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Nutritional (Fe, Mn, Ni, and Cr) and growth responses of rice plant affected by perennial application of two bio-solids

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Abstract Trace toxic elements often restrict the land application of different bio-solids in agriculture. In order to evaluate the separate influence of the municipal solid waste compost (MSW), sewage sludge (SS) and combined application with inorganic fertilizers (chemical fertilizer (CF)) on nutritional (Fe, Mn, Ni, and Cr) and growth responses of rice plant, a research was conducted on paddy soil from 2013 to 2015. Obtained results showed that SS levels were superior to MSW in most studied traits. The maximum chlorophyll content (46.52), plant height (162.6 cm), biomass (23.33 t ha^{-1}), soil available Fe (206.26 ppm), Ni concentration in the root (14.41 ppm) and shoots (3.16 ppm), Cr concentration in the root (12.43 ppm) and grain (3.65 ppm), and Mn concentration in grain (66.938 ppm) belonged to SS levels, specially enriched 40 t ha^{-1}, when it was added to the soil for three continuous years. The highest 1000-grain weight (29.89 g), yield (6.86 t ha^{-1}), harvest index (48.17%), and soil available Mn (712.7 ppm), Fe, and Ni concentration in grain (107.92 and 8.79 ppm, respectively) were recorded in 3 years of applying the enriched 40 t ha^{-1} MSW. Accumulation of Ni in grain in critical levels and negative effects of CF treatments on toxic element entry to soil and plant were two important findings of this research that need management.

Keywords Organic fertilizers · Plant growth · Trace metals

Introduction

Different bio-solids such as municipal solid waste compost (MSW) and sewage sludge (SS) contain high levels of essential elements for plants and organic matter that could improve physicochemical and biological properties of soils (Cesar et al. 2012). Positive effects of these bio-solids on promotion of nutrition and growth status of different field crops have been proved in different researches (Mousavi et al. 2010a; Van Zwieten et al. 2010; Mahdi 2011; Lehmann et al. 2011; Mousavi et al. 2013; Hall and Bell 2015). Thus, land application of these bio-solids as fertilizers in agriculture, which is the result of their low cost, reduction in chemical fertilizer application, and promotion of chemical fertilizers'

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effects on crop production, is the best management practice of fertilizing (Wang et al. 2005; Mahdi 2011).

Nowadays, soil contamination resulted from heavy metals has become inconvenient because of its persistence and a high tendency to bioaccumulation (Dartan et al. 2015). Therefore, applying MSW and SS as organic fertilizers in agriculture is continuously followed by a main concern which is inducing toxic metals' entry to soil ecosystem and consequently to food chains (Mc Bride 2003; Ghaedi et al. 2008; Mousavi et al. 2010b; Mousavi et al. 2013). The impact of organic and inorganic fertilizers on soil and plant contamination with toxic elements has been recorded in different studies (Afyuni et al. 2007; Mousavi et al. 2010a; Atafar et al. 2010; Qiong et al. 2012; Mousavi et al. 2013; Bouzaiane et al. 2014; Yuksel 2015; Dartan et al. 2015). The presence of toxic metals indicates that using these biosolids would be better done along with a scientific and special attention. Since very few field experiments have investigated the perennial effects of MSW and SS separately and enriched application with chemical fertilizers in paddy soil condition, this study aimed to evaluate the nutritional responses (Fe, Mn, Ni, Cr) and some yield and growth indexes of rice plant affected by 3 years of applying the MSW and SS separately and enriched with chemical fertilizers.

Materials and method

In order to study the effect of the MSW, SS individually, and combined application with inorganic fertilizers (chemical fertilizer (CF)), this study was conducted. The research was conducted during 3 years on nutritional responses, some yield, and growth indexes of rice plant. This work was performed in the research field of University of Sari Agricultural Sciences and Natural Resources, Sari, Iran (34° 33′ N; 52° 6′ E), as a split plot arrangement based on a randomized complete block design with three replications. In this research, fertilization years ($P_1 = 1$ year, $P_2 = 2$ years, and $P_3 = 3$ years of fertilization) were selected as sub-plot, and MSW, SS, and inorganic fertilizers (CF) were considered as main factors that were added to soil in 10 levels comprising 20 and 40 t ha^{-1} MSW, 20 and 40 t ha^{-1} MSW + 50% CF, 20 and 40 t ha^{-1} SS, 20 and 40 t ha^{-1} SS + 50% CF, CF (which was 100 kg ha^{-1} urea, 150 kg ha^{-1} triple superphosphate, and 100 kg ha^{-1} potassium sulfate, based on soil analysis), and control (without any fertilizer). This research started in 2013 with 30 plots (3 × 12 m) which all of their surfaces were fertilized. It continued in two thirds and one third of initial plots of fertilizer treatment, in 2014 and 2015, respectively. Results of studied soil (0–30 cm) and applied bio-solid analysis are presented in Table 1.

Through land plowing and rice nursery (*Tarom cultivar*) preparing, agricultural practices were started in April. To prevent the transition of organic and inorganic materials from neighboring plots to other plots, all plots were covered by plastic to the depth of 40 cm. The land application of fertilizers with certain amounts in plots and also transplantation of seedlings were done in May.

About 2 weeks after flowering stage, chlorophyll content was measured by SPAD, and other growth and yield traits such as biomass (t ha^{-1}), plant height (cm), 1000-grain weight (g), paddy yield (t ha^{-1}), and harvest index (the ratio of economic yield to the biologic yield × 100) (El Naim et al. 2012) were measured at the harvest stage. Soil sampling (0–30 cm) was done after the harvesting stage for measuring the total (Baker and Amacher 1982) and available Fe, Mn, Ni, and Cr (Lindsay and Norvell 1978) of soil by Varian Spectra A.A-10 Atomic Absorption Spectrometer (Varian Inc., Palo Alto, CA). Roots, shoot (stem + leaves), and grain of rice were sampled to determine Fe, Mn, Ni, and Cr concentration on maturation stage (AOAC 1990), as well. The statistical analysis was performed as the SPSS and MSTATC software were used, and comparison between applied means was done using Duncan's multiple range tests at the 5% significant level.

Results and discussion

Yield and growth indexes of rice plant affected by different treatments

Yield and growth indexes of rice plant were affected by fertilizer levels and fertilization periods significantly. The interaction effects of fertilizer × application periods were not merely significant in terms of 1000-grain weight (data not shown).

In most cases, SS treatments revealed the highest effects on growth indexes, but MSW treatments were more effective on yield parameters. The greatest chlorophyll contents (46.52) namely plant height (162.6 cm) and biomass (23.33 t ha^{-1}) were observed under three continuous years of applying enriched 40 t ha^{-1} SS with

Table 1 Some physicochemical properties of the examined soil (0–30 cm) and applied organic fertilizers

	Soil	MSW	SS	Unit
Soil texture	Silty clay	–	–	–
Sand	7.3	–	–	%
Silt	44.7	–	–	%
Clay	48	–	–	%
Acidity (pH)	7.63	7.41	6.2	–
Electrical conductivity (EC)	1.84	3.2	8.8	dS m^{-1}
Organic carbon (OC)	1.6	22.63	31.4	%
Cation exchange capacity (CEC)	10.21	–	–	cmolc kg^{-1}
Nitrogen	0.16	0.80	1.40	%
Available phosphorus	21.78	0.58	0.43	ppm
Available potasium	209.74	8485.8	4893.9	ppm
Total Ni	44.34	47.51	217.6	ppm
Available Ni	1.13	6.11	62.19	ppm
Total Cr	40.85	92.1	210.62	ppm
Available Cr	0.06	2.23	1.21	ppm
Total Fe	1654.11	7154.82	26,380	ppm
Available Fe	76.94	273.26	135.14	ppm
Total Mn	215.65	251.97	522.24	ppm
Available Mn	33.34	52.41	248.7	ppm

50% CF when it was added to the soil for three continuous years (data not shown) that coincides with the results of Jamali et al. (2008). High nitrogen (N) content in SS (based on Table 1) and CF (urea) applications is the most important reason to find out that it can enhance the growth of rice, and also, the translocation of N to leaves is favorable for chlorophyll formation (Follet et al. 1981).

Municipal solid waste compost levels significantly affected yield indexes more than SS levels. Based on our results, the maximum 1000-grain weight (29.89 g) belonged to 3 years of applying the 40 t ha^{-1} MSW + 50% CF when it was added to the soil for three continuous years which was about 57% more than control treatment (Table 2). Also, the maximum harvest index (48.17%) was measured under this treatment that was significantly different from other treatments and was about 82.5% more than control treatment (Table 3). Melero et al. (2007) reported that compost-amended soils exhibited increments in quality and quantity of organic carbon, nitrogen, phosphorus, micronutrients, microbial biomass, and enzymatic activities in which these positive traits will motivate high growth and yield of plants. Treatment of enriched 40 t ha^{-1} MSW in three continuous years of application affected paddy yield significantly as well. The greatest yield (6.86 t ha^{-1}) was recorded under this treatment which was about two more times than the control treatment (data not shown). Mahdi (2011) and Hall and Bell (2015) reported that compost application induced remarkable increases in yield due to its high nutrient contents.

Obtained results showed that by increasing application periods from 1 year (P_1) to 3 years (P_3), studied traits were enhanced as well. Accordingly, 1000-grain weight in P_2 was 5.6% more than P_1, and in P_3, it was 8.2% more than P_2 treatment (Table 2). Harvest index was also increased with the enhancement of application periods. As an instance, in enriched 40 t ha^{-1} MSW, harvest index enhanced from 1.57 to 20.6% from P_1 to P_3 (Table 3). Chlorophyll content, plant height, biomass, and yield of rice with increasing of fertilization periods enhanced regularly too (data not shown).

Nickel and chromium status in soil

Accumulation of Ni and Cr in soil was affected by studied treatments significantly. Interaction effects of fertilizer × application periods were significant on total

Table 2 Effect of fertilization and sampling year on 1000-grain weight (g) under different treatments

Treatments	1000-grain weight
Fertilizer	
20 t ha^{-1} MSW	22.44fg
40 t ha^{-1} MSW	22.87fg
20 t ha^{-1} MSW + 50% CF	22.57fg
40 t ha^{-1} MSW + 50% CF	29.89a
20 t ha^{-1} SS	25.98d
40 t ha^{-1} SS	27.18bc
20 t ha^{-1} SS + 50% CF	28.15ab
40 t ha^{-1} SS + 50% CF	23.33ef
CF	21.14h
Control	19.05i
Application periods	
P_1 = 1-year application	25.96c
P_2 = 2-year application	27.41b
P_3 = 3-year application	29.67a

Means within the same column followed by the same letter indicate non-significant difference according to DMRT ($P \leq 0.05$)

and available Cr and available Ni of soil (data not shown).

Levels of the SS had more effect on total Ni and Cr than MSW levels, such as the highest content of total Ni (57.79 ppm) belonged to 40 t ha^{-1} SS that was about 35.28% more than the control treatment. The application of 40 t ha^{-1} SS + 50% CF was also recorded as the maximum concentration of total Cr (46.65 ppm) (data not shown) in three continuous years that was less than reported critical confine in soil by Alloway (1990) (75–100 ppm). These results coincide with the results of Mousavi et al. (2011) and Qiong et al. (2012). Available form of Ni and Cr was more affected by MSW than SS. The highest content of available Ni (2.1 ppm) and available Cr (0.17 ppm) belonged to 40 t ha^{-1} MSW when it was added to the soil for three continuous years (Fig. 1). Mousavi et al. (2011) and Yuksel (2015) also reported similar results in a similar research.

Table 3 Effect of fertilization and sampling year on harvest index (%)

Treatments	Application periods		
	1 year	2 years	3 years
20 t ha^{-1} MSW	31.99i–n	33.73h–l	36.21gh
40 t ha^{-1} MSW	37.97fg	36.15gh	41.82ce
20 t ha^{-1} MSW + 50% CF	35.87f–l	40.03de	44.73b
40 t ha^{-1} MSW + 50% CF	39.31de	39.93de	48.17a
20 t ha^{-1} SS	25.70q	27.55op	34.85ij
40 t ha^{-1} SS	27.96op	28.43no	33.70h–l
20 t ha^{-1} SS + 50% CF	27.71op	28.29no	36.06gh
40 t ha^{-1} SS + 50% CF	26.35q	28.57no	29.11lno
CF	32.40h–n	32.51h–n	33.47h–l
Control	25.70q	26.43q	26.40q

Means within the same column and each treatment followed by the same letter indicate non-significant difference according to DMRT ($P \leq 0.05$)

With increasing application periods from 1 to 3 years (P_1 to P_3), Ni and Cr accumulation in soil increased regularly. For example, in enriched 40 t ha^{-1} MSW treatment, available Ni in P_2 was 23.4% more than P_1, and in P_3, it was 20.6% more than treatment in P_2 (Fig. 1). Moreover, available Cr in P_3 was 30.7% more than treatment in P_2, and in P_2, it was 18.2% more than treatment in P_1 (Fig. 1). Afyuni et al. (2007), Mousavi et al. (2011), and Mousavi et al. (2013) reported that with the repeated organic fertilizers application, accumulation of heavy metals in the soil will increase as well. The most noticeable finding in this part is the influence of CFs on available Ni referring to potential of CF in trace metal contamination. De Vries et al. (2002) stated that high fertilizer application and acid atmospheric deposition combined with insufficient liming may cause a decrease in pH, and thus increasing trace metal availability.

Nickel and chromium status of rice plant

Land application of different bio-solids and fertilization periods has shown significant effects on Ni and Cr accumulation in different parts of rice plants, and interaction effects of fertilizers × application periods significantly affected Ni accumulation in the root and grain (data not shown).

The greatest Ni concentration in the root (14.41 and 14.07 ppm) was measured in three continuous years of applying 40 t ha^{-1} SS + 50% CF and 40 t ha^{-1} SS, respectively, when they were added to the soil for three continuous years (Table 4) that was more than reported optimum confine in plants by Alloway (1990) (0.02–5 ppm). The highest Ni concentration in grain (8.79 ppm) happened in 3 years of applying enriched 40 t ha^{-1} MSW with 50% CF that was about 3.3 times larger than the

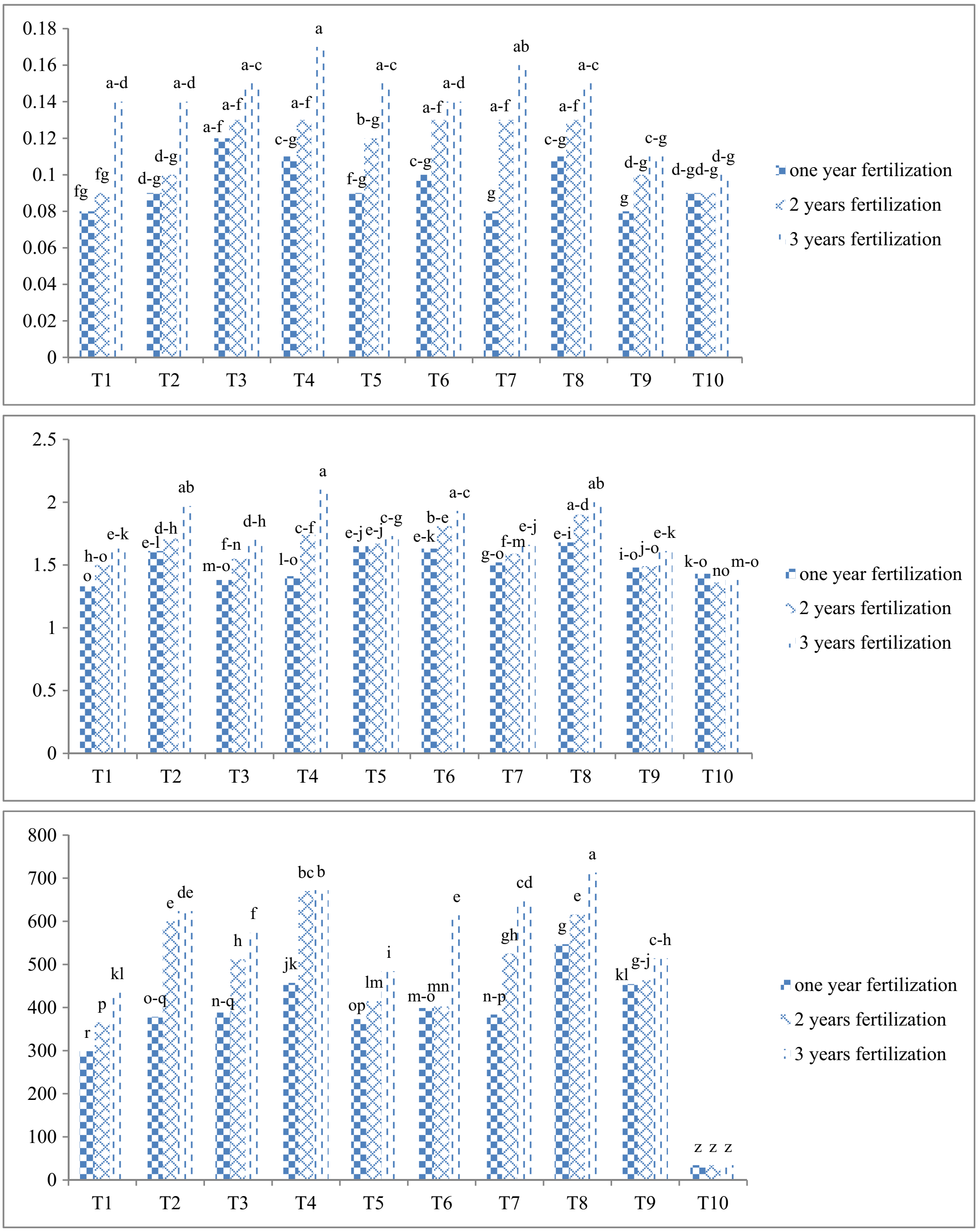

Fig. 1 Means comparison interaction effects of fertilizer × application periods on available Cr, Ni, and Mn (ppm). *Different letters above the bars* indicate statistically significant differences between treatments according to DMRT ($P \leq 0.05$): 20 t ha^{-1} MSW (*T1*), 40 t ha^{-1} MSW (*T2*), 20 t ha^{-1} MSW + 50% CF (*T3*), 40 t ha^{-1} MSW + 50% CF (*T4*), 20 t ha^{-1} SS (*T5*), 40 t ha^{-1} SS (*T6*), 20 t ha^{-1} SS + 50% CF (*T7*), 40 t ha^{-1} SS + 50% CF (*T8*), CF (*T9*), and control (*T10*)

control treatment and had significant difference with others, and it was also more than optimum confine but was in critical concentration, 10–100 ppm (Alloway 1990). In a similar research, Mousavi et al. (2011) reported similar results. In general, the range of Ni concentration in grain and in different treatments was from 3.25 ppm (in 1-year application of 40 t ha^{-1} MSW) to 8.79 ppm, which according to the reported optimum and critical confines by Alloway (1990) emphasizes

Table 4 Effect of fertilization and sampling year on Ni concentration (ppm) in rice plant

Treatments	Root			Grain		
	P_1	P_2	P_3	P_1	P_2	P_3
20 t ha^{-1} MSW	7.05k	9.77f–h	10.38fg	3.61k–m	5.04e–h	6.17d
40 t ha^{-1} MSW	9.00hi	10.04f–h	12.72bc	3.25mn	4.35h–j	6.30cd
20 t ha^{-1} MSW + 50% CF	9.68f–h	11.93c–e	12.76bc	7.69b	4.70f–j	6.27cd
40 t ha^{-1} MSW + 50% CF	8.00i–k	9.00hi	10.63fg	4.66f–j	4.81e–i	8.79a
20 t ha^{-1} SS	8.68hij	9.95f–h	12.08cd	5.48e	6.44cd	6.94cd
40 t ha^{-1} SS	10.03f–h	11.03d–f	14.07a	4.81e–i	5.24e–g	7.02c
20 t ha^{-1} SS + 50% CF	9.64gh	10.72e–g	13.68ab	4.00j–l	4.47g–j	6.70cd
40 t ha^{-1} SS + 50% CF	10.00f–h	10.05f–h	14.41a	5.28ef	5.55e	6.41cd
CF	7.11k	8.23i–k	9.69f–h	4.54f–j	5.20e–g	6.67cd
Control	5.89l	5.91r	5.92r	2.67n	2.65s	2.68s

Means within the same column and each treatment followed by the same letter indicate non-significant difference according to DMRT ($P \leq 0.05$). P_1 = 1-year fertilization, P_2 = 2-year fertilization, and P_3 = 3-year fertilization

the important role of applied organic fertilizers such as MSW on toxic metals' entry to food chains and may create a heavy metal risk in the long term (Yuksel 2015).

Sewage sludge treatments had more effects on Cr concentration in comparison with MSW treatments. Based on presenting results in Table 5, the maximum Cr accumulation in root happened in 40 t ha^{-1} SS which was about 88% more than control treatment (12.43 ppm). Applying enriched 20 t ha^{-1} SS with 50% CF was measured as the greatest content of Cr concentration in grain (3.65 ppm) (Table 5) which was in reported optimum confine range (0.03–14 ppm) (Alloway 1990). Among fertilized plots, the minimum Cr concentration in grain (3.01 ppm) belonged to enriched 20 t ha^{-1} MSW treatment that had no significant difference with other treatments (with the exception of the control treatment). In this research, MSW and SS levels had more effects on the Ni content of grain than Cr. Bouzaiane et al. (2014) stated that the most significant concern about organic fertilizers, such as MSW, is their heavy metal contents. Among the trace metals, Cd, As, Cr, Ni, and Pb are commonly considered as toxic to both plants and humans (Jamali et al. 2008). Based on the presented results in Tables 4 and 5, more Ni and Cr contents were accumulated in the root compared to the grain. This finding refers to the nature of the heavy metals which have low mobility (Panichasakpatana 1996). The other important finding of this research was the effect of the CF treatment on Ni and Cr status in rice plant tissues. As far as you see in Tables 4 and 5, Ni and Cr content of grain under CF treatment is not significantly different from most treatments that were fertilized by MSW and SS that coincides with the results of Huang et al. (2007) and Cheraghi et al. (2011, 2013).

Both application periods and fertilizer treatments significantly affected Ni and Cr concentration in rice

Table 5 Effect of fertilization and sampling year on Cr concentration (ppm) in rice plant

Treatment		
Fertilizer	Root	Grain
20 t ha^{-1} MSW	8.87e	3.06b
40 t ha^{-1} MSW	10.28cd	3.51a
20 t ha^{-1} MSW + 50% CF	10.48bc	3.01b
40 t ha^{-1} MSW + 50% CF	9.39de	3.35ab
20 t ha^{-1} SS	10.75bc	3.37ab
40 t ha^{-1} SS	12.43a	3.58a
20 t ha^{-1} SS + 50% CF	10.53cd	3.65a
40 t ha^{-1} SS + 50% CF	11.78ab	3.06b
CF	8.43e	3.34ab
Control	6.60f	2.11c
Application periods		
1-year application	8.14c	2.57c
2-year application	10.00b	3.09b
3-year application	11.73a	3.96a

Means within the same column followed by the same letter indicates non-significant difference according to DMRT ($P \leq 0.05$)

Table 7 Effect of fertilization and sampling year on Mn concentration in rice plant (ppm)

	Treatments	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Mn-flag leaf	P_1	41.02gh	41.36gh	45.56fgh	41.79gh	44.22fgh	43.56gh	48.76ef	44.99fgh	40.653h	40.76h
	P_2	64.77c	48.16ef	49.16de	44.09fgh	66.97c	51.36de	51.36de	46.11fg	42.54gh	40.65h
	P_3	69.92bc	81.47a	64.28c	48.16ef	72.12b	84.67a	67.48c	51.36de	53.96d	40.96h
Mn-grain	P_1	31.28gh	31.28gh	37.68ef	42.38de	34.28g	34.28g	40.70ef	45.39cde	28.77h	31.52gh
	P_2	39.52ef	32.65gh	41.37cde	46.56cd	42.54e	35.66fg	44.38cde	49.58c	33.87g	33.87g
	P_3	46.03cd	39.88ef	64.92a	52.37bc	48.05cd	42.89de	66.94a	55.39b	37.03fg	34.28g

Means within the same column and each treatment followed by the same letter indicate non-significant difference according to DMRT ($P \leq 0.05$). P_1 = 1-year fertilization, P_2 = 2-year fertilization, and P_3 = 3-year fertilization. T1 = 20 t ha^{-1} MSW, T2 = 40 t ha^{-1} MSW, T3 = 20 t ha^{-1} MSW + 50% CF, T4 = 40 t ha^{-1} MSW + 50% CF, T5 = 20 t ha^{-1} SS, T6 = 40 t ha^{-1} SS, T7 = 20 t ha^{-1} SS + 50% CF, T8 = 40 t ha^{-1} SS + 50% CF, T9 = CF, and T10 = control

plant tissues. By increasing fertilization years, accumulation content increases as well. Ni concentration in grains in 3 years of applying enriched 40 t ha^{-1} MSW was about 82.7% more than 2 years and about 88.6% more than 1 year (Table 4). The Cr content of the grain and Ni also enhanced with increasing fertilization years. The Cr root in 2 years was about 20.2% more than 1 year and about 28.2% less than 3 years of fertilization (Table 5). Applying periods of CF significantly affected Ni and Cr accumulation as well as MSW and SS treatments in plant tissues. The Ni content of grain under CF treatment increased from 70% in 1 year of fertilization to 148.88% in 3 years of fertilization compared to control treatment. Moreover, the Cr content of grain in 2 years of fertilizing CF was about 20.2% more than 1 year, and in 3 years of fertilization, it was about 28.2%, more than 2 years of fertilization (Table 5). Nicholson et al. (2003), Mousavi et al. (2011, 2013), and Liu et al. (2015) also reported that with a long-term application of chemical fertilizers, trace metals will be accumulated in soil and plant. Based on these results, we would be able to state that the perennial application of organic and inorganic fertilizers might create a heavy metal risk in the long term (Cheraghi et al. 2011; Mousavi et al. 2011, 2013; Yuksel 2015).

Table 6 Effect of fertilization and sampling year on Fe concentration in flag leaf and grain (ppm)

Treatments	Fe	
	Flag leaf	Grain
Fertilizer		
20 t ha^{-1} MSW	65.45a	104.44ab
40 t ha^{-1} MSW	58.93a	106.65a
20 t ha^{-1} MSW + 50% CF	65.45a	105.13ab
40 t ha^{-1} MSW + 50% CF	59.17a	107.92a
20 t ha^{-1} SS	63.35a	105.82a
40 t ha^{-1} SS	56.83a	103.03ab
20 t ha^{-1} SS + 50% CF	63.35a	102.34ab
40 t ha^{-1} SS + 50% CF	57.07a	104.55a
CF	47.81b	95.82bc
Control	48.95b	94.22c
Application periods		
1-year fertilization	51.49b	97.33b
2-year fertilization	57.89a	101.07ab
3-year fertilization	59.29a	104.51a

Means within the same column and each treatment followed by the same letter indicate non-significant difference according to DMRT ($P \leq 0.05$)

Iron and manganese status in soil

Results of variance analysis revealed that MSW, SS, and fertilization years significantly affected Fe and Mn accumulation in the soil. Moreover, total Fe and available Mn were significantly affected by interaction effects of fertilizer × application periods (data not shown).

Based on a comparison, the highest total Mn (about 2.74 times of control treatment) and available Fe (about 2.71 times of control treatment) belonged to the enriched 40 t ha^{-1} SS with 50% CF treatment (data not shown). Effects of SS on micronutrient accumulation in soil were reported in other studies (Qiong et al. 2012; Mousavi et al. 2013) that refer to high micronutrient contents of the SS (Table 1).

The comparison interaction effects of fertilizer × application periods illustrated that maximum content of total Fe (57,340 ppm) which was about 35.3 times more than control treatment (data not shown) occurred in 3 years of applying 40 t ha^{-1} SS + 50% CF. This treatment had also the most effect on available Mn compared to others when it was added to the soil for three continuous years (712.7 PPM). Based on different reports, organic fertilizers (such as MSW, SS, etc.) can enhance the supply of essential elements to plants both directly through element additions and indirectly through changes in soil acidity and the activity of biota (Chan and Xu 2009; Van Zwieten et al. 2010; Lehmann et al. 2011). At Ph levels between 6.0 and 8.0 (Table 1), trace elements (such as Fe and Mn) become much more available and less available at lower pH (<6.0) (Mizota and Van Reeuwijk 1989). Percentage of soil organic matter is one of the most important factors as well as soil acidity affecting trace metal bioavailability. Organic matter plays an important role in potential of soils in retaining trace elements in an exchangeable form. Furthermore, organic matter also induces organic chemicals added to the soil solution that can act as chelates and promote trace element bioavailability (McCauley et al. 2009). Moreover, Du Laing et al. (2009) reported that the mobility and uptake of trace metals to plants could be promoted by dissolved organic matters in soils. Therefore, the high concentration of available Fe and Mn in 3 years of applying 40 t ha^{-1} SS + 50% CF treatment compared to other treatments was probably due to the high concentrations of OM in the SS-treated plots and also lower PH of it than MSW-treated plots (Table 1).

The fertilization periods also significantly affected Fe and Mn accumulation in soil. Concentration of total Mn in 3 years of fertilization (P_3) compared to the second year (P_2) showed 2.68% of increment, and it was 5.44% more than 1-year fertilization (P_1) (data not shown). Moreover, available Fe in P_2 compared to P_1 enhanced to 20.27% and in P_3 compared to P_2 enhanced to 14.1%. Similar results were observed for total Fe and available Mn, as well (Fig. 1).

Iron and manganese status of rice plant

Fe and Mn content of rice plants were significantly affected by fertilizers and application periods of treatment. Moreover, interaction effects of fertilizers × application periods were significant only in terms of Mn concentration in rice plant tissues (data not shown). The highest amount of Fe in flag leaf belonged to 20 t ha^{-1} MSW + 50% CF (65.445 ppm); however, it was not significantly different from other MSW and SS treatments (Table 6). The maximum concentration of Fe in grains (107.921 ppm) was observed in 40 t ha^{-1} MSW treatment which was about 14.54% more than the control treatment having no significant difference with others (Table 6).

By increasing application periods, Fe accumulation in flag leaf enhanced as well. The concentration of Fe increased to 12.42% in P_2 which was compared to P_1, and in P_3, it was about 2.41% more than P_2 (Table 6). The Fe concentration in the grains in three consecutive years was about 3.41% more than two consecutive years, and it increased in two consecutive years about 3.83% compared to 1-year fertilization (Table 6).

The maximum amount of Mn in flag leaf was measured in 3 years of fertilizing 40 t ha^{-1} MSW (81.466 ppm) that was 98.9% more than control treatment (Table 7). In three continuous years of fertilization with enriched 20 t ha^{-1} SS and enriched 20 t ha^{-1} MSW, maximum content of Mn in grains (66.938 and 64.918 ppm, respectively) was about 1.9 times larger than the measured content under unfertilized plots and had significant difference with the other fertilized plots (Table 7). Generally, by increasing the fertilization periods from 1 to 3 years, the content of the studied elements in plant tissues also enhanced that coincided with results of Tejada and Gonzalez (2006). Wei et al. (2006) reported that due to long-term fertilization, by changes in basic soil properties such as soil acidity, soil organic matter, and soil nutritional condition, status and behaviors of micronutrients in soil and crop vary with different fertilization practices. Availability and uptake of Fe and Mn by crops are directly and significantly affected by soil organic matter, and the interaction of macronutrients and micronutrients (Zhang et al. 2001; Aulakh and Malhi 2005).

Conclusions

The findings of this research revealed that all the studied treatments in rice cultivation system significantly affected the nutritional (Fe, Mn, Ni, and Cr) responses and growth/yield indexes of the plant. The amount of the mentioned traits also enhanced in most investigated traits with increasing fertilization from 1 to 3 years. Municipal solid waste compost levels were superior to the SS levels with respect to the studied yield indexes. The highest harvest index, 1000-grain weight, and paddy yield happened in MSW treatments, while SS levels were more effective than MSW on the growth parameters (height, biomass, and chlorophyll content). Another important result of this research was the considerable effect of enriched treatments with CF on the studied traits than others did, referring to the role of chemical fertilizers on the motivation of the plant growth and also the status of trace elements in soil and plants. In three continuous years of applying enriched 40 t ha^{-1} MSW, the maximum Ni accumulation in grain (8.79 ppm) was recorded that was more than the reported optimum confine in plants (0.02–5 ppm). Moreover, in this treatment, the highest yield, harvest index, and 1000-grain weight happened that these results refer to positive and potentially hazardous effects of these bio-solids in agriculture. Generally, this research showed that the more fertilizer applies, the more trace metal supplies. Therefore, management of these bio-solid applications to reduce toxic metals' entry to the soil ecosystem is important. Finally, it was determined that more long-term investigations are needed to recommend the application of MSW and SS in different cropping systems and management procedures.

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