement from gypsum application, influenced by different local conditions, remains unknown (Zoca and Penn, 2017). Symbiotic root endophytes can enhance plant growth. Arbuscular mycorrhizal fungi from the phylum Glomeromycota form symbiotic associations with 72% of plants, improving nutrient uptake from the soil. They also improve plant tolerance to biotic and abiotic stress (Tian et al., 2021). Mycorrhizal fungi increase plants' ability to absorb nutrients and water, and plants provide fungal carbohydrates (Wang et al., 2017; Cukurcalioglu et al., 2023).

This study was conducted in view of the nutritional benefits of peanuts, which are rich in protein and oil and are widely consumed in most countries of the world, particularly in Africa and Asia (Pandey et al., 2014). Peanut grain oil is a good source of monounsaturated fatty acids, including oleic acid, that help lower bad cholesterol in the blood. Peanut grains also contain vitamin E and niacin, which help to maintain the health of the brain (Mekdad et al., 2021). Therefore, the aim of the present study was to investigate the heavy metal concentration in peanut grains and soil after treatment with MSWC, gypsum and mycorrhiza over two growing years.

MATERIALS AND METHODS

Land preparation and planting operations

The field experiment was carried out in the split factorial design based on a completely randomized block in three replications in Astaneh-Ashrafiyeh, Iran (Long=49º 57'10.64", Lat=37º19' 21.96", 2 m a.s.l) in 2018 and 2019 cropping year. Rainfall was 1211 mm on average per year. Mean daily maximum and minimum temperatures during the peanut growing season ranged from 29.7 to 37.9 °C and from 14.6 to 26.6 °C, respectively. The mean daily relative humidity was between 45% and 91%. Table 1 presents temperature, precipitation, and sunny hours during the plant growth period and long term of Astaneh-Ashrafiyeh region.

Table 1. Mean temperature, total precipitation and sunny hours per month during plant growth (Astaneh-Ashrafiyeh Weather Station)

Year	Metrological parameters	May	Jun	Jul	Aug	Sep
2018	Temp.Mean (ºC)	19.4	23.1	28.1	27	25.1
	Precipitation (mm)	37.2	48.7	30.8	68.4	13.8
	Humidity (%)	74	75	73	77	74
	Sunny hours (h)	170.4	230.3	295.4	164.9	209.7
2019	Temp.Mean (ºC)	19.2	24.6	27.2	25.4	23
	Precipitation (mm)	64.4	9.9	58.3	25.3	156
	Humidity (%)	73	67	76	71	83
	Sunny hours (h)	222	306.4	253.3	226.1	123.5
Long term	Temp.Mean (ºC)	18.3	22.7	25.1	26.2	22.5
	Precipitation (mm)	84.5	62.2	39.2	41.5	44.6
	Humidity (%)	82.6	78.6	72.3	78.4	81.4
	Sunny hours (h)	158.1	219	232.4	176.3	193.2

Samples were taken from a depth of 30 cm to analyse the soil properties. The soil of the experimental field was sandy-loam in texture, with neutral pH (7.22), low in organic C (0.94%) and low EC (0.297 dS m^{-1}). The soil type is the Alfisol that is common in this area. The results of the soil analysis are presented in Table 2.

Table 2. Soil analysis at the start of cultivation.

Depth	pH	EC (dS m^{-1})	OC (%)	P (mg kg^{-1})	K	N (%)	Ca (mEq L^{-1})	Sand (%)	Silt	Clay
30 cm	7.22	0.297	0.94	9.15	256.8	0.08	6.4	31	63	6

Treatments and experimental design

The research was carried out as the split factorial design based on a Randomized Complete Block Design with three replications. The main factor includes two levels of gypsum (0 and 150 kg ha^{-1}) and the sub-factors include the presence and absence of Arbuscular mycorrhizal fungi (AMF), and different levels of MSWC at five levels (0, 2, 4, 6, and 8 t ha^{-1}).

Before sowing, the field was cultivated with a plough and a disc harrow. To plant the seeds of cv. 'NC2' (North Carolina variety), 6 cm deep furrows were made in the soil and the seeds were placed in the furrows and covered with soil. Before planting, 50 kg ha^{-1} of phosphorus (as triple superphosphate) and potassium (as potassium sulfate) fertilizers were added to the soil. The 60 kg ha^{-1} urea fertilizer (25.2 kg N ha^{-1}) was also added to the soil in two stages (before planting and before flowering). For the application of the treatments, 60 plots of 2.5 × 3 m^2 were prepared. A space was left between the plots to avoid interference with the treatments. Weeds were pulled by hand as soon as they appeared.

Gypsum (gypsum with the chemical formula $CaSO_4.2H_2O$ (with a sulphur content of 18% and a calcium content of 22%) was applied in one stage (V3 stage; 20 days after germination). MSWC was applied in the presence or absence of mycorrhizal fungi in the vegetative stage and before flowering at five rates of 0, 2, 4, 6, and 8 t ha^{-1} before sowing. Table 3 shows the characteristics of the MSWC. The mycorrhizal fungi were also obtained from Pishtaz Varian Knowledge Enterprise and for each kg of seeds, 10 g of arbuscular mycorrhizal fungi were mixed in 1 Liter of water and 400 g of sugar and treated for 1 h.

Table 3. MSWC characteristics used for the treatment

EC (dS m^{-1})	pH	OM	OC	Particle diameter (mm)	CEC (mEq $100g^{-1}$)	P	N	K	C:N
		(%)					(%)		
10.93	7.56	36.77	21.32	1.18	8.11	0.001	1.66	0.31	12.84

Fe	Ca	Na	Cd	Ni	Cr	Pb	Cu	Mn	Zn
(%)					(mg kg^{-1})				
2.5	2.4	458.26	3>	7	100>	50	180	4	46

Irrigation and harvesting

Every two years, when rainfall was sufficient for peanut production in the area, the plants were irrigated by rain. Every two years, the harvest of the peanut crop was carried out at the same time as the physiological (grain care) arrival and 111 days after the planting, and by hand.

During harvest, plants in side rows and plants in beginning and end of plot were removed to eliminate marginal influence (Temel et al., 2024).

Heavy metal analysis

For this purpose, the prepared samples were crushed into particles smaller than 2 mm. Then 0.5 g of the sample with 6 mL of nitric acid was placed in a digestion vessel and stored for 1 h. Then 2 mL of hydrogen peroxide was added and the digestion vessel was placed in the microwave digester. After digestion, the tank was washed with water and the washing solution was filtered through a 0.22-µm filter. Finally, the heavy metal content was measured by inductively coupled plasma mass spectrometry (ICP-MS). A Perkin Elmer Elan 9000 ICP-MS with a quartz concentric nebuliser and an integrated quartz burner tube was used.

Statistical Analysis

Data analysis was performed with statistical analysis variance using SAS version 9.1 software and averages were compared using the Duncan's test at a 5% probability level, and charts were generated using Excel 2013.

RESULTS AND DISCUSSIONS

The results of the analysis of variance of this study showed that crop year had statistically significant effect on the concentration of studied metals in grain and soil (Table 4 and 5). Although applying different levels of MSWC had a significant effect on the concentration of studied metals in soil, it significantly affected B, Cd, Cr, Co and Pb in grain. Mycorrhizal treatment did not significantly affect the concentrations of the metals studied, except for Mn and Ni in grain. The gypsum treatment also did not have a significant effect on the metals in both the grain and the soil (Table 4 and 5). The results of the analysis of composite variance showed that the interaction effect of crop year × gypsum × mycorrhizal × MSWC had a significant effect on the concentration of the studied metals in both grain and soil. While the interaction effect of each of the three treatments did not have a significant effect on the concentration of studied metals in grain and soil (Table 4 and 5).

Overall, the maximum amount of B concentration in grain was 7.85 mg kg^{-1} obtained in the second year with 150 kg ha^{-1} gypsum and 8 t ha^{-1} MSWC in the presence of mycorrhizae, which was 9.94% higher than that in the first year. On the contrary, the highest value of boron in soil was observed in the absence of gypsum compared to values of boron in grain (Figure 1). Compared to the control and the MSWC rates of 2, 4 and 6 t ha^{-1}, the application of 8 t ha^{-1} MSWC increased the B concentration by 91.29, 47.51, 19.08 and 9.21% in the grain and by 71.04, 39.89, 19.38

and 8.05% in the soil (Figure 1). The lowest B concentrations in grain and soil were also observed in the plots not treated with MSWC. Moreover, the result of aplication of gypsum had positive effect on B concentraion in grain significantly. B is believed to play a crucial role in nitrogen metabolism by increasing nitrogenase and facilitating nitrate translocation and availability for reduction in leaves, stems, roots, and nodules (Ghazimahalleh et al., 2022).

Table 4. Combined variance analysis of the effect of year, gypsum, mycorrhiza and MSWC on the concentration of metals in grain of peanut

S.O.V	df	MS (Mean squares)							
		B	Cd	Cr	Co	Pb	Mn	Ni	Zn
Year (A)	1	26.3**	0.036	1.06**	20**	34.4**	15.4**	30.4**	2980**
Block (R)	4	1.05	0.0009	0.022	0.499	0.69	0.25	0.52	69.81
Gypsum (B)	1	94.8	0.164	4.43	76.1**	122	61.1	110.7	13369
B × A	1	13.6**	0.026**	0.71**	12.22	17.5**	9.72**	18.53**	2185**
Error 1	4	0.198	0.00007	0.00079	0.011	0.17	0.004	0.01	2.88
Mycorrhiza (C)	1	0.479	0.0038	0.036	0.686	0.67	0.48**	1.16**	133
MSWC (D)	4	30.8**	0.143**	1.46*	127**	55.4**	69.0	191	187
C × B	1	0.006	0.00075	0.002	0.032	0.008	0.01	0.01	20.2
C × A	1	1.2*	0.001*	0.078**	1.44**	1.56**	1.14**	2.31**	185**
C × B × A	1	1.15*	0.0005	0.07**	1.65**	1.59**	1.34**	2.18**	125**
B × D	4	2.63*	0.008	0.13*	7.06*	4.21*	3.94*	10.02	144
D × B × A	4	0.436	0.002**	0.019*	0.91**	0.62*	0.48**	1.42**	40.9*
D × C	4	2.14*	0.002	0.076*	1.34*	2.78 *	1.21 *	2.02 *	198
D × C × A	4	0.147	0.0002	0.011	0.162	0.19	0.14	0.18	33.9
D × C × B	4	0.933	0.001	0.038	0.536	1.16	0.5	0.71	119
D × C × B × A	4	0.46*	0.001*	0.026**	0.465**	0.59**	0.41**	0.68**	74.6**
Error 2	72	0.187	0.0002	0.006	13.8	0.2	0.06	0.12	15.29
CV (%)		9.2	7.3	7.6	8.6	8.54	6.84	7.28	6.87

*, ** Significant at 5% and 1% probability level, respectively and others are Non-significant

Table 5. Combined variance analysis of the effect of year, gypsum, mycorrhiza and MSWC on the concentration of metals in soil in peanut

S.O.V	df	MS (Mean squares)							
		B	Cd	Cr	Co	Pb	Mn	Ni	Zn
Year (A)	1	268.2**	0.183**	2345**	865**	17439**	2122**	2060**	24012**
Block (R)	4	10.2	0.0031	37.3	12.4	349	48.5	41.0	557
Gypsum (B)	1	1141.4	0.696	8646	3268	6424	8602	8229	91368
B × A	1	185**	0.111**	1468**	509**	10175**	1383**	1309**	14518**
Error 1	4	1.16	0.00002	7.31	0.094	20.66	6.47	0.57	14.26
Mycorrhiza (C)	1	9.08	0.005	75.9	43.08	563	75.0	73.9	797
MSWC (D)	4	273*	0.715**	8083**	4593**	149771**	5913**	7165**	148893**
C × B	1	0.641	0.00008	1.92	4.48	5.7	4.76	3.98	15.15
C × A	1	19.1**	0.014**	129**	52.7**	1319**	147**	145**	1777**
C × B × A	1	17.3**	0.014**	143**	60.6**	1702**	159**	158**	2157**
B × D	4	28.6*	0.043*	524*	277*	7484*	406*	460*	7945*
D × B × A	4	4.42	0.06**	64.3**	34.8**	920**	51.8**	57.8**	975**
D × C	4	19.0*	0.013*	155*	51.1*	1405*	150*	146*	1872*
D × C × A	4	2.83	0.0016	20.45	6.35	144.8	19.8	18.6	205
D × C × B	4	9.94	0.0056**	62.6**	18.14	491.08	68.0	63.3	707
D × C × B × A	4	9.95*	0.0046**	65.4**	19.3**	455**	53.1*	51.6**	627**
Error 2	72	2.43	0.00077	13.85	4.64	107.64	16.79	10.49	132
CV (%)		9.5	7.9	8.3	8.1	8.68	9.17	7.45	7.99

*, ** Significant at 5% and 1% probability level, respectively and others are Non-significant

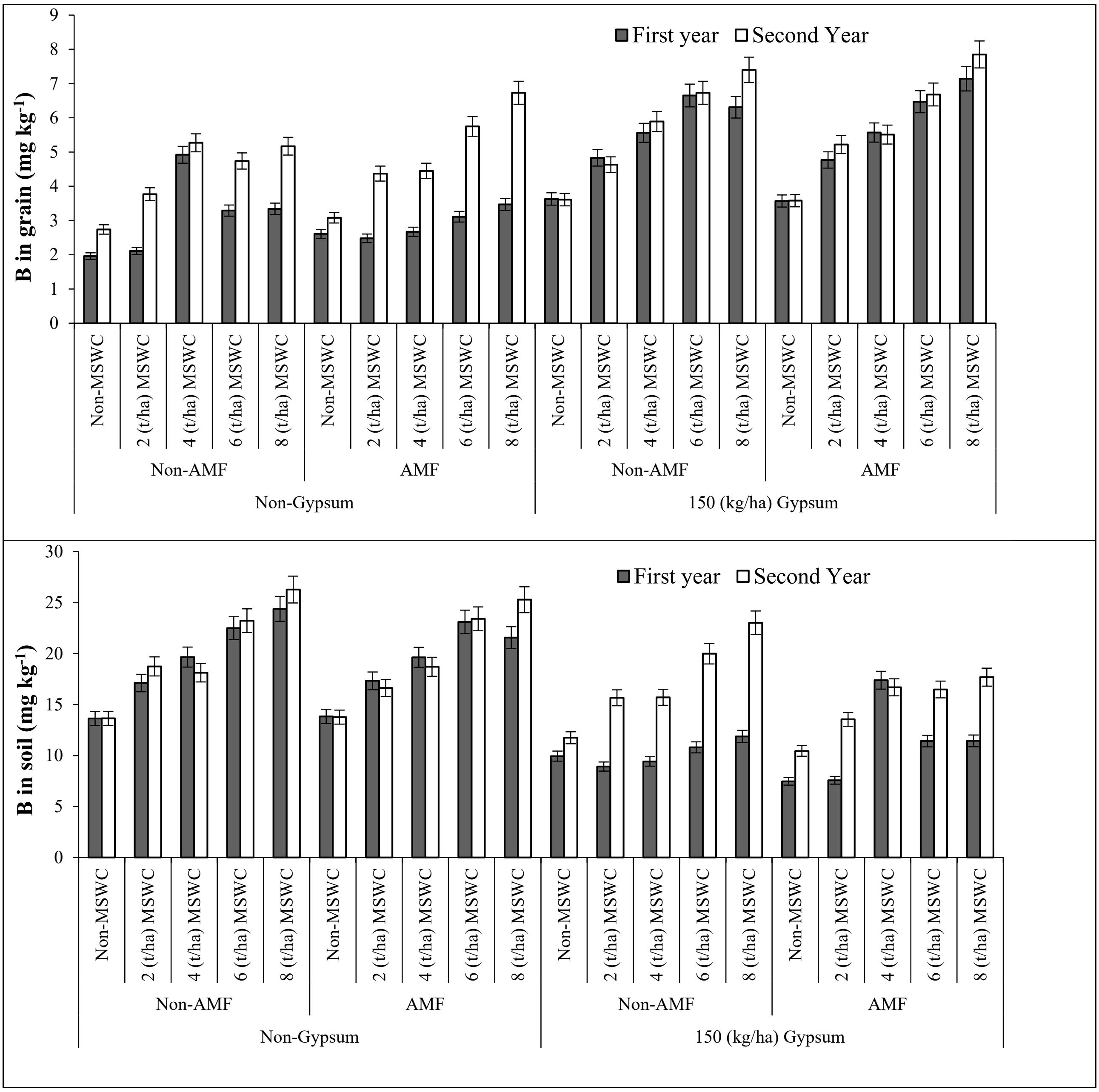

Figure 1. Effect of studied treatments on boron concentration in peanut grain and soil.

In both years, in both conditions of application and non-application of gypsum and mycorrhiza, the concentration of Cd in seeds and soil increased with the increase of MSWC application. But in the seed, the amount of this increase was lower under the application of mycorrhiza and gypsum, so that under the absence of application of mycorrhiza and gypsum, the level of 8 t ha^{-1} MSWC increased the concentration of Cd in the seed to 0.36 mg kg^{-1} in the first year and 0.39 mg kg^{-1} in the second year, while in mycorrhizal plants and under the application of gypsum, the concentration of Cd decreased to the same level as MSWC to 0.29 and 0.16 mg kg^{-1} in the first and second year, respectively. In other levels of MSWC application, the application of gypsum along with mycorrhiza, compared to the conditions of no application of gypsum and mycorrhiza, decreased the concentration of Cd in seeds from 6.6 to 25.6% in the first year and from 0.23% to 54.3% (Figure 2). Similarly, the results of the concentration of metals in peanut grown in fields contaminated with heavy metals were significantly higher than in those grown in a control plot, according to a study by Opaluwa and colleagues (2012). Similar findings have been reported in rice (Bakhat et al., 2017), wheat (Shrivastava et al., 2017) and veggies (Wang et al., 2006). There is evidence from studies that plants take up heavy and toxic metals through their roots and accumulate them in their tissues. Two main pathways, the apoplastic and symplastic pathways are often used for the entry of heavy metal ions into plant roots. A positive correlation between the amount of MSWC application and Cd uptake was reported, indicating that increasing MSWC application leads to an increase in Cd phytoavailability (Wang et al., 2023). In addition, Cd may strongly bind to insoluble organic matter such as large molecules of humic acid and humin and increase the Cd absorption capacity of soil (Lee et al., 2022).

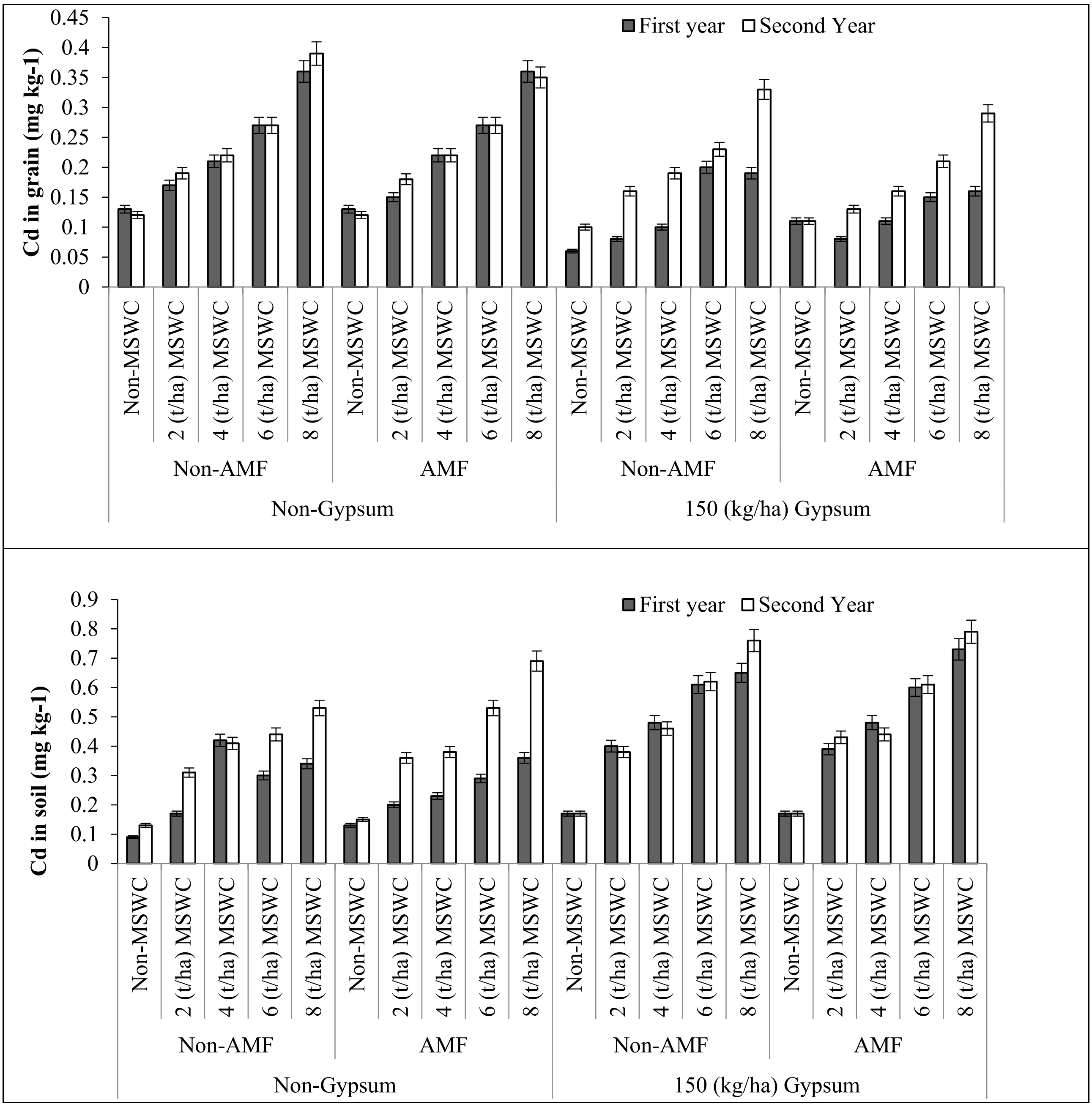

Figure 2. Effect of studied treatments on cadmium concentration in peanut grain and soil

In general, the maximum concentration of Cr in grain (1.57 and 1.69 mg kg^{-1} in the first and second year, respectively) was obtained from applying 8 t ha^{-1} MSWC without using gypsum in the presence of mycorrhiza. However, applying gypsum decreased the concentration of Cr in grain from 47.5 to 54.5% in the first year and from 12.1 to 26.3% in the second year compared to similar treatments under no application of gypsum. Also, the highest Cr concentration in soil (85.3 and 91.9 mg kg^{-1} in the first and second year, respectively) was obtained from the application of 8 t ha^{-1} MSWC along with the application of gypsum in the absence of mycorrhiza. In addition, at all levels of MSWC, the application of gypsum increased the concentration of soil Cr, whether in the presence or absence of mycorrhiza (Figure 3).

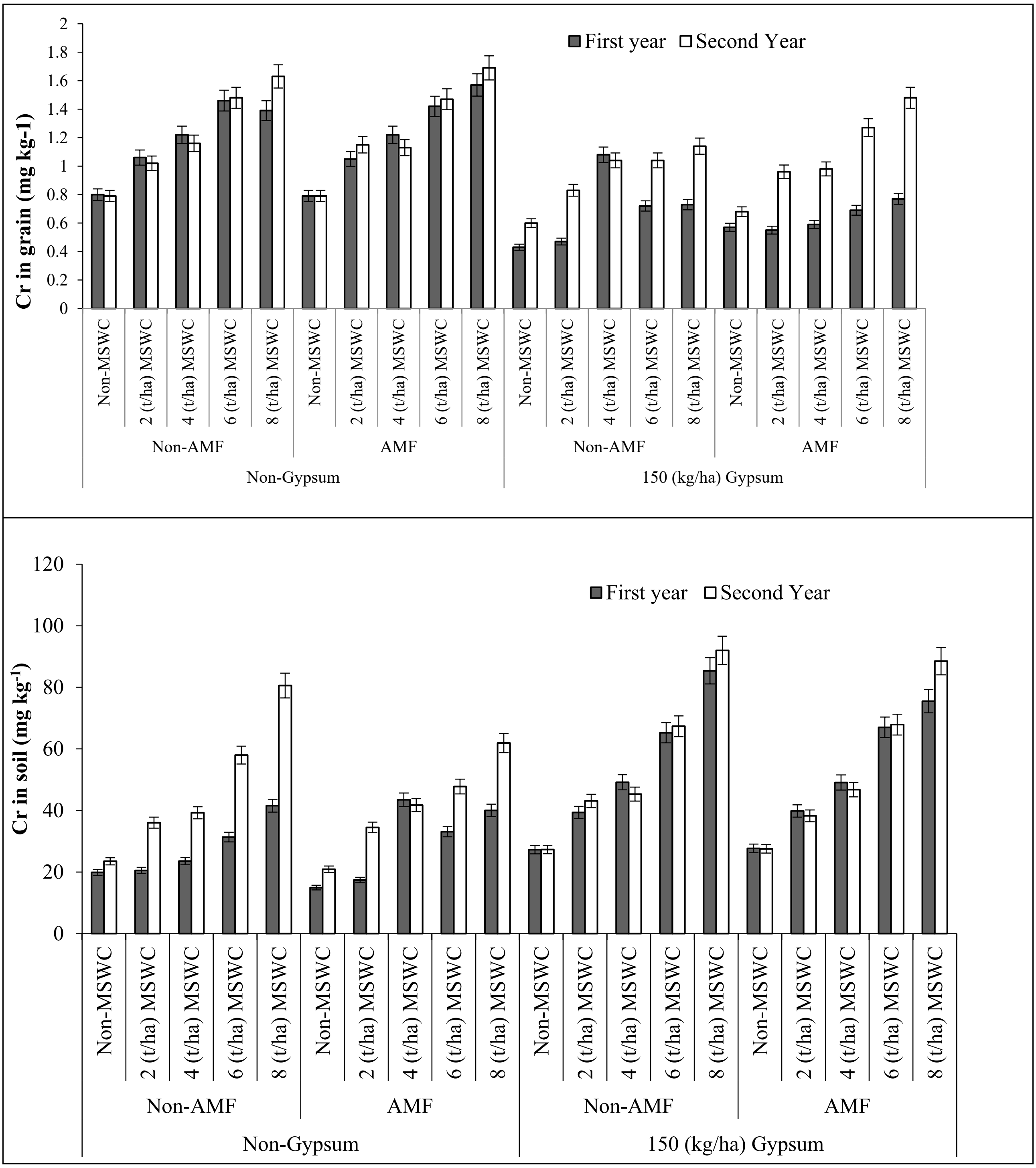

Figure 3. Effect of studied treatments on chromium concentration in peanut grain and soil.

Overall, the maximum amount of Co in the grain was 8.70 mg kg^{-1} obtained in the second year by application of 150 kg ha^{-1} gypsum and 8 t ha^{-1} MSWC under mycorrhizal conditions, and the highest Co concentration in the soil was 57.95 mg kg^{-1} observed in the second year without gypsum and mycorrhiza, and application of 8 t ha^{-1} MSWC (Figure 4). Significant concentrations of Co are highly toxic to crops. Co causes pale-coloured leaves, discoloured veins, leaf loss, and plant Fe deficiencies (Hu et al., 2021; Abugoufa et al., 2022). Peanut crops show hazardous effects when grown in soils with high Co concentrations (Abugoufa et al., 2022). Riaz et al. (2021) report that mycorrhiza might effectively immobilize Pb and Co in polluted soils. Mycorrhizal fungus has the ability to increase the absorption of less mobile nutrients such as P, Cu, Zn, Co, and Fe as a result of their interactions with soil cations such as Fe_3^{+}, Ca_2^{+} and Al_3^{+}. This is possible because the fungus can create a wide network of hyphae with a very large surface area and with great potential to explore a larger volume of soil to extract nutrients (Udo et al., 2023).

Arbuscular mycorrhizae can provide both macronutrients and micronutrients. This is perhaps due to the key role of mycorrhizae in maintaining soil stability and soil ions and preventing their loss, and even though improve root characteristics (e.g., mass, root length, and root surface) (Lazcano et al., 2014).

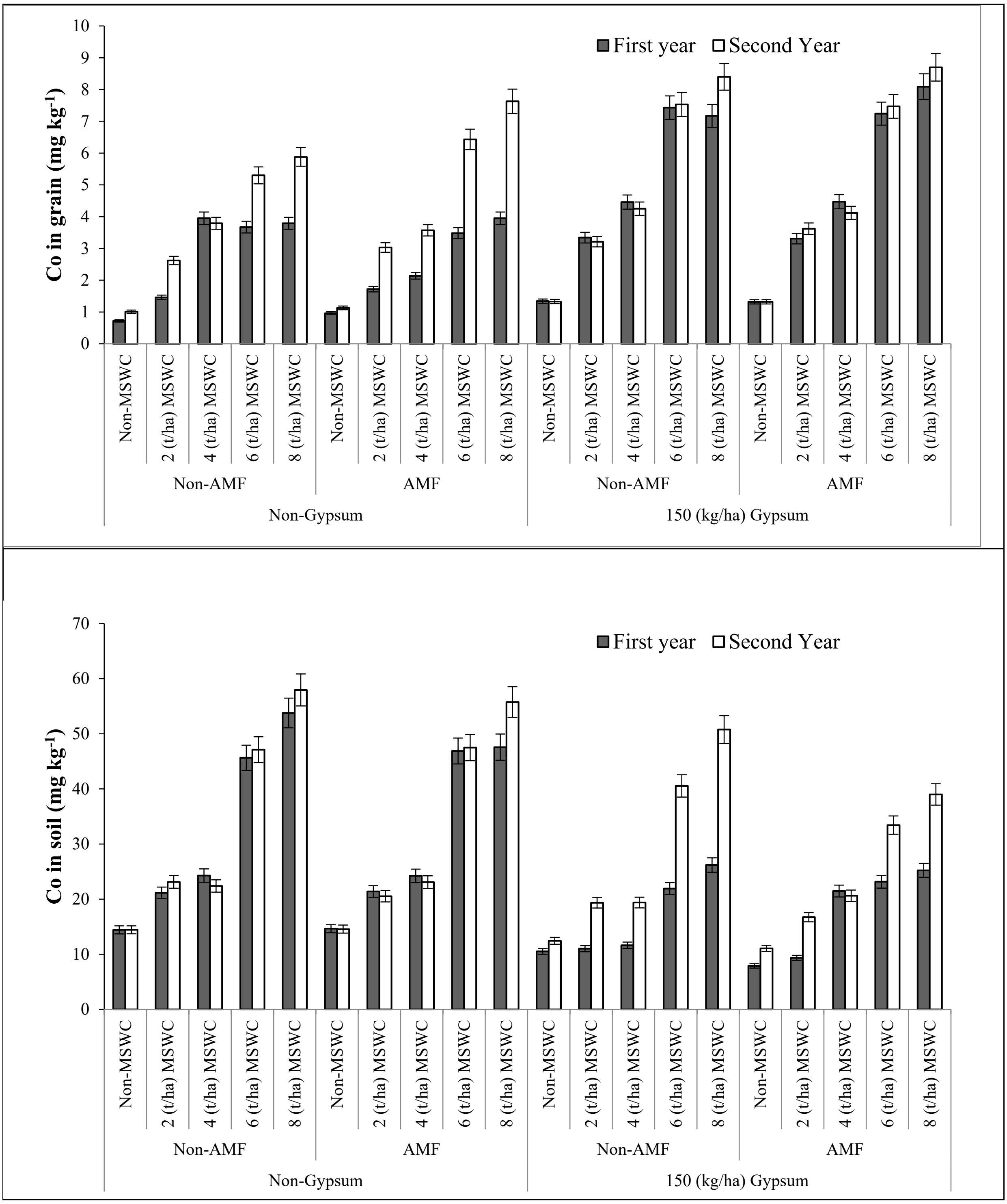

Figure 4. Effect of studied treatments on cobalt concentration in peanut grain and soil.

In general, the highest Pb concentrations in grain and soil were 9.42 and 285.55 mg kg^{-1}, respectively, observed in the second year at the gypsum level of 0 kg ha^{-1} in the presence of mycorrhizal fungi and the application of 8 t ha^{-1} MSWC, and in the second year treated with 150 kg ha^{-1} gypsum and 8 t ha^{-1} MSWC without mycorrhizal inoculation (Figure 5). As a result, the higher levels of all metals in the peanut soil are a cause of severe heavy metal contamination in soil and grain of peanuts. Pb increased significantly in the soil with the application of MSWC, probably because Pb was the element with the highest concentration in the applied MSWC (Arrobas et al. 2022). Damera et al. (2014) found that soil heavy metals can significantly affect heavy metal concentrations in peanut roots, stems, leaves, and seeds. Soil heavy metal contamination is the main cause of heavy metal contamination in crops, and heavy metals can be transferred to crops through the root system (Damera et al., 2014). Research in the last decade has shown a significant positive correlation between soil heavy metal concentrations and crops (Ran et al., 2016). The negative effect of heavy metals on germination indicators was shown by the results of Didwania et al. (2019) and Jaouani et al. (2018).

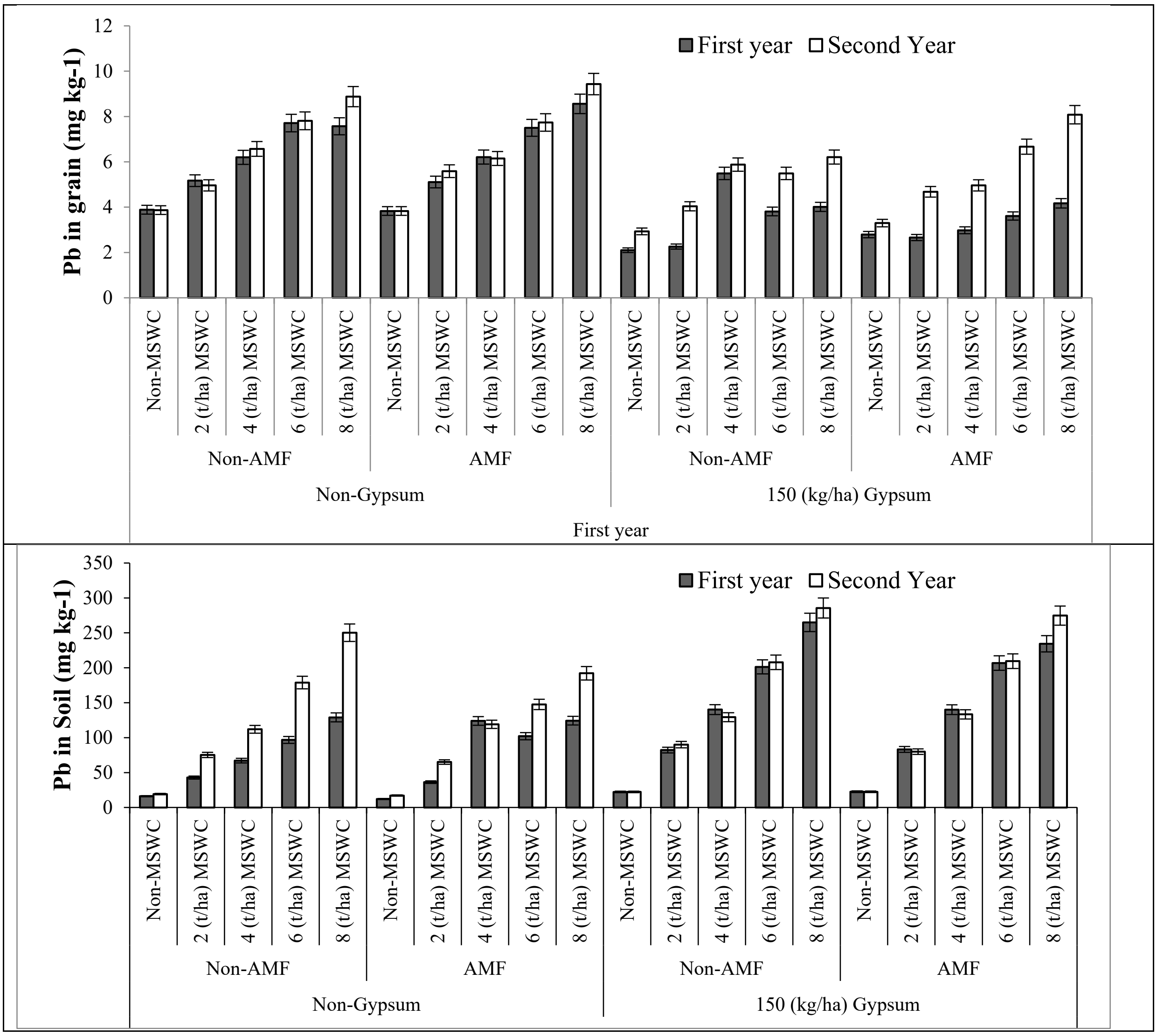

Figure 5. Effect of studied treatments on lead concentration in peanut grain and soil.

Heavy metals exert their inhibitory effect on germinating seeds in different ways. Some heavy metals reduce germination rate by inhibiting endosperm starch hydrolysis and preventing initial seed growth, others prevent seed germination by damaging embryo, and others prevent seed germination by damaging embryo. The highest increase in the amount of absorbable Pb in the soil was observed in the treatment of 50 tons of compost. Pb is one of the most important contaminants in the environment (Karak and Bhagat, 2010). Gu et al. (2019) revealed that the concentration of Pb in peanuts was 0.16 mg kg^{-1}. Blair and Lamb (2017) found that the Pb concentration of peanuts in the United States was 0.03 mg kg^{-1}. Zhao et al. (2010) analyzed the bioaccumulation of heavy metal in different parts of peanut and showed that peanut seed has the ability to bioaccumulate Cu, Zn and Cd.

Peanut shell had strong Pb and Cr bioaccumulation capability. Yang et al. (2020) reported the average concentration of heavy metals in peanut soil samples as 0.18, 47.49, 21.43, and 69.66 mg kg^{-1} for Cd, Cr, Pb, and Zn, respectively. Due to having higher amounts of Pb, urban waste compost has a greater effect on increasing this compound in the soil (Behaj et al., 2016; Marjavi and

Mashayikhi, 2018). Pb element is one of the most stable heavy metals in soil and it is stable in soil for about 150 to 5000 years (Kumar et al., 2017). The normal range of Pb concentration in plants is from 0.2 to 20 mg kg^{-1} and its critical limit is 30 to 300 mg kg^{-1} (Abbaspour et al., 2010). Pb prevents the division of meristem cells and the growth of root cells and reduces the function of plant roots. Also, this metal reduces the elasticity of the root cell wall and reduces the growth of plant roots (Kapata-Pendis, 2010). Mukai and Oyanagi (2021) showed that potential hazards could accompany the application of low-quality composts to the soil, the environment, and humans, caused by heavy metals and other pollutants. Consequently, the application of such composts could also Pb to low crop yields and economic returns to farmers, hence leading to its low use and adoption.

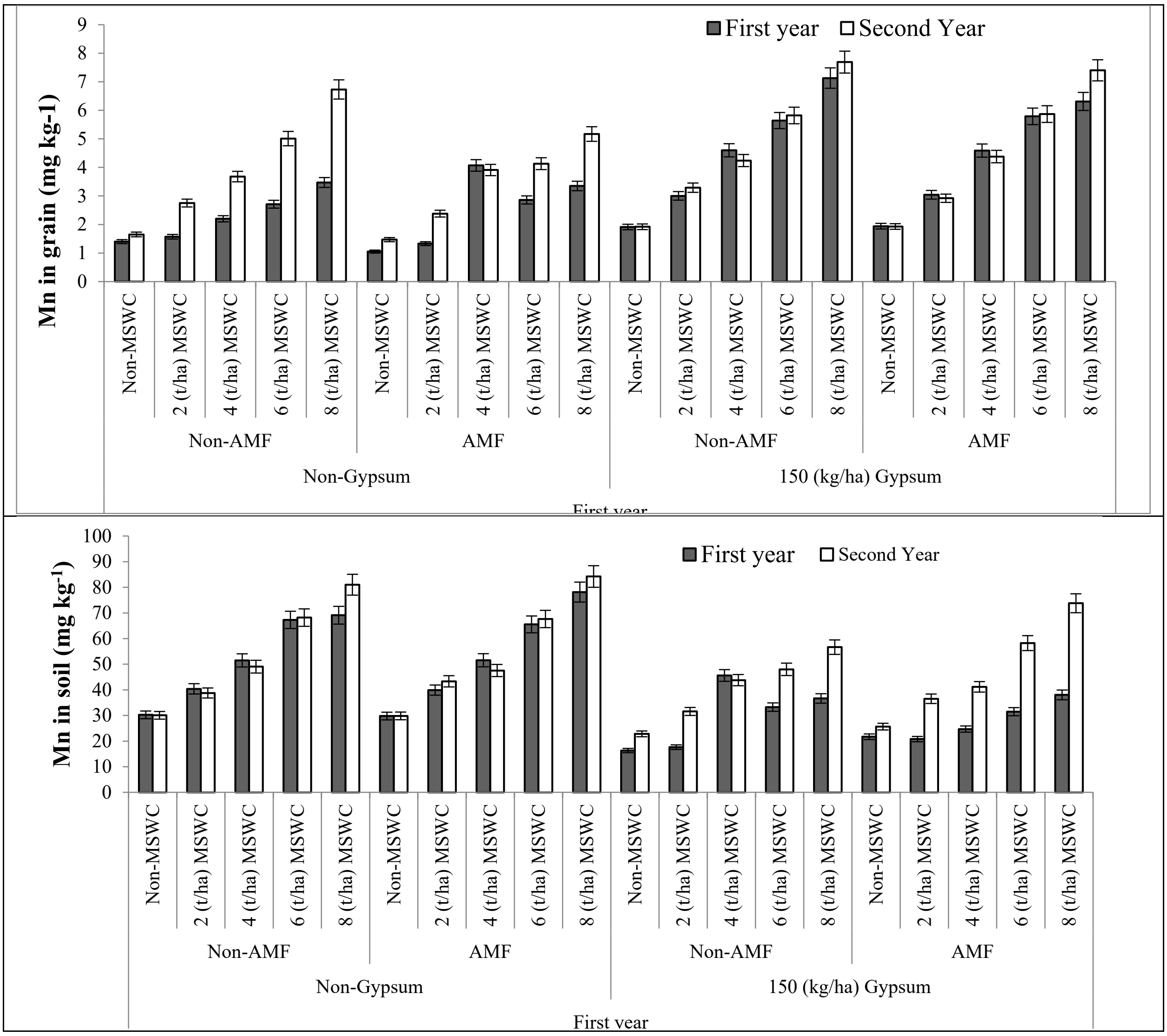

Figure 6. Effect of studied treatments on manganese concentration in peanut grain and soil.

The highest concentration of Mn in seeds (7.13 and 7.69 mg kg^{-1} in the first and second year, respectively) was obtained from the treatment of 150 kg of gypsum and 8 t ha^{-1} of MSWC without the application of mycorrhiza, while the highest amount of soil M (78.1 and 84.2 mg kg^{-1} in the first and second year, respectively) were observed in the treatment of 8 t ha^{-1} of MSWC in the presence of mycorrhiza (Figure 6). In addition, the presence of mycorrhizae in the soil reduced the concentration of Mn in the grain and increased its concentration in the soil. The application of 8 t ha^{-1} MSWC increased the Mn concentration in the grain by 256.02, 132.68, 42.24 and 24.95% compared to the control and the MSWC rates of 2, 4 and 6 t ha^{-1}, respectively. Similarly, application of 8 t ha^{-1} MSWC increased soil Mn concentrations by 150.72, 92.53, 45.87 and 17.74% compared to the control and MSWC rates of 2, 4 and 6 t ha^{-1}, respectively (Figure 6). Marjavi and Mashayikhi (2018) showed that organic matter treatments including municipal waste compost in the first stage of planting did not have a significant effect on the amount of plant-available Mn in the soil. However, in the second stage of onion planting, that is, after a period of five years of using organic fertilizers in defined amounts, the consumption of different amounts of organic fertilizers studied increased the amount of plant-available Mn in the soil, and this amount increased only in the 50 tonnes per hectare treatment. Composting of municipal waste was significant. The amount of soil Mn in this treatment was 10.49 mg kg^{-1} soil. Moreover, Arrobas et al. (2022) depicted conversely that the concentrations of heavy metals in plant tissues tended to decrease with the application of MSWC, and the levels in the pulp remained below the maximum values established as safe for food. However, continuing to apply MSWC each year at such high rates and in neutral and alkaline pH soils does not appear to be sustainable, as there is a risk that increasing soil pH will lead to nutrient imbalances.

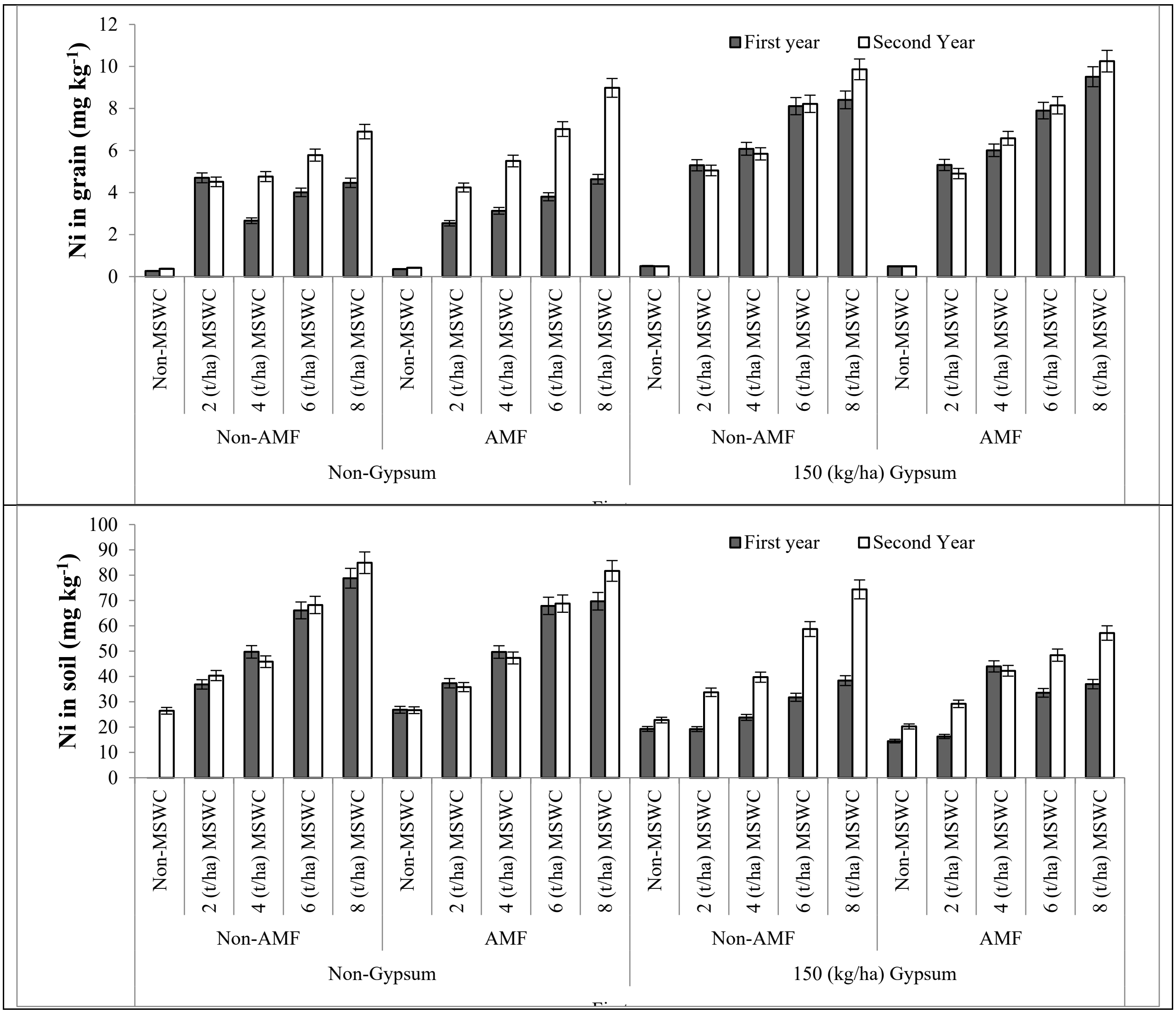

Figure 7. Effect of studied treatments on nickel concentration in peanut grain and soil.

In general, the maximum Ni concentration in the grain was 10.25 mg kg^{-1} in the second year by application of 150 kg ha^{-1} gypsum and 8 t ha^{-1} MSWC under mycorrhizal conditions, which was 7.78% higher than in the first year. Also, the maximum concentration of Ni in the soil was 84.95 mg kg^{-1} obtained in the second year by the application of 8 t ha^{-1} of MSWC, which was 7.77% higher than that of the first year (Figure 7). Therefore, compared to the control and the MSWC levels of 2, 4 and 6 t ha^{-1}, the application of 8 t ha^{-1} MSWC increased the Ni concentration in the grain by 1776.19, 72.43, 55.42 and 19.03%, respectively. Also, compared to the control and the MSWC levels of 2, 4 and 6 t ha^{-1}, the application of 8 t ha^{-1} increased the Ni concentration in the soil by 184.90, 109.74, 52.50 and 17.73%, respectively. However, in both years of the presence of mycorrhiza, especially under gypsum application, reduced soil Ni concentration at all levels of MSWC application (Figure 7). At all levels of MSWC and in both mycorrhiza application and non-application conditions, the application of gypsum increased the concentration of Ni in seeds, which according to García-Robles et al. (2022), this increase could be due to the effect of gypsum on soil pH. They reported that the effect of pH on the absorption of heavy metals from soil by plants and their bioavailability is very important, so that in alkaline pH, the transfer of heavy metals from soil to plant tissues is very low, and the decrease in pH reduces the movement and dynamics of these metals in Soil increases. As calcium is one of the main antagonistic elements against some heavy metals sorption and metabolism, its presence in the soil solution enhances the selectivity in the uptake of metabolic important elements against unwanted ones (Madejón et al., 2018). Moreover, sulphur may have also enhanced the availability of some heavy metals such as Ni and Co (Madejón et al., 2018). These results are consistent with findings of Carbonell et al. (2011), who reported that the changes in the transfer factor for the Pb in compost and its consumption frequency are much lower than that of Ni, so that contrary to the constant trend of Pb increasing. Thereby the levels of municipal waste use also increase the transfer of Ni from the root to the aerial part.

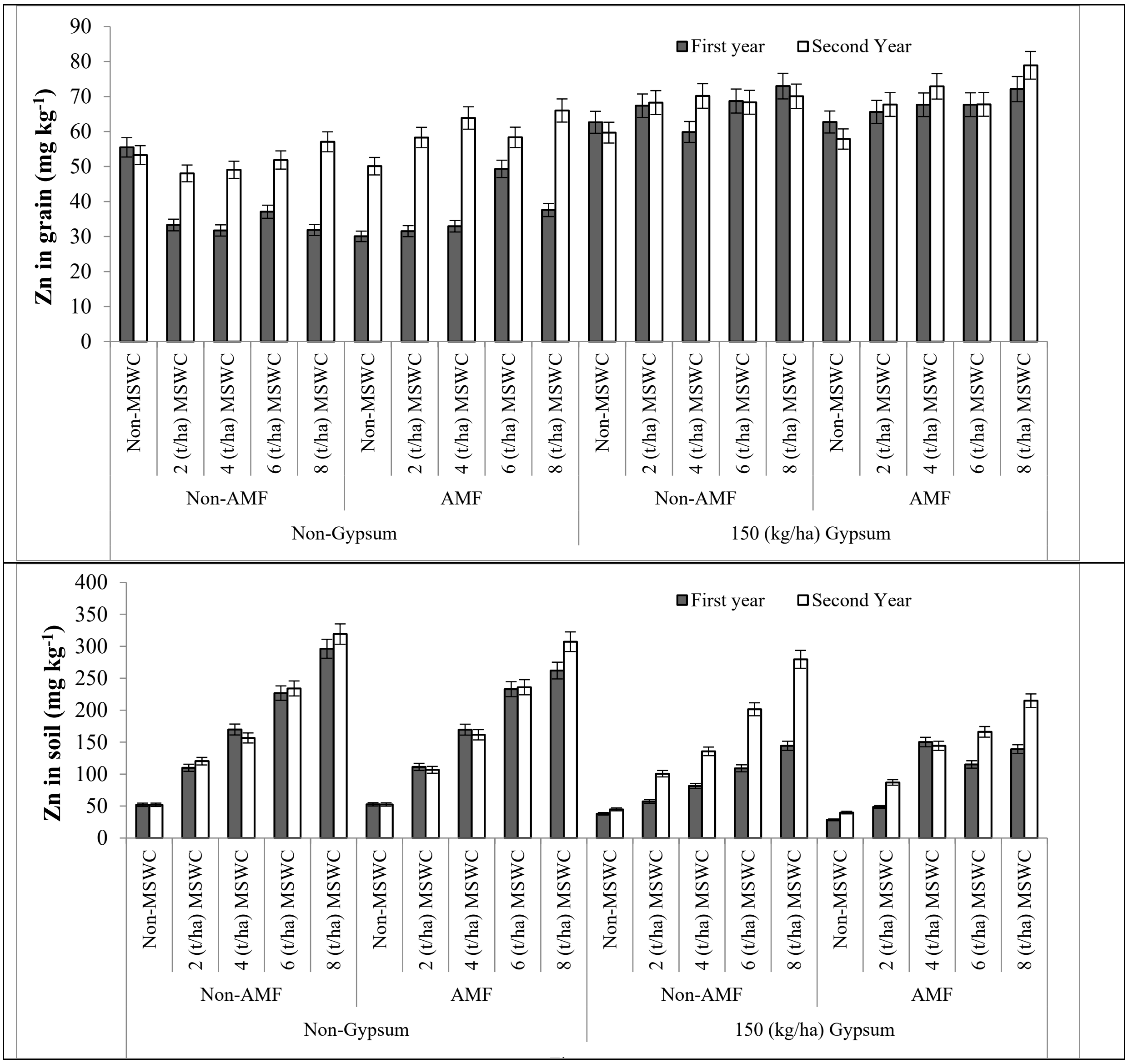

Figure 8. Effect of studied treatments on zinc concentration in peanut grain and soil.

The maximum amount of Zn in the soil was 319.14 mg kg^{-1} obtained in the second year using 8 t ha^{-1} MSWC in under non-use of gypsum and non-mycorrhizal conditions, which was 7.78% higher than that in the first year (Figure 8). The presence of mycorrhizal fungi in the soil, increased the Zn concentration in the grains and decreased its concentration in the soil (Figure 8). Zn, however, showed a slightly different behaviour in the grain, with an increase within the soil and a smaller reduction within tissues compared with other metals. High application rates of P fertilizers to soils low in available Zn can induce Zn deficiency (Broadley et al., 2012). An increase in the amount of compost in the soil resulted in a significant increase in the Zn concentration in the soil and an increase in the amount of MSWC of more than 4 ton/ha resulted in a significant increase in the Zn concentration in the grain. While the application of gypsum and mycorrhizae decreased the Zn concentration in the soil and increased the

Zn concentration in the grain, this concentration may be due to the interaction of calcium and Zn ions in the soil.Yang et al. (2020) reported that the average concentration of Zn in peanut grain samples was 31.42 mg kg^{-1}. Zhao et al. (2010) analyzed the bio-accumulation of heavy metals in different parts of peanuts and reported that the peanut grains had a strong bio-accumulation ability of Cu, Zn, and Cd. Peanut shells were strong bio-accumulators of Pb and Cr (Zhao et al., 2010). The highest amount of usable soil Zn in both stages was observed in the treatment of 30 tons of sewage sludge in the onion plant. In this treatment, the amount of plant usable Zn in the soil increased from 0.6 mg kg^{-1} soil in the control treatment to 4.46 mg kg^{-1} in the first stage and from 0.33 mg kg^{-1} soil to 82.5 mg kg^{-1} was reached in the second stage (Marjovi and Meshaikhi, 2012). The result depicted that the highest Cd, Cr, Pb, Mn contents were 0.3 and 0.6 mg kg^{-1}, 1.69 and 91.99 mg kg^{-1}, 9.42 and 285.55 mg kg^{-1}, 7.69 and 84.22 mg kg^{-1} in the grain and soil respectively. Also, the maximum Ni and Co concentration in the grain was 10.25 and 8.70 mg kg^{-1} in the grain and the maximum amount of Zn in the soil was 319.14 mg kg^{-1}. Other studies showed different results as: The mean concentrations of heavy metals in peanut soil samples were 0.18, 47.49, 21.43 and 69.66 mg kg^{-1} for Cd, Cr, Pb and Zn, respectively, reported by Yang et al. (2020). Lanre-Iyanda and Adekunle (2012), Blair and Lamb (2017), and Dai et al. (2016) found that peanuts from Nigeria and China contained 0.077 and 0.017 mg kg^{-1}, respectively. Among the heavy metals, Cd is of particular concern because of its potential to accumulate in plant organs and thus enter the food chain without showing signs of toxicity (Prince et al., 2002). The results of a study on sunflower showed that different concentrations of Cd in soils with roots inoculated with *P. indica* increased plant growth rate and photosynthetic pigment content in them. The results of the research showed that they had *P. indica.* In contrast to soil with uninoculated roots plant growth rate and the content of photosynthetic pigments and a reduction in the accumulation of Cd. It is also involved in improving the growth and performance of crops against the accumulation of ROS (Shahabivand et al., 2018). In addition, Yang et al. (2020) reported that the average Cr content in peanut kernels was 0.44 mg kg^{-1}, which was lower than that of our results.

The correlation between the studied traits in the first year showed a strong positive correlation among the Cr and Pb in grain with Cd in grain and Co, Zn , Ni, B and Mn in soil and also with each other, and smothly negative and positive correlation among with B, Mn, Ni and Co in grain and Cd and Pb in soil. Also the amount of Zn in grain had strong negative correlation with these parameters (Figure 9). While in the second year all metals in grain and soil except for Zn in grain had a strong positive correlation with each others. In most cases, metal ions are insoluble and immobile in the vascular system and are therefore immobilised in the apoplastic and symplastic compartments after forming carbonate, sulphate or phosphate precipitates. Heavy metal ions enter the xylem through the root symplasm and cross the plasma membrane. The electrochemical gradient across the plasma membrane, which has a high negative resting potential, facilitates the movement of metal ions. In the xylem, metals are transported by membrane transporter proteins. This is due to an active transport mechanism that requires energy (Edelstein and Ben-Hur 2018). Mounissamy et al. (2021) also concluded that after adding municipal waste compost to the soil, a significant increase in the amount of Pb, Mn and Cr was observed. Of course, the changes of heavy metals after adding compost depended on the amount of compost added and its characteristics. Aylaj et al. (2019) found that the application of municipal waste compost in an loamy sandy soil in a field study had no effect on the amounts of Cd, Cr, Ni and Pb, but the repeated application of compost increased the amount of total heavy metals in the surface layer of the soil. Studies show that the mobility and dynamics of elements change depending on the type of plant, the amount of organic matter, pH of the soil, metal concentration in the soil and the growth stage of the plant. The uptake and transport of elements in different plants is not the same. Usually, a plant species according to physiology, may act more specifically towards the transport of a specific metal, thereby increasing the amount of movement and transport of that metal. Many studies showed that the type of plant is one of the most important influencing factors in transfer of metals in soil and plant system (Mazumder et al., 2023; Ongun et al., 2023).

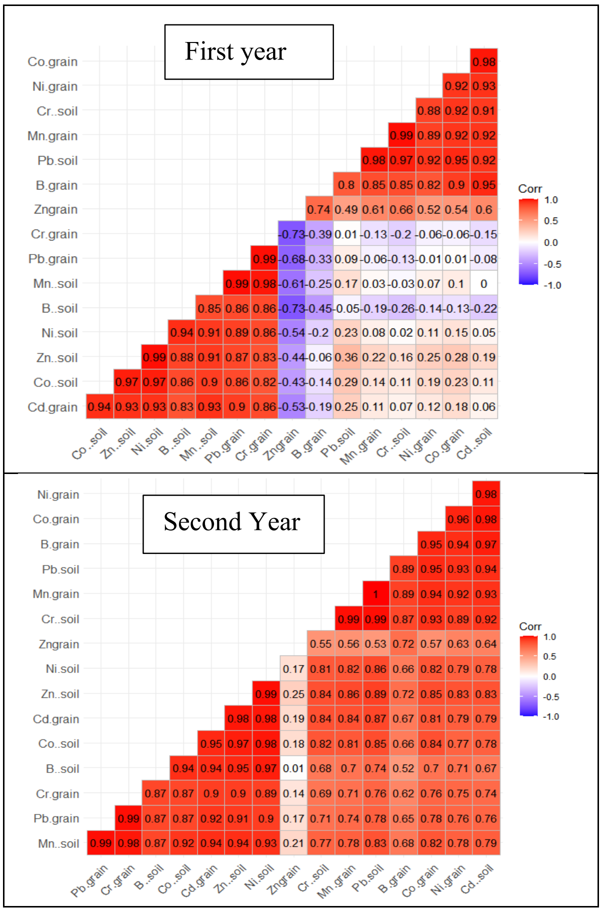

Figure 9. Correlation plot of traits of peanut under different treatments in two years.

CONCLUSION

MSWC can be a useful organic fertilizer for improving soil conditions and plant growth. However, the presence of heavy metals elements and toxic substances is one of the disadvantages of this fertilizer, which leads to soil and plant pollution, and our hypothesis was that the use of mycorrhiza and gypsum can reduce the negative effects caused by the use of MSWC in peanut cultivation. Our results showed that by increasing the application of MSWC from 2 to 8 t ha^{-1} compared to the absence of application, MSWC increased the concentration of Cd, Cr, Co, Ni, Mn and B in soil and grain. Alternatively, the application of 150 kg ha^{-1} of gypsum led to a significant increase in the concentration of Ni, Mn, Co, B, and Zn in the grain and Pb, Cd, and Cr in the soil. While the application of AMF led to an increase in the concentration of Ni, Co, and Zn in the grain and a decrease in the concentration of Ni, Mn, B and Zn in the soil. Therefore, according to the obtained results, the use of 4 t ha^{-1} of MSWC along with mycorrhiza in peanut cultivation is suggested in order to reduce the environment risks of soil and plants cause by the use of compost, and also use the benefits of urban waste compost.

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