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RESEARCH ARTICLE

PHYSICAL CHARACTERISTICS OF LOCALLY COMPOSTS PRODUCED IN SAUDI ARABIA AND THE NEED FOR REGULATIONS

***Ahmad I. Al-Turki, Fahd Al-Romian and Yasser El-Hadidi**

Promising Research Center in Biological Control and Agricultural Information, Qassim University, Saudi Arabia Kingdom

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ABSTRACT

Composting is the suitable way of recycling organic waste for agricultural application and environment protection. In Saudi Arabia, several composting facilities are available and producing high quantity of composts. The aim of this study is to evaluate the physical characteristics of composts manufactured in Saudi Arabia and acquire a comprehensive image of its quality through the comparative with international standards of compost quality such as CCQC and PAS-100. In the present study different locally produced compost were identified and most of the producing factories were visited during the manufacturing of composts. Representative samples of different compost production stage were collected and Physical characteristics were determined, which included moisture content, bulk density, percentage of sand and the size of distribution of the compost particles. Results showed wide variations in all parameters investigated. Results of the study indicated generally that there is a wide variation in the physical characteristics of the types of compost under study. The initial moister contents in composts were generally low, it was less than 60% in most samples and not sufficient for microbial activities for biodegradation in 96% of the 96% of the types of compost and this will impede the decomposition of organic materials. The initial bulk density values ranged from 117 gL^{-1} to 1110.0 gL^{-1}, while the final apparent bulk density ranged from 340.0 gL^{-1} to 1000gL^{-1} and about 45.4 % did not meet the ideal bulk density value. Sand percents in composts were between 3.3 % and 12.5%. This study has confirmed the need for a standard specification for compost manufactured in Saudi Arabia for agricultural use based on international standards for compost and soil characteristics and climatic conditions in Saudi Arabia.

INTRODUCTION

Composting is an excellent example of the practical use of biotechnology for decomposition of wastes such as chicken, cow manure and plant residues for production of matured and stabilized organic matter that is suitable for agriculture, but this process should be suspiciously monitored with appropriate properties. It involves a high complex biological process, involving many species of microorganisms, which converts a law value material into a higher value product. Organic wastes are natural, locally available and relatively cheap material that has been used for plant production. Compost is often produced in areas where it is needed for pastures and crop fertilization. The increased size and frequent clean out of many poultry operations make poultry manure available in sufficient quantities and on timely basis to supply most fertilizer needs. Mature compost improves soil physical, chemical properties and enhances plant growth and production. The composting process offers the potential to significantly reduce environmental problems associated with manure management (Carr *et al*., 1995). Unfortunately, the cost of composting relative of raw manures can be considerably higher (Ryunk, 1992). Therefore, compost of high quality must be produced consistently to offset these production costs. The terms stability and maturity are usually used interchangeably to describe the degree of decomposition and transformation of the organic matter into compost (Zmora Nahum *et al*., 2005), despite the fact they describe different properties of the composting substrate. Stability is strongly related to the rate of microbial activity in compost, and is evaluated by different respirometric measurements (Lasaridi and Stentiford, 1998) and/or by studying the transformations in the chemical characteristics of compost organic matter (Pichler and Ko-gel-Knabner, 2000). Respirometric tests have been shown to be adequate for assessing compost stability because they are able to measure the extent of which readily biodegradable organic matter has decomposed during the composting process (Adani *et al*., 2004). We believe that no technique or method can be successfully used alone for the assessment of compost quality, this is because using of one parameter or one method is not able to describe a complex matrix such as compost. On the other hand the integration use of different parameters, i.e. physical, chemical and biological parameters, surely gives a

****Corresponding author: Ahmad I. Al-Turki***
Promising Research Center in Biological Control and Agricultural Information, Qassim University, Saudi Arabia kingdom

more complete image of what compost is (Mondini *et al*., 2004). Different methods are proposed for determining compost maturity. These can be broadly categorized into different groups as: physical (moisture content, bulk density, percentage of sand and the particles size distribution), chemical (Electrical conductivity (EC), pH, the ratio of carbon to nitrogen (C/N ratio), the concentration of nitrate and ammonium, the percentage of organic matter (OM) and the concentration of heavy metals) and biological (respiration analysis, plant bioassay germination test and the presence of microbial contamination and pathogens) (Zmora-Nahum and Markovitch, 2005; Mondini *et al*., 2006; Aslam *et al*., 2008; Ko, Kim *et al*., 2008; Ofosu-Budu and Hogarh, 2010). Compost production in Saudi Arabia has been considered for many years. The quality of compost is important from maturity and stability viewpoint, but in most compost factories appropriate attention is not paid to it. In Saudi Arabia, compost factories are recently widely spread. Most of these factories do not comply with the specifications of quality compost and therefore may produce low quality compost that is harmful to the soil, plants and the environment. This study is one part of a group of research concerned with the study of physical quality of the locally produced compost in factories in the kingdom and in some organic farms and comparing it with the local and international standards of compost quality such as CCQC (2002) and PAS100-2005.

MATERIALS AND METHODS

Preparation of compost samples

Different commercial compost samples produced in Saudi Arabia were obtained during summer of 2011 from the factories in bags of 20-50L. They were identified, registered and a code system was used instead of brand names to ensure confidentiality (Table 1). Composts were immediately brought to the laboratory of soil analysis at college of Agriculture and Veterinary Medicine, Qassim University. Each compost bag was mixed thoroughly to insure maximum homogeneity and the samples were randomly taken. Each sample was divided into four parts; one of these parts was immediately frozen and used for ammonium nitrogen analysis, while the other parts were kept in labeled PVC bottles at room temperature for physical and chemical analysis.

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

Kind of compost	Compost code
Chicken manure	B, E, F, Q, R, S, V2, V3 and W
Cow manure	C, D, I, P, T, U and V1
Mixed manure (Chicken +cow manure)	A, G, H, J, K, L, M, N and O

Physical properties of composts

Moisture content

Moisture content in compost sample was determined as described by TMECC, 2001 method 03.09-A. Approximately 250g per sample was dried at 80°C ± 5°C for 24h to a constant weight. The percent moisture was calculated as the mass loss due to evaporation (g/g) divided by wet weight. Particle size distribution (%) was determined using dried compost samples according to Warp, 2004.

Bulk density (g/L)

Bulk density of compost samples were determined according to the method TMECC (2001) method 03.01 A using the mass per unit volume technique.

Water holding capacity (%)

The water holding capacity of compost samples were determined according to the method TMECC (2001) method 03. 10 A. Treatments were replicated three times.

Particle size distribution (%)

Particle size distribution was measured according to Warp (2004). Treatments were replicated three times. Different sizes of sieves were used depended on the particle size of the compost tested. If the compost sample appeared to be very fine, smaller sieve sizes were used and if the compost sample appeared to be shaved into large particles, large sieves were used.

Sand %

The sand % of the compost sample was determined according to the laboratory methods of soil analysis (2006).

RESULTS AND DISCUSSION

Moisture content

Initial moisture content varied from 2.1% (V2 facility) to 98.1% (R facility), while final moisture content were between 3.0% (N Facility) to 36.7% (factory S) (Table 2a, b and c). Initial moisture contents were generally less than 60% in 96% of produced composts which might impede the microbial decomposition of organic materials. It has been reported that initial moisture content should be between 60 to 70% for

Table (2a): Initial and final moisture contents (%) of the chicken compost samples

Compost Facility code	Type of raw materials	Moisture contents (%)	
		Initial	Final
B		29.0	9.4
E		12.1	8.2
F	Chicken manure	27.7	13.6
Q		5.9	4.8
R		98.1	20.7
S		36.6	36.7
V2		21.1	12.5
V3		21.3	11.4
W		13.7	9.4
mean		25.3	14.1

Table (2b): Initial and final moisture contents (%) of the cow compost samples

Compost Facility code	Type of raw materials	Moisture contents (%)	
		Initial	Final
C		29.5	19.9
D		5.3	8.0
I	Cow manure	36.7	9.8
P		18.4	13.5
T		3.5	11.0
U		5.5	27.0
V1		2.5	15.70
mean		14.5	15.0

Table (2c): Initial and final moisture contents (%) of the mixed compost samples

Compost Facility code	Type of raw materials	Moisture contents (%)	
		Initial	Final
A		22.3	22.5
G		2.9	10.0
H	Mixed organic materials	5.8	16.3
J		91.7	43.3
K		17.9	24.2
L		6.4	10.1
M		46.5	17.9
N		4.9	3.0
O		53.9	18.9
mean		18.9	17.4

optimum microbial activities in organic material decompositions. Proper moisture content in the compost can encourage the microorganisms' activity and increase the rate of decomposition (Keener *et al*., 2000). Microorganisms cannot survive if there is not enough moisture in the compost; the degradation slows when the moisture content decreases to 40% or less (Morse, 2001). In contrast, too much moisture can inhibit microbial activity by reducing the free pore space in the compost mixture, slowing, or even inhibiting, the flow of oxygen (Liang *et al*., 2003; Parkinson *et al*., 2004). High moisture content in compost will be confusing or misleading for consumers, especially when materials are marketed on weight basis (Schulze, 1961; Hussain *et al*., 2011). Compost which is too dry like compost N and Q factories can be dusty and irritating to work with wile compost like compost J factory which is excessively wet can heavy and difficult to uniformly apply. In our study, moisture contents in the final compost products were less than the proposed limit (25%) in 80% of the produced composts in California (CCQC, 2002) and PAS100-2005.

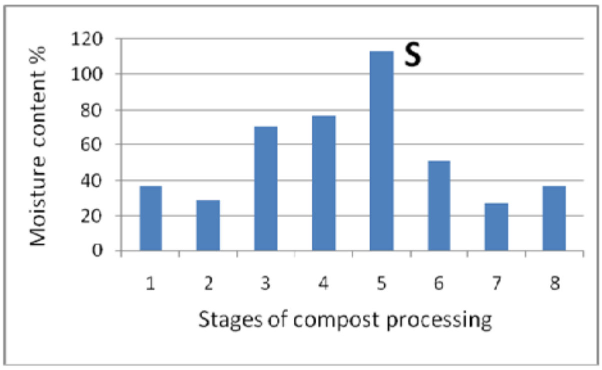


Figure (1a): Moisture content of chicken compost (Factory S)

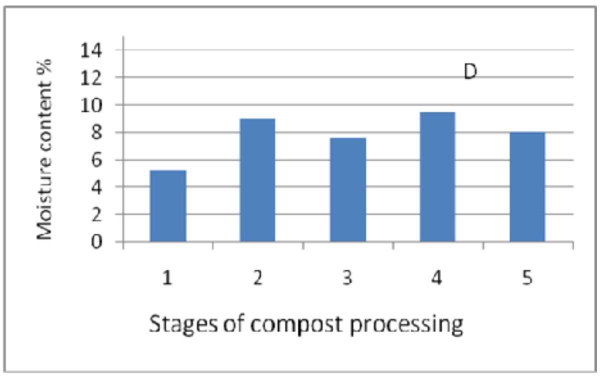


Figure (1b): Moisture content of cow compost (Factory D)

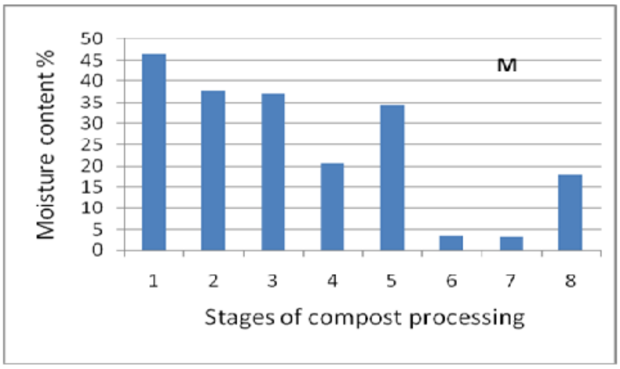


Figure (1c): Moisture content of mixed compost (Factory M)

During manufacturing composts, moisture contents exhibited a large fluctuation in most facilities either within a single manufacturing cycle or between different manufacturing cycles (Figure 1 a, b and c), this fluctuation was attributed to the lack of a fixed moisturizing system in these facilities.

Sand percent

We observed a high sand percent in organic material used for the manufacture of compost in some facilities. Initial sand percents ranged from 1.9% (in U facility) to 81.7% (in T facility), while sand percents in the final compost products were between 2.1% and 63.6% (Table 3a, b and c).

Table (3a): Sand percent (%) of chicken compost samples

Compost Facility code	Type of raw materials	Sand percent %	
		Initial	Final
B		5.0	2.5
E		12.0	2.1
F		11.8	6.2
Q		29.0	16.7
R	Chicken manure	2.6	4.4
S		3.9	2.9
V2		6.9	7.7
V3		7.3	5.4
W		7.1	3.7
mean		9.5	5.7

Table (3b): Sand percent (%) of cow compost samples

Compost Facility code	Type of raw materials	Sand percent %	
		Initial	Final
C		12.5	17.8
D		6.9	9.3
I		4.4	18.8
P		45.1	44.9
T	Cow manure	81.7	59.3
U		1.9	3.2
V1		11.0	8.2
mean		23.4	23.7

Table (3c): Sand percent (%) of mixed compost samples

Compost Facility code	Type of raw materials	Sand percent %	
		Initial	Final
A		40.1	18.1
G		2.8	15.0
H	Mixed organic materials	4.0	66.2
J		36.0	16.8
K		29.4	46.3
L		2.9	63.6
M		20.5	53.3
N		38.6	68.5
O		17.2	28.4
mean		21.3	41.8

The results showed that there was a large fluctuation in the sand percentage in the most factories during manufacturing, both within a single manufacturing cycle or between different manufacturing cycles Figure (2a, b and c). The initial sand percent in organic raw materials exceeded 20% in eight factories, these factories are Q factory (use chicken manure); P,T (use cow manure); A,J, K, M, and N (use mixed organic materials). Results showed that the sand percent decreased in final product, compared with the initial sand percent in only twelve factories (48%); seven of them used chicken manure, three used cow manure and two used mixed organic material. I contrast, the percentage of sand has increased in the final product in 52% of the types of compost under study, compared with the initial percent, which indicates that the source of increased sand in compost was inside the factory, either during flipping and use cranes, or added intentionally to this ratio of sand to tackle a problem or increasing production.

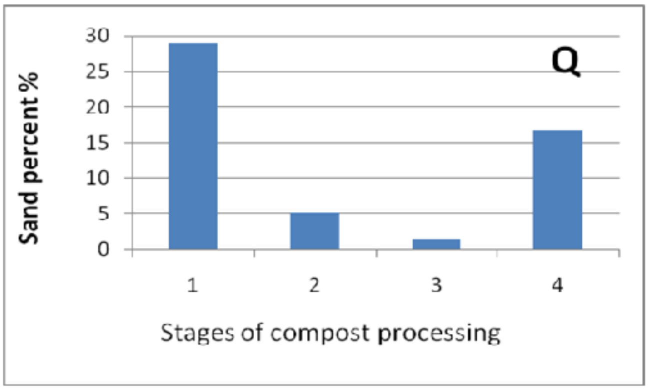


Figure (2a): Percentage of sand % in chicken compost (factory Q)

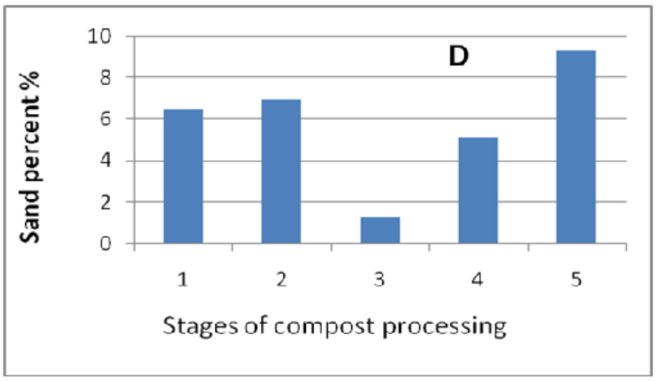


Figure (2b): Percentage of sand % in cow compost (factory D)

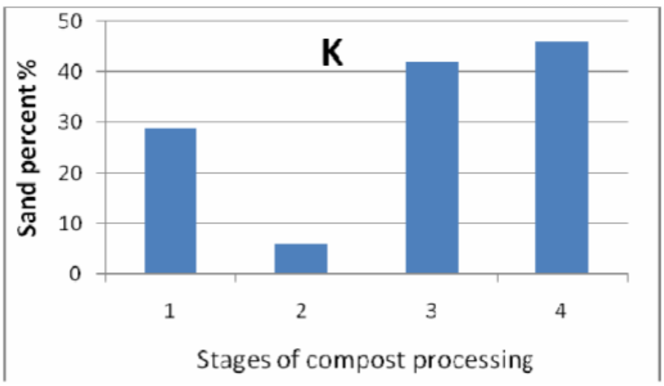


Figure (2c): Percentage of sand % in cow compost (factory K)

Bulk density

The initial apparent bulk density values of organic matters used in the manufacturing of compost ranged from 117gL^{-1} (in H factory) to 1110.0 gL^{-1} (in T factory), while the final apparent bulk density ranged from 340.0 gL^{-1} (in U factory) to 1000gL^{-1} (in P factory) Table (4a, b and c).

Table (4a): Bulk density of chicken compost samples

Compost Facility code	Type of raw materials	Bulk density gL-1		
		Initial	Final	Change in bulk density
B		510.0	404.3	-105.7
E		713.7	596.7	-117
F	Chicken Manure	565.3	583.3	18
Q		655.0	510.0	-145
R		370.0	620.0	250
S		760.0	391.7	-368.3
V2		758.3	426.7	-331.6
V3		548.3	530.0	-18.3
W		650.0	526.7	-123.3
mean		614.5	510.0	-

Table (4b): Bulk density of cow compost samples

Compost Facility code	Type of raw materials	Bulk density gL-1		
		Initial	Final	Change in bulk density
C		566.7	625.3	58.6
D		666.3	859.0	192.7
I		419.7	447.3	27.6
P		645.0	1000.0	355
T	Cow manure	1110.0	810.0	-300
U		271.7	340.0	68.3
V1		638.3	566.7	-71.6
mean		616.81	664.04	-

Table (4c): Bulk density of mixed organic materials compost samples

Compost Facility code	Type of raw materials	Bulk density gL-1		
		Initial	Final	Change in bulk density
A		523.3	404.7	-118.6
G		123.0	410.0	287
H		117.0	830.0	713
J		480.0	510.7	30.7
K	Mixed organic materials	524.3	546.7	22.4
L		174.0	973.3	799.3
M		313.3	616.7	303.4
N		508.3	800.0	291.7
O		476.7	780.0	303.3
mean		360.0	652.5	-

Bulk density is the weight per unit volume of compost and it used to determine the volume of compost which may be transported on a given occasion. It was found that the apparent bulk density was affected by the ratio of sand in the compost. About 59% of the compost types under study registered higher or lower values of the apparent density compared with the value suggested by CCQC. Although the saturation capacity of the final product of the compost ranged from 62.9 to 259.3%, but the available water for the plant was less than that and ranged from 2.3% to 25.2%. The particle densities of the compost materials, particularly the chicken compost, appear to be low, especially at the higher moisture contents. In the material with higher moisture contents, small pockets of air may have been surrounded by moisture, and the pressurized air may not have penetrated these trapped spaces, resulting in a low microbial development and a subsequently low particle density value. The remaining particle densities correspond with published values (Agnew and Leonard 2003). The control of parameters such as bulk density have determined to be key for composting optimization since it determine the optimal conditions for microbial development and organic matter degradation (Rhichard *et al*., 2002; Agnew and Leonard, 2003; Liang *et al*., 2003). Compost contains a wide variety of materials such as mixed organic materials compost which vary substantially in particle size. Compost particle size distribution will affect the porosity of the media to which it is added. Particle size distribution is an important factor influencing the bedding moisture content, compaction and bulk density. Bulk density decreases with increase in particle size. As the particle size becomes larger, the gap between the particles increased keeping more unoccupied space. The fine particles less than 1mm in diameter were decreased in the compost which produced from chicken manure, while the main particle size distribution is greater than 4mm (factories B, E, F, Q, R, S, V2, V3 and W). In F, Q, R and W composts the particle size distribution arranged from 4- 8mm in diameter (Table 5a, b and c).

Table 5(a): Particle size distribution of chicken manure compost

Compost Facility Code	Raw material	% of particle size distribution				
		<1mm	2-1 mm	4-2 mm	8-4 mm	>8 mm
B	Chicken manure	22.2	13.2	14.3	25.1	25.2
E		27.2	7.4	11.8	18.0	35.6
F		20.9	10.1	6.5	45.6	16.7
Q		20.2	16.3	28.5	18.2	16.8
R		19.4	21.4	22.7	22.9	13.5
S		11.1	11.4	16.2	19.9	41.8
V2		17.3	15.5	31.6	3.8	31.8
V3		20.6	19.04	21.0	7.4	32.2
W		21.3	19.4	28.00	24.4	6.9
mean		20.0	14.9	20.1	20.6	24.5

Table 5(b): Particle size distribution of cow manure compost

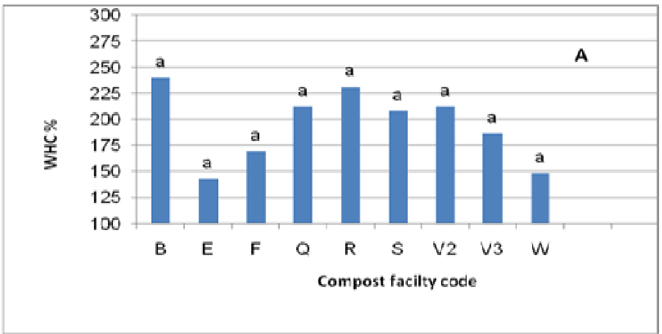
Compost Facility Code	Raw material	% of particle size distribution				
		<1mm	2-1 mm	4-2 mm	8-4 mm	>8 mm
C	Cow manure	35.0	14.0	14.3	19.9	15.2
D		48.9	7.5	9.3	14.5	19.8
I		41.9	13.9	18.6	17.5	8.0
P		31.8	14.3	18.5	9.5	25.4
T		53.8	13.1	16.7	7.7	8.8
U		34.1	18.2	25.5	9.5	12.7
V1		34.4	23.9	22.9	8.8	9.5
mean		40.0	14.9	17.9	12.5	14.2

Table 5(c): Particle size distribution of mixed organic materials manure compost

Compost Facility Code	Raw material	% of particle size distribution				
		<1mm	2-1 mm	4-2 mm	8-4 mm	>8 mm
A	Mixed organic materials	47.4	24.4	8.2	12.9	7.0
G		15.1	11.8	12.7	50.8	9.6
H		38.9	12.9	12.3	27.8	8.7
J		45.9	12.2	11.6	18.5	11.6
K		57.8	11.3	10.5	11.2	11.9
L		33.0	10.2	12.6	16.9	27.2
M		41.4	15.4	18.8	9.2	15.2
N		23.9	14.4	36.4	12.2	13.1
O		28.8	18.3	22.2	10.4	20.
mean		36.9	14.6	16.1	18.8	13.8

Particle size distribution of the compost is an important parameter that influences the water holding capacity, rate of microbial activity and aeration within the pack. The fine particles improve handling, mixing, aeration and composting (Janni and Jeff Reneau, 2005), while larger particle sizes increase gas exchange and surface drying. Water holding capacity of the compost increased with the decreasing particle size. Water holding capacity provides information on the amount of water that can be absorbed by the compost material. High water holding capacity allows the compost to absorb water into the mixture (Chang *et al*., 1983; McCoy, 1992). Water holding capacity varied from 62.9 % (T factory) to 259.3 % (V1 factory). The wide variations in water holding capacity in compost are usually attributed to quantity % of sand. Compost with high sand content 60% or more e.g., H, L, N and T had lower water hold capacity to 100,6%, 93.1%, 62.9% and 84.2% respectively, while compost with low sand content 6.2% or less e.g., B, F, R, S, U and V1 had high water hold capacity 169%, 240.2%, 230.9%, 208.1%, 225.8% and 295.3%.

(Figure 3a,b and c) showed the water holding capacity of the different kind of composts produced from chicken manure (A), produced from cow manure (B) and produced from mixed manure (C).



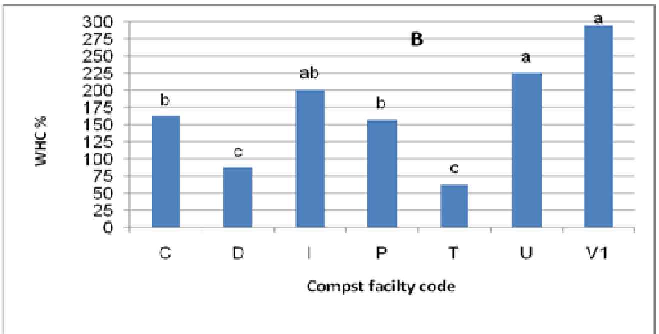


Figure (3): Water holding capacity of different kind of compost: (A) Chicken manure compost, (B) Cow manure compost, and (c) mixed manure

Conclusion

This study has confirmed the need for a standard specification for compost manufactured in the Kingdom for agricultural use based on international standards for compost and soil characteristics and climatic conditions in the kingdom. Comprehensive standard specification has been proposed in this study for the most important characteristics of compost that can evaluate the quality, maturity and suitability for agricultural use. These specifications included the physical, chemical and biological characteristics of compost. A laboratory method that must be followed to measure these specifications was also mentioned. The study also concluded a number of recommendations and suggestions that would develop and improve the production of compost in the Kingdom.

REFERENCES

Adani, F., Confalonieri, R. and Tambone, F., 2004a. Dynamic Respiration Index as descriptor of the biological stability of organic wastes. *Journal of Environmental Quality* 33, 1866–1876.

Agnew, J.M. and J.J. Leonard. 2003. The physical properties of compost. Compost Science and Utilization. 11(3): 238-264.

Aslam, Danielle, N., Horwath, William Vander Gheynst and Jean S. 2008. “Comparison of several maturity indicators for estimating phytotoxicity in compost-amended soil.” *Waste Management* 28 (11): 2070-2076.

Carr, L., Grover, R., Smith, B., Richard, T. and Halbach, T. 1995. Commercial and on-farm production and marketing of animal waste compost products. In: Steele, K. (Ed.), Animal Waste and the Land-Water Interface. Lewis Publishers, *Boca Raton*, pp. 485–492.

CCQC (California Compost Quality Council Compost Maturity Index) (2002). Technical Report. WWW.ccqc.org

Chang, A.C., Page, A.L. and Warneke, J.E. 1983. Soil conditioning effects of municipal sludge compost. *J. Envi. Eng*., 109:574–583.

http:// www.mda.state.mn.us/composting/default.htm

Hussain, N., G. Hassan, M. Arsh adullah and F. Mujeeb. 2001. Evaluation of amendments for the improvement of physical properties of sodic soil. *Intl. J. Agric. Bio*., 3:319-322.

Janni, K.A, M.I. Endres, J.K. Reneau and W.W. Schoper - Compost dairy barn layout and management recommendations, *Applied Engineering in Agriculture*, 2007. 23:97-102

Keener, H.M., Dick, W.A. and Hoitink, H.A.J. 2000. Composting and beneficial utilization of composted by product materials. In: Bartels, J.M. and Dick, W.A. (Eds.). Land application of municipal, agricultural, industrial, and municipal by products. *Soil Science Society of America*. Book Series 6. P. 315- 341. Available online at books.google.com.

Kim, Ko. H., Hyeon, T., Chi, K. and Umeda, M. 2008. Evaluation of maturity parameter and heavy metal contents in composts made from animal manure. *Waste Manage*, 5: 813-820.

Laboratory methods of soil analysis, Canada-Manitoba soil survey, April 2006.

Lasaridi, K.E., Stentiford, E.I. 1998. A simple respirometric technique for assessing compost stability. *Water Res*. 32, 3717–3723.

Liang, C., Das, K.C. and McClendon, R.W. 2003. The influence of temperature and moisture contents regimes on the aerobic microbial activity of a bio solids composting blend. *Bio resource Technology*, 86: 131–137.

Liang, C., Das, K.C. and McClendon, R.W. 2003. The influence of temperature and moisture contents regimes on the aerobic microbial activity of a bio solids composting blend. *Bio resource Technology*, 86: 131–137.

McCoy, E.L. 1992. Quantitative physical assessment of organic materials used in sports turf rootzone mixes. *Agronomy Journal* 84:375–381.

Mondini, C., Fornasier, F., Sinicco, T., 2004. Enzymatic activity as a parameter for the characterization of the composting process. *Soil Biol. Biochem*. 36, 1587–1594.

Mondini, C., Sanchez-Monedero, M.A., Sinicco, T., Leita, L., 2006. Evaluation of extracted organic carbon and microbial biomass as stability parameters in ligno-cellulosic waste composts. *J. Environ. Qual*. 35, 2313–2320.

Morse, D.E. July 2001. Composting Animal Mortalities. Minnesota Department of Agriculture, St Paul Minneapolis.

Ofosu-Budu, G. K. and Hogarh,. J. N. 2010. Harmonizing procedures for the evaluation of compost maturity in two compost types in Ghana.” *Resources, Conservation and Recycling*., 54(3): 205-209

PAS-100. 2005. Specification for composted Materials British Standards Institution, London.

Pichler, M., Ko-gel-Knabner, I., 2000. Chemolytic analysis of organic matter during aerobic and anaerobic treatment of municipal solid waste. *Waste Manage*. 29, 1337–1344

Richard T.L., Hamelers H.V.M., Veeken A. and Silvia T. 2002 Moisture relationship in composting process. *Compost Sci. Util*, 10(4), 286-302.

Rynk, R. (Ed.) 1992. On-farm Composting Handbook, NRAES-54. Northeast Regional Agricultural Engineering Service, Ithaca, N.Y.

Schulze, K.L. 1961. Relationship between moisture content and activity of finished compost. *Compost Sci*., 2(2): 32–34.

Test Methods of the examination of composting and compost, 2001.

WRAP 2004. Using Compote in Agriculture and Field Horticulture. Compost Information Package 1 [On line]. Available by Waste and Resources Action Program me (verified 25.10.2004).

Zmora-Nahum, S., Hadar, Y. and Chen, Y. 2007. Physico-chemical properties of commercial composts varying in their source materials and country of origin. *Soil Biol. Biochem*., 39: 1263–1276.

Zmora-Nahum, S., Markovitch, O., Tarchitzky, J., Chen, Y. 2005. Dissolved organic carbon (DOC) as a parameter of compost maturity. *Soil Biol. Biochem*. 37, 2109–2116

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