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RESEARCH ARTICLE

ASSESSMENT OF CHEMICAL PROPERTIES OF LOCALLY COMPOSTS PRODUCED IN SAUDI ARABIA COMPOSTS LOCALLY PRODUCED

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ABSTRACT

Chemical properties of twenty five composts produced in Saudi Arabia were investigated in order to evaluate their quality compared to local and international standards of compost quality. Generally results showed large variations between most chemical properties of composts under the study. Electrical conductivity (EC) Ec of final composts ranged from 0.6 dSm^{-1} to 25.4 dSm^{-1} and 92% of studied composts exceeded the upper limit of accepted EC set by CCQC and PAS-100. Most pH values tended to be alkaline and % were higher than 7.5. Ammonium contents were more than 500 $mgkg^{-1}$ (the maximum limit set by CCQC) in 40% of final products of compost, which may inhibit seed germination. Organic matter percentages were less than 25% (CCQC minimum limit) in 7% of composts and less than 40% (GCST minimum limit) in 76% of composts. Most C/N ratios (92%) of composts were less than 20% and complied with CCQC, GSCT standards. Nitrification index of 13 composts (52%) was above 3 and they are considered immature composts according to CCQC standards. Significant differences were shown between means of some chemical characteristics of all types of composts. Heavy metal contents of composts were below the upper limit set by CCQC and GCST with exception of Ni and Cd, which exceeded the allowable limit in 65% of and 79% respectively. In general, results showed that most local compost facilities are unable to produce a mature composts product. The high variability between chemical properties of composts confirmed the need for establishing quality assurance procedures to be applied by suitable mechanisms to produce mature compost and protect public health and the environment.

INTRODUCTION

In Saudi Arabia, several compost facilities have been constructed to produce composts for agricultural application using cow manure, chicken manure, and/or plant residuals. Compost production has several benefits of supplying plants with nutrients, increasing soil organic matter, and reducing environmental impact of manure (Simandi *et al*., 2005). Many studies have shown that composts can improve soil quality by enhancing nutrients, organic matter, water holding capacity, and cation exchange capacity (Al-Turki, 2010). However, composts with low quality may have some negative effect effects on plant growth and soil properties. Chemical characteristics of composts have been used to evaluate their maturity and stability which include electrical conductivity(EC) (Ec), pH, ammonium and nitrate levels, organic matter, C/N ratio and heavy metal contents (Bernal *et al*., 2008). Application of composts with high EC may result in increasing soil EC and negatively affect plant growth (Eu, 2006). Composts containing high amount of ammonium or nitrate have been shown to inhibit seed germination and contaminate environments (Larney *et al*., 2003). Previous studies reported that heavy metals present in composts accumulate in soil upon repeated compost application and may be absorbed by plants and enter food chain. It is worth mentioned that no single method can be sued used to evaluate compost stability or maturity, but rather several parameters should be considered to measure relative degree of compost quality. Some official and private organization have established regulations and standards for compost quality in order to assure compost quality for agricultural application and to protect public health and environment. Examples of fairly developed compost standards are those established by California Compost Quality Council (CCQC, 2002) and British Standards PAS-100 (BSI, 2005). Recently, some Arabic Gulf Countries proposed some regulations for local and imported compost quality (GCST, 2006). However, GCST regulations did not specify standards for some important maturity and stability indices such as ammonium and nitrate level, nitrification index, germination index and compost reparation rate. Up to date, according to our knowledge, there are neither mechanisms nor organizations responsible for assessment of local compost quality, which may result in production of low quality composts, which are harmful to public health, environments and plant growth. Present work was a part of a project that aims to evaluate locally produced compost quality in Saudi Arabia. Objective of this part was to study chemical characteristics of composts to drive their

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quality and examine their compliance with local and international regulations and standards of composts intended for agricultural applications.

MATERIALS AND METHODS

Preparation of compost samples

Compost facilities in Saudi Arabia were identified, and visited and described. Samples of composts at various stage of production were obtained three times during the year of 2011 in bags of 20-50L. Volumes of composts were reduced to p liter according to TMECC (2001). Samples were registered and immediately brought to the laboratory of soil analysis at college of Agriculture and Veterinary Medicine, Qassim University and kept in the refrigerator at 4^oC for analyses. A code system was used instead of brand names of facilities to ensure confidentiality (Table 1).

Table 1. Code system for different kind of compost locally produced in Saudi Arabia

Code of compost facility	Type of organic matter	System of production	End use
A, B, C, D, E, F, G, H, I	Chicken manure	Windrow	Agricultural soil improver and fertilizer
J, K, L, M, N, O, P	Cow manure	Windrow	Agricultural soil improver and fertilizer
Q, R, S, T, U, V, W, X, Y	Mixed organic materials: (chicken and/or cow manure + plant residuals) in random ratios	Windrow	Agricultural soil improver and fertilizer

Chemical properties of composts

Compost pH

Compost pH was measured in distilled water using 10g of compost sample and 50 ml distilled water (ratio 1: 5). The suspension was agitated for 3-5 min and placed for 1 hour before measuring the pH value using pH meter.

Electrical Conductivity

Compost Electrical Conductivity (EC) of the compost samples were determined using Electrical conductivity Meter according to TMECC method 04-10-A.

Organic Matter

The composting samples were analyzed for Organic Matter (OM) according to the method of Wakely and Black which described by Nelson and sommer, 1996. Organic matter content was determined by the method of $K_2Cr_2O_7$-H_2SO_4 oxidation. 0.1 g compost was mixed with $K_2Cr_2O_7$-H_2SO_4 solution and heated at 180°C. The solution was kept boiling for 5 min. After cooling, the residual $K_2Cr_2O_4$ was titrated by $FeSO_4$ standard solution using O-phenenthroline hydrate as indicator. Organic matter consumed was calculated based on the amount of $K_2Cr_2O_7$ consumed.

Total Nitrogen

Total nitrogen was determined using the micro-Kjeldahl distillation method according to Chapman and Partt (1961).

Ammonium and nitrate nitrogen (NO_3^- and NH_4^+)

Ammonium nitrogen and nitrate nitrogen were determined using micro-Kjeldahl distillation method. NO_3^- and NH_4^+ were determined according to the method of AOAC, 1990.

Total Phosphorus

Total phosphorus of composts samples were determined according to the method of Olsen and Dean, (1965).

Total Potassium

Total potassium of composts samples were determined according to the method of Chapman and Partt, (1961).

Heavy metals determination

The dried and ground samples were digested by HNO_3 and $HCLO_4$ (5:1 ratio v/v) to determine heavy metals concentrations in the compost, using AAS (Shimazu 6200 Atomic Absorption Spectrophotometer) according to Chapman and Pratt, 1961. A 1.000 ± 0.01 g sample was digested after adding 36 mL of acid mixture solution. Pb, Ni, Zn, Cd and Cu were determined in the resulting solution using Shimazu 6200 Atomic Absorption Spectrophotometer**.**

RESULTS AND DISCUSSION

Electrical Conductivity (EC)

Large variations were observed in initial and final EC values of compost samples. AS shown in Table 6, initial values of EC ranged from 0.6 dSm^{-1} (M and N facilities) to 22.5 dSm^{-1} (H facility), while the final EC values were between 0.6 dSm^{-1} (N facility) and 25.4 dSm^{-1} (F facility).

Table 6. Electrical Conductivity (EC) of different compost samples

Compost Facility code	Type of raw Materials	EC (dSm^{-1})	
		Initial	Final
A	Chicken Manure	15.3	14.1
B		15.6	9.1
C		9.4	12.4
D		4.9	12.1
E		14.4	7.6
F		17.3	25.4
G		15.0	15.0
H		22.5	12.5
I		10.1	12.4
Mean		13.8	13.4
ANOVA		**	**
J	Cow manure	10.9	12.2
K		14.4	11.6
L		1.4	17.6
M		0.6	4.9
N		0.6	0.6
O		20.8	11.9
P		13.4	23.3
Mean		8.9	11.7
ANOVA		*	**
Q	Mixed organic materials	14.8	12.8
R		2.6	8.5
S		17.5	2.7
T		8.9	9.0
U		13.3	12.9
V		7.4	7.0
W		3.7	6.6
X		2.2	2.8
Y		7.9	4.7
Mean		8.7	7.4
ANOVA		**	**

Generally, compost made from chicken manure or compost made from cow manure composts recorded higher EC values (with means of 13.8 dSm^{-1} and 11.7 dSm^{-1} respectively) compared with those made from mixed organic materials (with mean of 7.4 dSm^{-1}). Chicken and cow manures usually contain more soluble salts due to animal food. On the other hand, mixed organic materials are, beside manure, composed of plant residuals that contain low amount of soluble salts. Results showed significant differences ($p < 0.05$) between means of EC values of all compost samples. During manufacturing composts, we observed fluctuations in EC values of organic materials used for compost production in some facilities such as A and N facilities as shown in Figure (5a and b). However, changes in EC values were less in some facilities such as Q facility (Figure 5 c).

The upper limit of EC set by CCQC and PAS-100 for compost used for agricultural application is 4 dSm^{-1}. We noticed that 23 composts (92%) of studied composts have recorded EC values higher than this limit. However GCST (2006) is more lenient and proposed the value of 10 dSm^{-1} to be the upper limit of compost EC. Only eleven composts (44%) comply with the GCST standard. It seems that the most problematic characteristics of locally produced composts is the high concentration of dissolved salts. Repeating agricultural application of such compost in arid soil will negatively affect plant production and increase soil EC. It is therefore of importance to find out ways to reduce EC values of local composts to the accepted levels for sustainable plant production.

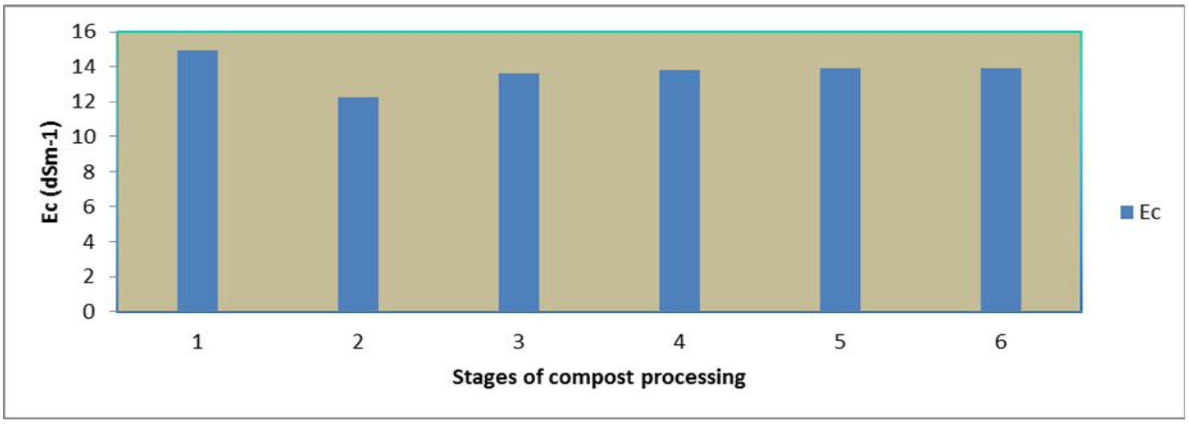

Figure (5a). Electrical conductivity of chicken compost during manufacturing (A facility)

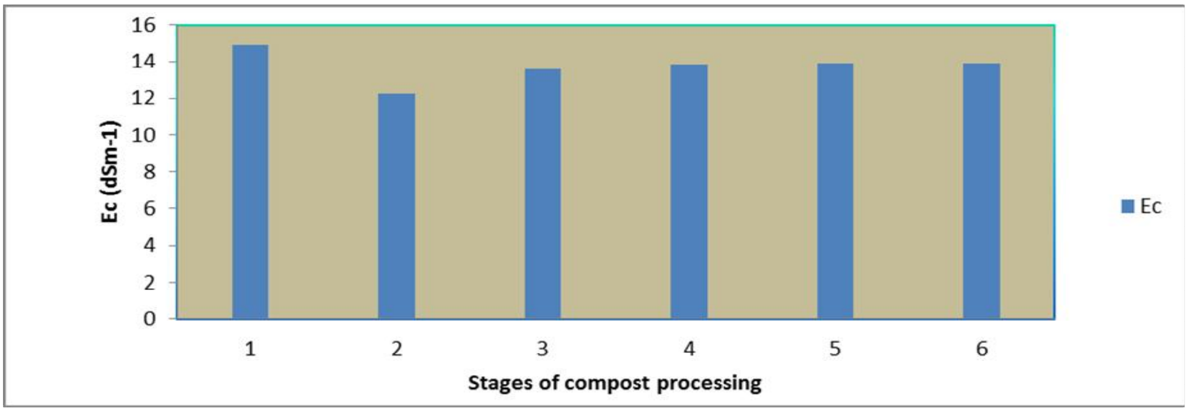

Figure (5b). Electrical conductivity of cow compost during manufacturing (N facility)

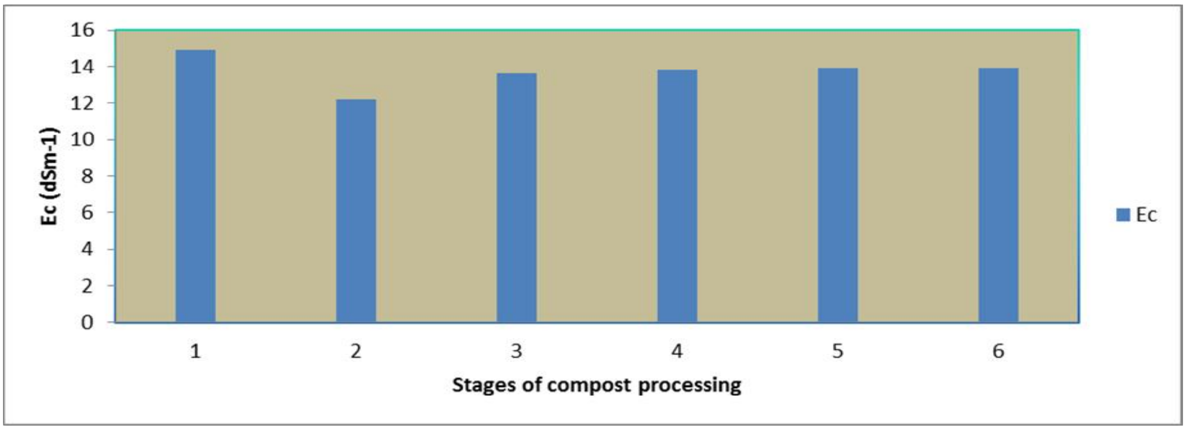

Figure (5c). Electrical conductivity of mixed organic materials compost during manufacturing (Q facility)

pH. Initial pH values of organic materials used for compost production ranged from 6.9 (C facility) to 9.3 (S facility) while final pH values ranged between 7.0 (F facility) to 8.9 (Q facility). Most initial and final pH values of compost tend to be alkaline. Final pH values increased in 15 composts (68%) under the study compared to the initial values. In the early stage of composting processes, pH values deceased below 7 because of organic acid formation. However, in cure stage, microorganisms consume organic acid and ammonium contents increase leading to raising pH values (Simandi *et al*., 2005). No significant differences ($p < 0.05$) were found between means of pH values of all composts. CCQC (2002) and PAS-100 (2005) proposed that pH of composts intended for agricultural application lies between 6 to 8.5. All composts exhibit pH values complying with the proposed range except compost Q which exceeded the upper limit. GCST (2006) requires that pH should not exceed 7.5 which was exceeded by 20 composts (80%). Since most soils in Saudi Arabia are arid with alkaline pH, composts with pH more than 7.5 should not be used for agricultural application.

Table 7. Initial and final pH values of local composts samples

Compost Facility code	Type of raw materials	pH	
		Initial	Final
A		8.1	8.4
B		7.5	8.0
C	Chicken manure	6.9	7.1
D		7.4	7.1
E		7.3	7.7
F		7.6	7.0
G		7.5	7.2
H		7.2	7.4
I		7.2	7.8
Mean		7.4	7.5
ANOVA		NS	NS
J		8.3	8.3
K		7.2	7.3
L		7.0	8.0
M		8.0	8.5
N	Cow manure	8.0	8.4
O		8.3	8.1
P		7.3	7.9
Mean		7.7	8.1
ANOVA		NS	NS
Q		9.2	8.9
R		7.3	8.1
S		9.3	7.9
T		7.7	8.2
U	Mixed organic materials	8.2	8.4
V		7.3	7.7
W		7.5	8.6
X		8.5	8.6
Y		8.6	7.9
Mean		8.2	8.3
ANOVA		NS	NS

Ammonium concentration

As shown in Table (7), initial contents of ammonium in organic materials used for compost production varied from 24 mgkg^{-1} (B facility) to 4199 mgkg^{-1} (G facility), while the final ammonium contents were between 17 mgkg^{-1} (V facility) and 2650 mgkg^{-1} (I facility). Generally, initial and final ammonium contents were the highest in chicken manure followed by cow manure followed by mixed organic materials. It is well documented that chicken manures contain up to 6% N (Hue, 1992). Significant differences ($p < 0.05$) have been shown between means of ammonium contents of all types of composts. CCQC (2002) and PSA- 100 (2005) require that ammonium level should not exceed 500 mg kg^{-1}. Results revealed that 10 composts (40%) contained more than 500 mg kg^{-1} and hence did not meet CCQC or PAS-100 standards. However, in sandy soil ammonium can be easily oxidized to nitrate and may not negatively affect seed germination.

Table 7. Ammonium concentration (NH_4^+) of different compost samples

Compost Facility code	Type of raw materials	NH_4^+ mgkg^{-1}	
		Initial	Final
A		1274	1761
B		24	660
C	Chicken manure	2007	1416
D		1470	523
E		2768	1052
F		1743	1285
G		4199	178
H		978	1913
I		1303	2650
Mean		1752	1271
ANOVA		**	**
J		330	272
K		374	427
L		252	404
M		71	106
N	Cow manure	233	286
O		53	1672
P		228	770
Mean		220	562
ANOVA		**	**
Q		24	90
R		30	330
S		141	135
T		199	314
U	Mixed organic materials	165	118
V		47	17
W		65	94
X		67	146
Y		651	346
Mean		154	312.1
ANOVA		**	**

Table 8. Concentration of nitrate (NO_3^-) in different compost samples

Compost Facility code	Type of raw materials	NO_3^- mg kg^{-1}	
		Initial	Final
A		37	225
B		34	86
C	Chicken manure	119	614
D		284	25
E		343	156
F		1366	2999
G		260	68
H		487	409
I		379	1345
mean		368	659
ANOVA		**	**
J		57	28
K		43	20
L		522	277
M		24	33
N	Cow manure	82	107
O		48	260
P		107	409
mean		126	162
ANOVA		*	*
Q		5	4
R		81	644
S		651	651
T		635	57
U	Mixed organic materials	370	134
V		65	173
W		24	25
X		22	21
Y		341	132
mean		243	291
ANOVA		*	*

Nitrate Concentration

The initial nitrate concentrations in organic materials ranged from 5 mg kg^{-1} (Q facility) to 1366 (F facility), while the final nitrate concentration in the final products ranged from 4 mg kg^{-1} (Q facility) to 2999 (F facility). The final concentration of nitrate was the highest in chicken manure compost with mean of 659 mg kg^{-1} followed by the mixed organic material composts with mean of 291 mg kg^{-1}, followed by cow manure composts with mean of 162 mg kg^{-1} (Table 8). Final contents of nitrate increased compared to the initial content in about 44% of compost facilities indicating the presence of high amount of ammonium susceptible to nitrification and more time was needed to reach to the end of this process (Hue and Liu, 1995). ANOVA tests exhibited significant differences ($p < 0.05$) between means of nitrate contents of all types of composts. Results showed that the concentrations of nitrate were higher than the upper limit set by the CCQC (150 mg kg^{1}) in 44 % of composts under present study. Our results were similar to those reported by Bernal *et al.* (2008) and Wang *et al*. (2004).

Organic Matter

Organic Matter (OM) is the measure of carbon based materials in the compost. The initial percentage of OM in compost samples varied widely from 19.7% (V facility) to 80.4% (A facility), while the final OM percentage were between 19.3 (V facility) to 68.1 (A facility) Table (9).

Table 9. Organic matter (%) of different compost samples

Compost facility code	Type of raw material	OM%	
		Initial	Final
A	Chicken manure	80.4	68.1
B		74.4	33.4
C		45.1	35.3
D		37.1	58.3
E		62.1	55.6
F		64.1	39.8
G		61.8	36.6
H		72.6	36.6
I		41.6	33.4
Mean		59.9	44.1
ANOVA		**	**
J	Cow manure	51.1	28.0
K		44.0	44.3
L		56.7	60.5
M		45.9	44.9
N		30.6	21.1
O		60.8	37.4
P		61.4	38.9
Mean		51.1	39.5
ANOVA		**	**
Q	Mixed organic matter	29.8	24.3
R		46.7	29.9
S		74.7	26.4
T		49.2	26.8
U		41.2	21.3
V		19.7	19.3
W		21.9	24.3
X		23.7	20.7
Y		49.6	30.8
Mean		47.6	38.1
ANOVA		**	**

The chicken manure composts had the higher OM in the final product with mean of 44.1% followed by the cow manure composts with mean of 39.5% followed by composts made from mixed organic materials with mean of 38.1%. The organic matter is known to have an important role in maintaining soil structure, nutrient availability and water holding capacity. Organic matter is decomposed and transformed to stable humic compounds, which had a capacity to interact with metal ions, buffer pH, and to act as a potential source of nutrients for plants. The minimum percentage of OM in composts recommended by CCQC (2002) and PAS-100 (2005) is 25%. As shown, only 7 composts (28%) contained OM less than 25% and did not meet CCQC and PAS-100 standards. GCST (2006) requires that the minimum percentage of OM is 40%. Accordingly, 19 composts (76%) failed to meet these standards. Significant differences ($p < 0.05$) were observed between means of OM of all compost types.

Nitrogen (N), phosphorus (P), and potassium (K) are essential nutrients for microorganisms involved in composting process, and for plants and therefore they influence compost quality. (Diaz *et al*., 1993; Sasaki *et al*., 2005). Almost all organic materials used for composting contained all of these nutrients at various levels. Barker, (1979) reported that the beneficial effects of the composts on plant growth were associated with increased supply of nutrients for the plant.

Total Nitrogen (TN)

Results in Table (10) showed that the initial contents of TN in compost were between 0.4% (X facility) and 5.8% (A facility), while the final contents of TN were between 1.0 (X facility) and 4.1 (A facility). We observed an increase in nitrogen level during maturation phase (data not shown) which could be possibly due to concentration effect caused by strong degradation of labile organic carbon compounds which reduces the weight of composting materials (Bermal *et al*., 1998). The increase in total nitrogen during composting is also caused by the decrease of carbon substrate resulting from the loss of CO_2 (because of the decomposition of the organic matter which is chemically bound with nitrogen). The chicken manure composts had the highest level in nitrogen content followed by mixed organic materials and then cow manure composts for both initial and final TN contents.

Total Phosphorus (TP)

The initial levels of TP were between 0.16 % (S facility) and 0.53 % (A facility), while the final total phosphorus contents were between 0.10 % (E facility) and 0.83 % (Q facility). Generally, chicken manure composts had the highest level in phosphorus contents with mean of 0.33 % and 0.39 % for the initial and final phosphorus contents respectively, followed by cow manure composts with the mean of 0.24 % and 0.38 % for the initial and final phosphorus contents respectively, while the mixed organic materials had the lowest phosphorus content with mean of 0.24 % and 0.32 % for the initial and final phosphorus contents.

Total Potassium content (TK)

The initial total potassium contents varied from 0.32 % (M facility) to 2.71 % (I facility), while the final total potassium contents varied from 0.60 % (N facility) to 2.52 % (G facility) Table (10). The chicken manure composts had the highest potassium contents followed by cow manure compost, while the compost made from organic mixed materials had the lowest potassium contents with the mean of 1.62 %, 1.39 % and 1.2 % respectively for the initial contents and 1.89 %, 1.41% and 1.3 % respectively for the final contents of potassium.

Table 10. Total Nitrogen (TN), Total Phosphorus (TP) and Total Potassium (TK) contents in different compost samples

Compost Facility code	Type of raw materials	TN%		TP %		TK %	
		Initial	Final	Initial	Final	Initial	Final
A		5.81	4.1	0.53	0.61	1.34	1.34
B		2.95	1.43	0.25	0.36	0.80	1.99
C	Chicken	2.42	2.39	0.46	0.39	1.90	1.69
D	manure	3.67	3.14	0.25	0.53	1.16	1.14
E		5.13	3.94	0.26	0.10	1.60	2.32
F		3.83	3.15	0.52	0.50	2.13	1.63
G		3.02	2.07	0.25	0.31	1.77	2.52
H		3.03	2.52	0.25	0.37	1.15	2.33
I		3.44	2.77	0.20	0.35	2.71	2.03
mean		3.70	2.83	0.33	0.39	1.62	1.89
J		1.80	1.29	0.18	0.62	1.76	1.48
K		1.3	1.62	0.26	0.31	1.70	1.02
L		1.69	1.67	0.40	0.41	1.13	1.73
M		1.08	0.66	0.16	0.24	0.32	0.86
N	Cow	0.44	0.64	0.22	0.30	1.00	0.60
O	manure	3.00	2.12	0.24	0.28	1.97	2.26
P		3.08	2.42	0.27	0.47	1.88	1.92
mean		1.77	1.49	0.24	0.38	1.39	1.41
Q		1.16	1.04	0.36	0.83	1.46	1.25
R		1.03	1.71	0.34	0.59	0.62	1.13
S		0.93	1.64	0.16	0.18	0.91	0.93
T		1.69	1.31	0.13	0.34	0.83	1.07
U	Mixed	1.49	1.36	0.38	0.42	2.19	1.72
V	organic	0.50	1.05	0.24	0.19	0.87	0.99
W	materials	1.03	1.01	0.29	0.44	0.91	1.33
X		0.43	1.00	0.48	0.42	1.03	1.61
Y		2.58	1.89	0.29	0.43	2.15	1.67
mean		2.55	2.63	0.24	0.32	1.2	1.3

Carbon

Nitrogen ratio (C/N ratio) is a key indicator of decomposition rate of organic materials used for compost production (Brinton, 2000). Several studies showed a decrease in C/N ratio during composting process to the range of 20:1 to 11:1 in the final products (Brewer and Sullivan, 2003; Ko *et al*, 2008). If the final compost product is intended for agricultural application, C/N ratio must be considered for compost evaluation. As shown in Table 10, initial C/N values ranged from 8 (R facility) to 52 (H facility), while final C/N ratio values ranged from 7 (S facility) to 28 (T facility). C/N ratio values decreased in about 68% of the final products. According to CCQC, 2002, PAS-100 (2005), and GCST (2006) the maximum limit accepted for C/N ratio of the final product of composts is 20. All C/N ratio values are less than 20 except that for I and T facilities.

Nitrification Index (NI) is another proposed indicator for maturity degree of compost (CCQC, 2002). NI is the ratio of nitrate content to ammonium content in final products of composts. Initial NI of organic materials under investigation ranged from 0.24 (S facility) to 34.39 (A facility), while final IN ranged from 0.2 (S facility) to 21.47 (K facility) (Table 11). All NI values of chicken manure decreased in the final products showing favorable conditions for nitrification. However, NI values of cow manure and mixed organic materials increased in about 40% of final composts probably due to the presence of organic material susceptible to more decomposition in particular J, K, W, X, and V facilities. CCQC (2002) suggested that NI should not exceed 3 for mature compost. NI of 13 composts (52%) was above 3 and they are considered immature composts.

Table 10. The initial and final C/N ratio of different compost samples

Compost Facility code	Type of raw materials	C/N ratio	
		Initial	Final
A		9	11
B		15	14
C	Chicken	11	10
D	manure	10	11
E		8	9
F		9	7
G		12	11
H		14	10
I		9	9
mean		10.7	10.2
J		15	17
K		18	13
L		21	22
M		23	19
N	Cow manure	40	28
O		12	10
P		11	11
mean		20.1	17.1
Q		16	13
R		23	12
S		52	10
T		19	12
U	Mixed organic	15	11
V	materials	29	12
W		14	17
X		34	12
Y		11	9
mean		23.7	12.0

Table 11. The initial and final nitrification index of different compost samples locally produced in Saudi Arabia

Compost Facility code	Type of raw materials	Nitrification Index (NI)	
		Initial	Final
A		34.39	8.69
B	Chicken	7.71	0.71
C	manure	19.15	2.41
D		21.7	5.34
E		8.17	6.84
F		1.32	0.97
G		4.81	2.79
H		9.43	4.99
I		3.78	0.41
mean		27.12	3.68
J		6.30	10.44
K		8.77	21.47
L		0.48	1.73
M		3.09	3.76
N	Cow manure	2.86	2.68
O		1.12	6.52
P		21.59	6.51
mean		6.32	7.59
Q		8.02	0.22
R		0.37	0.53
S		0.24	0.20
T		0.33	5.66
U	Mixed organic	0.45	0.90
V	materials	0.74	0.32
W		2.74	5.03
X		3.03	6.88
Y		1.93	3.15
mean		1.98	2.54

Heavy metals

Initial and final concentrations of heavy metals including Fe, Zn, Mn, , Cu, Ni, Pb and Cd in composts under investigation are presented in Tables 11, 12, and 13. Large variations were observed between concentrations of all investigated heavy metals. Some heavy metals such as Fe, Zn, Mn, Cu and Ni are essential micronutrients for plants and microorganisms, whereas Pb and Cd are not required for living system.

Table 11. Initial and final concentration of Zn, Mn and Fe in different compost samples

Compost Facility code	Type of raw materials	Fe mgkg^{-1}		Zn mgkg^{-1}		Mn mgkg^{-1}	
		Initial	Final	Initial	Final	Initial	Final
A		1580	1641	258	323	310	273
B		1510	1410	226	332	146	272
C		1573	1486	387	238	363	327
D	Chicken	1446	1176	190	116	177	145
E	Manure	1048	1158	263	132	205	226
F		1708	1494	321	303	310	312
G		1120	1387	235	215	274	245
H		1184	1304	182	281	163	349
I		1209	1008	329	318	349	334
mean		1375	1340	266	251	255	276
J	Cow	1962	1762	311	226	273	418
K	manure	1730	1638	292	312	242	307
L		1643	1455	221	205	250	239
M		1292	4803	151	176	194	191
N		1356	1305	139	144	185	184
O		1111	1124	178	273	185	173
P		1327	1304	243	300	242	323
mean		1489	1913	219	234	224	262
Q		1858	1488	183	152	279	213
R		1508	1423	174	298	226	318
S		1544	1530	453	158	143	199
T	Mixed	1644	1585	156	206	218	264
U	organic	1588	1401	197	149	238	196
V	materials	1309	1421	153	131	120	171
W		1389	1197	126	139	147	148
X		1173	1270	129	188	149	216
Y		1911	2484	178	205	325	439
mean		1547	1533	194	180	205	240

Table 12. Initial and final concentration of Cd and Cu in different compost samples

Compost Facility code	Type of raw materials	Cu mgkg-1		Ni mgkg^{-1}	
		Initial	Final	Initial	Final
A		51.83	55.07	26.13	31.17
B		50.93	64.30	45.80	50.17
C		70.27	72.33	38.97	62.8
D		38.60	43.43	25.50	20.33
E	Chicken	17.43	45.97	21.53	15.90
F	manure	75.17	61.97	36.17	27.90
G		47.03	79.10	12.2	36.33
H		69.00	74.70	19.80	42.97
I		86.60	66.33	25.67	22.1
mean		56.32	62.58	27.98	34.4
J		85.47	45.87	38.83	28.69
K		72.23	55.67	35.77	35.10
L		54.93	60.27	19.53	33.07
M	Cow	53.53	49.10	20.63	16.93
N	manure	34.30	19.20	15.04	18.43
O		75.83	71.60	19.07	24
P		69.57	70.23	23.43	23
mean		63.69	53.13	24.61	25.6
Q		60.83	43.67	44.57	42.57
R		55.40	77.07	42.03	51.40
S		24.27	17.63	33.67	47.10
T	Mixed	55.97	55.70	25.20	27.80
U	organic	45.50	57.33	29.20	41.77
V	materials	23.30	32.73	31.10	43.57
W		49.13	28.87	23.27	23.80
X		26.87	52.50	21.47	19.89
Y		46.80	45.00	38.10	43.57
mean		43.1	45.6	32.1	37.9

Table 13. Initial and final concentration of Pb and Ni in different compost samples

Compost Facility code	Type of raw materials	Pb mgkg^{-1}		Cd mgkg^{-1}	
		Initial	Final	Initial	Final
A		28.33	28.40	3.9	4.7
B		22.53	20.33	5.7	5.3
C	Chicken	32.90	26.80	4.4	4.0
D	manure	16.23	10.46	3.2	4.3
E		18.79	13.87	2.39	2.6
F		26.57	19.23	4.95	2.7
G		15.50	20.07	2.63	3.9
H		12.97	15.37	1.94	4.1
I		18.90	16.93	0.49	2.9
mean		21.41	19.05	3.30	3.8
J		32.53	21.40	2.99	4.0
K		28.60	21.20	4.05	5.7
L		29.43	28.13	4.35	3.5
M		25.17	21.23	2.95	2.61
N	Cow manure	11.2	7.8	2.16	3.27
O		13.87	17.27	2.98	3.75
P		21.93	16.57	1.89	3.87
mean		23.24	19.08	3.05	3.82
Q		35.80	26.67	4.03	4.24
R		38.5	31.6	3.10	4.25
S		21.27	25.03	3.44	5.01
T		28.13	26.40	3.51	4.23
U	Mixed	21.67	28.50	4.33	4.03
V	organic	21.23	29.67	6.00	5.37
W	materials	15.44	13.53	5.04	2.71
X		16.37	12.32	2.23	0.83
Y		20.50	23.80	1.40	0.83
mean		24.3	24.2	3.7	3.5

However, all heavy metals are toxic when their concentrations exceeded certain limits. The maximum permissible values for heavy metals in composts set by CCQC (2002), PAS-100 (2005) and GCST (2006) are 350, 150, 25, 120, and 3 mgkg^{-1} for Zn, Cu, Ni, Pb and Cd respectively. None of nation compost standards have specified upper limit for Fe or Mn. With exception of Ni and Cd, heavy metal contents in the final products of composts were below the upper limit set by CCQC and GCST. Concentrations of Ni exceeded the allowable limit (25 mg kg^{-1}) in 65% of the types of compost, and concentration of Cd exceeded allowable limit (3 mg kg^{-1}) in 79% of the types of compost.

Table 14. ANOVA analyses of means of chemical characteristics of composts

Compost facility code	EC	pH	NH4	NO3	OM
A	**	NS	**	**	**
B	**	NS	**	**	*
C	**	NS	**	*	**
D	**	NS	**	**	**
E	**	NS	*	**	**
F	**	NS	**	**	**
G	**	NS	**	**	*
H	**	NS	**	*	*
I	**	NS	*	**	*
J	**	NS	**	**	**
K	**	NS	**	*	**
L	*	NS	**	**	**
M	**	NS	**	**	**
N	**	NS	**	**	**
O	**	NS	**	**	**
P	**	NS	**	**	**
Q	**	NS	**	**	**
R	**	NS	**	**	**
S	*	NS	**	**	**
T	**	NS	**	**	**
U	*	NS	**	**	**
V	**	NS	**	*	**
W	**	NS	*	**	*
X	**	NS	**	**	**
Y	*	NS	**	**	*

Variability between compost production rotations

Compost samples were collected from three successive rotations in all examined compost facilities. Results revealed large variations between chemical properties of composts produced from the same facility in three successive rotations. ANOVA tests confirmed significant differences ($p < 0.05$) between means of EC, NH_4, NO_3 and OM of compost samples taken from the same facility during three rotations (Table 14). These finding indicated that local compost facilities are unable to produce composts with consistence chemical properties, probably due to the source of organic material and the lack of fixed system of compost production in each facility.

Conclusion

Analyses of twenty five types of composts produced in Saudi Arabia revealed broad variations between examined chemical characteristics of all types of composts. Most composts, in particular those processed from chicken and cow manure, exhibited high values of EC which may inhibit seed germination and affect plant growth. It is of importance to explore methods for reducing level of EC to comply with CCQC standards. Organic matter, ammonium, nitrate, and nitrification index revealed also that more than 50% of local composts did not comply with international standards and they are considered immature products. Level of Cd and Ni exceeded the permissible limit in 65% and 79% of composts respectively, indicating the possibility of contaminating soil and plant upon agricultural application. Present results confirmed the need for establishing comprehensive standards and regulations in order to assure composts quality produced for agricultural application.

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