Statement of Academic Integrity

We, hereby, declare that this thesis titled "Fertilizer Potential of Landfill MSW" is based on our original research work. We affirm that all the results and findings presented in this thesis are genuine and have not been manipulated or fabricated to suit any predetermined hypothesis or conclusion. All sources of information, data and ideas used in this thesis have been appropriately acknowledged and cited in accordance with the recognized academic conventions and referencing styles. Any direct quotations or paraphrased material from external sources are clearly identified and attributed to their respective authors. We have taken care to avoid plagiarism by providing proper citations and references for all works consulted, ensuring the intellectual property rights of other researchers and scholars are duly respected. The experimental procedures, methodologies, and analysis presented in this thesis are accurate, transparent, and faithfully represent the conducted research.

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Abstract

The effective management of landfill waste is crucial for achieving sustainable development goals. The landfill is an environmental hazard that contains a wealth of organic and inorganic materials. These materials can be harnessed to enhance soil fertility and support agricultural productivity. This study includes the determination of nutrients level and maturity parameters of the compost prepared from landfill waste to find out the eligibility of compost to be used as fertilizer. Moisture content (MC), pH, electrical conductivity (EC), nitrogen (N), carbon to nitrogen ratio (C/N), concentration of light and heavy metals and germination index were considered for physicochemical characterization of the sample. Some major findings are, C:N ratio- 90.73, 27.69 and 125.80, N-P-K ratio- 1.5:1:6.23, 11.18:1:7.61, 7.55:1:24.55 for 5 ft, 10 ft and 15 ft correspondingly. The result indicated the potential level of utility of the compost to be used as fertilizers. According to the study, the compost samples were matured enough which indicated the absence of phototoxicity. However, the result of other major parameters indicated that though the samples cannot be directly used as organic fertilizer, they can be used by some further treatment. It was recommended to apply some further decomposition treatments such as vermicomposting and co-composting to the samples in order to use them as organic fertilizer. The findings of this study will contribute to the sustainable waste management practices by transforming landfill MSW into a valuable resource for agriculture. By reducing dependence on chemical fertilizers and promoting organic alternatives, this research aims to enhance soil health, preserve natural resources, and foster sustainable food production systems

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Chapter 1
Introduction
1.1 Background
The rapid growth of the global population is exerting increasing pressure on food production and agricultural resources. As a result, there is a crucial need to explore alternative strategies that promote sustainable agriculture, ensuring food security while mitigating the environmental impact. One such strategy involves the utilization of landfill municipal solid waste (MSW) as a potential source of fertilizer.

Waste management has become a major concern over the last few years. As the rate of urbanization is increasing worldwide, waste is also increasing. Global statistics have shown an increase in solid waste from annually 0.68 billion tons to 1.3 billion tons just within 10 years (2000-2010). It is estimated annual solid waste generation will increase to 2.2 billion tons by the year 2025 and 4.2 billion tons by 2050 (Islam, 2016). As the population and industrialization of Bangladesh are increasing significantly, the amount of waste is also increasing. Thus, the requirement for managing these wastes is also rising. If the wastes are not handled properly and dumped randomly, they will cause a detrimental effect on the environment along with reducing the dumping area of waste. Dhaka city is already facing difficulties such as blocked roads and public areas, clogged drainage systems, and water contamination due to the uncontrolled dumping of solid wastes (Hai et al., 2005). These wastes can be turned into assets by treating them properly. Bangladesh already has taken steps to recycle and decompose solid wastes long ago from 1990 (Waste Report, 2019-20).

Bangladesh also published solid waste management regulations in 2021, including disposal and recycling of non-biodegradable products along with waste composting and energy recovery (Solid Waste Management Regulations, 2021). However, as the amount of municipal solid waste (MSW) is increasing quickly, these taken measures are not enough for treating solid waste. In urban areas of Bangladesh solid waste generation is daily 25,000 tons which are yearly 150 kg per capita. Dhaka city alone produces one-fourth of this total waste. Estimation shows that the generation rate of waste will be increased up to 47,000 tons/day within 2025. From different residential, industrial, and commercial areas, MSW is collected. Dhaka south city corporation (DSCC) dumps their waste in the landfill which is located at Matuail and Dhaka North City Corporation (DNCC) dumps them at Amin Bazar (Waste Report, 2019-20). For the disposal of MSW, the landfill method is widely used worldwide. However, due to the increasing amount of waste generation, these landfills are going to fill up which would require new landfill sites for upcoming MSW which is going to be costly in the current economy. Besides, methane gas can be produced or disease can be spread from these landfill wastes. That's why the waste should be recycled and used as compost if they are compatible enough.

1.2 Objectives

The specific objectives of this study are listed below.

- to explore the fertilizer potential of landfill MSW
- to investigate its chemical composition, nutrients concentration, presence of potential contaminants, maturity level.
- to find the eligibility of landfill MSW conversion into effective organic fertilizers.

Chapter 2

Literature Review

2.1 Waste Management

The conversion of landfill waste into organic fertilizer can contribute in management and reduction of waste. Landfill waste has mainly two parts. One is the non-biodegradable part which includes glass, plastic etc. which may be recycled and used for a construction site or pave tiles. Other is the organic part which can be turned into compost. In literature, most analysis has been done on fresh municipal solid waste (MSW) for treatment. There is hardly any research on landfill waste. But landfill waste should get more importance for being treated. Because they being on landfill for a long time, may have gain enough calorific value to be used as compost in agriculture. if they are compatible enough to be treated, space would be freed up in landfill sites which would be economically beneficial. This thesis work is intended to perform analysis on landfill waste and find their usefulness. The objective here is to check the parameters of the organic part collected from landfill waste in order to find out if they are adequate to be used as compost or not.

2.2 Characteristics of Landfill waste

The study of the physical and chemical properties of the waste is very important for better operation and management of landfill waste. Municipal solid wastes (MSW) are dumped at landfill sites. MSW is composed of food, fruits, wood, paper, plastic, clothes, polythene, glass, industrial waste, metals, etc. It can be classified into organic and inorganic materials. Inorganic parts can be recycled and turned into construction materials. According to the study, 25% of the inorganic waste is recyclable and 80% of the organic waste of fresh MSW is turned into compost and the remaining is left in landfills. Waste is in the landfill for a long time and thus organic content is reduced.

In developing countries, the moisture content in the waste is around 50-60%. In Dhaka city, it can be up to 80%. Higher moisture content prefers anaerobic conditions which make decomposition faster. Composting process depends on the chemical characteristics of waste such as the C/N ratio. The ideal C/N ratio is 20:1 to 25:1. Higher than that value slows down composting and a lower value causes loss of nitrogen. That’s why the C/N ratio would need some balancing before the waste composting process (Yousuf & Rahman, 2007).

2.3 Impact of Landfill Waste

MSW is disposed of following 3 major techniques- incineration, composting, and landfilling. Incineration is the method where the waste is burned in the presence of uncontrolled oxygen supply. Though this is the most efficient method, due to the need for large investment and a greater amount of technical content this process is not used much.

The landfill method is mostly used worldwide because of its low cost and easy operation (Yang R., et al). But as the amount of waste is increasing along with population, the landfill sites are becoming inadequate for handling this huge load of waste. In estimation, it was found that the landfilling area would be required 206.31 acres in 2020 for 50% collection efficiency and 309.46 acres for 75% collection efficiency. Without any steps of composting or others, the requirement for landfill space would increase in the upcoming years (Hai et al., 2005). In the present economy, lands are very costly. So this would cause a serious crisis.

Besides, landfilling may have many failures such as waste pile collapse and landslides due to high pore pressure and high leachate levels which may cause the destruction of a huge area and pose a huge threat to human life (Yang R. et al., 2018).

Solid waste is dumped in these landfill sites in the open air which is very unhygienic. It can cause aesthetic problems and nuisance along with spreading various diseases. Leachate sample collected from the landfill sites has shown a high concentration of chloride and fecal coliform which is very harmful and can pollute water bodies. At the landfill, as the organic solid waste compounds undergo anaerobic decomposition, methane gas is produced. Methane is a greenhouse gas. Thus it is harmful to the environment. Moreover, as methane is highly combustible, landfill sites are at risk of explosion (Hai et al., 2005) By composting the waste not only the amount of methane gas would be reduced but also other problems of landfilling would be solved by a large amount.

Composting is a very good method for MSW recycling. Dependency on landfill sites will be reduced by composting the landfill wastes. It requires high cost and high technical content in turning waste into compost. But as the waste is dumped in the landfills for a long time, it automatically turns into compost. Now, a study has to go through this compost if they are eligible to be used as organic fertilizer.

2.4 Compost Maturity

The degree of stability or maturity of a compost, which means a stable organic matter content and the absence of phytotoxic chemicals and plant or animal diseases, is the most important criteria for it to be utilized safely in soil. Maturity is connected to plant growth potential or phytotoxicity, whereas stability is linked to the microbial activity of the compost (Bernal et al., 1998). Compost maturity is becoming more widely acknowledged as a critical criterion for rating compost. Immature and inadequately stabilized composts are known to cause issues during storage, marketing, and use. Immature composts are or may become anaerobic in storage, resulting in smells and/or the formation of hazardous organisms. Compounds, as well as bag swelling and bursting, are all possible outcomes for immature compost. During shipment, immature composts may heat up in pallets. When these composts are put to soil or growth media, continued active decomposition may have detrimental effects on plant growth due to decreased oxygen in the soil-root zone, reduced available nitrogen, or the presence of phytotoxic chemicals (Brinton, 2016). So, Compost maturity is important.

A number of criteria and parameters for determining compost maturity have been presented, however the majority of them apply to composts made from municipal waste. Physical qualities such as color, odor, and temperature provide a general indication of the stage of decomposition reached, but they provide little information on the degree of maturation. Chemical approaches, such as measurement of the C/N ratio in the solid phase and in water extract, inorganic nitrogen, the cation exchange capacity, and the degree of organic matter humification, are extensively employed for this (Bernal et al., 1998). According to California Compost Quality Council (CCQC), a mature compost should have characteristics of composting process completion and little potential for detrimental consequences on plant development, the latter being carefully defined. The maturity index is based on "passing" two or more specific tests taken from two sets of criteria- Group A and Group B, as maturity is not characterized by a single property, according to the new definitions of CCQC (Brinton, 2016). Maturity index tests included in Group A and Group B are listed in Table 2.4.1-

Table 2.4.1: Classification of maturity index tests (Brinton, 2016)

C:N ratio <25	
Group A parameters	Group B parameters
1. CO_2 evolution 2. O_2 uptake 3. Dewar Self Heating Test	1. Ammonium: Nitrate Ratio 2. Ammonia concentration 3. Volatile Organic Acids 4. Plant test

2.4.1 Compost Maturity Parameters

Moisture content- One of the vital physical parameters for compost is moisture content. If the moisture content is too high, water can displace air from pore spaces, creating anaerobic areas inside the material. If the moisture content is too low, microorganisms won't be active. Additionally, excessive moisture contents may weaken the material matrix, making it easier to compress. So, moisture content should be maintained at an optimum value(Agnew & Leonard, 2003). Optimum moisture content for compost is in the range of 40%-65%, preferred range is 50%-60% (Garg & Tothill, 2009) . If there is enough air in the compost pile to meet the microbes' needs for oxygen, composting may be possible even when the moisture level is higher than 60% (Agnew & Leonard, 2003).

pH- Due to changes in chemical composition, the pH value varies during composting. In general, the pH goes below neutral in the beginning due to the synthesis of organic acids and increases above neutral subsequently due to the consumption of the acids and the production of ammonium. Optimum pH value of mature compost is 6.5-8. Acetic and lactic acids are formed during the storage of municipal solid waste, and these acids can drop the pH of source-separated organic waste to 4-5 (Sundberg, 2005)

Electrical Conductivity- Electrical conductivity (EC) is the most frequently measured electrical parameter of compost. This parameter indicates the material's overall salt (or electrolyte) content and, as a result, is of interest to the product's end users. The EC of the manure compost extract is in the range of 0.7 to 1.5 mS/cm and showed no phytotoxic effects on plants cultivated in the compost-soil mixture. EC levels greater than 5 mS/cm may cause phytotoxicity (Agnew & Leonard, 2003). Different values of electrical conductivity for different wastes are presented in Table 2.4.2-

Table 2.4.2: Electrical Conductivities (Agnew & Leonard, 2003)

Material	Conductivity Range (mS/cm)
Yard waste compost	1.1-1.9
Composted paper mill sludge	1.49-1.67
Aerobic sewage sludge	2.8-4.6
Organic city refuse	7.8-9.8
Grape debris	2.8-4.6
Two manure composts	3.62-3.65
Yard trimmings	1.5-3.3

Separated cattle manure	2.35-5.42
Cattle manure	1.2-1.4

C:N ratio- Carbon to nitrogen ratio (C:N) is the proportion of mass of carbon to nitrogen in a substance (USDA, 2011). The C:N ratio must be in the range of 20:1-40:1 to perform a successful composting process (on dry weight basis). Energy and protein production are fueled by carbon and nitrogen, respectively. When the C:N ratio is less than 20:1, the available carbon is entirely utilized, resulting in the creation of NH_3, which causes smell annoyance. When the C:N ratio surpasses 40:1, the breakdown of organic molecules is slowed due to a lack of nitrogen. The C:N ratio should be in the range of 25:1 to 30:1 for mature compost. Supplement material is added to meet the need if the raw material has an insufficient or excessive ratio (Garg & Tothill, 2009). C:N ratios for different materials are presented in Table 2.4.3-

Table 2.4.3: C:N ratios for different materials (Garg & Tothill, 2009)

Materials	C:N ratio
Vegetable waste	12-20:1
Fruit waste	35:1
Grass clippings	12-25:1
Leaves	40-80:1
Paper	150-200:1
Saw dust	100-500:1
Poultry manure	10:1

Macronutrients- Macronutrient includes N, P, K which are vital for plants. Total N includes total organic N which is TKN + NO_3-N determined by Kjeldahl digestion method because this method is a popular technique for determining total N. (Imunication, 1974). Amount of P and K are also important for compost which are measured using different modern techniques like UV spectrophotometry and flame photometer.

Micronutrients and heavy metals- Micronutrients include Ca, Mg, Zn, Cu, Fe, Mn, Co, B and heavy metals include As, Pb, Cd, Ni, Cr, Hg etc. Amount of these elements are measured using atomic absorption spectrophotometry. Proposed standard values of concentration of heavy metals for MSW compost in developing countries are given in Table 2.4.4-

Table 2.4.4: Concentrations of heavy metals in compost (Hoornweg, n.d.)

Metals	Proposed standard concentrations for MSW compost in developing countries (mg/kg dw)
As	10
Cd	3
Cr	50
Pb	150
Ni	50
Zn	300
Cu	80
Hg	1

NH_4-N to NO_3-N ratio- The presence of considerable amounts of Nitrate-N indicates that the compost is maturing and that oxidizing agents are still present. By several times, the level of nitrate-N in completely mature composts exceeds the quantity of ammonium-N. As a result, the ammonium to nitrate ratio is a valuable measure for determining maturity. Ammonium-N to Nitrate-N ratio should be 0.5-3.0 for mature compost. If the ratio is <0.5, the compost is very mature, if the ratio is >3.0, the compost is immature (Brinton, 2016)

2.4.2 Compost Maturity Indicator

Germination Index (GI)

One of the most essential criteria for determining the suitability of compost is to determine phytotoxicity of compost to avoid environmental hazard. The best technique to test phytotoxicity is to measure germination index (GI). The result of this test are obvious and efficient. Germination bioassays are commonly used to check for salinity, soil pathogens, poisonous compounds, and other physical and chemical features of compost, all of which could be substantial contributors to phytotoxicity (Selim et al., 2012).

The germination index is a maturity test that uses a liquid extract from the compost to measure seed germination and initial plant growth. It depicts the phytotoxicity of compost extracts at various phases of the composting process. When compared to the control with distilled water, the compost is termed mature when the germination index is greater than 60%. When the germination rate is greater than 85% and the plant seedling weights are greater than 90%, the compost is non-toxic. Germination index of 80% indicates the disappearance of phytotoxicity.

The percentage of seed germination, root elongation and germination index are calculated according to the following formulas (Selim et al., 2012) -

Seed germination (%) = $\frac{no.of\ seeds\ germinated\ in\ extract}{no.of\ seeds\ germinated\ in\ control} \times 100 \quad \ldots\ldots\ldots\ldots\ldots (1)$

Root elongation (%) = $\frac{mean\ root\ lengt\ \ \ in\ extract}{mean\ root\ lengh\ \ \ in\ control} \times 100 \quad \ldots\ldots\ldots\ldots\ldots (2)$

Germination Index (GI) = $\frac{seed\ germination\ (\%) \times root\ elongation\ (\%)}{100} \quad \ldots\ldots\ldots\ldots\ldots (3)$

The GI values should be evaluated with caution because they are influenced by the type of seed used and the compost source.

Chapter 3

Experimental Methodology

3.1 Introduction

This chapter includes the experimental methods and procedures for determining moisture content, pH, conductivity, amount of nutrients, heavy metals and phototoxicity level for evaluating compost maturity of landfill MSW. From the top of a 60-foot pile of landfill waste, three samples of waste were collected at heights of 5 feet, 10 feet, and 15 feet. These wastes were converted into compost. Then the experimental analysis was performed on the compost sample to find their eligibility for use as fertilizer. Most of the experiments were performed following the standard ASTM methods.

3.2 pH

To measure the pH of the samples, 10% solution was prepared. In a beaker, 10 g of the sample was taken in 100 mL water in a beaker. Then the solution was stirred rigorously to properly mix the chemical components into water. There were some solids such as dust particles or soil which were insoluble. So, the solution was filtered out and only the liquid solution was taken for analysis. Before measuring the pH of the sample, the pH meter was calibrated using a buffer solution. Then the probe of the pH meter was placed into the beaker and was allowed to stabilize to ensure accuracy. Then the pH value was recorded in a scale of range 0-14. These steps were repeated for each of the three samples. For each sample, the experimental process was repeated 3 three times and 3 sets of data were collected.

3.2 Electrical Conductivity

The previously prepared 10% solutions were used for measuring the conductivity of the sample. Then the samples were filtered out and the conductivity meter was placed inside the filtered solution. Then conductivity values were recorded in µS/cm. These steps were repeated for each of the three samples. For each sample, the experimental process was repeated 3 three times and 3 sets of data were collected.

3.3 Moisture Content

The moisture content of three samples was measured in Moisture Analyzer. In this apparatus, definite amount of solid samples is weighed and placed inside it. Then it was heated for a definite time at a specific temperature. Then the moisture content was recorded. This procedure was repeated for each of the three samples -

- The 5 ft sample was weighed 2.037 g and kept inside the moisture analyzer for 9 minutes and 50 seconds at 120 ^{0}C. Then the moisture content was recorded.
- The 10 ft sample was weighed 2.62 g and kept inside the moisture analyzer for 9 minutes and 48 seconds at 120 ^{0}C. Then the moisture content was recorded.
- The 15 ft sample was weighed 2.413 g and kept inside the moisture analyzer for 12 minutes and 36 seconds at 120 ^{0}C. Then the moisture content was recorded.

This moisture content was measured in the initial days of the experiment. After that, before any test, the moisture contents were again measured to find their variation in order to use them to convert wet basis into dry basis calculation.

3.4 Elements and Ion Measurement

To measure various metals, nutrients, heavy metals and ions, the samples were digested by ASTM method 3050B- "acid digestion of sediments, sludges and soil." Following this method, 2 g of a sample was weighed and taken into a digestion vessel. Then 10 mL of 1:1 HNO_3 and water was added to the digestion vessel. Then the digestion vessel was placed on a heater by covering it with a watch glass. The sample was heated at around 100 ^{0}C. and refluxed for 10 to 15 minutes without boiling. Then the sample was allowed to cool down and 5 mL of concentrated HNO_3 was added to the solution, covered by watch glass and refluxed for 30 minutes. Then it was again allowed to cool down. If brown fumes were generated, the steps were repeated again until no brown fumes are given off by the sample indicating a complete reaction with HNO_3. When there are no more brown fumes, then the sample was heated till half of the initial volume-produced without covering the vessel with a watch glass. Then the remaining solution was cooled down and filtered by the Whatman 42 filter paper. Then distilled water was added to it to make it a 1L solution.

Using the digested solution, Na and K were measured by the flame photometry method. Ca, Mg, Cd, Pb and Cr were measured by Atomic Absorption Spectrometry (AAS) method. The remaining elements such as Cu, Zn, Ni, Co, Mn, Fe, P, B etc. were measured in the DR6000 UV VIS Spectrometer using the digested sample solution. Hg was measured using Cold Vapor Atomic Absorption Spectroscopy (CVAAS) after digesting the sample with a mixture of H_2SO_4 acid and $K_2Cr_2O_7$ solution. Hg is highly volatile, so the digestion was done at lower temperature (40-50 °C). Hg was usually present as oxides of Hg, so $K_2Cr_2O_7$ solution was added to reduce Hg compound so that free Hg can be measured in CVAAS apparatus.

To measure the NO_3^- – N ratio, NH_4^+, NH_3-N ratio, $NO_3^-$and NH_3, the acid-digested solution was not used but a different approach was used. In that approach, three solutions were made by dissolving 1g, 2g and 5g solid samples into 100 mL distilled water and heated at around 50 ^{0}C for a short time to make sure those components mix properly into the solution. Then they were filtered and those components were measured using the filtered solution by DR6000 UV-VIS Spectrometer.

3.5 Germination Index Test

To conduct this test, 5 solutions of different concentrations were prepared for each of the 3 samples. These concentrations are 10%, 20%, 40%, 50%, 60%. To make a 10% solution, 10 g (wet basis) solid sample in added to 100 mL of distilled water. To make 20%, 40%, 50% and 60% solution, respectively 20 g, 40 g, 50 g and 60 g (wet basis) solid samples were added to 100 mL of distilled water. Then the solutions were stirred for 1 hr in a glass beaker. Then the extracts were made by filtering the solution using the Whatman 42 filter paper. 5 Petri dishes for each solution were lined with Whatman 42 filter paper. 10 mL of the extract was added to each petri dish while the control received 10 mL of deionized water. Radish seeds were used for germination which were soaked overnight. 10 radish seeds were placed on damp filter paper in each petri dish. The Petri dishes were then sealed with aluminum foil to prevent water loss while allowing air penetration. After that, they were kept in the dark for 96 hours at room temperature for germination. The percentage of seed germination, root elongation and germination index (GI) was calculated according to Zucconi et al. (1981a) by the following formula-

Seed germination (%) = $\frac{no\ of\ seeds\ germinated\ in\ extract}{no\ of\ seeds\ germinated\ in\ control} \times 100$ …………(1)

Root elongation (%) = $\frac{mean\ root\ length\ \ in\ extract}{mean\ root\ lengt\ \ \ in\ control} \times 100$ …………(2)

Germination Index =$[seed\ germination(\%) \times root\ elongation\ (\%)]\ /100$ ………….(3)

Chapter 4
Results and Discussions

4.1 Introduction

This thesis was done on the purpose of finding characteristics for landfill municipal solid wastes to use it as fertilizer. The characteristics that were measured are – Physicochemical parameters (pH, electrical conductivity, moisture content), maturity parameters (C: N, NO_3-N/NH_4-N ratio), maturity indicator (germination index), macro nutrients (N, P, K) concentration, micro nutrients concentration (Cu, Zn, Ni, Co, Mn, Fe, Na, B, Ca, Mg, S), heavy metals concentration (As, Pb, Cd, Hg, Cr). Different test procedures were followed. Results found from the tests are presented and discussed below.

4.2 Physicochemical parameters

pH in 10% (W/V) solution

pH was measured for 3 samples taken from 3 different depth of pile by making 10% (W/V) solution of dry sample. Digital pH meter was used for this purpose. pH meter was calibrated before measuring the pH of sample solutions. pH results are shown as bar charts (with error bars) in Figure 4.2.1 (A).

For samples taken from the depth of 5 ft, 10 ft and 15 ft, pH values are 5.216 ± 0.04, 5.436 ± 0.02, 5.736 ± 0.31. pH values increase gradually. pH should be in the range of 6.5- 8 for appropriate microbiological activity in composting process (Bhagwan et al., 2008) . As the samples were collected from landfills, organic acids might be in higher amount and the pH of the solutions are in acidic range. Again, 15 ft sample has higher pH comparative to two other samples. It can be said that amount of organic acid is higher at surface and decreases with depth of pile. Primary treatment can be done to increase the pH by adding alkaline compounds like limestone.

Electrical conductivity in 10% (W/V) solution

Electrical conductivity was measured for 3 samples by making 10% (W/V) solution of dry sample. Digital EC meter was used for the measurement. Before measurement, EC meter was calibrated. Electrical conductivity is plotted against depth from pile surface to show the trend of change in EC. Results are shown as bar charts (with error bars) in Figure 4.2.1 (B).

Electrical conductivity at depth of 5 ft, 10 ft and 15 ft are 11.037 ± 0.03 μS/cm, 12.46 ± 0.15 μS/cm and 8.33 ± 0.35 μS/cm correspondingly. Conductivity is higher for 5 ft and 10 ft samples comparative to 15 ft. For mature compost, electrical conductivity should be in the range of 0.7

to 1.5 mS/cm. (Agnew & Leonard, 2003). Measured values are quite lower than the required values. To meet the EC requirement, ion concentration can be increased in the samples. As sample collected from the depth of 15 ft has lowest value of conductivity, this sample needs more treatment if it is used as organic fertilizer.

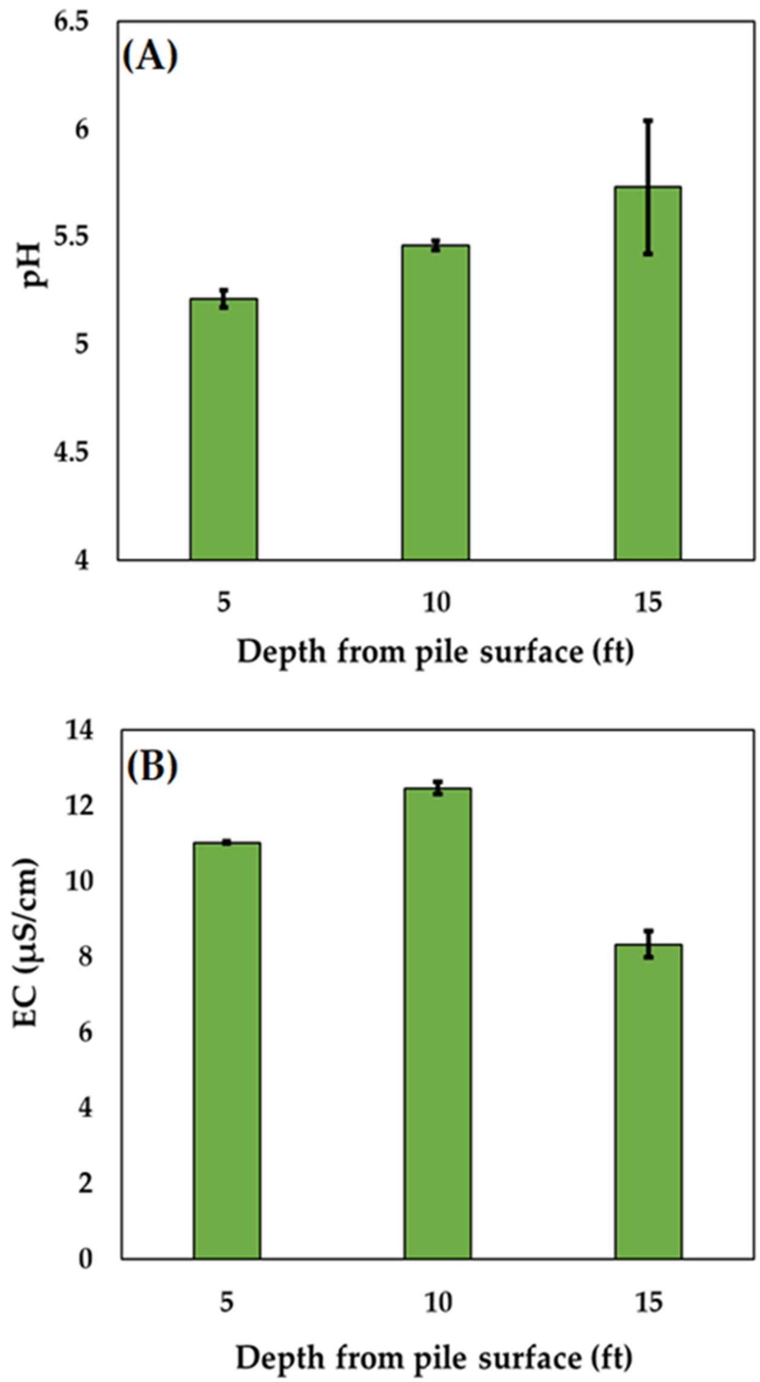

Figure 4.2.1: (A) pH and (B) electrical conductivity of samples taken from different depths of pile

Moisture Content

Moisture content was measured by moisture analyzer. Initially, the moisture content was higher. For samples at depth of 5 ft, 10 ft and 15 ft, initial moisture contents are 28.96%, 25.84% and 28.58% correspondingly. Moisture content was also measured before measuring nutrient concentrations and other parameters. As mentioned in section 2.4.1, optimum moisture content for compost is 40% - 65%. In that case, moisture content is very low comparative to the requirement for composting. Reasons of lower moisture contents in the sample might be – Excessive drying, improper storage of samples. These problems can be overcome by controlled drying of landfill wastes during composting process, store them in covered storage etc. All of these physicochemical parameters are enlisted in Table 4.2.1.

Table 4.2.1: pH, Electrical Conductivity and initial moisture contents

Depth from pile surface (ft)	pH	Electrical Conductivity (µS/cm)	Initial Moisture Content (%)
5	5.216 ± 0.04	11.037 ± 0.03	28.96
10	5.436 ± 0.02	12.460 ± 0.15	25.84
15	5.736 ± 0.31	8.330 ± 0.35	28.58

4.3 Maturity Parameters

4.3.1 C:N ratio

C:N ratio is one of the major parameters for composting. C, N and H were measured on dry mass basis in CHNS analyzer. Average C:N ratio are calculated from the measured values and are the results are plotted as bar chart. The chart is shown in Figure 4.3.1.

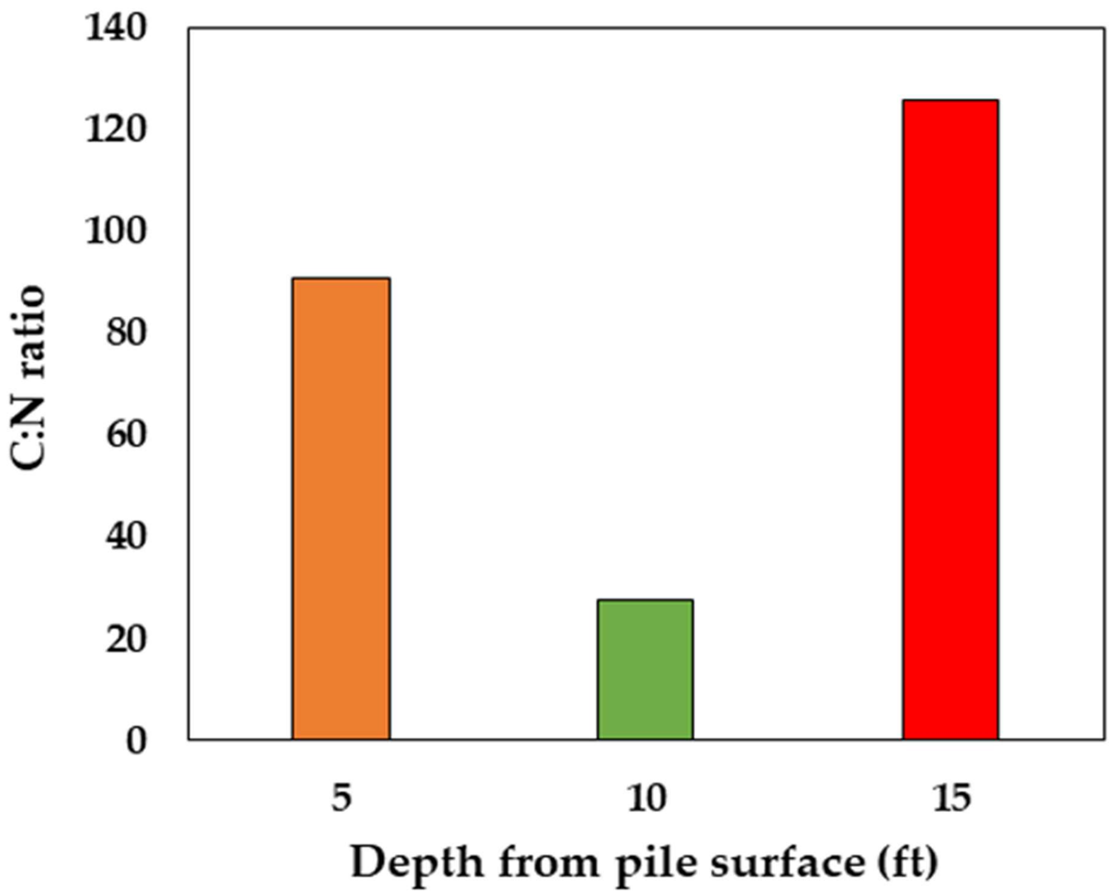

Figure 4.3.1: C:N ratio for samples taken from different depths of pile

According to literature data, optimum C:N ratio for matured compost is less than 20:1. Values in the range of 20:1 – 40:1 is reasonable. Higher C:N ratio denotes higher percentage of C which means lack of N and breakdown of organic matter slows down because of lack of N(Garg & Tothill, 2009). C:N ratio in sample collected from 10 ft is quite reasonable, C:N ratio in samples collected from 5 ft and 15 ft are higher than that range. So samples collected from the depth of 10 ft can be used for co-composting. Supplement material can be added to reduce excessive ratio.

4.3.2 Ammonium-N to Nitrate-N ratio

Ammonium-N to Nitrate-N is another important parameter. This ratio was measured for 3 samples at different concentrations after drying them and making the solution of dry samples. These values were also measured for blank solution, then measured values were adjusted by subtracting the blank values. The obtained results are shown as bar chart in Figure 4.3.2.

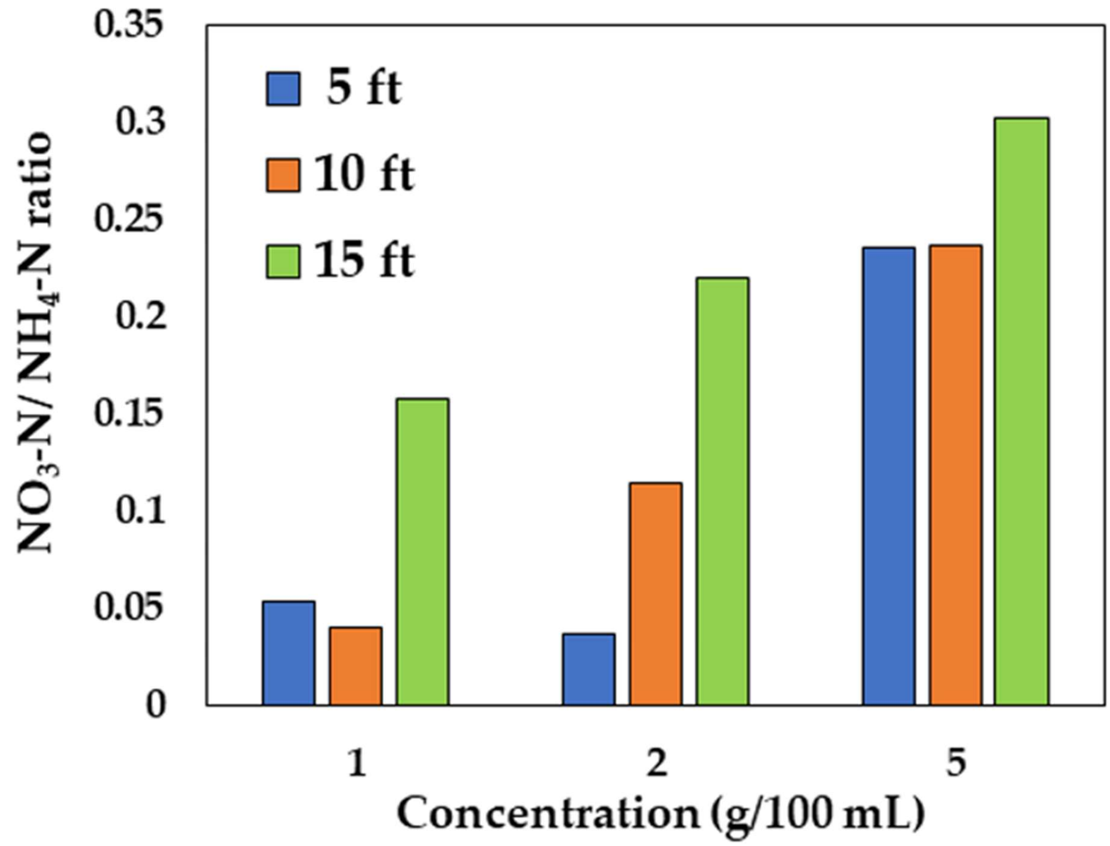

Figure 4.3.2: Change in Ammonium-N to Nitrate-N ratio with increase in concentration

As mentioned in literature review, NO_3-N/ NH_4-N ratio should be in the range of 0.5-3.0 for mature compost. If the ratio is less than 0.5, the compost is said to be very mature (Brinton, 2016). For landfill MSW, the value is less than 0.5 upto 5 g/100 mL solution. For samples collected from the depth of 10 ft and 15 ft, NO_3-N/ NH_4-N ratio shows increasing pattern. For the samples collected from the depth of 5 ft, NO_3-N/ NH_4-N ratio decreases at 2 g/100 mL and then increases. To obtain optimum NO_3-N/ NH_4-N ratio, highly concentrated solution may be required but toxicity will be higher at highly concentrated solution. So, these landfill wastes cannot be applied directly as compost. It can be used in co- composting. Test results are given in Appendix-A, Table A.5.

4.4 Nutrient Concentrations

4.4.1 Macronutrient concentrations

Macro nutrient are usually the vital nutrients for plants such as N, P and K. A mature compost should contain optimum amounts of macro nutrients. To determine fertilizer potential, different experiments were done to measure concentrations of N, P and K in samples collected from landfills. Before every measurement, the samples were made dry. N was measured at CHNS analyzer, P was measured in UV Vis Spectrometer and K was measured in Flame Photometer. Acid digestion was done before measuring P and K. Result of the N, P, K measurement are plotted as bar charts (with error bars) shown in the Figure 4.4.1.

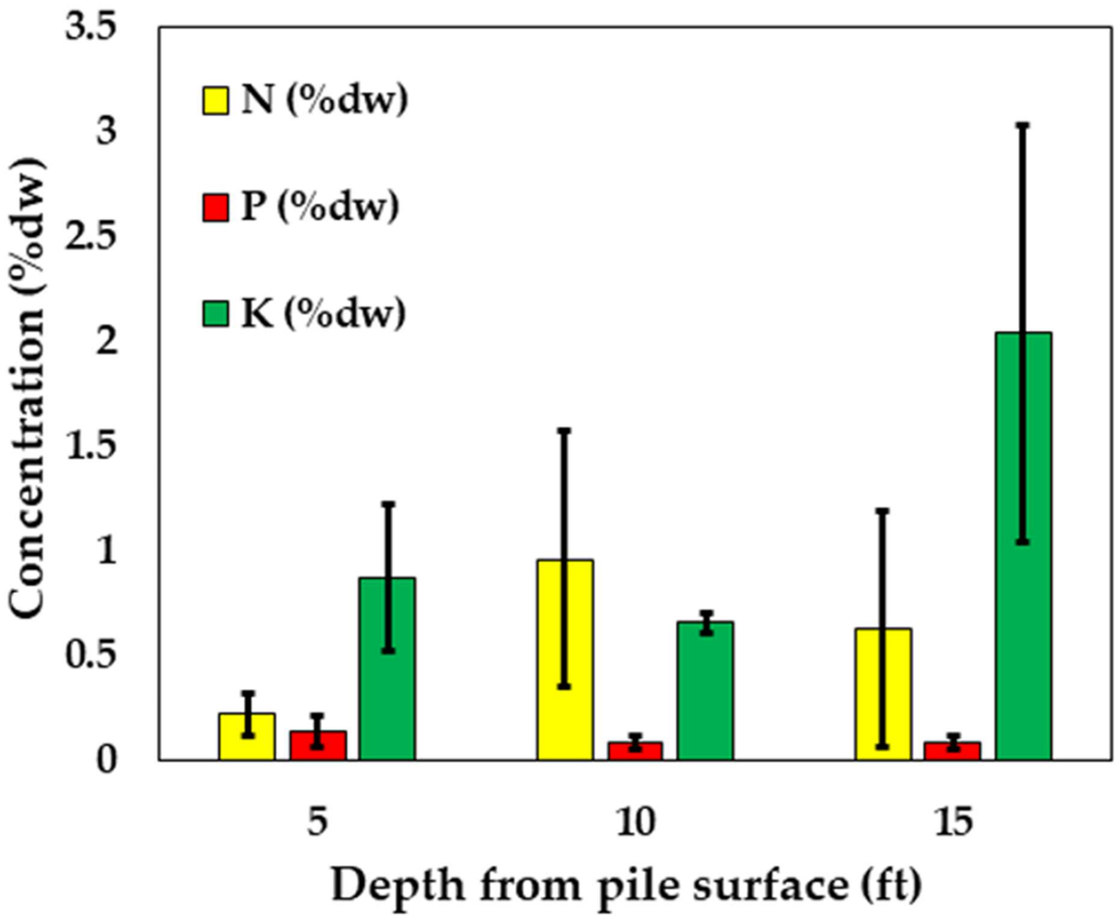

Figure 4.4.1: Macronutrient concentrations in samples taken from different depths of pile

Figure 4.4.1 shows that N (% dw) increases at the depth of 10 ft and again decreases at 15 ft. P (% dw) decreases with depth of pile. K (% dw) decreases at the depth of 10 ft and again increases. K concentration is highest at 15 ft which is 2.038 % (dw). The calculated results are shown in Table 4.4.1.

Table 4.4.1: Macronutrient concentrations and N-P-K ratio

Depth from pile surface (ft)	N (%dw)	P (%dw)	K (%dw)	N-P-K ratio
5	0.22 ± 0.10	0.14 ± 0.076	0.873 ± 0.352	1.5:1:6.23
10	0.96 ± 0.61	0.086 ± 0.033	0.655 ± 0.048	11.18:1:7.61
15	0.62 ± 0.56	0.083 ± 0.032	2.038 ± 0.990	7.55:1:24.55

A study shows that, N-P-K concentration at ideal condition for solid waste composting where sawdust, sewage sludge and vegetable wastes were used as raw material, is 9.62%, 8.97% and 5.62% (Asadu et al., 2019). It means N-P-K ratio would be 1.71:1.59:1. For organic fertilizers, recommended N-P-K ratio is 3:1:2 (*NPK Ratio for Vegetables - Fertilizer 101 | Gardens Alive!*, n.d.). For this study, N-P-K ratio does not match with the studies. So, this landfill samples cannot be used as fertilizer directly to agricultural field. Rather it can be used after co-composting with other organic materials.

4.4.2 Micro nutrient concentrations

Micro nutrients include Cu, Zn, Ni, Co, Mn, Fe, Na, B, Ca, Mg and S. These nutrients were measured after digesting the solid samples. UV Vis Spectrometer, Flame Photometer, Atomic Absorption Spectrometer were used. Obtained result are shown below as a bar chart (with error bars) in Figure 4.4.2.

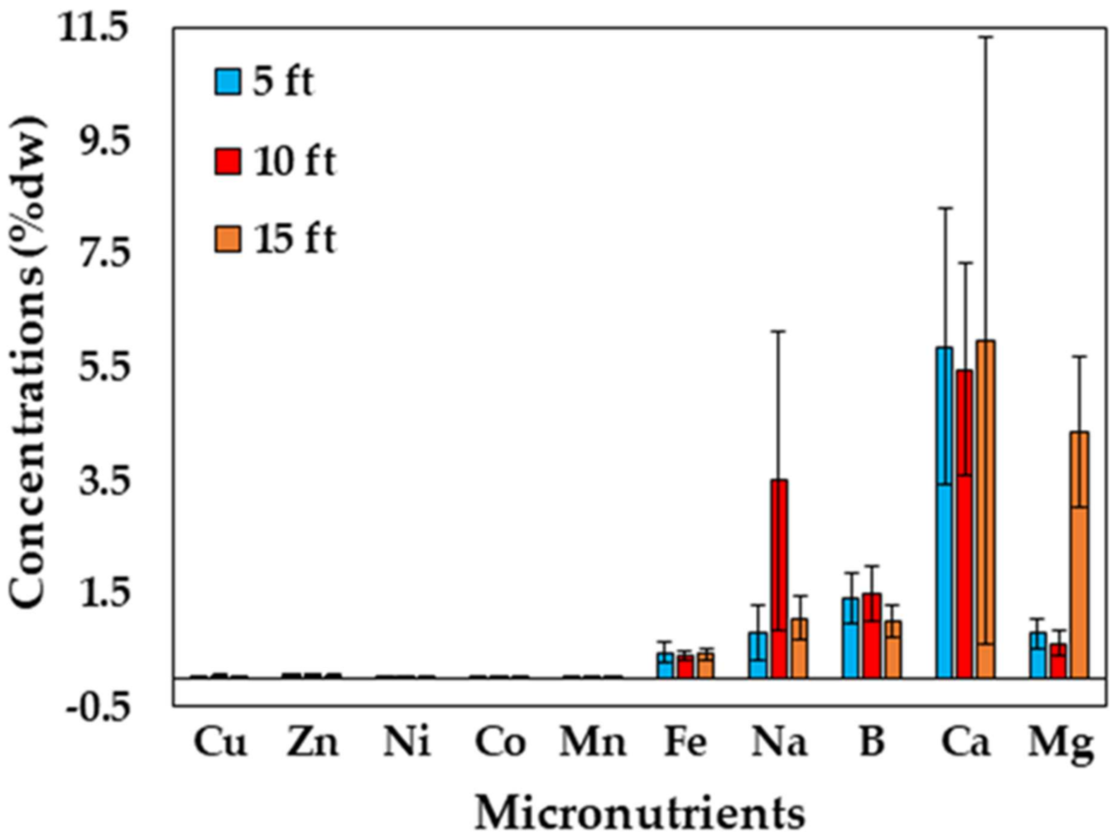

Figure 4.4.2: Micronutrient concentrations

The Figure 4.4.2 shows comparatively higher concentrations for Na, Ca, Mg and B. On the other hand, Co, Ni, Cu, Zn, Mn has lower values. Concentration of Ca is higher in all the samples. S is absent in samples. Average concentrations of the nutrients are given in Table 4.4.2. The concentrations were calculated in % dry weight basis.

Table 4.4.2: Micronutrient concentrations

Nutrients Concentrations (% dry weight basis)	Depth from pile surface (ft)		
	5	10	15
Cu	0.029 ± 0.011	0.043 ± 0.020	0.031 ± 0.012
Zn	0.061 ± 0.015	0.062 ± 0.023	0.050 ± 0.023
Ni	0.004 ± 0.0006	0.004 ± 0.0006	0.003 ± 0.001
Co	0.002 ± 0.001	0.013 ± 0.008	0.011 ± 0.004
Mn	0.020 ± 0.002	0.015 ±0.005	0.018 ± 0.003
Fe	0.460 ± 0.179	0.389 ± 0.079	0.440 ± 0.099
Na	0.819 ± 0.488	3.489 ± 2.637	1.061 ± 0.388
B	1.418 ± 0.448	1.492 ± 0.492	1.025 ± 0.284
Ca	5.858 ± 2.445	5.464 ± 1.869	5.974 ± 5.351
Mg	0.789 ± 0.259	0.623 ± 0.208	4.347 ± 1.322

4.4.3 Heavy metals

Heavy Metals include As, Pb, Cd, Hg, Cr. As was tested in DR6000 UV VIS Spectrometer. Hg was measured using Cold Vapor Atomic Absorption Spectroscopy (CVAAS). Pb, Cd and Cr were measured in Atomic Absorption Spectrometer. The solid samples were dried and digested before measurements. As and Hg were absent in all the 3 samples. The results are given in Table 4.4.3.

Table 4.4.3: Heavy metals concentrations

Heavy metals Concentrations (% dry weight basis)	Depth from pile surface (ft)		
	5	10	15
Cr	0.0027 ± 0.002	0.023 ± 0.038	0.0003 ± 0.0005
Pb	0	0.00027 ± 0.000025	0
Cd	0.0009 ± 0.00002	0.0004 ± 0.000075	0.00036 ± 0.000053

Table 4.4.3 shows heavy metal concentrations in % dry weight basis. Average concentrations for these materials in mg/kg dry basis are listed below-

5 ft: Cr – 27 mg/kg dw, Pb – 0 mg/kg dw, Cd – 9 mg/kg dw

10 ft: Cr – 230 mg/ kg dw, Pb – 2.7 mg/kg dw, Cd – 4 mg/kg dw

15 ft: Cr – 3 mg/kg dw, Pb – 0 mg/kg dw, Cd – 3.6 mg/kg dw

Comparing these results with Table 2.4.4, it can be said that the concentrations are below the standard threshold limit of heavy metals except Cr concentration at 10 ft. So, the results are acceptable.

4.5 Germination Index

To perform the germination index (GI) test, 5 solutions of different concentrations for each sample were prepared. The concentrations are- 10%, 20%, 40%, 50% and 60% on dry weight basis. For this test, 10 radish seeds were used in each petri dish containing the extract of different solutions. Then the number of seeds germinated and root elongation for each seed at every petri dish were assessed. The tendency of germination index changing was observed. For the 10 ft sample, GI initially increased from lower to higher concentration. For the 10% solution of the 10 ft sample, GI was 145. As the GI was >80, it indicated that the compost was fully matured and the phototoxicity level in that sample was absent. The highest value of GI was observed at 40% solution which was 216, as shown in Figure 4.5.1(C). That means when the extract of 40% solution was used, the radish seeds germinated higher in number and they gained higher root growth than the other ones. When the concentration of the solution prepared from that sample was further increased to 50% and 60%, GI was decreasing. For 60% solution GI decreased to 75 which indicates that even if the sample was matured, there might be some presence of phototoxicity. Here, it can be concluded that 40% solution would be a better choice for achieving higher seed germination and root growth for the 10 ft sample.

The same trend was followed by the germination index of 15 ft solution. It also had lower germination index of 120 for 10% solution which increased till 40% solution to a value of 209. It has shown decreasing GI value for concentrations higher than 40%. Also for 15 ft solution, extract from 40% solution would support better seed germination and root growth.

The tendency of changing the germination index (GI) was not the same for the 5 ft solution. It showed a different pattern. For 10% solution, GI was highest at 220 which indicated mature compost free of phototoxicity. When the concentration was increased to 20% and 40%, GI as decreasing. GI here was the lowest at 40% solution. It was 72 indicating the presence of phototoxicity. But higher concentrations-50% and 60% showed again the higher value of GI. These values indicated that for the 5ft sample lower concentrations (10%) and higher concentrations (> 40%) would be better for seed germination. At 40%, germination would be too low and phototoxic components also might be present.

The difference of 5 ft sample with 10 and 15 ft samples might be due to the variation in the presence of different nutrients, chemical components and phototoxicity levels.

Root elongation (%), seed germination (%) and Germination Index (GI) are plotted against concentration of solution for 5 ft, 10 ft and 15 ft samples correspondingly and shown in Figure 4.5.1.

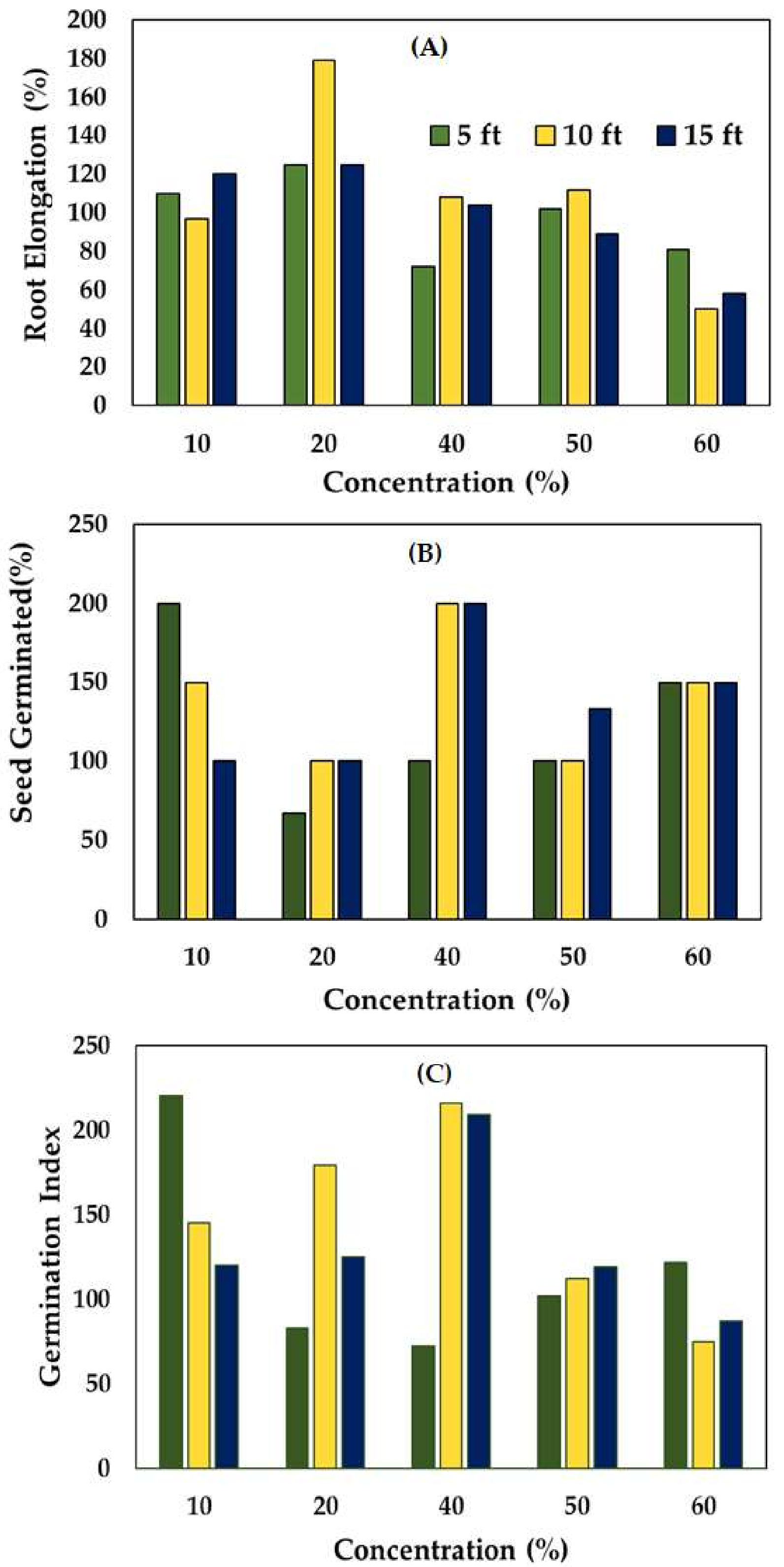

Figure 4.5.1: (A) Root Elongation, (B) Seed Germination in the extract of solutions, and (C) Germination Index over different concentrations for different samples

Calculated results for different concentrations are given in Table 4.5.1 to Table 4.5.5-

Table 4.5.1: Calculated data of Germination Index (for 10% solution)

Depth of pile from surface (ft)	5	10	15
Seed germination (%)	200	150	100
Root elongation (%)	110	97	120
GI	220	145	120

Table 4.5.2: Calculated data of Germination Index (for 20% solution)

Depth of pile from surface (ft)	5	10	15
Seed germination (%)	67	100	100
Root elongation (%)	125	179	125
GI	83	179	125

Table 4.5.3: Calculated data of Germination Index (for 40% solution)

Depth of pile from surface (ft)	5	10	15
Seed germination (%)	100	200	200
Root elongation (%)	72	108	104
GI	72	216	209

Table 4.5.4: Calculated data of Germination Index (for 50% solution)

Depth of pile from surface (ft)	5	10	15
Seed germination (%)	100	100	133
Root elongation (%)	102	112	89
GI	102	112	119

Table 4.5.5: Calculated data of Germination Index (for 60% solution)

Depth of pile from surface (ft)	5	10	15
Seed germination (%)	150	150	150
Root elongation (%)	81	50	58
GI	122	75	87

Chapter 5

Conclusion and Recommendations

5.1 Conclusion

Landfill wastes have higher portion of organic parts and it decomposes with time. Decomposed organic part may possess potentiality of using it as organic fertilizer in agricultural fields. Key findings of this thesis topic were done for the organic part of landfill wastes to measure different parameters relatable to compost maturity. Preliminary findings were done to find out a way for managing the large amount of landfill wastes, to make the organic portions reusable and to reduce dependency on chemical fertilizers. Three samples were collected from different depth of landfill piles – 5 ft, 10 ft and 15 ft. Then the organic portions were separated from non-biodegradable portion. Different experimental tests were done for these 3 samples to find physicochemical parameters, compost maturity parameters, compost maturity indicator and nutrient concentrations. Physicochemical parameters are found lower than the optimum values. It signifies that, the organic portion of landfill wastes need further treatment to increase its pH, EC and moisture content. Compost maturity parameters including C:N ratio and NO_3-N/ NH_4-N ratio were calculated based on different experimental methods. C:N ratio came 90.73, 27.69 and 125.80 which denotes further decomposition is needed to reach the optimum values. NO_3-N/ NH_4-N ratio came lower as the samples were rich in organic C. Nutrient concentrations were measured for macronutrients, micronutrients and heavy metals. Though heavy metal concentrations were lower which is good for fertilizers, macronutrient and micronutrient concentrations were insufficient. N-P-K ratio came 1.5:1:6.23, 11.18:1:7.61, 7.55:1:24.55. One of the compost maturity indicators is germination index (GI) was also calculated for solutions having different concentrations of the 3 samples such as 10%, 20%, 40%, 50% and 60% on dry weight basis. Radish seeds was used for measuring germination index. Germination index found higher in 40% solution. GI decreased after increasing the concentration of solution as concentration of toxic materials also increased and toxicity built up which inhibits seed germination. The test results obtained from the above experiments implies that these samples cannot be used directly to agricultural fields. Besides landfill wastes can be used after further treatment such as by vermicomposting process using earthworms, by co-composting with other organic components like animal manure, faecal sludge, crop residues which will increase values of C:N ratio and NO_3-N/ NH_4-N ratio. Modification of pH, electrical conductivity will increase the fertilizer potentiality of landfill MSW and will be made the compost favorable to soil environment.

5.2 Recommendations

This study is done on landfill solid wastes instead of fresh municipal solid wastes because landfill wastes have become a major concern nowadays as landfilling consumes large amount of lands and also causes environment pollutions like soil pollution, water pollution. To face this issue, potentially of the landfill organic wastes as fertilizer have been examined and some primary parameters have been found out. Based on these preliminary findings, elaborate studies can be done to give landfill MSW an economic value and to make large scale production of organic fertilizer from these wastes. Some future studies are recommended below-

- Study of vermicomposting of landfill MSW.
- Study of co-composting of landfill MSW with animal manure, crop residues and faecal sludge and detailed characterization of the co- composted products.
- Study of finding optimum composition of landfill organic wastes for large scale production of organic fertilizer.

A proposed pathway of managing the landfill wastes is presented in Figure 5.2.1.

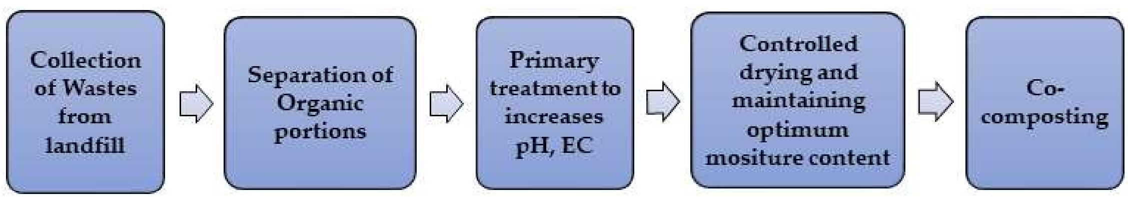

Figure 5.2.1: Proposed pathway for making organic fertilizer from landfill wastes

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Appendices

Appendix-A

Data Tables

Table A.1: pH for different samples

Depth from pile surface (ft)	pH	Average pH	Standard Deviation
5	5.18	5.216	0.04
	5.21		
	5.26		
10	5.44	5.463	0.02
	5.46		
	5.49		
15	5.38	5.736	0.31
	5.85		
	5.98		

Table A.2: Electrical Conductivity for different samples

Depth from pile surface (ft)	Conductivity (µS/cm)	Average conductivity (µS/cm)	Standard Deviation
5	11.01	11.036	0.03
	11.02		
	11.08		
10	12.34	12.460	0.15
	12.40		
	12.64		
15	8.10	8.333	0.35
	8.16		
	8.74		

Table A.3: Initial moisture content of the samples

Depth from pile surface (ft)	Moisture content (%)
5	28.96
10	25.84
15	28.58

Table A.4: C:N ratio on dry mass basis

Depth from pile surface (ft)	C (%)	N (%)	H (%)	C: N	Average
5	14.402	0.258	4.987	55.82	90.73
	15.203	0.100	6.229	152.00	
	19.311	0.300	6.772	64.37	
10	12.692	0.334	5.051	38.00	27.69
	34.197	1.552	7.192	22.03	
	23.031	0.999	5.282	23.05	
15	20.422	1.179	5.529	17.32	125.80
	19.737	0.655	6.044	30.13	
	15.837	0.048	6.849	329.90	

Table A.5: Ammonium-N to Nitrate-N ratio on dry mass basis

Depth from pile surface (ft)	Concentration (g/100 mL)	Ammonium-N to Nitrate-N ratio on dry basis
5	1	0.053
	2	0.036
	5	0.235
10	1	0.040
	2	0.114
	5	0.236
15	1	0.158
	2	0.220
	5	0.302

Table A.6: Nutrient concentration in sample taken from 5 ft depth

Nutrients	% wt (dry) basis				
	Trial 1	Trial 2	Trial 3	Average	Standard Deviation
Cu	0.018	0.031	0.039	0.029	0.011
Zn	0.044	0.071	0.067	0.061	0.015
Ni	0.003	0.004	0.004	0.004	0.00006
Co	0.001	0.003	0.003	0.002	0.001
Mn	0.020	0.019	0.022	0.02	0.002
Fe	0.289	0.444	0.646	0.46	0.179
PO_4^{2-}	0.052	0.179	0.188	0.14	0.076
P	0.031	0.058	0.062	0.05	0.017
P_2O_5	0.067	0.133	0.141	0.114	0.041
Na	1.382	0.553	0.522	0.819	0.488
Cr	0.005	0.002	0.001	0.003	0.002
B	0.901	1.656	1.696	1.418	0.448
K	0.631	0.711	1.277	0.873	0.352
Cd	0.0009	0.00087	0.00089	0.0009	0.00002
Pb	-0.00001	-0.000015	-0.000013	-0.00001≈ 0	0.000003
As	0.000	0.000	0.000	0	0
S	0.000	0.000	0.000	0	0
Hg	0.000	0.000	0.000	0	0
Ca	3.068	7.626	6.880	5.858	2.445
Mg	0.490	0.940	0.936	0.789	0.259

Table A.7: Nutrient concentration in sample taken from 10 ft depth

Nutrients	% wt (dry) basis				
	Trial 1	Trial 2	Trial 3	Average	Standard Deviation
Cu	0.025	0.064	0.039	0.043	0.02
Zn	0.036	0.071	0.079	0.062	0.023
Ni	0.003	0.004	0.004	0.004	0.00006
Co	0.006	0.012	0.021	0.013	0.008
Mn	0.010	0.019	0.017	0.015	0.005
Fe	0.303	0.459	0.406	0.389	0.079
PO_4^{2-}	0.050	0.096	0.113	0.086	0.033
P	0.016	0.031	0.037	0.028	0.011
P_2O_5	0.038	0.071	0.084	0.064	0.024
Na	3.090	1.075	6.303	3.489	2.637
Cr	0.002	0.000	0.068	0.023	0.039
B	0.924	1.770	1.783	1.492	0.492
K	0.600	0.684	0.682	0.655	0.048
Cd	0.00036	0.00038	0.0005	0.000413	0.000075
Pb	0.0003	0.00025	0.00027	0.000273	0.000025
As	0.000	0.000	0.000	0	0
S	0.000	0.000	0.000	0	0
Hg	0.000	0.000	0.000	0	0
Ca	3.309	6.456	6.628	5.464	1.869
Mg	0.383	0.741	0.746	0.623	0.208

Table A.8: Nutrient concentration in sample taken from 15 ft depth

Nutrients	% wt (dry) basis				
	Trial 1	Trial 2	Trial 3	Average	Standard Deviation
Cu	0.020	0.028	0.044	0.031	0.012
Zn	0.029	0.074	0.048	0.05	0.023
Ni	0.002	0.003	0.004	0.003	0.001
Co	0.007	0.012	0.014	0.011	0.004
Mn	0.015	0.019	0.021	0.018	0.003
Fe	0.329	0.470	0.521	0.44	0.099
PO_4^{2-}	0.047	0.094	0.109	0.083	0.032
P	0.018	0.014	0.036	0.023	0.012
P_2O_5	0.035	0.071	0.083	0.063	0.025
Na	1.491	0.735	0.958	1.061	0.388
Cr	0.000	0.001	0.000	3E-04	6E-04
B	0.700	1.156	1.220	1.025	0.284
K	3.097	1.899	1.119	2.038	0.996
Cd	0.0003	0.00038	0.0004	0.00036	0.000053
Pb	-0.004	-0.0043	-0.0044	-0.00423	0.0002
As	0.000	0.000	0.000	0	0
S	0.000	0.000	0.000	0	0
Hg	0.000	0.000	0.000	0	0
Ca	5.583	11.510	0.830	5.974	5.351
Mg	2.821	5.107	5.114	4.347	1.322

Table A.9: Collected data on the number of seeds germinated and root length (for 10% solution)

Sample	No of seed Germinated	Root Length (cm)	Mean number of seeds	Mean root length (cm)
Control	2	4.8	2	3.2
		1.5		
5 ft	4	2.6	4	3.5
		2.2		
		2.5		
		0.6		
	4	3.9		
		3.8		
		3.1		
		1.2		
	4	5.8		
		5.1		
		4.5		
		4.0		
	4	3.2		
		2.6		
		7.2		
		3.6		
10 ft	4	5.1	3	3.1
		5.0		
		3.8		
		3.3		
	3	3.5		
		1.3		
		0.8		
	3	6.0		
		3.6		
		1.2		
	3	3.2		
		1.8		
		1.1		
15 ft	3	5.5	2	3.8
		3.9		
		3.3		
	2	4.4		
		5.1		
	1	0.5		

Table A.10: Collected data on the number of seeds germinated and root length (for 20% solution)

Sample	No of seeds Germinated	Root Length (cm)	Mean number of seeds	Mean root length (cm)
Control	3	3.0	3	2.8
		3.8		
		1.6		
5 ft	1	1.3	2	3.5
	1	6.8		
	3	7.0		
		3.5		
		1.0		
	2	2.8		
		0.5		
	4	3.7		
		4.0		
		3.6		
		4.2		
10 ft	1	5.0	3	5
	1	6.4		
	2	4.4		
		3.5		
	5	3.7		
		6.9		
		4.6		
		3.7		
		8.2		
	4	1.0		
		7.0		
		5.6		
		5.3		
15 ft	3	0.6	3	3.5
		2.4		
		3.4		
	2	3.0		
		4.1		
	3	4.3		
		2.6		
		1.5		
	5	2.7		
		4.5		

		3.0		
		2.6		
		4.0		
	4	5.7		
		5.2		
		5.5		
		5.0		

Table A.11: Collected data on the number of seeds germinated and root length (for 40% solution)

Sample	No of seed Germinated	Root Length (cm)	Mean number of seeds	Mean root length (cm)
Control	2	4.8	2	3.2
		1.5		
5 ft	3	3.7	2	2.3
		2.1		
		1.8		
	1	3.6		
	3	3.0		
		1.5		
		0.7		
	1	1.8		
10 ft	3	6.3	4	3.4
		3.9		
		1.6		
	6	2.0		
		4.2		
		4.2		
		3.6		
		4.0		
		3.1		
	5	3.6		
		3.9		
		3.1		
		2.8		
		2.0		
	2	4.4		
		2.3		
15 ft	2	3.1	4	3.4
		3.5		
	4	3.6		
		4.0		
		5.7		
		3.3		
	6	5.5		
		3.5		
		2.0		
		3.0		
		1.4		
		2.5		
	2	4.2		
		1.6		

Table A.12: Collected data on the number of seeds germinated and root length (for 50% solution)

Sample	No of seed Germinated	Root Length (cm)	Mean number of seeds	Mean root length (cm)
Control	3	3.2	3	3.0
		2.8		
		3.0		
5 ft	5	5.0	3	3.1
		6.0		
		2.0		
		1.0		
	3	6.0		
		1.0		
		1.0		
	3	3.0		
		2.0		
		3.5		
10 ft	3	4.0	3	3.4
		3.5		
		3.2		
	3	3.0		
		3.2		
		3.0		
	2	4.0		
		3.2		
15 ft	4	3.0	4	2.7
		2.0		
		1.8		
	3	2.0		
		4.5		
		3.0		
	4	2.0		
		2.5		
		3.0		
		3.2		
	4	3.0		
		2.6		
		3.0		
		1.8		

Table A.13: Collected data on the number of seeds germinated and root length (for 60% solution)

Sample	No of seed Germinated	Root Length (cm)	Mean number of seeds	Mean root length (cm)
Control	2	3.5	2	3.8
		4.0		
5 ft	5	5.0	3	3.1
		6.0		
		2.0		
		1.0		
	3	6.0		
		1.0		
		1.0		
	3	3.0		
		2.0		
		3.5		
10 ft	4	2.0	3	1.9
		1.0		
		1.0		
		3.5		
	2	4.0		
		1.5		
	2	1.0		
		1.0		
15 ft	4	4.0	3	2.2
		1.0		
		2.0		
		1.0		
	3	5.5		
		1.0		
		1.2		