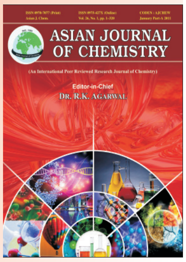
Asian Journal of Chemistry; Vol. 26, No. 10 (2014), 3095-3100

ASIAN JOURNAL OF CHEMISTRY

http://dx.doi.org/10.14233/ajchem.2014.16874



Toxic and Essential Elements in Different Types of Compost Samples

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Received: 16 December 2013; *Accepted*: 25 March 2014; *Published online*: 10 May 2014; AJC-15188

The aim of this study is the evaluation of toxic and essential elements levels in compost of main farming areas in Yunnan, China. The determination of the nitric acid/hydrogen peroxide soluble contents of 18 micro- and macro-elements (As, Pb, Cd, Ni, Cr, Hg, Co, Mo, Se, Cu, Zn, Mn, B, P, K, Ca, Mg and Fe) in composts was developed by the microwave digestion technique combined with inductively coupled plasma optical emission or mass spectrometry. This investigated was focused on different types of compost. All of the results were compared with standards and guidelines for marketable composts. Mean characteristics of composts proved to be in good agreement with the specification of the GB quality assurance for compost except a small portion of arsenic content and cadmium in samples could be above the GB specifications, as well as one sample of chromium and mercury content which may cause serious environmental impacts. The experimental study was conducted using three GB standard reference materials. Additional validation data are provided bases on the analysis of 9 different types of samples by the proposed method and using comparative methods of official GB methods. The calculated accuracy and precision confirmed the good performance of the adopted procedures.

Keywords: Compost, Toxic element, Essential element, Limits.

INTRODUCTION

Compost is defined as the product resulting from the controlled biological decomposition of organic material. It can be derived from a number of feed stocks including yard trimmings, biosolids (sewage sludge), wood by-products, animal manures, crop residues and food scraps. Composting not only helps reduce the amount of waste going to landfills but it produces a valuable soil amendment which can improve the texture and fertility of soil, also improved plant growth and stress tolerance[1,2]. However, a wide range of compost sources caused a series of safty problems that led by ecological and environmental should not be ignored[3].

Trace element, contaminant as environmental issues, most of them has significant harmful effects to the ecosystem[4]. Firstly, specific trace elements, often referred to as heavy metals include arsenic, lead, cadmium, nickel, chromium, mercury, cobalt, molybdenum, copper, zinc, selenium. Many of these elements are actually needed by plants for normal growth, although in very limited quantities[5]. Therefore, measuring the concentration of these elements, as well as other plant nutrients can provide valuable management data relevant to the compost requirements of plants and subsequent compost application rates. Secondly, certain heavy metals and trace elements are also known to cause phytotoxic effects in plants[6], These elements include boron, manganese, molybdenum, nickel and selenium. However, the accumulation of these elements in environmental samples such as composts increases a potential risk to human health through the transfer of these elements in aquatic media, their uptake by plants and their subsequent introduction into the food chain[7]. Finally, macronutrients such as potassium, calcium, iron, magnesium, phosphorus may protect plants against disease through improved nutritional status, direct toxicity toward the pathogen or induced systemic resistance[8].

In this research, the content of micro- and macro-elements of different types of compost in Yunnan province (China) were examined applying the microwave assisted, HNO_3/H_2O_2 digestion method. Based on the results, the contamination level of the composts with the examined toxic elements was evaluated and the similarity in the behaviour and origin of these elements were determined. Methods for which their calculated accuracy and precision confirmed their good performance were applied for the determination of the elements. The results of this investigation have implications for the farming management and should be used for comparison with future compost quality data. In addition, such scientific and preventive approaches based on a better understanding of the source, fate and effects of metallic contaminants in an agriculture system are also of great interest for the development of pollution control and compost-remediation strategies and for an estimation of the quality of the other polluted farming systems in China and the World.

EXPERIMENTAL

A pressurized closed-vessel Microwave Digestion system (Multiwave 3000, Anton Paar, Germany) was used to perform microwave assisted digestion procedures for the compost samples. The system was equipped with PTFE vessels, platform with a 48-vessel 48MF50 rotor.

Analyses were carried out with an inductively coupled plasma mass spectrometer equipped with a reaction cell (KED-ICP-MS NexION 300X, Perkin Elmer, Norwalk, CT, USA) operating Helium as the reaction gas (99.999 %, Messer, China). Sample introduction system was composed by baffled quartz cyclonic spray chamber and a Meinhard® nebulizer connected by Tygon® tube to the ICP-MS's peristaltic pump (set at 20 rpm). The ICP-MS was operated with Pt sampler and skimmer cons.

Metal determination in digests was also carried out using an inductively coupled plasma optima emission spectrometer with dual view configuration (ICP-OES Optima 8300, PerkinElmer, Shelton, CT, USA) equipped with a GemTip™ cross-flowllnebulizer coupled to a scott-type spray chamber, single-slot quartz torch and alumina injector (2 mm internal diameter) was used.

For ICP-MS and ICP-OES determinations, high-purity argon (99.999 %, Messer, China) was used for plasma generation, nebulization and auxiliary gas. All consumables and accessories purchased from Perkin Elmer.

Reagents, standards and samples: All the reagents used were of analytical-reagent grade (Merck, Darmstadt, Germany). Water was purified using a Milli-Q system (18·2 MΩ cm, Millipore, Bedford, MA, USA) and it was used to prepare all reagents and standard solutions. Multielement stock standard solution containing 10 mg L^{-1} of heavy metal/metalloids elements studied (PerkinElmer, Norwalk, CT) for ICP-MS, 1000 mg L^{-1} of each conventional element standard (National Analysis Centre for Iron and Steel, Beijing, China) for ICP-OES, both two set of analytical calibration standards were dilution in 5 % (v/v) HNO_3 by sequential.

The accuracy was checked using analyte addition and by analysis of stream sediment SRMs (GBW07311, GBW07312) and soil SRMs (GBW07404) purchased from Institute of Geophysical and Geochemical Exploration and Institute of Rock and Mineral Analysis, China.

For addition validation purposes different areas of compost samples were collected from Yunnan Academy of Tobacco Agricultural Science and using comparative methods with atomic absorption spectrophotometry (AAS), atomic fluorescence spectrophotometry (AFS) or ultraviolet spectrometry (UVS) as the detector.

Sample preparation procedures: Microwave-assisted digestion was performed for all samples investigated. In this sense, about 200 mg of compost samples were weighted inside PTFE vessels and 5 mL of concentrated nitric acid and 1 mL of 30 % (v/v) H_2O_2 were added. The operational conditions and the heating program used were carried out according to conditions as follow: ramp power to 900 W over 20 min, then hold at 900 W for 50 min, after digesting, they were allow to cool to approximately 50 centigrade or lower before handing. After cooling, digests were diluted with ultrapure water to 100 mL in a polypropylene vials for further analysis. Blanks were treated in the same way without sample for all procedures. This procedure completed in 85 min approximately.

To meet the calibration curve range, appropriate dilution factors were applied to the samples so that they would fall within the calibration ranges.

Experimental parameters for different instrumental analysis are listed in Table-1. The method limit of detection (LOD) and limit of quantitation (LOQ) were determined based on sample replicates measurement. The LODs were determined as 3 SD of the 20 consecutive measurements of the reagent blanks multiplied by the dilution factor used for sample preparation (200 mg of sample/100 mL). The LOQs values were determined as 3 times the LOD.

TABLE-1
OPERATIONAL PARAMETERS FOR ELEMENT DETERMINATION BY ICP-MS AND ICP-OES

Parameter	ICP-MS	ICP-OES
Rinse/wash solution	2 (%) HNO_3 solution	2 (%) HNO_3 solution
Wash time (s)	30	30
Sample flush time (s)	45	15
Read delay time (s)	15	35
RF Power (W)	1150	1300
Plasma gas flow rate (L min^{-1})	16	15
Auxiliary gas flow rate (L min^{-1})	1.2	0.2
Nebulizer gas flow rate (L min^{-1})	0.85	0.55
He Reaction gas flow (mL min^{-1})	4.5	-
Integration time (ms)	1000	Auto
View	-	Axial
Replicates	3	3
Oxide ratio (%)	< 3 % ($^{140}Ce^{16}O/^{140}Ce$)	-
Doubly charged ratio (%)	< 3 % ($^{69}Ba^{++}/^{138}Ba^{+}$)	-
Isotope (*m/z*)	^{75}As, ^{208}Pb, ^{111}Cd, ^{60}Ni, ^{52}Cr, ^{202}Hg, ^{59}Co, ^{98}Mo, ^{82}Se	-
Wavelength (nm)	-	P 213.617, K 766.490, Ca 317.933, Mg 285.213, Fe 238.204, Cu 327.393, Mn 257.610, Zn 213.857, B 249.772

The linear calibration curve was established for each instrument. The concentration range was determined when the linear regression correlation coefficient in all cases was 1 > r > 0.999. In order to ensure the accuracy for determination, the same extract from the original sample was shared between two instruments to avoid sample variation and extraction variations.

RESULTS AND DISCUSSION

The results of the calculations of the accuracy and precision for the applied method are given in Table-2 for conventional and toxic elements, from which it can be seen that the measured concentration values are in excellent agreement with the certified values of the GBW07311, GBW07312 and GBW07404 reference materials, the accuracy ranged from 85.49 to 118.75 %. The precision is expressed as the relative standard deviation (RSDs). The RSDs of the means of duplicate measurement were less than 10 %.

Additional validation were provided by the analyses of 9 different types of compost samples (including straw, poultry manure, organic waste and sewage sludge) analyzed by the proposed method and using comparative methods (National Standard of the People's Republic of China for compost) with AAS/AFS/UVS as detector, the analysis method just included 10 elements among the standard of compost in China (Table-3). The values of certified and found levels for Certified Reference Materials analysis were in good agreement. Moreover, no significant statistical differences at 95 % confidence level were observed between values of comparative methods and proposed method for ordinary sample analysis by applying paired t-test. In this case, the calculated t-values are lower than the tabulated t-value ($t_{0.05, 9} = 2.306$). Therefore, the applied method is considered a valid procedure.

Furthermore, the LODs obtained for As, Pb, Cd, Ni, Cr, Hg, Co, Mo, Se were 30, 5, 20, 6, 8, 4, 5, 1, 20 ng/g in ICP-MS and Cu, Zn, Mn, B, P, K, Ca, Mg, Fe were 0.8, 0.5, 0.9, 0.7, 4, 72, 1, 0.7, 3 μg/g in ICP-OES, respectively. All of these results, combined with the accuracy and precision described before, consistently show that is highly sensitive detection method to meet the actual needs of sample analysis.

Elements content in the investigated elements and quality guidelines for compost: Compost quality guidelines are relatively new, dating to the mid-1980's. With regard to organic soil amendments, perhaps the only comparable standard similar to what has emerged for compost in some countries is the system of classification of peats[12]. Compost has been widely used for decades in organic farming, but issues concerning composition and quality have only recently emerged largely by external pressure[13,14]. Of all potential quality standards, heavy metals have been the focus of most attention, in addition, most of conventional elements are essential for a wide variety of plants and animals, hovever, excessive loading of them may damage to the ecosystem. Thus it is useful to explore the details of these standards country by country, beginning with an overview of the range of standards that are evident (Table-4). These data of permissible metal ranges reveal significant variation within different European countries and in Canada, even in China.

The contents of elements in 30 compost samples (as min, max, median and mean), result of the SE (standard error) and CV (coefficient of variation) which from different area are presented in Table-5.

Survey of real samples: In this comparison study, all samples were analysis following the methods as mention. An inquiry into national limits for all measured elements, limited standards relate only 13 elements (As, Pb, Cd, Ni, Cr, Hg, Co, Mo, Se, Cu, Zn, P, K), of which seven kinds of them, including Pb, Cd, Ni, Cr, Hg, Cu, Zn are the most discussed. Moreover, micronutrient elements other than the listed limits are take into consideration which is necessary for plant growing. The specific results of the survey are as follows: Arsenic limits involving France, Canada and China, 5 samples were over the limit of all country except one of them does not exceed the limits of the French. Nickel and chromium just only one have

TABLE-2
ACCURACY AND PRECISION OF APPLIED METHODS (μg/g)

Element	GBW07311			GBW07312			GBW07404		
	Certified value	Found value	Accuracy (%)	Certified value	Found value	Accuracy (%)	Certified value	Found value	Accuracy (%)
As	188 ± 20	194	103.19	115 ± 9	123	106.96	58 ± 3	55	94.83
Pb	636 ± 34	665	104.56	285 ± 16	287	100.70	58 ± 7	64	110.34
Cd	2.3 ± 0.2	2.4	104.35	4 ± 0.4	4.3	107.50	0.35 ± 0.08	0.34	97.14
Ni	14.3 ± 1.5	14.7	102.80	12.8 ± 1.9	12.4	96.88	64 ± 7	64	100.00
Cr	40 ± 4	37	92.50	35 ± 4	31	88.57	370 ± 24	360	97.30
Hg	0.072 ± 0.014	0.077	106.94	0.056 ± 0.008	0.058	103.57	0.061 ± 0.008	0.065	106.56
Co	8.5 ± 1.2	7.4	87.06	8.8 ± 1.1	8.0	90.91	97 ± 9	90	92.78
Mo	5.9 ± 0.8	6.5	110.17	8.4 ± 0.9	8.5	101.19	2.9 ± 0.4	3.0	103.45
Se	0.20 ± 0.06	0.23	115.00	0.25 ± 0.04	0.28	112.00	0.32 ± 0.09	0.38	118.75
Cu	79 ± 4	81	102.53	1230 ± 51	1208	98.21	40 ± 4	44	110.00
Zn	373 ± 21	387	103.75	498 ± 27	511	102.61	210 ± 19	212	100.95
Mn	2490 ± 130	2504	100.56	1400 ± 73	1457	104.07	1420 ± 117	1457	102.61
B	68 ± 7	61	89.71	24 ± 3	27	112.50	97 + 13	101	104.12
P	255 ± 42	218	85.49	235 ± 34	205	87.23	695 ± 43	688	98.99
K_2O %	3.28 ± 0.10	3.33	101.52	2.91 ± 0.06	2.64	90.72	1.03 ± 0.09	1	97.09
CaO %	0.47 ± 0.04	0.45	95.74	1.16 ± 0.07	1.16	100.00	0.26 ± 0.05	0.26	100.00
MgO %	0.62 ± 0.10	0.63	101.61	0.47 ± 0.12	0.45	95.74	0.49 ± 0.07	0.48	97.96
Fe_2O_3, %	4.39 ± 0.11	4.32	98.41	4.88 ± 0.13	5.02	102.87	10.30 ± 0.16	10.38	100.78

not developed a national standard limit, namely China and Switzerland. In most of the compost, the content of Ni, Cr were in the range of limits, but only a sample of Ni and two samples of Cr above the legal limits, which content is 37.10 mg/kg for Nickel and 72.21, 180.52 mg/kg for Chromium, respectively. Both Lead, cadmium and mercury limits are developed in all countries for this surveyed. A sample of Pb exceeded the legal limits of Switzerland. The Cd contents between 1 and 1.5 mg/kg or 1.5 and 3 mg/kg were 3 and 1, respectively, Which greater than 3 mg/kg were 4 samples. Similarly, Hg contents between 0.45 and 0.8 mg/kg or 0.8 and 2 mg/kg were 3 and 2, respectively, which greater than 2 mg/kg were only just a sample. The Co and Mn contents in the studied composts were tidily uniform in most of the samples,

TABLE-3
ANALYTICAL PERFORMANCE FOR THE DETERMINATION OF CONVENTIONAL AND TOXIC ELEMENTS IN DIFFERENT TYPES OF COMPOST SAMPLES: COMPARISON BETWEEN AAS/AFS/UVS AND ICP-MS/ICP (PROPOSED METHOD)

Sam. No.		1#	2#	3#	4#	5#	6#	7#	8#	9#	t value
As	ICP-MS	15.13	9.61	13.44	10.92	8.35	25.17	8.16	21.26	22.92	0.8654
	AFS[a]	14.43	9.02	12.7	11.91	8.14	24.38	7.59	20.7	24.11	
Pb	ICP-MS	66.83	18.74	52.86	49.83	13.37	29.99	9.54	51.61	31.91	1.7778
	AAS[a]	66.31	20.08	61.42	55.73	12.56	31.05	8.46	55.53	31.64	
Cd	ICP-MS	1.06	0.89	0.66	3.12	0.41	2.08	1.46	1.15	1.87	0.8038
	AAS[a]	1.24	0.68	0.4	3.09	0.65	1.83	1.32	1.07	1.97	
Cr	ICP-MS	45.0	38.14	72.54	25.41	38.82	39.83	20.62	20.11	37.11	0.6583
	AAS[a]	46.75	34.65	74.75	20.95	41.35	36.15	18.67	24.05	33.8	
Cu	ICP	0.173	0.14	0.131	0.087	2.721	0.175	0.071	0.186	2.728	2.1153
	AAS[b]	0.242	0.155	0.168	0.095	2.924	0.209	0.042	0.182	2.891	
Zn	ICP	0.109	0.071	0.112	0.098	0.406	0.1	0.087	0.113	0.088	0.7295
	AAS[b]	0.103	0.119	0.124	0.112	0.357	0.142	0.086	0.125	0.079	
Mn	ICP	3.57	1.87	2.32	2.0	5.32	4.66	1.65	2.33	5.25	1.8750
	AAS[b]	3.66	1.97	2.62	2.1	5.62	4.73	1.42	2.33	5.42	
P	ICP	19.35	9.4	13.23	13.38	9.89	3.9	8.08	11.44	10.21	1.4375
	UVS[c]	20.26	10.19	14.33	14.74	10.83	4.34	6.13	12.44	10.01	
K	ICP	59.44	14.14	109.36	51.95	17.14	62.92	11.8	22.46	16.78	0.874
	AAS[c]	60.26	13.6	115.34	52.82	16.61	66.76	10.75	21.1	15.45	
Fe	ICP	7.48	4.42	6.20	9.01	28.03	6.88	1.93	6.23	27.33	0.1305
	AAS[b]	7.35	3.53	6.16	9.15	29.43	8.62	1.67	6.38	25.63	

[a]Accroding to the official GB method GB/T 23349-2009 [9], China, [b]Accroding to the official NY method NY/T 305-1995 [10], China. Chater 1 to 4 is for Cu, Zn, Fe, Mn, respectively; [c]Accroding to the official NY method NY 525-2011 [11], China

TABLE-4
PROPOSED STANDARDS AND GUIDELINES FOR COMPOSTS IN DIFFERENT COUNTRIES

	Germany-Quality Label RAL-GZ 251[Ref.15] (For fresh compost, mature compost, mulch compost and (a) substrate compost)	Great-Britain PAS 100:2005[Ref.16] (apply to compost from source separated biowaste)	Switzerland-Quality Guidelines for composts 2010[Ref.17] (values given for horticultural use: on field or covered)	France-NF U 44-051[Ref.18] (Apply to soil improvers excluding those coming from wastewater treatment sludge)	Canada-CCME Compost Quality Guidelines[Ref.19] (compost that can be used in any type of application)	ECN quality assurance for compost[Ref.20]	China-Organic fertilizer NY525-2011[Ref.11] (Apply to animal manure, plant and animal residues, animal and plant by-products)
As	-	-	-	< 18 mg/kg DM	< 13 mg/kg DM	-	≤ 15
Pb	< 150 mg/kg DM	< 200 mg/kg DM	< 120 mg/kg DM	< 180 mg/kg DM	< 150 mg/kg DM	< 130 mg/kg DM	≤ 50
Cd	< 1.5 mg/kg DM	< 1.5 mg/kg DM	< 1 mg/kg DM	< 3 mg/kg DM	< 3 mg/kg DM	< 1.3 mg/kg DM	≤ 3
Ni	< 50 mg/kg DM	< 50 mg/kg DM	< 30 mg/kg DM	< 60 mg/kg DM	< 62 mg/kg DM	< 40 mg/kg DM	-
Cr	< 100 mg/kg DM	< 100 mg/kg DM	-	< 120 mg/kg DM	< 210 mg/kg DM	< 60 mg/kg DM	≤ 150
Hg	< 1 mg/kg DM	< 1 mg/kg DM	< 1 mg/kg DM	< 2 mg/kg DM	< 0.8 mg/kg DM	< 0.45 mg/kg DM	≤ 2
Co	-	-	-	-	< 34 mg/kg DM	-	-
Mo	-	-	-	-	< 5 mg/kg DM	-	-
Se	-	-	-	< 12 mg/kg DM	< 2 mg/kg DM	-	-
Cu	< 100 mg/kg DM	< 200 mg/kg DM	< 100 mg/kg DM	< 300 mg/kg DM < 600 mg/kg OM	< 400 mg/kg DM	< 200 mg/kg DM	-
Zn	< 400 mg/kg DM	< 400 mg/kg DM	< 400 mg/kg DM	< 600 mg/kg DM < 1200 mg/kg OM	< 700 mg/kg DM	< 600 mg/kg DM	-
P_2O_5	(a) <1200 or 2400 mg/L depending on the mixed component quantity	-	-	< 3 % of total weight	-	-	-
K_2O	(a) < 2000 or 4000 mg/L depending on the mixed component quantity	-	-	< 3 % of total weight	-	-	-

DM = Dry matter; OM = Organic matter

TABLE-5
CONTENT OF ELEMENTS IN
DIFFERENT AREA COMPOST (µg/g)

	Range	Median	Mean	SE	CV
As	1.30-125.40	7.91	14.38	4.76	1.741
Pb	5.21-127.24	13.70	25.85	5.34	1.059
Cd	0.12-9.74	0.50	1.44	0.433	1.569
Ni	3.28-37.10	14.52	15.92	1.28	0.424
Cr	9.20-180.52	23.10	33.18	6.70	1.030
Hg	0.040-2.02	0.195	0.40	0.106	1.31
Co	0.608-12.32	4.02	4.77	0.549	0.58
Mo	0.430-2.08	1.11	1.16	0.084	0.36
Se	0.568-10.56	3.81	4.68	0.586	0.63
Cu	7-281	26	46.00	11.93	1.296
Zn	22-772	89	132.24	30.60	1.157
Mn	76-594	307	291.72	28.51	0.489
B	10-204	49	59.12	9.35	0.791
P_2O_5 %	0.215-9.32	2.30	2.75	0.459	0.835
K_2O %	0.234-13.18	2.59	3.52	0.629	0.893
Ca %	1.71-15.13	4.37	5.40	0.761	0.705
Mg %	0.211-5.41	0.666	0.90	0.205	1.140
Fe %	0.193-2.63	1.02	1.04	0.110	0.529

none of them were higher than the limits. There is only China without the content of Cu and Zn in limited. A comparison of Cu and Zn contents in compost with their permissible values, the higher contents which 175 and 281 mg/kg for Cu or 772 mg/kg for Zn were beyond the permitted values in some country. There seem like a higher contents of Se are in the range of permissible values of France but not great fit with Canada presently. In other words, the standard limits of selenium which France and Canada were in some difference. The contents of macronutrients such as P and K higher than permissible values of Canada were account to 50 % approximately.

In general, for elements that may exist somewhat high level in the agricultural material. The value of the contents in the composts which above the legal limits were Switzerland or ECN, always. On the one hand, the mean concentrations of elements noted in this investigation were far below the limits of China, higher contents of arsenic which close but not exceed was included. On the other hand, statistical analysis showed that all of the median, except manganese are lower than the average. These results indicate that most of the sample are satisfactory in this survey. In summary, for main farming area of Yunnan, China, show a wide variation of the concentration of elements, however, overall levels of these elements are low. Standard limits in France and Canada were complete relatively. The comparative analysis results of metal limits of compost among different country showed the strictest compost quality levels do not differ so much from each other. For China, complex terrain and vast land require limit standards need further improvement. Relevant departments not only strengthen supervision and management mechanism but also practical guidance for compost application.

All of these samples involved in mainly cultivated areas for Yunnan in this survey. Although this kind of comparison is not sufficient, it can gives rise to a series of questions and suggestions from this study. Above all, adapting to the increasing demand through classification levels of precautionary for compost produced as much as possible. Secondly, compost application to land may require special permits based on soil metals for each soil type. Last but not least, improving limits of elements not only heavy metal but also essential element so as to develop a scientifically valid guidelines. All of these opinions were provided better guidance for compost application, which has great practical significance to the forecast, prevention and control of agriculture pollution.

Conclusion

This study focused on ICP-MS and ICP-OES based quantitative estimation of 18 elements in various compost products. The method was validated by analyzing certified reference material. Good agreement between recovered and certified values showed effective recovery of the elements after microwave digestion and subsequent accurate detection. One may also note that whatever the type of the sampled compost, no significant difference was measured for global parameters compared to official GB method among samples. The limits of detection for heavy metal or conventional elements ranged between 1-30 ng/g or 0.5-72 µg/g, respectively. Which were much better when compared with the studies reported in literature. It can provides reliable data about the metals distribution in some commonly consumed farm products. Hence, this study would be helpful for toxicologists and environmental chemists to evaluate the health effects of farm products. In addition, the comparative analysis results of metal limits of compost among different country showed the strictest compost quality levels do not differ so much from each other. For our samples, results of such examinations are satisfactory except high concentrations of elements, especially of As, Cd which may cause serious environmental impacts. All of these results will have deep and profound impact on the compost applications as well as the revision of national standards in the future.

ACKNOWLEDGEMENTS

This research was supported by the Tobacco Monopoly Bureau Foundation of Yunnan Provincial (No. 2011YN01). The authors thank the Yunnan Academy of Tobacco Agricultural Science for providing the compost samples. The authors are also grateful to Mrs Y.P. Wu and Mr G.H. Kong for valuable comments and stimulating discussions.

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