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Article

Content and Availability of Micronutrients in Manure-based Composts

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The objective of this study was to evaluate the effects of the application of compost on the availability of micronutrients in lettuce. Micronutrient contents of manure-based composts containing various other source materials were investigated. Total and extractable contents of micronutrients in the composts were analysed. Pots containing soil of relatively low micronutrient levels were treated with 1,000 and 2,000 kg $10a^{-1}$ of compost and used to grow lettuce plants under greenhouse conditions. Fresh and dry weights of lettuce and micronutrient uptake were determined after harvest. Manure-based composts of various other source materials contained very different amounts of total and extractable micronutrients. Total contents of B, Cu, Fe, Mn, Mo and Zn were in the range of 26-42, 27-160, 4,300-9,500, 290-790, 0-0.5 and 140-420 mg kg^{-1}, respectively. The contents of 0.1 N HCl extractable B, Cu, Fe, Mn and Zn were 23-32, 1.3-2.6, <1, 7-32 and 0.5-5% of total content, respectively. Contents of micronutrients extractable in DTPA solution were generally higher than those extractable in 0.1 N HCl. It was found that the fresh and dry matter productions of the plants were significantly higher in the compost treatment of 2,000 kg $10a^{-1}$. Lettuce grown in soil treated 1,000 and 2,000 kg $10a^{-1}$ of manure-based compost contained higher levels of B, Cu, Mo and Zn than lettuce grown without compost application. However, contents of Fe and Mn in lettuce were relatively lower in the compost treatments. In the compost treatments the proportions of micronutrients in soil and plant were all in the optimum ranges and below the toxicity levels. The results obtained allow us to establish that commercial composts could be used as soil amendment for plastic film house crop production with sufficient supply of micronutrients.

Key words : Compost, Lettuce, Micronutrient, Phytoavailability, Plastic film house soil

Introduction

Proper plant nutrition is essential for successful greenhouse production of vegetable crops. In addition to the macronutrients, micronutrients are also important for plant growth as plants require a proper balance of all the essential nutrients for normal growth and optimum yield.

Although micronutrients are needed in small amounts, they must be available in the correct proportions, and they must be administered at the right intervals. While specific needs vary according to climate, soil, and choice of crop, it is vital that the proper balance is maintained. If a plant lacks any of the micronutrients it requires, its development, growth or reproduction will be affected, resulting in lower yields (Romheld and Marschner, 1991; Graham and Webb, 1991). For common crops, typical ranges of critical levels in soil are 0.1-2.0, 1.0-2.0, 1.0-5.0, 10.0-16.0, and 1.0-4.0 mg kg^{-1} for B, Cu, Zn, Fe and Mn, respectively (Sims and Johnson, 1991).

Jung et al. (1997) reported that contents of Cu and Zn in the soils of plastic film house were relatively higher than those found in the paddy and upland soils. In the southern area of Korea, the levels available B, Zn and Cu in plastic film house soils were found to be 8.4-15.4, 8.4-12.7, and 21.1-50.7 mg kg^{-1}, respectively (Ha et al., 1997). However, farmers apply various micronutrient fertilizers through foliar spray and fertigation systems for the plastic film house crops without enough information about the optimum application levels and/or the availability of those nutrients in their soils. Excessive application of micronutrients probably accounts for more micronutrient disorders in the greenhouse than does insufficient application. Excessive application of micronutrients, in addition to toxicities, can lead to micronutrient

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deficiencies. Deficiencies in this case are due to antagonisms between micronutrients during plant uptake (Morgan and Mascagni, 1991). A high level of iron in the substrate commonly causes manganese deficiency and to a lesser extent can suppress zinc uptake. Conversely, a high level of manganese in the substrate causes iron deficiency and also to a lesser extent zinc deficiency. Super-optimal levels of copper cause zinc deficiency and conversely, high levels of zinc cause copper deficiency. Thus, it is possible to encounter deficiencies of iron, manganese, copper or zinc as a result of excess application of other micronutrients. These deficiencies can occur even when a normally sufficient concentration of the deficient micronutrient exists in the soil.

For the vegetable crop cultivations in plastic film house, compost applications at the rates of 1,000-4,000 kg $10a^{-1}$ are common. Most of the commercial composts consist of animal manures and food wastes and they contain various micronutrients. A number of feed additives, such as As, Co, Cu, Fe, Mn, Zn and Se, are added to improve animal growth and performance, but most of these micronutrients pass directly through the animal, producing elevated levels in the slurries (Moreno-Caselles et al., 2005).

Although the availability of N, P and K in compost is considered in the soil fertility management, little attention has been paid on the availability of micronutrients in composts applied in the soil. Therefore, for better management of micronutrients in the cultivations of plastic film house crops, the availability of micronutrients in the compost must be evaluated before application of micronutrient fertilizers. This study was conducted to investigate the micronutrient availability of composts in lettuce cultivation.

Materials and Methods

Composts Five commercial composts were purchased and used in the experiment (Table 1). The composts commonly consist of animal manures and sawdust. Other various materials including sesame oil cake, rice bran, herb dust, zeolite and perlite were used as source materials.

Contents of micronutrients in the composts were analyzed in the forms of total, 0.1 N HCl soluble and DTPA soluble. Total contents of micronutrients, B, Cu, Zn, Fe, Mn and Mo, were analyzed after sample digestion in aqua regia (a mixture in 3:1 ratio of 12 M HCl and 16 M HNO_3) as described by McGrath and Cunliffe (1985). Compost sample was ground to pass 0.18-mm sieve, and 3 g of the samples was digested in 15 mL aqua regia for 1 hr at 70℃. The digest was filtered with Whatman No. 42 filter paper and after rinsing the digest several times with water, the filtrate was combined and transferred quantitatively to a 50-mL volumetric flask and diluted to volume with water. For determination 0.1 N HCl extractable micronutrients, 10 g of compost sample air-dried and ground to pass 1-mm sieves was placed in 100-mL flask and 50 mL of 0.1 N HCl was added, and after shaking the suspension for 1 hr at 30℃ the suspension was filtered with Whatman No. 2 filter paper (NIAST, 1988). Micronutrients were extracted by DTPA (0.005 M DTPA, 0.1 m triethanolamine and 0.01 M $CaCl_2$ at pH 7.3) with a 1:2 (v/v) volume ratio (Lindsay and Norvell, 1978). Quantitative determination of micronutrients in the extracts was carried out using inductively coupled plasma-atomic emission spectrophotometer (ICP-AES, Varian Liberty Series II, Mulgrave, Australia).

Soil Soil used in the lettuce cultivation was collected from the experimental farm of Yeoungnam University. General characteristics of the soil were presented in Table 2. Contents of total and extractable micronutrients in the soil were analyzed using the methods described in the compost analyses and data are presented in Table 3.

Cultivation of lettuce Seeds of lettuce (*Lactuca sativa* L., var. chungchima) were obtained from Seminis Korea. Seedlings were grown in seed-boxes filled with a 1:1 mixture of perlite and vermiculite from March 25 to

Table 1. Composts used in the experiment and their source materials

Compost	Source materials
Sample 1 (Sejin plus compost)	manure 35%, sawdust 45%, sesame oil cake 20%
Sample 2 (Pleasant compost)	animal manure 50%, sawdust 40%, microbial enzyme 1%, zeolite 9%
Sample 3 (Jichun compost)	cow manure 30%, poultry manure 35%, sawdust 30%, sesame meal 5%, perlite 5%
Sample 4 (Chunha compost)	animal manure 35%, sawdust 35%, rice bran 20%, dolomite 10%
Sample 5 (Herb compost)	animal manure 30%, sawdust 30%, herb dust 25%, rice bran 12%, others 3%

Table 2. General characteristics of the soil used in the experiment

pH	Texture	EC	Total N	Organic matter	Available P_2O_5	Extractable cation		
						K	Ca	Mg
		dS m^{-1}	g kg^{-1}	g kg^{-1}	mg kg^{-1}	-------------- $cmol_c$ kg^{-1} --------------		
6.5	Silty clay loam	0.11	0.03	3.70	1.68	0.09	5.33	3.69

Table 3. Contents of total and extractable micronutrients in the soil

	B	Cu	Fe	Mn	Mo	Zn
	--------------------- mg kg^{-1} ---------------------					
Total	27.0	11.0	17,391	571	9.4	27.1
0.1 N HCl extractable	0.3	1.9	417	68	0.1	5.1
DTPA extractable	nd	0.7	38	74	nd	0.5

† Not detected.

April 27 in 2005. Four-leaf stage seedlings were transplanted into 1 L pots (15 cm diameter) filled with the soil. Compost (sample 4 in Table 1) was treated at two rates of 1,000 and 2,000 kg $10a^{-1}$ and control of no compost application was also included in the experiment. Chemical fertilizers of N, P and K (20-10-15 kg $10a^{-1}$) were applied using urea, fused phosphate and potassium chloride, respectively. Compost and chemical fertilizers were added into the soil and mixed before transplanting of lettuce seedling. Pots were arranged in a completely randomized design with seven replicates. Pots were maintained around field capacity by daily watering with distilled water. Four weeks after transplanting, plants were harvested.

Another set of pots of soil treated with compost and chemical fertilizers as above was prepared to investigate the net changes of micronutrient contents in compost treated soil. This set of pots were also maintained in the greenhouse and watered for field capacity without lettuce cultivation. Soil samples were collected at the same time of lettuce harvest.

Growth measurement and analysis Shoot fresh weight was measured and then dried at 60°C and after measuring dry weight the plant sample was ground to a fine powder using a Wiley mill. For total micronutrient analysis, sample was digested in ternery solution (HNO_3 : H_2SO_4 : $HClO_4$, 10 : 1 : 4) and the contents were determined using inductively coupled plasma-atomic emission spectrophotometer (ICP-AES, Varian Liberty Series II, Mulgrave, Australia). Contents of 0.1 N HCl extractable micronutrients in the soil without lettuce cultivation were determined using the method described in the compost analysis.

Results and Discussion

Micronutrient contents in composts produced for greenhouse vegetable crops are presented in Table 4. Contents of Mo in the composts were very low and 0.1 N extractable Mo were not detected in all of the composts. Contents of B were not much different among the composts, but contents of other micronutrients were various among the composts. Total Fe contents were highest and in the range of 4,300-9,500 mg kg^{-1}, and total Mn contents were 300-800 mg kg^{-1}. The governmental regulation values of total Cu and Zn contents in compost are 200 and 500 mg kg^{-1}, respectively. Total Cu and Zn contents found in the composts were lower than the governmental regulation values (RDA, 2006).

Contents of B extracted in 0.1 N HCl were 23-32% of total contents and less amounts of B were extracted in DTPA solution. Contents of 0.1 N HCl extractable Cu were lower than 3% of total Cu contents, but DTPA extractable Cu contents were more than 12% of total contents and especially in the sample 4. DTPA extractable Cu content was about 48% of total content. In the case Fe, 0.1 N HCl extractable Fe contents in the composts were less than 1% and DTPA extractable Fe contents were 4-9% of total contents. Although total contents of Fe were high in the composts but availability of Fe seems to be relatively low comparing to the other micronutrients. Contents of 0.1 N HCl and DTPA extractable Mn of the composts were in the ranges of 7-32 and 20-32% of total contents, respectively, and the extraction in the two solutions were not significantly

Table 4. Contents of total and extractable micronutrients in composts

	Compost	B	Cu	Fe	Mn	Mo	Zn
		mg kg^{-1}					
Total	Sample 1	33.5	30.5	4,482	294	0.3	216
	Sample 2	36.5	60.8	4,283	793	0.5	373
	Sample 3	26.1	26.5	7,126	401	0.1	140
	Sample 4	41.8	159.7	7,642	322	nd†	403
	Sample 5	33.3	36.9	9,543	603	nd	417
0.1 N HCl extractable	Sample 1	9.5	0.8	8	69	nd	6
	Sample 2	11.7	0.9	5	60	nd	2
	Sample 3	8.3	0.4	2	53	nd	1
	Sample 4	9.7	2.1	1	104	nd	21
	Sample 5	7.5	0.7	6	114	nd	8
DTPA extractable	Sample 1	5.1	5.4	295	93	0.1	149
	Sample 2	8.0	10.1	212	156	0.2	238
	Sample 3	4.6	3.4	241	83	nd	42
	Sample 4	5.5	75.7	678	83	nd	260
	Sample 5	4.4	7.8	359	151	nd	252

† Not detected.

different. Contents of 0.1 N HCl extractable Zn in the composts were lower as found in Cu, but large amounts of Zn were extracted in DTPA solution.

Although DTPA extractable micronutrients were lower than those extracted in 0.1 N HCl in soil of low organic matter contents (Table 3), more micronutrients were extracted in DTPA solution than in 0.1 N HCl in composts with the exception of B (Table 4). In accordance with this, Kuo (1990) observed that sewage sludge mineralization increased the concentrations of soluble organic compounds, especially low molecular weight organic acids, in soils, which could mobilize not only the exogenous micronutrients from the sewage sludge but also the nonavailable metal fraction in the soil. These results suggested that compost application can supply certain amount of micronutrients depending on the application rate. The input of Fe, Mn, Cu and Zn associated with manure could be an important pathway for the supply of these essential elements to arable crops in bioavailable forms (Clapp et al., 1986).

Although we compared contents of micronutrients extractable in 0.1 N HCl and DTPA solution in composts and soil, the availability of those nutrients is not certain. Availability of mineral nutrients are related not only to the amount of nutrients extracted but also to various soil and plant factors. Micronutrient uptake by lettuce was compared with the soil micronutrients extractable in 0.1 N HCl in the following experiment of lettuce cultivation with compost application, since there are many test data for predicting the availability of micronutrients using 0.1 N HCl extraction.

Lettuce was cultivated in soil amended with compost sample 4 in Table 1, and micronutrient uptake of lettuce and extractable micronutrient contents in compost treated soil were measured.

Contents of extractable micronutrients in soil 4 weeks after amending compost at 1,000 and 2,000 kg 10a^{-1} without plant cultivation were shown in Table 5. Extractable B and Mo in 0.1 N HCl were not detected in both soils of with and without amending compost. Since the soil contained very low levels of extractable B and Mo, the treatment of compost containing relatively low amounts of the micronutrients could not increase the extractable B and Mo in the soil. However, 0.1 N HCl extractable Cu, Fe, Mn, and Zn contents were significantly increased in the soil amended with compost. Compared with the extractable micronutrient contents in control, 0.1 N HCl extractable Cu, Fe, Mn and Zn contents in the soils amended with compost at 1,000 and 2,000 kg 10a^{-1} were increased by 0.8-1.5, 17-34, 28-43 and 3.8-7.0 mg kg^{-1}, respectively. These increments of micronutrients with compost applications were sufficient for maintaining optimum levels of those micronutrients for most of crops in soil (Sims and Johnson, 1991). This result indicates that compost application can supply the needed amounts of micronutrient Cu, Fe, Mn, and Zn for crop production even in soils containing relatively low levels of those micronutrients.

Continuous application of compost would lead to the accumulation of micronutrients in soil. In plastic film house soils of vegetable crops, micronutrient contents were found to be mostly higher than the optimum levels of crop production (Jung et al., 1998; Ha et al., 1997). The application of compost to maintain proper soil physical quality and status of major mineral nutrients including N, P and K would further increase micronutrient levels in soil beyond the optimum level. Therefore further application of micronutrient fertilizers in plastic film house soils seems to be unnecessary unless any other soil and plant factors limit the availability of micronutrients. And long-term effect of compost application on the phytoavailability of micronutrients in soils should be further investigated.

Fresh and dry weights of lettuce and micronutrient contents in lettuce leaf were presented in Table 6 and Table 7.

Compost treatments increased lettuce growth around 10 and 30% in the application rates of 1,000 and 2,000 kg 10a^{-1}, respectively. The added fertilizer seems to be failed to cover all crop nutrient requirement. In the case of B and Mo, although the contents in soil and compost were very low and mostly not detected in the measurement, lettuce absorbed the nutrients more than the lower limit of optimum level for growth with exception of Mo in the control soil. Contents of B in lettuce were significantly increased in the compost treatments. There would be continuous supply of available B and Mo at low concentration from soil and compost during the lettuce

Table 5. Contents of 0.1 N HCl extractable micronutrients in soils 4 weeks after amending compost without plant cultivation

Treatment	B	Cu	Fe	Mn	Mo	Zn
	----------	----------	---------- mg kg^{-1}	----------	----------	----------
Control	nd[§]	1.8 a[†]	253 a	54 a	nd	3.5 a
Compost (1,000 kg 10a^{-1})	nd	2.6 ab	270 ab	82 b	nd	7.3 b
Compost (2,000 kg 10a^{-1})	nd	3.3 b	287 b	97 b	nd	10.5 b
Optimum level for crops[‡]	0.1-2.0	1.0-2.0	10-16	1.0-4.0	0.1-0.3	1.0-5.0

[†] Means followed by the same letter are not different at the 0.05 probability level.
[‡] Sims and Johnson (1991).
[§] Not detected.

Table 6. Growth of lettuce and micronutrient uptake as influences by compost treatment rates

Treatment	Fresh weight	Dry weight	Micronutrient uptake[†]					
			B	Cu	Fe	Mn	Mo	Zn
	g plant^{-1}		----------	----------	---------- mg plant^{-1}	----------	----------	----------
Control	34.2 a[‡]	2.9 a	0.04	0.01	0.64	0.54	nd[§]	0.16
Compost (1,000 kg 10a^{-1})	36.7 ab	3.2 ab	0.09	0.02	0.38	0.47	0.002	0.20
Compost (2,000 kg 10a^{-1})	44.3 b	3.7 b	0.19	0.02	0.49	0.53	0.001	0.27

[†] The uptake was calculated from micronutrient content and dry weight of lettuce.
[‡] Means followed by the same letter are not different at the 0.05 probability level.
[§] Not detected.

Table 7. Micronutrient contents in lettuce as influences by compost treatment rates

Treatment	B	Cu	Fe	Mn	Mo	Zn
	----------	----------	---------- mg kg^{-1}	----------	----------	----------
Control	14.9	4.6	220	185	nd[†]	56
Compost (1,000 kg 10a^{-1})	28.3	4.7	119	147	0.6	46
Compost (2,000 kg 10a^{-1})	52.3	6.0	133	143	0.3	72
Optimum level for crops[‡]	10-200	5-30	100-500	20-300	0.1-2	20-150

[†] Not detected.
[‡] Jones (1991).

cultivation. Contents of Fe and Mn in lettuce were lower in compost treatments than those found in control, but the differences were not significant. Since the soil contains relatively large amounts of available Fe and Mn, compost treatment could not affect contents of those nutrients in lettuce. Contents of Cu and Zn in lettuce were also increased with compost treatment. Contents of Cu in lettuce of control and compost 1,000 kg $10a^{-1}$ treatments were below the lower limit of optimum range for crop production, but in the treatment of compost 2,000 kg $10a^{-1}$ the content of Cu in lettuce was higher than the lower limit of optimum range. Contents of Fe, Mn and Zn in lettuce were within the optimum range and quite lower than the upper limit of the optimum range.

Micronutrient uptake by lettuce was estimated from the nutrient content and dry weight of lettuce and the results are presented in Table 6. The amounts of Cu, Fe, Mn and Zn absorbed by lettuce were much less than the increased amounts of 0.1 N HCl extractable Cu, Fe, Mn and Zn in the soils amended with compost (Table 5). Therefore, it can be suggested that compost application could supply the amounts of micronutrients required by lettuce.

Conclusions

The pattern of micronutrient accumulation was not uniform among the elements, but in all treatments the proportions of micronutrients in soil and plant were all in the optimum ranges and below the toxicity levels. The results allow us to establish that commercial composts could be used as soil amendment for plastic film house crop production with sufficient supply of micronutrients.

Land application of biosolids increases heavy metal concentration of soils (Solan et al., 1998), which can results in an increase in trace metal uptake into crop tissue (Berti and Jacobs, 1996; Yuran and Harrison, 1986; Shiralipour et al., 1992). Plant uptake is one of the major pathways by which biosolids-borne potentially toxic metals enter the food chain (Chaney, 1990). Zubillaga and Lavado (2002) found that contents of Cu, Zn and Ni in lettuce leaf were within the optimum levels when the plant was grown with biosolids compost. Ozores-Hampton et al. (2005) also found that Cu, Ni and Zn in pepper fruit were increased with application of organic amendments but were lower than the maximum acceptable levels. Generally no adverse effects on plant growth or excessive amounts of metal uptake were noted in long-term high application rate of biosolids and concentrations of Cu and Zn in all crops were well within the sufficiency range observed for agronomic crops (Sukkariyah et al., 2005; Kabata-Pendias and Pendias, 1991). The results of this study also suggest that the possibility of any toxicity problems of the heavy metal micronutrients in lettuce cultivation can be eliminated with the compost treatment of around 2,000 kg $10a^{-1}$. However, the long-term effect of compost treatment on the heavy metal accumulation in soil and plant uptake should be further examined.

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퇴비의 미량원소 함량과 작물에 대한 유효도

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가축분과 톱밥을 주원료로 하고 기타 농산부산물과 무기 자재로 제조된 퇴비의 미량원소 함량을 조사하고 이러한 퇴비의 처리가 토양의 미량원소 함량과 작물의 미량원소 흡수 이용에 미치는 영향을 상추 재배를 통하여 조사하였다. 시중에 유통되고 있는 5종의 퇴비를 구입하여 실험에 사용하였으며, 미량원소는 총 함량과 가용성 함량으로 분석하였다. 미량원소 함량이 낮은 토양에 퇴비 1종을 1,000 및 2,000 kg 10a-1 수준으로 처리하고 포트 시험으로 온실에서 상추를 재배하였으며, 생육과 식물체중의 미량원소 함량을 조사하였다. 퇴비중의 미량원소 함량은 원료물질이 다른 만큼 퇴비의 종류별로 총 함량과 가용성 함량 모두 다양하였다. 미량원소 총 함량은 B, Cu, Fe, Mn, Mo, Zn이 각각 26-42, 27-160, 4,300-9,500, 290-790, 0-0.5, 140-420 mg kg^{-1} 범위로 나타났다. 퇴비중의 0.1 N HCl 가용성 B, Cu, Fe, Mn, Zn 은 각각 총 함량의 23-32, 1.3-2.6, 〈1, 7-32, 0.5-5% 수준이었으며 DTPA 가용성 함량은 0.1 N HCl 가용성 함량보다 높았다. 퇴비를 2,000 kg $10a^{-1}$ 수준으로 처리한 경우 퇴비를 처리하지 않은 대조구에 비하여 통계적으로 유의성 있게 생육이 증가하였으며, 대조구에 비하여 퇴비 처리구 모두에서 상추 잎 중의 B, Cu, Mo, Zn 함량이 높게 나타났다. 그러나 퇴비 처리가 Fe와 Mn의 흡수는 증가시키지 못하였다. 퇴비 2,000 kg $10a^{-1}$ 수준의 처리를 통하여 토양에 공급되는 0.1 N HCl 가용성 미량원소의 양은 상추 생육에 필요한 양보다 많았으며, 이러한 결과로부터 적절한 수준의 퇴비 시용을 통하여 작물이 필요로 하는 미량원소를 원활히 공급할 수 있을 것으로 판단된다. 따라서 퇴비 시용량이 비교적 많은 비닐하우스 농가에서 사용되고 있는 미량원소 비료의 시용 효과는 미량원소 흡수에 미치는 토양 환경이나 작물 요인을 고려하여 면밀히 검토되어야 할 것이다.