American Journal of Environmental Science, 9 (2): 88-102, 2013
ISSN: 1553-345X

doi:10.3844/ajessp.2013.88.102 Published Online 9 (2) 2013 (http://www.thescipub.com/ajes.toc)

DRYING POULTRY MANURE FOR POLLUTION POTENTIAL REDUCTION AND PRODUCTION OF ORGANIC FERTILIZER

A.E. Ghaly and M. Alhattab

Department of Process Engineering and Applied Science,
Dalhousie University, Halifax, Canada

Received 2013-03-26, Revised 2013-04-12; Accepted 2013-04-13

ABSTRACT

Disposal and storage of raw poultry manure has become an environmental problem because of the associated air, water and soil pollution. Poultry manure begins to decompose immediately after excretion giving off ammonia which, in high concentrations, can have adverse effects on the health and productivity of birds as well as the health of the farm workers. Application to land is the most common way for utilizing poultry manure as a viable source of major plant nutrients and soil conditioner to improve soil tilth and reduce the problems associated with soil compaction. The aim of this study was to investigate the effects of drying depth and temperature on the nutritional profile of dried poultry manure and its suitability as a plant fertilizer. Drying temperature and manure depth had no significant effects on manure pH, but the loss of ammonia during the drying process decreased the pH (from 8.4 to 6.4-6.7). Greater nitrogen losses (44-55 %) were observed at the deeper manure layer (3 cm) and the higher temperature (60°C) which resulted in a reduction of N:P:K (from 4.58:1.29:1 to 2.07:1.30:1-2.57:1.28:1). Drying of poultry manure helped reduce the presence and offensiveness of odor by 65.3 and 69.3%, respectively. Drying of poultry manure also achieved significant reductions in bacteria (65.6-99.8%), yeast and mold (74.1-99.6%) and E. coli (99.97 %). Dried poultry manure can be used as a fertilizer source for plants because of its high nitrogen, phosphorus and potassium contents which are essential for plant growth. Other elements (such as calcium, magnesium, sulfur, boron, copper, iron, manganese, molybdenum, cobalt and zinc) which are lacking in commercial fertilizer are also present in manure in significant amounts.

Keywords: Poultry Manure, Drying, Temperature, Depth, Moisture Content, pH, Odor, Microorganisms, Organic Fertilizer, NPK, Plant Nutrients

1. INTRODUCTION

Rearing of birds has grown from a side-line occupation into a commercial enterprise with single farms having thousands of birds. The current poultry industry is one of the largest and fastest growing sectors of livestock and poultry production in the world. The meat and egg production increased by 35% during the period of 2000-2008. The 2010 world flock is estimated to be over 18 billion birds with an estimated annual output of 22 million tonnes of manure (FAO, 2010). It is, therefore, necessary to find economically viable and environmentally acceptable ways of utilizing such large quantities of waste (Joshi and Devrajan, 2008; Jokela, 1992; Bittman *et al*., 2005).

Storage and disposal of raw poultry manure has become an environmental problem because of the associated air, water and soil pollution (Benali and Kudra, 2002). Poultry manure begins to decompose immediately after excretion giving off ammonia which, in high concentrations, can have adverse effects on the health and productivity of birds as well as the health of the farm workers (Pierson *et al*., 2001; Zhang and Lau, 2007; Amon *et al*., 2006). Manure is a source of odor caused by the activity of microorganisms in the manure and can also serve as a breeding ground for pathogenic microorganisms as well as a transmitting medium for diseases among the birds (Berry and Miller, 2005; Fares *et al*., 2005). Flies and other

Corresponding Author: Abdel Ghaly, Department of Process Engineering and Applied Science, Dalhousie University, Halifax, Nova Scotia, Canada Tel: (902)494-6014, E-mail:abdel.ghaly@dal.ca.

undesirable insects can breed on the manure leading to nuisance and health hazards (Lay *et al*., 2011; Axtell, 1999). It is, therefore, necessary to subject poultry manure to some treatments in order to improve its storage and handling and to minimize the risk of disease transmission and environmental pollution. Proper poultry manure management systems that will preserve the environment, contribute to both animal and human health and return a profit on investment to farmers, need to be developed.

Traditionally, land application has been the most common way of utilizing poultry manure as a viable source of major plant nutrients and soil conditioner to improve soil tilth and reduce the problems associated with soil compaction (Kelleher *et al*., 2002; Zhang and Lau, 2007; Wen *et al*., 2007; Tanabe *et al*., 1985; Chambers and Smith, 1992; Martin and McCann, 1998). However, environmental problems such as odor and pathogens may arise during and after land application of raw manure (Ghaly and Sihgh, 1991; Sims and Wolf, 1994; Risse *et al*., 2006; Rappert and Muller, 2005). Several solid-liquid separation techniques have been tried for poultry manure treatment before land application. These include: mechanical separation (Shirley and Butchbaker, 1975), filtration, stationary screens and thermal separation or drying (Ford and Flemming, 2002; Burton, 2007). Among these, drying is one of the most common method used to prevent environmental problems associated with application of raw manure.

Drying results in the removal of moisture from the manure thereby reducing the rate of deterioration from chemical and biological activities. It improves manure stickiness and hence makes manure handling easier (Ghaly and MacDonald, 2012a). Drying with heated air offers a number of advantages over unheated air drying including: higher rate of oxidation and pathogen destruction (Cummings and Jewell, 1977; Ghaly and MacDonald, 2012b). Drying with heated air can be carried out using a variety of heat sources such as solar energy, electricity, natural gas and other fossil fuels. However, solar energy offers many advantages over other energy sources: (a) it is available in abundance all year round and it is relatively cheap to collect and utilize (Hatem and Ghaly, 1994; Ghaly and MacDonald, 2012a) and (b) it has higher rate of oxidation, waste stabilization, odor control and pathogen destruction (Ludington and Sobel, 1977; McCaskey *et al*., 1985; Ghaly and MacDonald, 2012b).

The main aim of this study was to evaluate the effect of manure drying on suitability of dried manure as an organic fertilizer. The specific objectives were to (a) evaluate the drying behaviour of laying hen manure at temperatures in the range that can be achieved by solar energy (40-60°C) and different depths of manure and (b) determine the changes in the properties of the manure due to the drying process as measured by its plant nutritional value, pathogens content and presence and offensiveness of odor.

2. MATERIALS AND METHODS

2.1. Drying Trays

Three sets of trays, each set consisting of three trays of the same dimensions, were constructed of galvanized steel and used for the drying of poultry manure. The trays have drying surface areas of 100 cm^2 each. The depths of the trays were 1 cm, 2 cm and 3 cm for the sets 1, 2 and 3, respectively. **Figure 1** shows the dimensions of a drying tray.

2.2. Manure

Poultry manure was obtained from a layers house on Archibald Farms located in Stewiack East, approximately 80 km from Halifax, Nova Scotia. The manure was collected under battery cages of a laying house accommodating approximately 50,000 hens. The manure collected was fresh and was not subjected to any treatment on the farm. It was then placed in clean plastic bags and transported to the Waste Management Laboratory at Dalhousie University, Halifax, Nova Scotia where it was stored at -18°C. Some characteristics of the poultry manure used in this study are presented in **Table 1**.

2.3. Experimental Procedure

The effects of three drying temperatures (40, 50 and 60°C) and three manure depths (1, 2 and 3 cm) on the manure drying rate, drying time, manure characteristics and plant nutritional value were investigated. Prior to placing the manure in the drying trays, it was removed from the freezer and allowed to thaw for 24 hours at room temperature (22°C). The three sets of trays were weighed PM4600, Fisher Scientific, Montreal, Quebec). The trays were then filled to their respective depths with the manureand weighed.

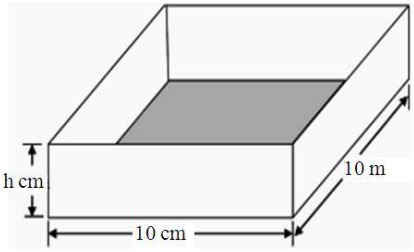

Fig. 1. The dimensions of the drying tray (h=1, 2 or 3 cm)

Table 1. Some characteristics of the poultry manure used in the study

Item	Measured value
Moisture content	78.4%
Density	960 kg/m^3
Total solids	215520 mg/L
Volatile solids	139770 mg/L
Ash	75750 mg/L
Total chemical oxygen demand	328500 mg/L
Soluble chemical oxygen demand	130000 mg/L
Total kjeldahl nitrogen	18960 mg/L
Ammonium nitrogen	9470 mg/L
Calcium	19760 mg/L
Phosphorous	5590 mg/L
Potassium	4140 mg/L
pH	8.40

They were then placed in a forced draft oven (Isotemp Oven Model 655F, Fisher Scientific, Montreal, Quebec) adjusted to the required temperature. The drying rate was monitored by determining the change in weight at 2 h time intervals, until there was no change in weight. The oven temperature was then readjusted to the next level and the same experimental procedure was followed. Three replications for each temperature-manure depth combination were carried out.

2.4. Experimental Analyses

The properties of the manure were determined before drying. These were pH, moisture content, density, total solids and volatile solids, total and soluble chemical oxygen demand, total-Kjeldahl nitrogen, ammonium-nitrogen, phosphorus and potassium. The pH, moisture content, total plate count, pathogens, odor and nutritional analyses were performed on the dried samples. The pH was measured using a pH meter (Model 808MP, Fisher Scientific, Montreal, Quebec) according to the procedure described in the Methods of Soil Analysis (ASA, 1982). The density, total solids and chemical oxygen demand analyses were performed in the biotechnology laboratory of Dalhousie University, Halifax, Nova Scotia according to the procedures described in the Standard Methods for Examination of Water and Wastewater (APHA, 1998). The total Kjeldahl and ammonium nitrogen analyses were performed using Kjeltic Auto Analyzer (Model 1030, Tecator, Högenäs, Sweeden) according to Kjeldahl method. The elemental analysis was performed at the Minerals Engineering center of Dalhousie University using flame atomic adsorption spectroscopy. The nutritional analysis was performed at Nova West Laboratory Ltd, Saulnierville, Nova Scotia, Canada. The moisture content and microbial analyses and the odor evaluation were performed as follows.

2.4.1. Moisture Content

The moisture content was determined using the oven drying method according to the procedure described in the ASAE Standards (ASAE, 1991). Samples of approximately 10 g were dried at 103°C for 24 h in a drying oven (Isotemp Oven Model 655F, Fisher Scientific, Montreal, Quebec) and the Moisture Content (MC) was calculated as follows Equation 1:

$$MC_{wb} = \frac{(\text{Weight of wet samples} - \text{Weight of dry samples})}{\text{Weight of dry samples}} \text{x100} \quad (1)$$

2.4.2. Total Microbial Count

The total plate count was employed to estimate the numbers of viable aerobic and facultative microorganisms based on the assumption that each viable cell will develop into a colony under the specific condition of incubation. The manure samples were collected in wide mouth sterilized containers. Each sample was diluted to insure that one of the final plates would have 30-300 colonies; as the number of colonies within this range would give the most accurate approximation of the microbial population. The initial dilution (1:10) was prepared by placing 1 g into a 10 mL dilution blank (physiological saline water). The bottle was shaken vigorously to obtain a uniform distribution of organisms. Further dilutions (1:10^3, 1:10^4, 1:10^5, 1:10^7, 1:10^8) were made by pipeting measured aliquots into additional dilution blanks. Sterile petri dishes were first labeled (specimen and dilution). Then, each bottle was thoroughly shaken and 1 mL of appropriate dilution was pipetted into a petri dish. Samples from each dilution were plated in duplicate. Approximately 15 mL of the cooled melted medium (Standard Methods Agar, Tryptone Glucose Yeast Agar, Neogen Corporation, Lansing, Michigan) were poured into each petri dish. Immediately thereafter, the plate was gently rotated 6 times in each direction to distribute the inoculum throughout the medium. The plates were allowed to solidify and were incubated in the inverted position in an incubator (Model Number 2020, VWR International, Cornelius, Oregon) at 35-37°C for 48 hours. The plate that contained a number of colonies in the range of 30-300 was selected. An accurate count of these colonies was made by placing the plate on the platform of a colony counter (Cat.No.7-910, Fisher Scientific, Montreal, Quebec). This instrument facilitated the counting process since the colonies were illuminated and

seen against a ruled background. The number of colonies counted on a plate multiplied by the dilution of the specimen which the plate represents was equal to the cell count per milliliter of the specimen.

2.4.3. Microbial and Insect Analyses

The following analyses were also performed on raw dried manure samples: (a) yeast and mold enumeration (b) *E. Coli* estimation and (c) *Salmonellae* examination. These analyses were performed at Nova Scotia Research Foundation Corporation, Dartmouth, Canada.

2.4.4. Odor

A specially developed organoleptic test for measurement of odor from animal waste was used to measure the presence and offensiveness of odor in both the raw and dried poultry manures. This method was chosen because of the complex nature of manure odor which is best judged by the human nose. In this test, a scale of 0-10 was utilized to rate the odor as to its presence and offensiveness. No odor was 0 and very strong odor was 10. A similar scale of no offensive odor (0) and very offensive odor (10) was used. The intermediate numbers 1-9 are described in the Score Sheet (**Figure 2**), which was used by the panel members to rate the samples (50 g) placed before them in 125 Erlenmeyer flasks. They were asked to rate the contents of the flasks according to the scale 0-10. The lower limit (0) was assigned to distilled water, whereas the upper limit (10) was assigned to fresh poultry manure. The odor testing panel consisted of technician, graduate and undergraduate students and faculty. The size of the panel was 10 members. Each panel member was asked to rate the samples as to the presence of odor and the odor offensiveness according to the 0-10 scale and to describe the odor on the data sheet.

3. RESULTS AND DISCUSSION

3.1. Drying Process

The data on the drying time, moisture content and drying effectiveness at various manure depths and drying temperatures are presented in **Table 2**. The parameter "drying effectiveness" was defined in this study as the time needed to drive off 1 g of moisture from the manure. The results indicated that the 1 cm deep manure layer dried the fastest at all temperatures, followed by the 2 cm deep layer and the 3 cm deep manure layer.

ODOR EVALUATION DATA SHEET

Name: _____

Date: _____

A. Rate the samples to the presence of odor and the odor as to offensiveness according to the following scale using samples "0" as having 0 rating and samples "10" as having 10 rating.

Presence		Offensiveness	
No odor	0	No offensive odor	0
Very faint	1-2	Very faint offensive odor	1-2
Faint	3-4	Faint offensive odor	3-4
Definite	5-7	Definite offensive odor	5-7
Strong	8-9	Strong offensive odor	8-9
Very strong	10	Very strong offensive odor	10

B. Describe the odor of each sample by giving an appropriate descriptive term. Possible terms that might be used are given in the list below or you may use a term of your choice which you feel properly describes the odor.

Mold, musty	Yeast
Fish	Ammonia
Stagnant water	Grain, animal feed
Sulfide, rotten eggs	Sour, fermented
Petroleum	Rotten cabbage, mercaptans
Earth	Other (Please specify)

RATING

Sample	Presence Rating	Offensiveness Rating	Odor Description
1			
2			
3			

Thank you for your time

Fig. 2. Odor evaluation sheet

The thinner the manure layer, the lower the amount of moisture it contained and consequently the shorter the time duration required to drive off the moisture. The time required to dry the 2 cm deep manure layer was more than the time required to dry the 1 cm deep manure layer by about 106, 100, and 87%, while the time required to dry the 3 cm deep manure layer was more than the time required to dry the 2 cm deep manure layer by 22, 12 and 7 % for 40, 50 and 60°C, respectively. The results showed that the difference in drying time between the shallower and deeper manure layers decreased as the drying temperature increased, However, when considering the drying effectiveness, the 3 cm deep manure layer was superior at all levels of temperature as less time was required to remove one gram of water from the manure. The results also showed that more time was required to remove one gram of water from the 2 cm deep manure layer than those required for the 1 and 3 cm deep manure layers at all temperatures as shown in **Figure 3**.

Table 2. Drying time and drying effectiveness of poultry manure

Drying Temperature(°C)	Drying Depth (cm)	Drying Time (h)	Weight(g) Initial	Weight(g) Final	Moisture (g)	Drying Effectiveness (h/g)
40	1	55	125.95	27.15	98.80	0.56
	2	106	224.70	48.43	176.27	0.60
	3	120	312.72	67.41	245.31	0.50
50	1	44	129.16	27.84	101.32	0.43
	2	84	226.21	48.71	177.50	0.47
	3	90	314.28	67.74	246.54	0.37
60	1	28	127.18	27.41	99.77	0.28
	2	52	227.86	49.11	178.75	0.29
	3	60	322.57	69.52	253.05	0.24

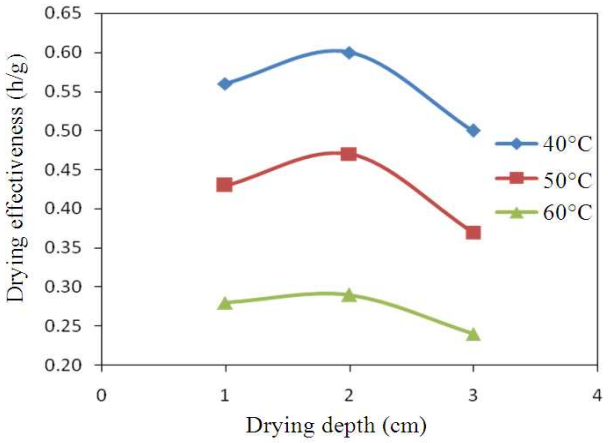

Fig. 3. Manure drying effectiveness

There is no information in the literature on this layer drying of manure and most of the work done was on grains, fruits and vegetables. Rao *et al*. (2007) investigated the thin layer drying of parbroiled paddy at depths between 5 and 20 cm and observed the fastest drying time at a depth of 5 cm and the optimum drying effectiveness at a depth in the range of 7-10 cm. Nazghelichi *et al*. (2010) investigated the effect of bed depth on the drying of carrot cubes at 30, 60 and 90 mm bed depth and found the optimum time and efficiency to be achieved at 30 mm depth. Maskan *et al*. (2002) investigated the effect of layer thickness, temperature and air velocity on the drying of the fruit leather and reported that the minimal drying layer thickness resulted in the fastest drying rate and effectiveness. Ertekin and Yaldiz (2004) studied the effect of drying eggplant slices with a 0.63, 1.27 and 2.54 cm thickness and found the fastest drying time with the 0.63 cm thick slices and the most effective drying with the 2.54 cm slices.

3.2. Manure pH

The manure pH dropped from 8.4 to about 6.4-6.7 (**Table 3**) due to the loss of ammonia. In this study, the drying temperature and manure depth did not seem to have any significant effects on the pH of the dried manure. Gislason and Oelkers (2003) reported a pH range of 5.23-5.91 for basaltic glass drying over the temperature range of 30-100°C. Himathongkham and Riemann (1999) noted that a decrease in ammonia content from 5.5 mgg^{-1} to 0.75 mg g^{-1} caused the pH to drop from 9.5 to 7.75 in fresh chicken manure. Sistani *et al*. (2001) reported a significant pH drop in broiler chicken litter upon drying at a temperature of 105°C. Derikx *et al*. (1994) noted that during the drying of poultry, cattle and pig manure, all ammonia was volatilized when the pH was above 8 and the fatty acids evaporated when the pH was below 5.

3.3. Elemental Analyses

The concentration of nitrogen, phosphorous and potassium in the dried poultry manure are shown in **Table 3**. Very small changes in the concentration of phosphorous and potassium occurred during the drying process. However, 44-55% of the nitrogen in the manure was lost depending on the depth of the manure layer and drying temperature, the deeper the layer and/or the higher the temperature the greater was the nitrogen loss. On average, 51% of total kjeldahl nitrogen (13% organic nitrogen and 38% ammonium nitrogen) in the manure was lost during the drying process as shown in **Table 4**. As a result the initial N:P:K of 4.58:1.29:1 was reduced to 2.07:1.30:1-2.57:1.28:1 due to loss of nitrogen, depending on the drying temperature and depth.

Ribeiro *et al*. (2001) reported an increase in nitrogen loss from 8.3 to 13.2% in poultry manure upon increases in temperature from 55 to 100°C. Raviv *et al*. (1999) noted a reduction in nitrogen content in poultry manure upon exposure to temperatures above 65°C.

Table 3. pH and essential elements in raw and dried poultry manure

Drying Temperature(°C)	Drying Depth (cm)	Elements (%DB) Nitrogen	Phosphorous	Potassium	NPK Ratioa	pH
40	1	4.92	2.46	1.91	2.57:1.28:1	6.6
	2	4.63	2.45	1.90	2.43:1.30:1	6.4
	3	4.48	2.46	1.91	2.35:1.29:1	6.6
50	1	4.45	2.45	1.90	2.34:1.29:1	6.7
	2	4.35	2.45	1.89	2.30:1.30:1	6.7
	3	4.23	2.46	1.90	2.23:1.29:1	6.7
60	1	4.16	2.45	1.89	2.20:1.30:1	6.6
	2	3.99	2.44	1.90	2.10:1.28:1	6.5
	3	3.92	2.45	1.89	2.07:1.30:1	6.6
Raw Manure		8.8	2.48	1.92	4.58:1.29:1	8.4

Table 4. Nitrogen concentrations and losses

Drying Temperature(°C)	Drying Depth (cm)	Nitrogen Content (mg/kg) TKN	Org-N	Am-N	Losses (%) Total	Org-N	Am-N
40	1	49350	36370	12980	19.73	12.31	7.42
	2	46340	33450	12890	24.62	17.06	7.61
	3	43810	32960	10850	28.74	17.86	10.88
50	1	44900	33920	10980	27.00	16.30	11.30
	2	43490	32610	10880	29.26	18.43	10.83
	3	41880	32060	9820	31.88	19.32	12.56
60	1	41280	32930	8350	32.86	17.91	14.95
	2	39890	31600	8290	35.11	20.07	15.83
	3	39260	30940	8220	36.30	21.15	15.15
Raw manure		61480	43940	17540	-	-	-

Abdalla and Abu Bakar (2004) noted that an increase in drying temperature from 30°C to 70°C decreased the nitrogen content by 12-26% and 9-42% in maize and groundnut plant residues.

Researchers have noted that phosphorous content is affected by drying process (Ajiboye *et al*., 2004; Akinremi *et al*., 2003; Gerritse and Eksteen, 1978; Sistani *et al*. 2001). Sistani *et al*. (2001) noted a lower phosphorous content in broiler chicken manure as a result from freeze or oven drying at 105°C. Akinremi *et al*. (2003) achieved the lowest concentrations of phosphorous in poultry, cattle and pig manure upon drying at 105°C as appose to freeze-dried and air-dried samples (30°C). Chapuis-Lardy *et al*. (2004) noted lower concentrations of phosphorous in dried feces as appose to wet dairy feces. Tagoe *et al*. (2008) noted that poultry manure that has been carbonized at 500°C has a higher phosphorus content (18.17 g/kg) available than in dried poultry manure (4.47 g/kg).

Ghosh *et al*. (2004) reported nitrogen, phosphorous and potassium contents in poultry manure of 2.14, 1.09 and 1.23%, respectively. Ayoola and Adeniyan (2006) noted nitrogen, phosphorous and potassium contents in poultry manure of 1.98, 1.74 and 2.00 %, respectively.

3.4. Odor

At the start of a new experiment, the odor given off near the oven during the drying process was noticeable. However, when the drying process progressed, the presence and offensiveness of the odor decreased with the time and the final product (dried manure) did not have any offensive odor. The result of the organoleptic test (**Table 5**) showed that both the presence and offensiveness of the odor in the dried poultry manure were reduced by 65.3 and 69.3% (as compared to that of the fresh poultry manure). The odor present in the dried manure was not offensive (23.3% of the panel members described the odor as that of grain, 20% described it as a mold musty, 13.3% described it as ammonia, 13.3% described it as fermented, 6.7% described it as fish odor, 6.7% described it as yeast odor ad 6.7% described it as rotten eggs odor).

Lekasi *et al*. (2003) stated that air drying of animal manure reduces the smell. Ghaly and MacDonald (2012a) reported that drying of poultry manure over the temperature range of 40-60° achieved reductions in odor intensity and offensiveness of 65 and 69%, respectively.

Table 5. Odor rating

Parameter	Dried	Raw
Presence	3.47±1.25	10
Offensiveness	3.07±1.53	10
Description		
Grain, Feed	10	-
Mold, Musty	6	-
Sour, Fermented	4	-
Yeast	2	-
Earth	2	-
Fish	2	-
Sulfide, Rotten Egg	2	12
Ammonia	2	6
Stagnant water	-	5
Rotten Cabbage Mercaptans	-	7

* Total number of observations-30

Nahm (2003) noted that the reductions in hydrogen sulphide and ammonia concentrations during drying reduced the of poultry manure.

3.5. Microbial Count

The results of the microbial analyses are shown in **Table 6**. Generally, high numbers of bacteria (477×10^7 manure) were found in the raw manure. The drying process reduced the number of bacteria by 65.62%-99.83% (from 477×10^7 to 164×10^7 -808×10^4 cells/g manure), the yeast and mold cells by74.07%-99.63% (from 2700 cells/g manure to 700 -<10 cells/g manure) and the number of *E. coli* by 99.97% (from 21,986,666 to 6263- <10 cells/g manure). *Salmonellae* was detected in the raw manure and the dried manure samples collected from the 3 cm deep manure layer after drying at 40°C. The results indicated that the higher the drying temperature and/or the thinner the manure layer, the more destruction of microorganisms in the dried manure. The killing actions of heat appeared to be time-temperature dependent.

Several researchers reported that 90% of microorganisms in manure will be destroyed in a few days at temperatures in the range of 20-40°C and a few weeks at temperatures of 4-10°C (Himathongkham and Riemann, 1999; Placha *et al*., 2001; Hutchison *et al*., 2005). Larney *et al*. (2003) noted that a period of 7 days was necessary to eliminate *Escherichia coli* in beef cattle manure at temperatures in the range of 33.5 - 41.5°C. Wang *et al*. (1996) reported that *Escheriahia coli* in bovine feces can survive 42-49, 49-56 and 63-70 days at temperatures of 37, 22 and 5°C, respectively. In this study, higher temperatures (40-60°C) were used which resulted in less time (28-120 h) for elimination of microorganisms and lower nitrogen losses compared to other studies.

3.6. Plant Nutritional Requirements

Plants require essential nutrients for growth. These nutrients can be divided into macronutrients and micronutrients.

3.6.1. Macroelements

Macroelements are required by plants in relatively large amounts (>100 mg/kg dry diet) and include calcium (Ca), Nitrogen (N), Magnesium (Mg), Phosphorus (P), potassium (K) and Sulfur (S). These elements function in cellular metabolism, have important roles in osmoregulation and acid-base balance and serve as structural components of tissues (Brady and Weil, 1996; Ecosystem Restoration, 2004). The deficiency and toxicity symptoms of macroelements are listed in **Table 7**.

Calcium is an essential nutrient in plants which functions in structural components (protein) of plants cell wall and membranes (Marschner, 1995). It is required for growth of root and shoot tips (Evans, 2003). Calcium also plays a role in the plant cell division and elongation processes (Rudd and Franklin-Tang, 2001), membrane permeability and the maintenance of cellular integrity (Hepler, 2005). It reduces the toxicity of manganese and aluminium (Evans, 2003).

Nitrogen plays a major role in plant growth because it is a part of all amino acids. Amino acids are the building blocks of proteins and enzymes which play a role in biological processes. Nitrogen stimulates development, root growth and the uptake of nutrients (Brady and Weil, 1996). Plants require nitrogen in the forms of NO_3^- and NH_4^+ (Glass and Siddiqi, 1995). Uptake of nitrogen is affected by the pH, NH_4^+ uptake is depressed under acidic conditions (Rygiewicz *et al*., 1984) and NO_3^- uptake is depressed under alkaline conditions (Aslam *et al*., 1995).

Magnesium functions in metabolic processes of plants. These processes include photophosphorylation, photosynthetic carbon dioxide fixation, chlorophyll formation, phloem loading, synthesis of proteins, reactive oxygen species generation and photooxidation in leaf tissues. Magnesium deficiencies result in growth and yield impairment (Cakmak and Yazici, 2010).

Phosphorus is essential for several plant functions including energy transfer, reproduction, optimum growth, photosynthesis, nutrient movement within the plant, transfer of genetic characteristics and the transformation of starches and sugars. Phosphorous uptake occurs in the form of orthophosphate. Plants require inorganic phosphate in order to export energy from the chloroplast by Adenosine Triphosphate (ATP) (Sultenfuss and Doyle, 1999). Phosphorous increases plant resistance to disease (Evans, 2003).

Table 6. Average microbial count in raw and dried poultry manure

Drying Temperature (°C)	Drying Depth (cm)	Bacteria (10^4 cells/g)	Yeast/Mold (cells/g)	*E. Coli* (10^4 cells/g)	*Salmonellae* (preserve)
40	1	55000	250	10	ND
	2	69000	370	20	ND
	3	75000	430	30	PP
50	1	2100	170	<10	ND
	2	2900	210	10	ND
	3	4100	310	20	ND
60	1	440	<10	<10	ND
	2	530	<10	<10	ND
	3	620	<10	<10	ND
Raw Manure		477000	2700	2290	PP

PP- Partially Detected
ND-Not Detected

Table 7. Macroelement deficiency and toxicity symptoms in plants (Evans, 2003)

Element	Deficiency symptoms	Toxicity symptoms
Calcium (Ca)	Root tips often die Bud development is inhibited Young leaves become distorted and small with irregular margins and necrotic or spotted areas	No visible symptoms
Nitrogen (N)	Plant growth is restricted Lack of chlorophyll (older leaves) results in yellow colored leaves	Color is dark green Abundant foliage Restricted growth of root system
Magnesium (Mg)	Reduction in plant growth Puckering effect on leaf margins	Affects Ca uptake Necrotic spots develop Smaller veins turn brown
Phosphorous (P)	Reduction in plant growth Dark green leaves Distorted leaf shape Stems are thin Root growth is limited	Deficiency in Zn, Fe, or Cu micronutrients can result
Potassium (K)	Reduced plant growth Internodes are shortened Older leaves can become chlorotic and burn Necrotic spots Lateral breaks are reduced and wilt readily Root system is poorly developed Stalks are weak	Deficiency in Mg, Zn, Mn or Fe
Sulfur (S)	Leaves become yellow Stems and roots are small, woody and hard	Reductions in leaf size and plant growth

Potassium is essential for good crop yield and quality as it plays various regulatory roles in the development of the plants. These roles include enzyme activation, stomatal activity (water use), photosynthesis, transport of sugars, synthesis of starch and proteins and in nutrient and water transport (Van Brunt and Sultenfuss, 1998). It also helps overcome drought conditions, improves winter hardiness and increases resistance to diseases (Evans, 2003).

Sulfur is present in two major amino acids known as cysteine and methionine which are essential for plants primary and secondary metabolism (Droux, 2004). Sulfur is an essential compound in the vitamin thiamine which has been implicated to respond to DNA damage and pathogen attack in plants (Raschke *et al*., 2007).

3.6.2. Microelements

Microelements are required by plants in trace amounts (<100 mg/kg dry diet) and include boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), Chlorine (Cl) and zinc (Zn) (Ronan, 2007).

Table 8. Microelement deficiency and toxicity symptoms in plants (Evans, 2003)

Element	Deficiency symptoms	Toxicity symptoms
Boron (B)	Breakdown (internal) of fruit or vegetables Failure in normal root tip elongation Leaves become thick, chlorotic and leathery Disintegration of internal tissues	Development of necrotic spots on tips and edges of leaves Plants become damaged
Copper (Cu)	Young plants become dark green, twisted or misshapen Interveinal chlorosis (young leaves)	Result in Fe deficiency Reduced branching and thickening Abnormal darkening of rootlets
Iron (Fe)	Young tissue interveinal chlorosis	Not evident in natural conditions
Manganese (Mn)	Interveinal chlorosis Necrotic lesions and shedding of leafs Chloroplast lamellae is disorganized	Results in chlorosis Uneven distribution of chlorophyll Reduction in plant growth
Molybdenum (Mo)	Older leafs interveinal chlorosis Cupping or marginal scorching of leaves	Rarely observed
Chlorine (Cl)	Wilted leaves become necrotic and chlorotic and eventually become a bronze color	Leaf burn Reduction in leaf size and growth rate
Zinc (Zn)	Leaf size reduction and internode length Distorted or puckered leaf margins	Results in production of iron chlorosis

Microelements are involved in the regulation of cellular metabolism and are required for proper growth and development. Plant deficiency and toxicity symptoms of microelement are listed in **Table 8**.

Boron is an essential micronutrient in plants which functions in the synthesis of protein, flowering set increase, plant maturity, water retention and formation of plant hormones. It also affects the carbohydrate and nitrogen metabolism process (Ronan, 2007; Dick, 2010; Blevins and Lukaszewski, 1998).

Copper in plants possess numerous functional characteristics such as activation of enzymes, photosynthesis, reproductive phase and respiratory enzymes. Copper also plays a role in chlorophyll production(indirectly), increases the content of sugar present in plants, increases color intensity and improves the flavours in fruits and vegetables (Ronan, 2007; Rehm and Schmitt, 2009).

Iron in plants is responsible for photosynthesis and respiration processes and functions in enzyme mechanism which is responsible for the operation of the respiratory system. It also promotes chlorophyll formation, cell division and cell growth (Connolly and Guerinot, 2002; Ronan, 2007).

Manganese is the predominant element in organic acid metabolism of plants. It plays a role in some of the important enzymes in plants which are involved in enzyme synthesis and respiration. It works as an activator of enzymes that are involved in oxidation/reduction and hydrolysis reactions. It also works to activate the reduction process of hydroxylamine and nitrite to ammonia (Ronan, 2007; Spectrum Analytic Inc., 2012a; Millaleo *et al*., 2010).

Molybdenum is an essential component of enzymes which is used to carry out redox reactions. Molybdenum requiring enzymes include those that work in nitrate reduction, aldehyde oxidation and xanthine dehydrogenase. Molybdenum is also essential for plant growth (Ronan, 2007; Kaiser *et al*., 2005; Uchida, 2000).

Chlorine activates the enzyme which releases oxygen during photosynthesis, from water. It is important in drought resistance (stomata gate cells aperture) because chlorine regulates the growth of the cells and the turgor pressure. Chlorine is also the counter ion to the cations (positively charged ions) in the cell (Ronan, 2007; Uchida, 2000).

Zinc is responsible for the formation of auxin (growth hormones). It also plays a role in external elongation, protein synthesis, consumption and transformation of carbohydrates, stimulates maturity and the formation ofseed and grains (Ronan, 2007; Broadley *et al*., 2007; Waters and Sankaran, 2011).

Table 9. Plant tissue nutrient sufficiency (Vitosh *et al*., 1994)

Element	Corn	Wheat	Soybeans	Potato
Macronutrients (%)				
Nitrogen (N)	2.76-3.50	2.59-3.00	4.26-5.50	2.50-4.00
Phosphorus (P)	0.25-0.50	0.21-0.50	0.26-0.50	0.18-0.22
Potassium (K)	1.71-2.50	1.51-3.00	1.71-2.50	6.00-9.00
Calcium (Ca)	0.21-1.00	0.21-1.00	0.36-2.00	0.36-0.50
Magnesium (Mg)	0.16-0.60	0.16-1.00	0.26-1.00	0.17-0.22
Sulfur (S)	0.16-0.50	0.20-0.40	0.21-0.40	0.21-0.50
Micronutrients (ppm)				
Manganese (Mn)	20-150	16-200	21-100	30-200
Iron (Fe)	21-250	11-300	51-350	30-300
Boron (B)	4-25	6-40	21-55	15-40
Copper (Cu)	6-20	6-50	10-30	7-30
Zinc (Zn)	20-70	21-70	21-50	30-100
Molybdenum (Mo)	0.1-2.0	0.03-5.0	1.0-5.0	0.5-4.0

3.7. Plant Nutritional Value of Dried Poultry Manure

The concentration range of nutrient requirement in plant tissue for sufficient growth is listed in **Table 9**.

Plant tissues with values lower than the given range are nutrient deficient and plants with values higher than the sufficiency range are toxic. The plant symptoms caused by deficiency and toxicity are listed in **Table 7 and 8**. Nutrient deficiency in plants can be fixed by application of fertilizer to the soil. Toxicity can be avoided by applying less frequently or applying lower amounts (Vitosh *et al*., 1994).

Numerous studies performed on poultry manure illustrated that poultry manure exerted a positive influence on crop production and improved the physical properties of soil (Guisquiani *et al*., 1995; Tam and Wong, 1995; McConnell *et al*., 1993). Zhou *et al*. (2005) studied the effect of different amounts of copper and zinc (present in poultry manure) on the growth of radish and pakchoi and concluded that the manure improved the growth of both plants and that the presence of the heavy metals in the manure did not cause acute toxicity to the plants. Sturgeon (2008) and Tewolde *et al*. (2005) reported that plant fertilized with broiler littler had greater concentrations of potassium in tissues then those receiving commercial fertilizer, but no harm on plants was observed. Ghosh *et al*. (2004) reported that sorghum responded better to poultry manure than farmyard manure as the fertilizer. Ayoola and Adeniyan (2006) reported of poultry manure increasing grain yield from 0.85-0.95 t/ha to 2.04-2.19 t/ha.

The nutrient requirement by plants for growth and the nutritional composition of poultry manure are listed in **Table 10**. Organic fertilizers are always applied on the basis of nitrogen required by plants. Poultry manure can be used as fertilizer for plants because of its high nitrogen, phosphorous and potassium content. For example the corn crop requires 2520-3089 kg of manure per acre to meet the nitrogen requirement (62-76 kg/acre) for growth. This would also supply 0.86, 3.83, 560, 110, 8.48, 4.66, 22.4, 2.11, 6.20, 93.0, 106, 0.28 and 10.2 % of the required calcium, magnesium, phosphorous, potassium, sulfur, boron, copper, iron, manganese, molybdenum, chlorine, cobalt and zinc, respectively. Crops have a high phosphorous tolerance level and thus excess phosphorous (460 %) will not harm the corn (Daniels, 1998). Also, the excess in potassium (10%) and chlorine (6%) nutrients are not significant. The deficiencies in calcium, magnesium, sulfur, boron, copper, iron, manganese, molybdenum, cobalt and zinc will be provided by the soil nutrients (Liu *et al*., 2000; Vitosh *et al*., 1994; McKenzie, 1992). Most commercial fertilizers supply nitrogen, phosphorus and potassium and do not have significant amounts of macro and micronutrients (McCauley, 2003; Finn and White, 1966).

4. CONCLUSION

Thin layer (1-3 cm) drying of poultry manure was effective at temperatures within the range provided by solar heaters (40-60°C). The temperature and manure depth had no significant effects on the dried manure pH. The loss of ammonia from manure resulted in a drop in the pH from the initial value of 8.4 to finial values in the range of 6.4-6.7. Greater nitrogen losses (44-55 %) were observed at the deeper manure layer and higher temperature which resulted in a reduction in N:P:K from the initial value of 4.58:1.29:1 to final values in the range 2.07:1.30:1-2.57:1.28:1.

Table 10. Nutritional composition of dried poultry manure and plant nutrient requirement

Nutrient	Dried Poultry Manure	Plant Requirement (kg/Acre)			
		Corn[a]	Wheat[b,c]	Potato[d]	Soybean[e,c]
Macroelements (mg/kg)					
Calcium	42	13.6	23-68	28	5-75
Nitrogen	24 600	62-76	39	90.8-109	13.6-224
Magnesium	180	13.2	27	18	1.8-25
Phosphorus	24 500	11-13.5	18-23	11-16	1.2-21.9
Potassium	19 000	43.7-53.1	29	127-145	10.2-150
Sulfur	200	5.9-7.3	4.5	8-11	0.91-13
Mircoelements (mg/kg)					
Boron	1	0.06	0.03	0.08	0.04
Copper	4	0.05	<0.05	0.04	0.05
Iron	4	0.53	0.28	0.8	2.87
Manganese	4	0.18	0.20	0.4	0.46
Molybdenum	1	0.003	<0.5	0.002	<0.5
Chlorine	190	0.5	3.2	4.54	0.5
Cobalt	0.5	<0.5	<0.5	<0.5	<0.5
Zinc	4	0.11	0.12	0.05	0.34
N:P:K	1.3:1.28:1	1.4:0.25:1	1.3:0.7:1	0.7:0.1:1	1.5:0.15:1

(a) Bundy (1998)
(b) McKenzie (1992)
(c) Bierman and Rosen (2005)
(d) Hopkins *et al*. (2003)
(e) Spectrum Analytic Inc. (2012b)

Drying of poultry manure helped reduce the presence and offensiveness of odor by 65.3 and 69.3%, respectively. Drying of poultry manure also achieved a reduction in bacteria (65.6-99.8%), yeast and mold (74.1-99.6%) and E. coli (99.97 %). Dried poultry manure can be used as a fertilizer source for plants because of its high nitrogen, phosphorus and potassium contents which are essential for plant growth. Other elements (such as calcium, magnesium, sulfur, boron, copper, iron, manganese, molybdenum, cobalt and zinc) which are lacking in commercial fertilizer are also present in poultry manure in significant amounts.

5. ACKNOWLEDGEMENT

This research was funded by the Natural Science and Engineering Research Council (NSERC) of Canada.

6. REFERENCES

Abdalla, M.A. and R. Abu Bakar, 2004. The effect of drying temperature on nitrogen mineralization form above and below ground crop residues. University Khartoum J. Agricultural. Sci., 12: 47-65.

Ajiboye, B., O.O. Akinremi and G.J. Racz, 2004. Laboratory characterization of phosphorus in fresh and oven-dried organic amendments. J. Environmental Quality, 33: 1062-1069. PMID: 15224945

Akinremi, O.O., N. Armisen, M.A. Kashem and H.H. Janzen, 2003. Evaluation of analytical methods for total phosphorus in organic amendments. Communi. Soil Sci. Plant Analysis, 34: 2981-2991. DOI: 10.1081/CSS-120025220

Amon, B., V. Kryvoruchko, T. Amon and S. Zechmeister-Boltenstern, 2006. Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. Agricul. Ecosystems Environment, 112: 153-162. DOI: 10.1016/j.agee.2005.08.030

APHA, 1998. Standard methods for the Examination of Water and Wastewater. 20th Edn., American Public Health Association, Washington, D.C. ISBN: 0-87553-175-X.

ASA, 1982. Methods of soil analysis part I: physical and mineralogical methods. Second Edn., (Klute- editor), American Society of Argonomy, Inc, Madison, Wisconsin. ISBN: 0891188118.

ASAE, 1991. Standards American Society of Agricultural Engineering, Saint Joseph, Michigan. ISBN: 8755187.

Aslam, M., R.L. Travis and R.C. Huffaker, 1995. Effect of pH and calcium on short-term NO^{3-} fluxes in roots of barley seedlings. Plant Physiol., 108: 727-734. PMID: 11536695

Axtell, R.C., 1999. Poultry integrated pest management: Status and future. Integrated Pest Manage. Rev., 4: 53-73.

Ayoola, O.T. and O.N. Adeniyan, 2006. Influence of poultry manure and NPK fertilizer on yield and yield components of crops under different cropping systems in south west Nigeria. African J. Biotechnol., 5: 1386-1392.

Benali, M. and T. Kudra, 2002. Thermal dewatering of diluted organic suspensions: Process mechanism and drying kinetics. Drying Technol., 20: 935-951. DOI: 10.1081/DRT-120003770

Berry, E.D. and D.N. Miller, 2005. Cattle feedlot soil moisture and manure content: II. impact on Escherichia coli O157. J. Environmental Quality, 34: 656-663. PMID: 1575811

Bierman, P.M. and C.J. Rosen, 2005. Nutrient cycling and maintaining soil fertility in fruit and vegetable crop systems. University of Minnesota, Minneapolis, Minnesota.

Bittman, S., T.A. Forge and C.G. Kowalenko, 2005. Responses of the bacterial and fungal biomass in a grassland soil to multi-year applications of dairy manure slurry and fertilizer. Soil Biol. Biochemi., 37: 613-523. DOI: 10.1016/j.soilbio.2004.07.038

Blevins, D.G. and K.M. Lukaszewski, 1998. Boron in plant structure and function. Annual Rev. Plant Physiol. Plant Molecular Biol., 49: 481-500. PMID: 15012243

Brady, N.C. and R.R. Weil, 1996. The nature and properties of soils. 1st Edn., Prentice-Hall, Upper Saddle River, New Jersey, ISBN-10: 0132431890, pp: 740.

Broadley, M.R., P.J. White, J.P. Hammond, I. Zelko and A. Lux, 2007. Zinc in plants. New Phytologist., 173: 677-702. PMID: 17286818

Bundy, L.G., 1998. Corn fertilization. University of Wisconsin-Madison, Madison, Wisconsin.

Burton, C.H., 2007. The potential contribution of separation technologies to the management of livestock manure. Livestock Sci., 112: 208-202. DOI: 10.1016/j.livsci.2007.09.004

Cakmak, I. and A.M. Yazici, 2010. Magnesium: A forgotten element in crop production. Better Crops, 94: 23-25.

Chambers, B.J. and K.A. Smith, 1992. Soil mineral nitrogen arising from organic manure application. Aspects Applied Biol., 30: 135-143.

Chapuis-Lardy, L., J. Fiorini, J.D. Toth and Z. Dou, 2004. Phosphorus concentration and solubility in dairy feces: Variability and affecting factors. J. Dairy Sci., 87: 4334-4341. PMID: 15545398

Connolly, E.L. and M.L. Guerinot, 2002. Iron stress in plants. Genome Biol., 3: 1024.1-1024.4.

Cummings, R.J. and W.J. Jewell, 1977. Thermophilic aerobic digestion of dairy waste. In: Food, Fertilizer and Agricultural Residues, Loehr, R.C. (Ed.), Ann Arbor Science Publishers Inc., Michigan. Illinois.

Daniels, M., 1998. Soil phosphorus levels: Concerns and recommendations. Cooperative Extension Service, University of Arkansas.

Derikx, P.J.L., H.C. Willers and P.J.W. Ten Have, 1994. Effect of pH on the behaviour of volatile compounds in organic manures during dry-matter determination. Bioresou. Technol., 49: 41-45. DOI: 10.1016/0960-8524(94)90171-6

Dick, C., 2010. Low boron and excess iron, is there an interaction? Calcium Products, Iowa.

Droux, M., 2004. Sulfur assimilation and the role of sulfur in plant metabolism: A survey. Photosynthesis Res., 79: 331-348. DOI: 10.1023/B:PRES.0000017196.95499.11

Ecosystem Restoration, 2004. Analytical Methods. Montana State University Boseman.

Ertekin, C. and O. Yaldiz, 2004. Drying of eggplant and selection of a suitable thin layer drying model. J. Food Eng., 63: 349-359. DOI: 10.1016/j.jfoodeng.2003.08.007

Evans, E., 2003. Nutrient deficiency. NC State University, Raleigh, North Carolina.

FAO, 2010. Agricultural Handbook: Poultry Meat and Eggs. 1st Edn., FAO Investment Centre Division, Rome Italy.

Fares, F., A. Albalkhi, J. Dec, M.A. Bruns and J. Bollag, 2005. Physicochemical characteristics of animal and municipal wastes decomposed in arid soils. J. Environmental Quality, 34: 1392-1403. PMID: 15998862

Finn, R.F. and D.P. White, 1966. Commercial fertilizers increase growth in a yellow-poplar plantation. J. Forestry, 64: 809-810.

Ford, M. and R. Fleming, 2002. Mechanical solid-liquid separationof livestock manureliterature review. University of Guelph, Ridgetown College, Ridgetown, Ontario.

Gerritse, R.G. and R. Eksteen, 1978. Dissolved organic and inorganic phosphorus compounds in pig slurry: Effect of drying. J. Agricultural Sci., 90: 39-45. DOI: 10.1017/S0021859600048577

Ghaly, A.E. and K.N. MacDonald, 2012a. Drying of poultry manure for use as animal feed. Am. J. Agricultural Biological Sci., 7: 239-254. DOI: 10.3844/ajabssp.2012.239.254

Ghaly, A.E. and K.N. MacDonald, 2012b. An effective passive solar dryer for thin layer drying poultry manure. Am. J. Eng. Applied Sci., 5: 136-150. DOI: 10.3844/ajeassp.2012.136.150

Ghaly, A.E. and R. Singh, 1991. Laboratory evaluation of the pollution potential of land applied dairy manure. Waste Manag., 11: 307-318. DOI: 10.1016/0956-053X(91)90077-I

Ghosh, P.K., P. Ramesh, K.K. Bandyopadhyay, A.K. Tripathi and K.M. Hati *et al*., 2004. Comparative effectiveness of cattle manure, poultry manure, phosphocompost and fertilizer-NPK on three cropping systems in vertisols of semi-arid tropics. I. Crop yields and system performance. Bioresou. Technol., 95: 77-83. DOI: 10.1016/j.biortech.2004.02.011

Gislason, S.R. and E.H. Oelkers, 2003. Mechanism, rates and consequences of basaltic glass dissolution: II. An experimental study of the dissolution rates of basaltic glass as a function of pH and temperature. Geochimica et Cosmochimica Acta, 67: 3817-3832. DOI: 10.1016/S0016-7037(03)00176-5

Glass, A.D.M. and M.Y. Siddiqi, 1995. Nitrogen absorption by plant roots. In: Nitrogen Nutrition in Higher Plants, Srivastava, H.S. and R.P. Singh, (Eds.), pp: 21-56.

Guisquiani, P.L., M. Pagliai, G. Gigliotti and A. Benetti, 1995. Urban waste compost: Effects on physical, chemical, and biochemical soil properties. J. Environmental Quality, 24: 175-182. DOI: 10.2134/jeq1995.00472425002400010024x

Hatem, M.H. and A.E. Ghaly, 1994. Composting of municipal solid waste. Misr J. Agricultural Eng., 11: 548-558.

Hepler, P.K., 2005. Calcium: A central regulator of plant growth and development. Plant Cell, 17: 2142-2155. DOI: 10.1105/tpc.105.032508

Himathongkham, S. and H. Riemann, 1999. Destruction of Salmonella typhimurium, Escherichia coli O157:H7 and Listeria monocytogenes in chicken manure by drying and/or gassing with ammonia. FEMS Microbiol. Lett., 171: 179-182. PMID: 10077842

Hopkins, B.G., J.C. Stark, D.T. Westermann and J.W. Ellsworth, 2003. Nutrient management efficiency. nutrient management, potato production systems. University of Idaho, Moscow, Idaho, pp: 115-134.

Hutchison, M.L., L.D. Walters, T. Moore, D.J. Thomas and S.M. Avery, 2005. Fate of pathogens present in livestock wastes spread onto fescue plots. Applied Environmental Microbiol., 71: 691-696. PMID: 15691918

Jokela, W.E., 1992. Nitrogen fertilizer and dairy manure effects on corn yield and soil nitrate. Soil Sci. Society Am. J., 56: 148-154.

Joshi, V.K. and A. Devrajan, 2008. Ethanol recovery from solid state fermented apple pomace and evaluation of physico-chemical characteristics of the residue. Natural Product Radiance, 7: 127-132.

Kaiser, B.N., K.L. Gridley, J.N. Brady, T. Phillips and S.D. Tyerman, 2005. The role of molybdenum in agricultural plant production. Annals Botany, 96: 745-754. DOI: 10.1093/aob/mci226

Kelleher, B.P., J.J. Leahy, A.M. Henihan, T.F. O'Dwyer and D. Sutton *et al*., 2002. Advances in poultry litter disposal technology--a review. Bioresou. Technol., 82: 27-36. PMID: 12058828

Larney, F.J., L.J. Yanke, J.J. Miller and T.A. McAllister, 2003. Fate of coliform bacteria in composted beef cattle feedlot manure. J. Environmental Quality, 32: 1508-1515. DOI: 10.2134/jeq2003.1508

Lay Jr., D.C., R.M. Fulton, P.Y. Hester, D.M. Karcher and J.B. Kjaer *et al*., 2011. Hen welfare in different housing systems. Poultry Sci., 90: 278-294. DOI: 10.3382/ps.2010-00962

Lekasi, J.K., J.C. Tanner, S.K. Kimani and P.J.C. Harris, 2003. Cattle manure quality in maragua district, central kenya: Effect of management practices and development of simple methods of assessment. Agriculture, Ecosystems Environment, 94: 289-29. DOI: 10.1016/S0167-8809(02)00037-3

Liu, A., C. Hamel, R.I. Hamilton, B.L. Ma and D.L. Smith, 2000. Acquisition of Cu, Zn, Mn and Fe by mycorrhizal maize (*Zea mays* L.) grown in soil at different P and micronutrient levels. Mycorrhiza, 9: 331-336. DOI: 10.1007/s005720050277

Ludington, D.C. and A.T. Sobel, 1977. Storability of partially dried laying hen manure. Food, Fertilizer and Agricultural Residues, Produced by Cornell Agriculture Waste Management Conference, Loehr, R.C., (Ed.), Ann Arbor Science Publishers Inc. Michigan, Illinoise.

Marschner, H., 1995. Mineral nutrition of higher plants. 2nd Edn., Academic Press, London, ISBN-10: 0124735428, pp: 889.

Martin, S.A. and M.A. McCann, 1998. Microbiological survey of Georgia poultry litter. J. Applied Poultry Res., 7: 90-98.

Maskan, A., S. Kaya and M. Maskan, 2002. Hot air and sun drying of grape leather (pestil). J. Food Eng., 54: 81-88. DOI: 10.1016/S0260-8774(01)00188-1

McCaskey, T. A., A.L. Sutton, E.P. Lincoln, D.C. Dobson and J.P. Fontenote, 1985. Safety aspects of feeding animal wastes. In: Agricultural Waste Utilization and Management, ASAE Publication, Michigan.

McCauley, A., 2003. Commercial fertilizers and soil amendments. Nutrient Management Module 10. Montana State University Extension, Bozeman, Montana.

McConnell, D.D., A. Shiralipour and W.H. Smith, 1993. Compost application improves soil properties. BioCycle, 34: 61-63.

McKenzie, R.H., 1992. Micronutrient requirements of crops. Agriculture and Rural Development, Edmonton, Alberta.

Millaleo, R., M. Reyes-Diaz, A.G. Ivanov, M.L. Mora and M. Alberdi, 2010. Manganese as essential and toxic element for plants: Transport, accumulation and resistance mechanisms. J. Soil Sci. Plant Nutrition, 10: 470-481. DOI: 10.4067/S0718-95162010000200008

Nahm, K.H., 2003. Evaluation of the nitrogen content in poultry manure. World's Poultry Sci. J., 59: 77-88.

Nazghelichi, T., M.H. Kianmehr and M. Aghbashlo, 2010. Thermodynamic analysis of fluidized bed drying of carrot cubes. Energy, 35: 4679-4684. DOI: 10.1016/j.energy.2010.09.036

Pierson, S.T., M.L. Cabrera, G.K. Evanylo, H.A. Kuykendall and C.S. Hovel and *et al*., 2001. Phosphorus and ammonium concentrations in surface runoff from grasslands fertilized with broiler litter. J. Environ. Quality, 30: 1784-1789. PMID: 11577887

Placha, I., J. Venglovsky, N. Sasakova and I.P. Svoboda, 2001. The effect of summer and winter seasons on the survival of Salmonella typhimurium and indicator micro-organisms during the storage of solid fraction of pig slurry. J. Applied Microbiol., 91: 1036-1043. PMID: 11851811

Rao, P.S., S. Bal and T.K. Goswami, 2007. Modelling and optimization of drying variables in thin layer drying of parboiled paddy. J. Food Eng., 78: 480-487. DOI: 10.1016/j.jfoodeng.2005.10.019

Rappert, S. and R. Muller, 2005. Odor compounds in waste gas emissions from agricultural operations and food industries. Waste Manag., 25: 887-907. PMID: 16129591

Raschke, M., K. Burkle, N. Muller, A. Nunes-Nesi and A.R. Fernie *et al*., 2007. Vitamin B1 biosynthesis in plants requires the essential iron sulfur cluster protein, THIC. Proc. National Academy Sci. United States Am., 104: 19637-19642. PMID: 18048325

Raviv, M., S. Medina and Y. Shamir, 1999. Cocomposting-a method to improve results of poultry manure composting. Compost Sci. Utilization, 7: 70-73.

Rehm, G. and M. Schmitt, 2009. Copper for crop production. University of Minnesota. Minneapolis, Minnesota.

Ribeiro, A.M.L., A.M. Penz, T.K. Belay and R.G. Teeter, 2001. Comparison of different drying techniques for nitrogen analysis of poultry excreta, feces, and tissue. J. Applied Poultry Res., 10: 21-23.

Risse, L.M., M.L. Cabrera, A.J. Franzluebbers, J.W. Gaskin and J.E. Gilley *et al*., 2006. Land application of manure for beneficial reuse. Biol. Syst. Eng.

Ronan, E., 2007. Micro-elements in agriculture. Practical Hydroponics Greenhouses, 95: 39-48.

Rudd, J.J. and V.E. Franklin-Tong, 2001. Unravelling response-specificity in Ca^{2+} signalling pathways in plant cells. New Phytologist, 151: 7-33. DOI: 10.1046/j.1469-8137.2001.00173.x

Rygiewicz, P.T., C.S. Bledsoe and R.J. Zasoski, 1984. Effects of ectomycorrhizae and solution pH on [^{15}N]ammonium uptake by coniferous seedlings. Canadian J. Forest Res., 14: 885-892.

Shirley, R. and A. Butchbaker, 1975. A rotating conical screen separator for liquid solid separation of beef waste. Managing Livestock Wastes. Publication PROC 2-75. American Society of Agricultural Engineers (ASAE), St. Joseph, MI, USA.

Sims, J.T. and D.C. Wolf, 1994. Poultry waste management: Agricultural and environmental issues. Advances Agronomy, 52:2-72.

Sistani, K.R., D.M. Miles, D.E. Rowe, G.E. Brink and S.L. McGowen, 2001. Impact of drying method, dietary phosphorus levels, and methodology on phosphorus chemistry of broiler manure. Communications Soil Sci. Plant Analysis, 32: 2783-2793. DOI: 10.1081/CSS-120000961

Spectrum Analytic Inc., 2012a. Manganese basics. Spectrum Analytic Inc., Washington Court House, Ohio.

Spectrum Analytic Inc., 2012b. Soybean growth - nutrient management. Spectrum Analytic Inc., Wahington Court House, Ohio.

Sturgeon, L.E., 2008. Fertilizer value of densified broiler litter. Auburn University, Auburn, Alabama.

Sultenfuss, J.H. and W.J. Doyle, 1999. Functions of phosphorous in plants. Better Crops, 83: 6-7.

Tagoe, S.O., T. Horiuchi and T. Matsui, 2008. Effects of carbonized and dried chicken manures on the growth, yield, and N content of soybean. Plant Soil, 306: 211-220. DOI: 10.1007/s11104-008-9573-9

Tam, N.F.Y. and Y.S. Wong, 1995. Spent pig litter as fertilizer for growing vegetables. Bioresou. Technol., 53: 151-155. DOI: 10.1016/0960-8524(95)00074-O

Tanabe, Y., K. Tanaka and Z. Kato, 1985. Feeding poultry waste to chickens, swine and cattle. In: Agricultural Waste Utilization and Management, ASAE Publication, St. Joseph, Michigan, pp: 13-85.

Tewolde, H., K.R. Sistani and D.E. Rowe, 2005. Broiler litter as a sole nutrient source for cotton: nitrogen, phosphorus, potassium, calcium, and magnesium concentrations in plant parts. J. Plant Nutrition, 28: 605-619. DOI: 10.1081/PLN-200052633

Uchida, R., 2000. Essential nutrients for plant growth: nutrient functions and deficiency symptoms. In: Plant nutrient management in Hawaii soils, Silva, J.A. and R. Uchida, (Eds.), University of Hawaii, Manoa, pp: 31-55.

Van Brunt, J.M. and J.H. Sultenfuss, 1998. Functions of potassium in plants. Better Crops, 82: 4-5.

Vitosh, M.L., D.D. Warncke and R.E. Lucas, 1994. Secondary and micronutrients for vegetables and field crops. Michigan State University Extension, Lansing, Michigan.

Wang, G., T. Zhao and M.P. Doyle, 1996. Fate of enterohemorrhagic Escherichia coli O157:H7 in bovine feces. Applied Environmental Microbiol., 62: 2567-2570.

Waters, B.M. and R.P. Sankaran, 2011. Moving micronutrients from the soil to the seeds: Genes and physiological processes from a biofortification perspective. Plant Sci., 180: 562-574. DOI: 10.1016/j.plantsci.2010.12.003

Wen, B.P., A. Aydin, N.S. Duzgoren-Aydin, Y.R. Li and H.Y. Chen *et al*., 2007. Residual strength of slip zones of large landslides in the Three Gorges area, China. Eng. Geol., 93: 82-98. DOI: 10.1016/j.enggeo.2007.05.006

Zhang, W. and A. Lau, 2007. Reducing ammonia emission from poultry manure composting via struvite formation. J. Chemi. Technol. Biotechnol., 82:598-602. DOI: 10.1002/jctb.1701

Zhou, D., X. Hao, Y. Wang, Y. Dong and L. Cang, 2005. Copper and Zn uptake by radish and pakchoi as affected by application of livestock and poultry manures. Chemosphere, 59: 167-175.