MAURITIUS RESEARCH COUNCIL

USE OF COMPOST BY FARMERS AS AN ADAPTATION STRATEGY FOR CLIMATE CHANGE: LAND APPLICATION AND SIMULATION STUDIES

Final Report

December 2012

MAURITIUS RESEARCH COUNCIL

Address:

Level 6, Ebene Heights,
34, Cybercity,
Ebene,
P.O Box: 72201
Mauritius.

Telephone: (230) 465 1235
Fax: (230) 465 1239
Email: mrc@intnet.mu
Website: www.mrc.org.mu

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Use of compost by farmers as an adaptation strategy for climate change: Land application and Simulation Studies

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Dr Geeta Devi SOMAROO
Principal Investigator
Department of Chemical & Environmental Engineering, Faculty of Engineering, University of Mauritius, Reduit, Mauritius

Prof Romeela MOHEE
Co-Investigator
National Research Chair in Solid Waste Management, Tertiary Education Commission, Mauritius

Mr Ackmez MUDHOO
Co-Investigator
Department of Chemical & Environmental Engineering, Faculty of Engineering, University of Mauritius, Reduit, Mauritius

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Contents

List of Figures & Tables

Executive Summary

This study comprised analyzing different treatments namely: (a) Soil only(S), (b) Compost and soil (SC), (c) Soil and Manure (SM), Soil and Manure(SM) and (e) Compost, Soil and Chemical fertilizers (SFC) for comparing greenhouse gas (GHG) emissions. The GHG emissions were monitored and compared by quantifying CO_2 and CH_4 fluxes using a static flux chamber. The following chemical and physical analyses of soil properties were monitored: pH, electrical conductivity, moisture content, bulk density, porosity, water holding capacity, volatile solids, Nitrogen, Phosphorus, Potassium and Total Organic Carbon (TOC). Further investigations involved analysis of crop yield and root system formation of *Lactuca Sativa* seedlings (lettuce) which were grown on the each treatment. The results showed that organic treatments such as MSW compost and chicken manure addition helped to maintain the pH of soil between 7.3-7.5 which is deemed conducive for vegetation. It was also deduced that both compost and chicken manure were successful in reducing the bulk density of the soil by at least 8 %. After 7 weeks, incorporation of compost triggered an increase of 135% in the TOC of the soil while the TOC of SM and SF increased by 108% and 86.9% only. A maximum flux of 46.41 g/m^2/day of CO_2 was measured from treatment SM on the 49^{th} day. Thus, treatment SM acted as a source of CO_2. Treatment SC was a sink for CO_2, since the net fluxes of both CO_2 and CH_4 was zero. Application of fertilizer resulted in higher N_2O emissions (31.98 kg N_2O/yr) compared to compost application (25.86 kg N_2O/yr) and chicken manure application (25.80 kg N_2O/yr). The total greenhouse gas emissions from treatment SF, SC, SM, SFC were 10533, 8318, 25160 and 9805 kg CO_2 equivalent/yr respectively. Compared to treatment SF, compost application reduced total GHG emissions by 21% while chicken litter increased GHG emissions by 139%. The number of leaves formed and height of shoots per plant were the highest in treatment SC and SM. The dry mass of *Lactuca Sativa* (Lettuce) from treatment SC was 10.9% compared to 10.3%, 10.5%, 10.1%, and 10.8% from treatments S, SM, SF and SFC respectively. The % crop yields of SC and SM was 100%. Treatments SF and SFC produced lower crop yields (75% and 65%) compared to the control, where the crop yield was 95%.

List of abbreviations

GHG	**Greenhouse gas emission**
GWP	**Global warming Potential**
IPCC	**Intergovernmental Panel on Climate change**
LCA	**Life Cycle Assessment**
SOM	**Soil Organic carbon**
OM	**Organic matter**
TOC	**Total Organic Carbon**

Chapter 1

INTRODUCTION

1.1 Background

Climate change, a complex biophysical process is already happening. It is not possible to predict precise future climate conditions, but the scientific consensus is that global land and sea temperatures are warming under the influence of greenhouse gases, and will continue to warm regardless of human intervention for at least the next two decades (IPCC, 2007). In spite of international effort to reduce emissions of the greenhouse gases that cause climate change, the climate system will keep on adjusting for the next few decades to past and present emissions. This will unavoidably affect both natural and human systems. Climate change is a genuine concern for sustainable expansion of agriculture. While some features of climate change such as extended growing seasons and warmer temperatures may benefit the agricultural systems there will also be a series of unfavorable impacts including reduced water availability and more frequent extreme weather such as increased intensity and frequency of storms, drought and flooding, altered hydrological cycles and precipitation variance. These impacts will indeed put agricultural activities, both at the level of individual land managers and farm estates, at momentous risk. Even if agriculture is complex and has highly evolved, it is still directly proportional to the climate since heat; sunlight and water are the main drivers of crop growth.

The burning of fossil fuels and the mineralization of organic matter (as a result of land use) have largely contributed to the current change in global climate. These processes have been caused by mankind's exploitation of fossil resources, clearing of natural vegetation and use of these soils for arable cropping. These activities have principally led to a measurable increase in the carbon dioxide content of the atmosphere, an increase which results in global warming, since CO_2 hinders the reflection of sunlight back in space, and therefore more is trapped in the earth's atmosphere. Molecules of methane and nitrous oxide have a similar, but greater effect; the Global Warming Potential (GWP) of methane is 20 while that of Nitrous Oxide is 300 times more than that of Carbon dioxide. The total Greenhouse Gas contribution of all sectors related to agriculture (including production of mineral based fertilizers) may potentially add up to 25-30% of total GHGs emissions, thereby making agriculture the second most potent GHG emission sector after that of energy production.

1.2 Rationale

Agriculture accounts for about 30% of Africa's gross domestic product (GDP) and 75% of total employment (World Bank, 2007). However, nearly half of the area of Africa, which is home to more than 14% of the low-income countries in the world, is either arid or semi-arid, and over 90% of agricultural production is rain-fed (Fischer *et al.*, 2004). This implies that erratic rainfall patterns present serious challenges to crop cultivation and food production in these areas, and this will be further worsened by climate change which is expected to increase rainfall variability in many African countries that are already at least partly semi-arid and arid.

Sustainable agricultural practices, such as organic agriculture, strongly reduce the reliance on external inputs by:

1. recycling wastes as nutrient source,
2. using nitrogen-fixing plants,
3. improving cropping systems and landscapes,
4. avoiding synthetic pesticides,
5. integrating crops and animals into a single farm production sector and including grass

The potential of organic agriculture for both effects is high, as data gained from modeling both long-term field trials and pilot farms show (UNCTAD/WTO, 2007). The GWP of organic farming systems is much smaller than that of conventional or integrated systems when calculated per land area. It is also to be noted that under dry conditions or water constraints, organic agriculture may outperform conventional agriculture, both per crop area and per harvested crop unit. Mader *et al* (2002) and Nemecek *et al* (2005) deduced that, in comparison to conventional farming, organic farming helped to reduce the GWP of all crops by 18%. A reduction in warming potential has also been found in Dutch dairy farms and in some vegeTable crops. Kustermann *et al* (2007) deduced that GWP decreased by 80% after carrying out the Scheyem experiment based on organic agriculture. Similar results have been recorded by Robertson *et al* (2000), where a decrease of 64% was noted in the station experiment in Michigan following application of organic agriculture.

According to the Rodale Institute, organic agriculture can remove 3175 kg of CO2 from the atmosphere per acre every year. If the US converted all of its cropland to organic techniques it would be the equivalent of eliminating 217 million cars from the roads. *"If only 10,000 medium sized farms in the U.S. were to be converted to organic production, they would store so much carbon in the soil that it would be equivalent to taking 1,174,400 cars off the road, or reducing car miles driven by 14.62 billion miles."* On average, organic farming practices produce 28% higher soil carbon levels than non-organic farming in Northern Europe, and 20% for in Europe and North America (Soil Association, 2009).

1.3 Literature review

1.3.1 Greenhouse gases and Climate change

Nearly one-third of the solar energy that reaches the top of Earth's atmosphere is reflected directly back to space and the remaining two-thirds is absorbed by the surface and, to a lesser extent, by the atmosphere (IPCC, 2007). In order to balance the absorbed incoming energy, the Earth must normally radiate the same amount of energy back to space. Since the temperature of the Earth is much lower than that of the Sun, the former radiates at much longer wavelengths, principally in the infrared part of the spectrum. Thus, much of this thermal radiation emitted by the land and ocean is absorbed by the atmosphere, including clouds, and reradiated back to Earth. This is called the ***greenhouse effect.*** It is the ***greenhouse gases*** (GHG) which trap some of the energy the Earth releases to space. GHGs include primarily of Carbon dioxide (CO_2), Methane (CH_4) and Nitrous oxide (N_2O). The GHGs in the atmosphere control the climate of the Earth. Without this natural greenhouse effect, the average temperature on Earth would have been -18°C instead of +15°C. However, owing to human activities, such as burning of fossil fuels and clearing of forests, the natural greenhouse effect has greatly increased, causing global warming. The Earth's climate has always been evolving. Many climatologists and scientific researchers are of the opinion that increasing concentrations of the GHGs will lead to temperature increases big enough to bring about major ***climatic changes***. Changes in atmospheric concentrations of GHGs and aerosols, land-cover and solar radiation alter the energy balance of the climate system. Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (IPCC, 2007). Carbon dioxide is the most important anthropogenic (man-made) greenhouse gas. Its annual emissions grew by about 80% between 1970 and 2004. Atmospheric concentrations of Carbon dioxide (379ppm) and Methane (1774 ppb) in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO_2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution (IPCC, 2004). It is not possible to predict precise future climate conditions, but the scientific consensus is that global land and sea temperatures are warming under the influence of greenhouse gases, and will continue to warm regardless of human intervention for at least the next two decades (IPCC, 2007).In spite of international effort to reduce emissions of the greenhouse gases that cause climate change, the climate system will keep on adjusting for the next few decades to past and present emissions. This will unavoidably affect both natural and human systems. Climate change is a genuine concern for sustainable expansion of agriculture. While some features of climate change such as extended growing seasons and warmer temperatures may benefit the agricultural systems, there will also be a series of unfavorable impacts including reduced water availability and more frequent extreme weather such as increased intensity and frequency of storms, drought and flooding, altered hydrological cycles and precipitation variance. These impacts will indeed put agricultural activities, both at the level of individual land managers and farm estates, at momentous risk. It has therefore become very important to devise policies that would contribute to breaking this perverse chain and ensure that less greenhouse gas is emitted into the atmosphere (reduction of sources) and more carbon dioxide is removed from it (creation of sinks) (Marmo, 2008). Figure 1.1 shows the annual GHG emissions by sector. It can be observed that the agricultural sector contributed to 40% of CH_4 and 62% of N_2O emissions.

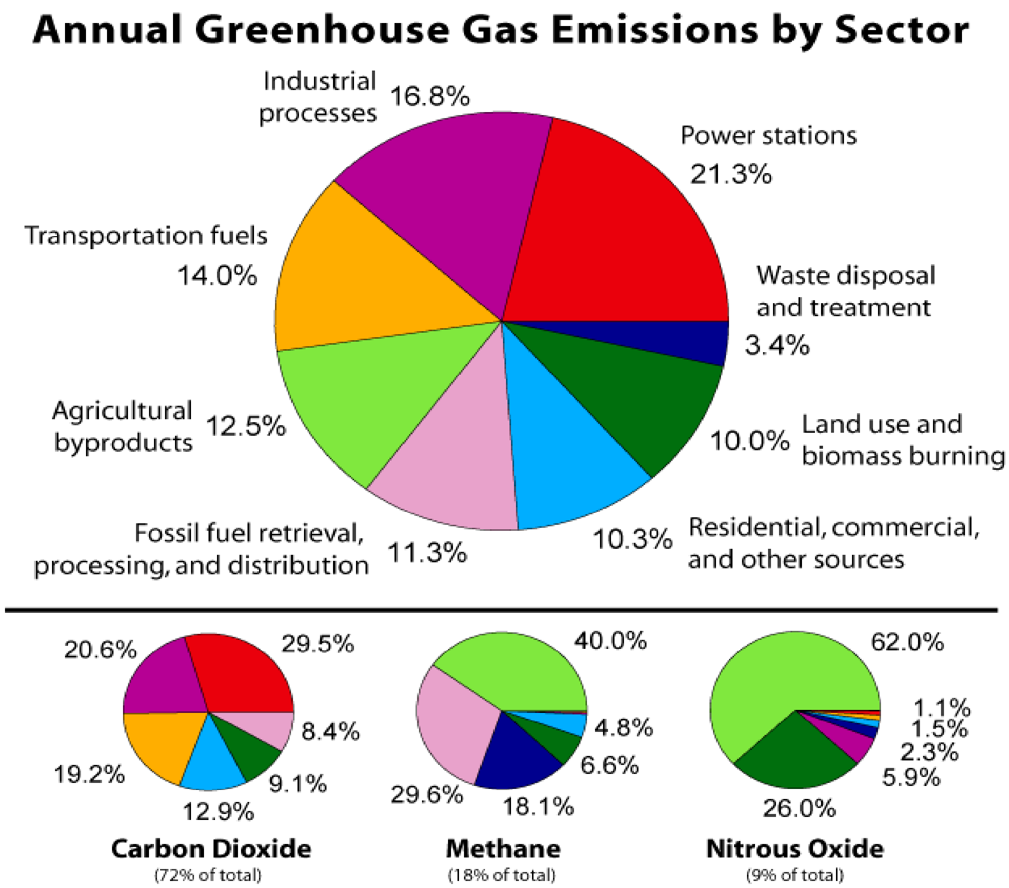


Figure1.1: Annual greenhouse gas emissions by sector

Source: Global Warming Art, 2000

1.3.2 Mitigation and Adaptation measures

As identified by the United Nations Framework Convention on Climate Change (UNFCC), the two responses to climate change are ***mitigation*** of climate change by decreasing greenhouse-gas emissions and enhancing sinks, and ***adaptation*** to the impacts of climate change. ***Mitigation*** is defined as an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2001). ***Adaptation*** is defined as adjustment in natural or human system in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001). From the definitions, it can be concluded that mitigation reduces all impacts (positive and negative) and thus reduces the adaptation challenge, whereas adaptation is selective; it can take advantage of positive impacts and reduce negative ones (Goklany, 2005). Adaptation and mitigation are believed to be complementary to each other. If mitigation measures are undertaken effectively, there will be declined impacts to which there will be a need to adapt. Similarly, if adaptation measures are strong, lesser might be the impacts associated with any given degree of climate change. It is obvious that both responses are equally important and can help reduce the impact of climate change to natural and human systems. For instance, mitigation measures will have global benefits, whereas adaptation benefits are from local to regional in scale. Nevertheless, adaptation benefits can be immediately visible as compared to mitigation, for which the effects may not be evident immediately after.

According to (IPCC, 2007), the annual amount of greenhouse gases emitted by the agricultural sector was estimated between 5.1 to 6.1 Gt CO_2 equivalents in 2005 (Barker *et al.*, 2007). Of these emissions, methane accounts for 3.3 Gt equivalents and nitrous oxide for 2.8 Gt CO_2 equivalents annually, while net emissions of CO_2, at only 0.04 Gt CO_2 equivalents. Based on current practices, agriculture is the main emitter of nitrous oxides.

Emissions of Nitrous Oxide originate mainly from:

1. High soluble nitrogen levels in the soil form synthetic and organic sources (fertilizers)
2. Animal housing and manure management

The main sources of methane emissions are:

1. Enteric fermentation by cattle
2. Anaerobic turnover in rice paddies
3. Manure handling
4. Compaction of soils resulting from the use of heavy mechanization
5. Biomass burning- results in emissions of both nitrous oxide and methane.

The CO_2 flux is nearly balanced in agriculture with net emission of 0.04 Gt CO_2 equivalents per year which represents less than 1% of global anthropogenic CO_2 emissions. Considerable emissions of CO_2 from soils, however, originate from land use changes such as deforestation. On the other hand, reforestation and afforestation act as carbon dioxide sinks. Including all gases (Carbon dioxide, Nitrous oxide and Methane), the global technical ***mitigation*** potential from ***agriculture*** (excluding fossil fuel offsets from biomass) by 2030 is estimated to be around 5500-6,000 $MtCO_2$-eq/yr (IPCC, 2007).

Soil carbon sequestration is the method responsible for most of the mitigation potential with an estimated 89% contribution to the technical potential, out of which mitigation of CH_4 emissions and N_2O emissions from soils account for 9% and 2%, correspondingly (IPCC, 2007). There are interactions between mitigation and adaptation in the agricultural sector, which may occur simultaneously, but differ in their spatial and geographic characteristics. In many regions, non-climate policies related to macro-economics, agriculture and the environment have a larger impact on agricultural mitigation than climate policies. However, little progress has been made in the implementation of mitigation measures worldwide. Owing to population growth and changing diets, current GHG emission rates may intensify in the future. Greater demand for food could result in higher emissions of CH_4 and N_2O if there are more livestock and greater use of nitrogen fertilizers. Hence, implementation of new mitigation practices for livestock systems and fertilizer applications will be indispensable to prevent any further increase in emissions from agriculture after 2030. Moreover, soil carbon may be more vulnerable to loss with climate change and other pressures, though increases in production will offset some or all of this carbon loss. Current initiatives suggest that collaboration between climate change policies; sustainable development and improvement of environmental quality will likely lead the way forward to realize the mitigation potential in this sector.

Three main mechanisms are responsible for ***mitigating GHGs*** in the agricultural sector, namely:

1. ***Reduced emissions***: The GHGs fluxes can be reduced by more efficient management of carbon and nitrogen flows in agricultural ecosystems. For example, practices that deliver added N more efficiently to crops often reduce N_2O emissions (Bouwman, 2001), and enhanced management of livestock to make most efficient use of feeds often reduces amounts of CH_4 given off (Clemens and Ahlgrimm, 2001). However, the above mechanism is dependent on local conditions prevailing, and thus, varies significantly from region to region.
2. ***Enhanced removals***: Agricultural ecosystems hold large carbon reserves (IPCC, 2001a), mostly in soil organic matter. Absorption of atmospheric CO_2 can also aid in recovering the lost in Carbon through improved management. Moreover, practices that increases the photosynthetic input of carbon and/or slows the return of stored carbon to CO_2 via respiration, fire or erosion will increase carbon reserves, thereby

‘sequestering’ carbon or building carbon ‘sinks’. Many studies, worldwide, have now shown that significant amounts of soil carbon can be stored in this way, through a range of practices, suited to local conditions (Lal, 2004). Significant amounts of vegetative carbon can also be stored in agro-forestry systems or other perennial plantings on agricultural lands (Albrecht and Kandji, 2003). Agricultural lands also remove CH_4 from the atmosphere by oxidation (but less than forests; Tate *et al (*2006), but this effect is small compared to other GHG fluxes (Smith and Conen, 2004).

3. ***Avoided emissions:*** Crops and residues from agricultural lands can be used as a source of fuel, either directly or after conversion to fuels such as ethanol or diesel (Schneider and McCarl, 2003; Cannell, 2003). These bio-energy feedstocks still release CO_2 upon combustion, but now the carbon is of recent atmospheric origin (via photosynthesis), rather than from fossil carbon. The net benefit of these bio-energy sources to the atmosphere is equal to the fossil-derived emissions displaced, less any emissions from producing, transporting, and processing. GHG emissions, notably CO_2, can also be avoided by agricultural management practices that forestall the cultivation of new lands now under forest, grassland, or other non-agricultural vegetation (Foley *et al.*, 2005).

Figure 1.3: shows the Global technical mitigation potential by 2030 of each agricultural management practice showing the impacts of each practice on each GHG.

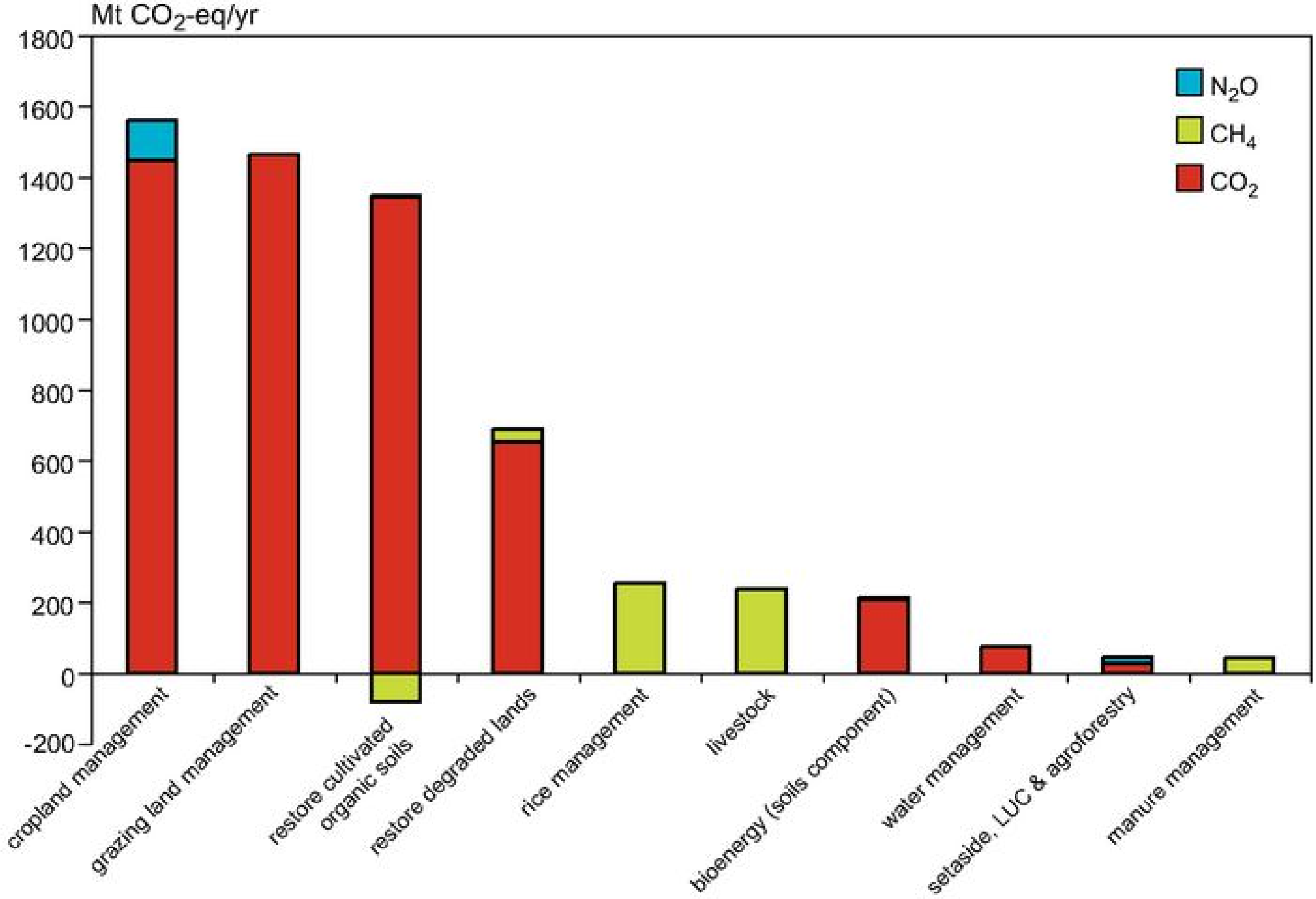


Figure 1.3: Global technical mitigation potential by 2030 of each agricultural management practice showing the impacts of each practice on each GHG.

Source: Smith et al., 2007

1.3.3 Composting and Climate change

Composting is the biological decomposition and stabilization of organic substrates, under conditions that allow the development of thermophillic temperatures as a result of biologically produced heat, to produce a final product that is sTable, free of pathogens and plant seeds and can be applied to land (Haug, 1993). Compost is a source of organic matter which has beneficial impacts on the soil physical and chemical properties, hence, plays a significant role in crop production. The advantages of applying compost to soil are that it improves the soil structure by decreasing bulk density, increasing porosity, aeration and soil strength. The amount of water available to plant and soil water content also augment. Compost application to soil reduces erosion and run off. Moreover, soil's chemical properties such as cation exchange capacities, organic matter content, pH, electrical conductivity and NPK are enhanced as soil is treated with compost. Agronomic and horticultural use represents a large potential market for MSW compost (Shiralipour *et al.,* 1992), therefore, from a disposal perspective soils potentially represent an almost infinite sink for organic residues. The nutritive value of MSW composts and their potential to enhance soil quality makes them ideal for agriculture, provided that correct precautions are taken to mitigate against environmental damage and to gain public acceptance. The addition of compost to agricultural land may unnecessarily increase the heavy metal content of the soil (Ramos and Lopez-Acevedo, 2004). At normal application rates, however, there is little risk to plants or the wider environment (Greenway and Song, 2002). When applied to land, these residues have the potential to significantly increase soil organic matter (SOM) contents, an aspect that is in critical decline in many regions of the world, particularly in more arid environments (Bellamy *et al.,*2005). Maintaining and increasing soil organic matter stocks, a key soil quality indicator, is now seen politically as a key priority for preserving ecosystem function. Numerous trials have shown that addition of MSW compost to soil can at least transiently increase SOM contents as well promoting soil biological activity. Additional benefits of compost addition also include reduced erosion losses, a decrease in bulk density and improved structural stability (Tejada and Gonzalez, 2007).Regardless of the risks of heavy metal pollution, if applied responsibly MSW compost can improve nutrient availability and plant uptake in agricultural soils (Andersen *et al.,*2010). MSW compost can provide similar amounts of P to mineral fertilizers in some soils (Mkhabela and Warman, 2005). For typical application rates of 10–100 t/ha, the uncertainty over nutrient availability during acropping season also makes it difficult to accurately predict crop demands and therefore optimal compost application rates in comparison to conventional inorganic fertilizers. In a study investigating the growth and nutrient content of maize under different additions of MSW compost, Tambone *et al.,* (2007) found that although yield did not increase over their control treatment, maize grains from compost-treated treatments were enriched in C, N and P as a result of the increased nutrient status of the soil. Similarly, Zheljazkov *et al* (2006) found that MSW compost produced comparable yields to chemical N addition, and improved crop yields over solid manure addition. Quality of the crop (fibres and energy), and residual nitrates were similar to those from the inorganic treatment. In addition to erosion reduction and increased soil stability, the addition of composts to agricultural soils has been found in increase the water holding capacity of soils (Shiralipour *et al.,* 1992). The application of two paper-based composts increased the amount of water held both at field capacity and permanent wilting point in a loamy sand soil (Foley and Cooperband, 2002). Since the increase in water held at field capacity increased to a greater extent than at wilting point, it can be inferred that plant available water increases following compost addition to soil. Another study by Mamo *et al* (2000) on the growth of maize on a loamy sand soil using MSW composts produced mixed results, increasing the soil water holding capacity without greatly increasing the estimated plant available water within the soil. They concluded that increases in water stress in the corn may also be due to increased salt loading in the soil due to the relatively high electrical conductivity of the compost. However, one year after the application of MSW compost, soil water content increased, along with corn yield, and an associated reduction in plant water stress (Farrell and Jones, 2009). With future changes to climate and rainfall patterns, this area of research will become increasingly important (Farrell and Jones, 2009)

By sequestering carbon dioxide in the soil, agriculture may contribute to the carbon cycle in a positive way. Agriculture has the potential to be a considerable CO_2 sink, if good farming practices, like organic farming (use of compost) are employed. Predictions concerning the future global trends for greenhouse gas emissions from agriculture largely depend on physical and economic parameters that have a strong influence on total emissions. These parameters include; cost of fuel, economic development, evolution of livestock numbers, increase in productivity, new technology, availability of water, deforestation, and consumer attitudes and diet (Smith *et al.,* 2007).

Based on recent research, it has been proved that application of 47.6 ton compost/ha/yr over 30 years on organic arable fields in Egypt, resulted in an average carbon sequestration of 0.88 ton/C/ha/yr (3.23 tonCO_2/ha/yr) (Luske & Van der Kamp, 2009). Values in the same order of magnitude have been found in other studies. For instance, as reported by Saft & Kortman (2004), between 0-22 % of the applied carbon in the compost was sequestered. Luske (2010) carried out a study to determine the reduction in GHG emissions due to compost production and compost use in Egypt. The results obtained in the study depicted that composting results in 90% less emissions than the baseline scenario (whereby organic waste is landfilled and agriculture uses chemical nitrogen fertilizer). Production and application of compost lead to a total emission of 149 kg CO_2e/ton citrus compared to fertilizer production and use, where the emission was

1559 kg CO_2e/ton citrus. The results also indicated that the carbon footprint per kg N of compost (18kg CO_2/kg N) is higher than for ammonium nitrate 3-7 kgCO_2/kg N). Another similar study was carried out by Martinez-Blanco *et al.*,(2009). The authors analyzed the Life cycle assessment of the use of compost from municipal organic waste for fertilization of tomato crops. The objectives of the study were to assess the agricultural and environmental viability of using compost on a tomato crop in open field production in a Mediterranean area and to detect the critical phases of the system from the environmental point of view by the use of LCA. Moreover, the results obtained by the use of compost were compared with the burdens associated with mineral fertilization. The LCA was carried out by using SimaPro 7.0 and the functional unit was the horticultural production of a ton of commercial tomatoes. The study revealed that the production of a ton of tomatoes using compost consumes 2,584 MJ of energy with 136 kg CO_2eq emitted. The stage with the major impact is compost production with between 53 and 98% of the total impact, depending on the impact category, mainly due to emissions generated and energy consumption at the composting facility. However, when the burdens avoided by not depositing the composted organic and green MSW in landfill is compared to the production and application of fertilizers, compost appears to be an environmentally better option than mineral fertilization. Compost production and application implies the consumption of 1,074 MJ eq/t tomatoes and avoids the emission of 786 kg CO_2eq/t tomatoes. The application of compost as a fertilizer for tomato crops does not appear to have a negative effect on production or product quality. To improve treatment with compost, there is a need to focus on the compost production stage, optimizing the exhaust gas treatment systems and minimizing energy consumption.

1.3.4 Methods for measuring GHG emissions

Li *et al.*, (2000) evaluated Methods for Determining NH_3 and N_2O emissions from soil applied manure. According to the study, three measurement schemes are commonly used for the chamber method to measure gaseous emission from the soil: the open chamber method, the closed chamber static method, and the closed chamber dynamic method. All methods employ an inverted chamber covering a small area of soil. The lower edge of the chamber is usually inserted into the soil to a shallow depth. In the open chamber method, pumps are used to provide a steady airflow through the chamber and the concentrations of the target gas are measured at both the inlet and outlet. In the closed chamber static method, the chamber is closed and a chemical absorbent, which acts as a chemical trap, is placed inside the chamber. In the closed chamber dynamic method, the concentration of the target gas in the chamber is monitored over time. The increase in concentration of the gas is used to calculate the rate of gas emissions from the covered soil surface. For the purpose of their study, Li *et al.*,(2000) modified the chamber method for measuring NH_3 and N_2O emissions from soil and a sampling protocol developed and tested in the field. N_2O and NH_3 emissions were measured using a dynamic chamber method; NH_3 emissions also were measured using a static chamber method. Gas chromatography (GC) was used to determine the concentrations of N_2O and NH_3 in air samples from the dynamic chambers. A solution of 0.02 N H_2SO_4 was used as an absorbent chemical to trap NH_3 emissions from the static chambers. After applications of cattle manure, N_2O emissions from the soil ranged from 0 to 1.28 $x10^3$µg $m^{-2}h^{-1}$ and NH3 emissions ranged from 0 to 1.4 x 10^3µg $m^{-2}h^{-1}$ Ammonia emissions reached 8 x 10^3 µg$m^{-2}h^{-1}$one day after hog manure was applied and then declined rapidly. The rate of $NH_3$and N_2O emissions was positively correlated with the rate of manure application, with the highest rate of manure application for both cattle and hog manure giving the highest rates of emissions. It was found that Measurements from both chamber methods are comparable to data found in the literature, suggesting that the methods are suiTable for measuring NH_3 and N_2O emissions in the reported ranges.

Miyata *et al.,* (2000), conducted a study where, Methane fluxes were measured using a closed chamber. The bottom-less chamber, 0.36m^2 in area and 1 m in height was made of acrylic resin and an electric fan for circulation. The measurement was conducted at two sites in the measurement treatment. At each site, two chambers were placed 4 m apart to examine the spatial variation of the flux. Air temperature inside the chamber T_c and soil temperature below it were monitored using thermistor thermometers. Air was sampled four times at 10 min intervals by pumping air into a Tedlar bag. The chamber was placed 5 min before the first air sampling, and was removed immediately after the last sampling. Volume mixing ratios of methane were analyzed using a gas-chromatograph. The volume mixing ratio was converted to density using Tc and the partial pressure of dry air in the chamber pa. The CH_4 flux was deduced from the rate of change of CH_4 density with time as determined using linear regression. Leakage into the chamber caused by air sampling had an insignificant effect on the flux measurement because sampling removed approximately 1% (4 dm^3) of the chamber volume. The study revealed that the fluxes of methane were between 1.2 and 2.7 mg CH^4 $m^{-2}s^{-1}$.

Based on a study on Quantification of greenhouse Gas Emissions from Windrow Composting of Garden waste, Andersen *et al* (2010) suggested that measurement of Greenhouse Gas emission can be carried out using either the

1. Static Flux Chamber method (Transport mechanism- Diffusion only, lower flux)
2. Funnel method (Used to estimate ammonia emissions from compost windrows)
3. Or Dynamic Plume Method (SuiTable for measuring emissions from composting facilities where convection plays an important role to increase the flux)

The authors concluded that the dynamic plume method was a more effective tool for accounting for Carbon losses. Thus, the dynamic plume method was more suiTable for measuring GHG emissions from composting facilities. The total emissions were found to be 2.4 $\pm$ 0.5 kg CH_4-C/Mg wet waste and 0.06 $\pm$ 0.03 kg N_2O-N/Mg wet waste from a facility treating 15,540 Mg of garden waste per year or 111 $\pm$30 kg CO_2 equivalents /Mgwet waste.

Static Flux chambers are typically used on locations where diffusion is the dominant transport mechanism, as for example emissions from soil surfaces.

1.4 Objectives of the research project

The objectives of this research project were to:

- Conduct a comprehensive (and critical) literature review on the essentials, research conducted so far on the application of composts on soil as well as the impacts of composts application on the growth rate and quality of food crops.

- Set up different treatments namely: (a) Soil only; (b) Compost and Soil; (c) Soil and Chemical Fertilizers; (d) soil and manure, and (e) Compost, Soil and Chemical Fertilizers; for comparing their effects on changes in soil characteristics structure, plant growth, as well as for monitoring GHG emissions.

- Conduct experiments and analyzes on the different treatments namely food crop yields, root systems network, bulk density, porosity, water holding capacity and mineralization of organic carbon contents.

- Assess the environmental impacts associated with the use of compost and identifying the gaseous and aqueous emissions that contribute significantly to climate change using SimaPro software; and also determining the carbon footprint of the compost treatments.

- Use the results obtained in this study to inculcate the concept of Sustainable Agricultural Practices in the farmers' community in Mauritius through the use of compost for better adaptation against climate change in the agriculture sector.

Chapter 2

Methodology

2.1 Introduction

This section describes the methodology used to assess the greenhouse gas emissions, crop yield and soil analysis in terms of moisture content, volatile solids, Total Organic carbon, pH, Electrical conductivity, bulk density, water holding capacity, porosity and NPK nutrients of the different scenarios, as described in section 2.3.

This study was carried out in different phases, namely:

Phase 1: Initial analysis of soil and different Substrates

Phase 2: Design of treatments

Phase 3: Determination of application rate and analysis of treatments

Phase 4: GHG monitoring and Carbon footprint calculations

2.2 Initial analysis of soil and different substrates

The experimental set up was mounted at the University of Mauritius farm over a plot of land of 30 m^2. The site selected for the purpose of this study was not subjected to the application of any type of fertilizer or pesticide and was only used for cultivation purposes. MSW compost, Chicken manure and Urea-based fertilizer were used as substrates in the study. The MSW compost was obtained from Mauritius Solid Waste Recycling Ltd and the chicken litter was obtained from Innodis Ltd. Finally, the Urea-based fertilizer (16 16 23) was purchased from an agricultural shop.

Table 2.2 below shows the initial characteristics of the dry soil, MSW compost, Chicken litter and fertilizer used.

Table 2.2: Initial Characteristics of dry soil and substrates used

Parameters	soil	Finished compost	Chicken Litter	Fertilizer
Moisture Content %	79	57	67	-
Ash%	81	63	15	-
pH	6.55	6.88	8.01	6.89
Electrical conductivity (µS)	50.5	962.33	2858	42800
Bulk Density (kg/m^3)	893	658.7	837	256
Total Organic Carbon %	1.8	11.3	31.4	-
N%	-	1.75	2	16
P%	0.036	1.16	1	16
K%	0.047	1.83	1	23
Germination Index	1.97	2.33	4.87	0
Water Holding Capacity %	3.46	2.32	8.51	-
Porosity %	94	92	74	-

2.3Definition and Design of treatments

As illustrated in Figure 2.3, five different treatments were devised as follows:

1. Soil only (S) - Control
2. Soil and MSW compost (SC)
3. Soil and Chicken litter (SM)
4. Soil and Fertilizer (SF)
5. Soil, Fertilizer and MSW compost (SFC)

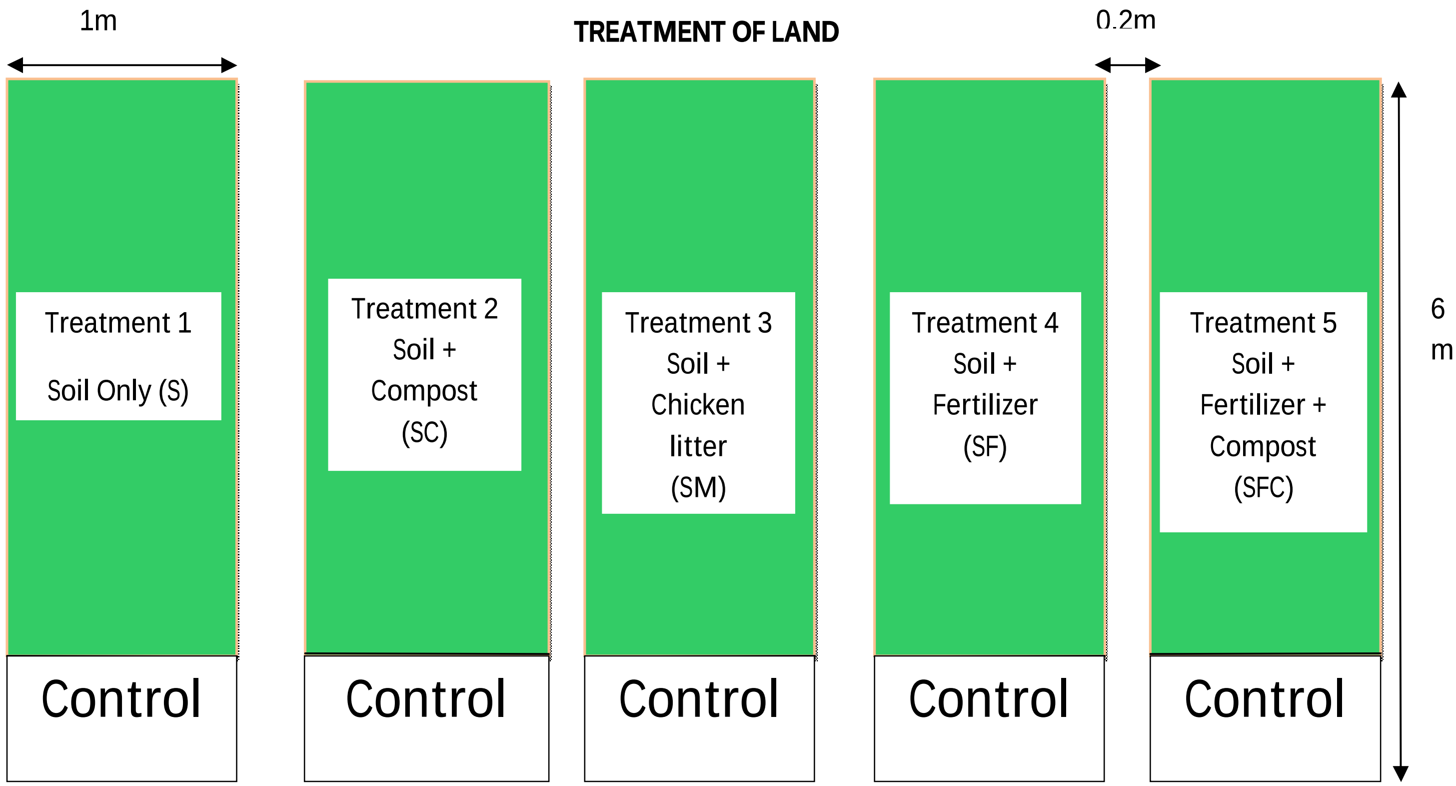


Figure2.3: Illustration of various treatments

Key:

Vegetation area

Note: The treatments were irrigated thrice a week so as to ensure that a moisture content of at least 50 % was maintained throughout the experimental analysis. Sampling was done on a weekly basis for a period of two months.

2.4 Determination of application rate and monitoring

2.4.1 MSW Compost

In order to determine the optimum application rate of MSW compost, a review of various studies (as summerised in Table 2.4) was carried out. The studies suggested that an application amount of 11 - 66 t/ha Municipal Solid Waste compost is sufficient to provide crops with required nutrients in order to increase the crop yield, whereby 30t/ha of MSW compost is the optimum application amount from an economic economic perspective . Manios and Syminis (1998) carried out a study to assess the crop yield of cucumber using 15 and 30 t/ha of town refuse compost respectively. It was found that 30 t/ha of compost increased the yield of cucumber by 20.8 %. Similar results were also reported by Sabrah *et al* (1995), who deduced that application of 33 t/ha of composted municipal solid waste was found to be the most economical for wheat crops giving 26 – 34% yield increase over the control. Thus, for the purpose of this study, an application rate of 33t/ha of MSW compost was selected. The Nitrogen, Phosphorus and Potassium (NPK) value of compost was 1.75, 1.16, 1.83. This value was chosen based on the income of Mauritius (Jilani, 2007). The application rates of the other treatments were determined based on the NPK values of compost. Thus, the amount of chicken manure or fertilizer that would provide the NPK would be provided by compost was applied to the other treatments. A summary of the findings are tabulated in Table 2.4.1.

Table 2.4.1: Review of studies related to MSW compost application rate

Study	Description	Compost Application Rate	Findings
Roig *et al.*, 2012	Long-term treatment of Spanish soils with sewage sludge: Effects on soil functioning	40t/ha	Maximum dose was 40t/ha/yr, beyond which soil properties do not improve, and may even worsen
Angus Campbell, 2007	Life Cycle Inventory and Life Cycle Assessment for Windrow Composting Systems	25t/ha for cotton crops and 50t/ha for grapevine	Plant productivity for both crops increased by 19.5 and 21.52% respectively

Movahedi Naeini and Cook (2000)	Influence of municipal compost on temperature, water, nutrient status and the yield of maize in temperate soil	50t/ha	Soil available moisture content increased by 2.0%
Bazzofi*et al* (1998)	The effects of urban refuse compost and different tractors tyres on soil physical properties, soil erosion and maize yield.	64t/ha	Runoff reduction due to compost ranged between 7 and 399m^3/ha. Compost application reduced soil loss by 31% compared to the control.
Bresson*et al* (2001)	Soil surface structure stabilization by municipal waste compost application	39t/ha	Compost application reduced the sediments in the runoff from 36.4 to 11 g L-1 (by 69.7%).
Manios and Syminis (1988)	Town refuse compost of Heraklio	15 and 30 t/ha	Cucumber Yield was increased by 17.6% and 20.8% with 15 and 30 t ha-1 treatments respectively
Sabrah*et al* (1995)	Optimizing physical properties of a sandy soil for higher productivity using town refuse compost in Saudi Arabia	16.5, 33, 49.5 and 66 t/ha	Application of 33 t/ha of composted Urban was found to be the most Economical one for wheat crops giving 26 – 34% yield increase over the control.
Aguilar *et al* (1997)	Agricultural use of municipal solid waste compost on tree and bush crops	11.2-45 t/ha	Compost application resulted in an average yield increase of olive and orange crops by 50 and 17% respectively

			compared to the control.
Aguilar *et al* (1997)	Agricultural use of municipal solid waste compost on tree and bush crops	30t/ha	Produced an average increase in grape yield by 30% compared to the control
Khalilian *et al* (2002a)	Effects of surface application of MSW compost on cotton production – soil properties, plant responses, and nematode management	11.2, 22.4 and 33.6 t/ha	Observed average cotton yield increase of 3.6, 10.2, and 19.7% with 11.2, 22.4 and 33.6 t/ha

2.4.2 Chicken manure

The NPK value of chicken litter was 2,1,1 respectively (Hati *et al.*, 2004). It was found that 17.5 kg of chicken manure would supply the equivalent NPK of MSW compost.

2.4.3 Urea-based Fertilizer

13-13-20-2MgO (nitrate-based) and 16-16-23 (urea-based) fertilizers are used for the cultivation of vegeTables and fruits in Mauritius. Since the NPK nutrient value of 16-16-23 (urea- based) fertilizer is higher compared to the nitrate-based fertilizer, the application of the urea-based fertilizer was considered for the purpose of the study. It was found that 1.44 kg of urea-based fertilizer would provide supply the equivalent NPK of MSW compost.

2.4.4 Compost and Fertilizer

Comparatively, treatment SFC was treated with a mixture of MSW compost and urea-based fertilizer. 16.7 tonnes/hectare MSW compost and 1.2 tonnes/hectare urea-based fertilizer were added to treatment SFC.

A summary of the application amounts of the different treatments that provide the equivalent NPK nutrients of MSW compost can be found in Table 2.4.2 below.

Table 2.4.2: Application amount of the different treatments.

Treatments	**Treatments – To provide equivalent NPK of MSW compost**

S	Bare Soil- Control
SC	33 tonnes/hectare of MSW compost
SM	29.2 tonnes/hectare Chicken litter
SF	2.4tonnes/hectareUrea-based fertilizer
SFC	16.7 tonnes/hectare MSW compost and 1.2 tonnes/hectareUrea-based fertilizer

The maximum temperature, close to the seasonal mean at Reduit during the months of August-October was 18-22 °C. During the same season, the weather remained partly cloudy with isolated showers. The climatic conditions that prevailed in the region were optimum for the cultivation of *Lactuca Sativa* which is a cool-weather annual crop. Moreover, the exported value of lettuce from South Africa in 2010 was USD 40,000, which makes Mauritius a high consumer of lettuce (Profile of the South African Lettuce Market value chain, 2011) Hence, the crop yield of *Lactuca Sativa* was studied. After three weeks, 20 seedlings of lettuce were prepared and were transplanted to the different treatments.

Plate 1: showing transplantation of lettuce seedlings

2.4.5 Analysis of treatments

The five treatments were analyzed in terms of the following parameters, namely:

Number of plants harvested:

The total number of plants which were able to sustain growth in each treatment was noted.

Average number of leaves per plant formed in the different treatment:

The average number of leaves was determined by counting the number of leaves formed in each crop.

Plant Height:

The average height of three plants from each treatment was measured.

Dry mass of the crops:

The dry mass was determined by placing the plant (shoot and root) in an oven set at 60°C for a period of 72 hours. Thus, three crops which were cultivated under each different treatment were placed in the oven for a period of at 60°C for 72 hrs, time after which the mass of the plants were noted.

Shelf life of the crops

The shelf-life of *Lactuca Sativa* is an important property of the plant. In order to determine the treatment which aids in conserving the *Lactuca Sativa* plant for a longer period, a test methodology was devised whereby three crops from each treatment, placed in a plastic bag were kept in the refrigerator. For the purpose of control, another three crops from each treatment were placed in a plastic bag and were then stored at room temperature. The qualities of the leaves were then assessed visually on a daily basis.

Soil properties

Various soil properties such as Moisture content, Porosity, Bulk Density, Volatile solids, pH, Electrical Conductivity and Water Holding Capacity were carried out on a weekly basis. Total Organic Carbon and Nutrient value (NPK) of soil samples were tested on a biweekly basis. The methods are as per the procedures described in Appendix 1. Nitrogen, Phosphorus, Potassium (NPK) content and Cation exchange capacity (CEC) of the samples were tested by CHEMCO.

2.5 GHG Monitoring

2.5.1Chamber Design

De Klein *et al.*,(2011) highlighted that the Chamber method, which is the most widely used for measurement of trace gas emissions at landscape scale, is relatively low cost and simple to deploy. A recent review of N_2O emissions studies using chamber methodologies from around the world highlighted that there is large variation in chamber design, deployment and data analysis (Rochette and Ericksen-Hamel, 2008). This has implications for the reliability of N_2O emission factors that are derived from these data. Through the development of internationally applicable guidelines and standards, it will be possible to improve both the quality of measurements that support national inventory verification and international intercomparability of these data. The guidelines that were used for the design of the chamber and are as listed below:

Chamber material

The chamber material should be inert. Various options such as plexiglass, stainless steel, aluminium, PVC, polypropylene and polyethylene exist.

For the purpose of this study, plastic bucket made of polyethylene (PET) was utilized as the chamber.

Chamber size

Small chambers ensure adequate mixing of gas emissions. The size of the chamber should be sufficient to capture the soil gas emission from a given surface. Increasing the size of the chamber will increase risk issues associated with inadequate sealing at the soil and/or the base to cover. Moreover, a bigger chamber will increase the time and resources required to displace the chambers. Common chamber size varies from 0.02 m^2 upto greater than 2$m^{2.}$

A chamber of 0.03 m^2 was used in this study.

Chamber height

According to De Klein *et al* (2011), a chamber height which exceeds 15 cm is problematic to accurately measure headspace volume which will introduce error into flux calculations. Plant growth should also be accounted while designing chamber heights.

The height of the plastic bucket was 15 cm, which was appropriate for the height of Lactuca Sativa plant and also for flux error prevention.

Insulation

Placing an insulation or reflective material or paint minimizes the artificial increase in temperature inside the chamber during the enclosure period. Reflective foil or white PVC can be used for insulation purposes.

The chamber (bucket) used in this study was white in color and insulated using Aluminium foil as a reflective material.

Construction of Static flux chamber

Five chambers were constructed for the purpose of this study. A 5 liter plastic bucket served as chamber. A 30 cm Teflon tubing was connected to each chamber, as shown in Plate 2.

Plate 2: Construction of Chamber-Step 1

The Teflon tubing was fixed in the hole and silicon adhesive was used to prevent leakages.

Plate 3 Construction of chamber- Step 2

Finally, aluminium foil was wrapped around each chamber. Aluminium foil helps to reflect light and thus does not allow heating up of the chambers during deployment.

Plate 4: Construction of chamber- Step 3

2.5.2 Deployment of static chamber and sampling of soil gas emissions

The set up was designed as described in Fig 2.5 below.

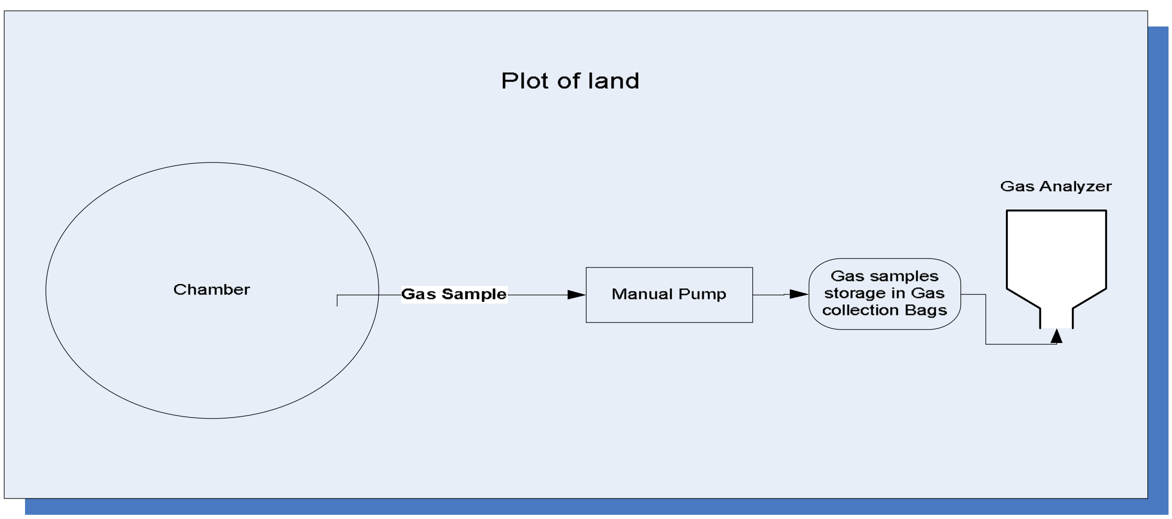


Figure 2.5: Experiment set up to analyze GHG emissions

For the measurement of CO_2 and CH_4, the chamber was placed above the plant and left for 5 minutes prior to sampling so as to allow stabilization. The chamber was inserted in the soil to a depth of 5 cm atleast, thereby preventing any type of leakage (Deklein *et al.*, 2011).

The gases from the chamber were then drawn from the manual pump to a gas collection bag after 30 mins (Plate 5). The above procedure was repeated for the other treatments including their controls. Gas samples were captured every Monday between 10 hrs and noon. Analysis of the gas samples was carried out using the GEM 2000 Gas analyzer.

In measuring gas emissions by using the chamber method, diffusion of the target gas from the soil into the chamber results in increases in the concentration of the gas in the chamber. The change in concentration is used to calculate the rate of gas emission. In the simplest application, the rate of gas emission is calculated by:

$Q = V/A\ (C-C_0)/t$

Where Q is the emission rate, V is the volume of the chamber; A is the area of soil covered by the chamber; C is the concentration of the gas in the chamber at time t, and C_0 is the initial concentration at t = 0 (Hutchinson and Livingston, 1993).

Plate 5: Showing deployment of static flux chambers on the treatments.

2.5.3 Nitrous Oxide (N_2O) Calculation

While CO_2 and CH_4 emissions were captured using the gas analyser, the Nitrous oxide fluxes from the treatments were calculated from IPCC guidelines on N_2O emissions from managed soils, and CO_2 emissions from lime and urea application.

Total N_2O emissions from soil surface are the sum of direct and indirect N_2O emissions. Direct emissions include increase in N_2O emissions due to increase in the available amount of Nitrogen in soil. Indirect emissions involve emissions due to atmospheric deposition and leachate formation. Equations depicting both types of emissions are depicted below.

Direct Emission:

$N_2O\text{-}N_{inputs} = (F_{SN} + F_{ON}) \times EF_1$

Indirect Emission:

Due to Atmospheric deposition: $N_2O\text{-}N_{Atm} = ((F_{SN} \times Frac_{GASF}) + (F_{ON} \times Frac_{GASM})) \times EF_4$

Due to Leachate formation: $N_2O\text{-}N_L = ((F_{SN} \times Frac_{Leach}) + (F_{ON} \times Frac_{Leach})) \times EF_5$

Where,

$N_2O = N_2O\text{-}N \times 44/28$

F_{SN} =Annual amount of synthetic fertilizer applied to soil, kg N yr^{-1}

F_{ON}= Annual amount of compost added to soil, kg N yr-1

$Frac_{GASF}$ =0.10, Fraction of synthetic fertilizer N that volatilizes as NH_3 and NOx

$Frac_{GASM}$ = 0.20, Fraction of compost N that volatilizes as NH_3 and NOx

$Frac_{Leach}$ = 0.30, N loses by leaching

EF_1 =0.01, Emission factor

EF_4 = 0.01, Emission factor

EF_5 = 0.0075, Emission factors

Values for fraction of fertilizers that volatilizes as NH_3 and Nox ($Frac_{Leach}$,$Frac_{GASM,}$$Frac_{GASF}$)and emission factors (EF_1 , EF_4, EF_5) have been used as outlined in IPCC 2006.

2.6Analysis of environmental impacts and carbon footprint calculation

As outlined in ISO 14044-2006, Life Cycle Assessment (LCA) addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (cradle-to-grave).
An LCA Study comprises of four phases; namely,

1. the goal and scope definition phase
2. the inventory analysis phase
3. the impact assessment phase, and
4. The interpretation phase.

2.6.1 Goal Definition

The goal of this study was to assess the environmental impacts associated with the application of compost to agricultural land in view of adapting to climate change.

The scope of this study was to compare the environmental impacts associated with the following scenarios:

Scenario 1: Application of urea-based fertilizer to soil (Baseline scenario)

Scenario 2: Application of MSW compost

Scenario 3: Application of Chicken Manure to soil

Scenario 4: Application of MSW Compost and Urea-based fertilizer to soil.

2.6.2 Scope of the study

Functional Unit

The purpose of the functional unit is to quantify the service delivered by the product system. The first step is thus to identify the purpose served by the product system; i.e. its function or functions (ISO 14049: 2000). The functional unit used in this study was the application of ***1155***

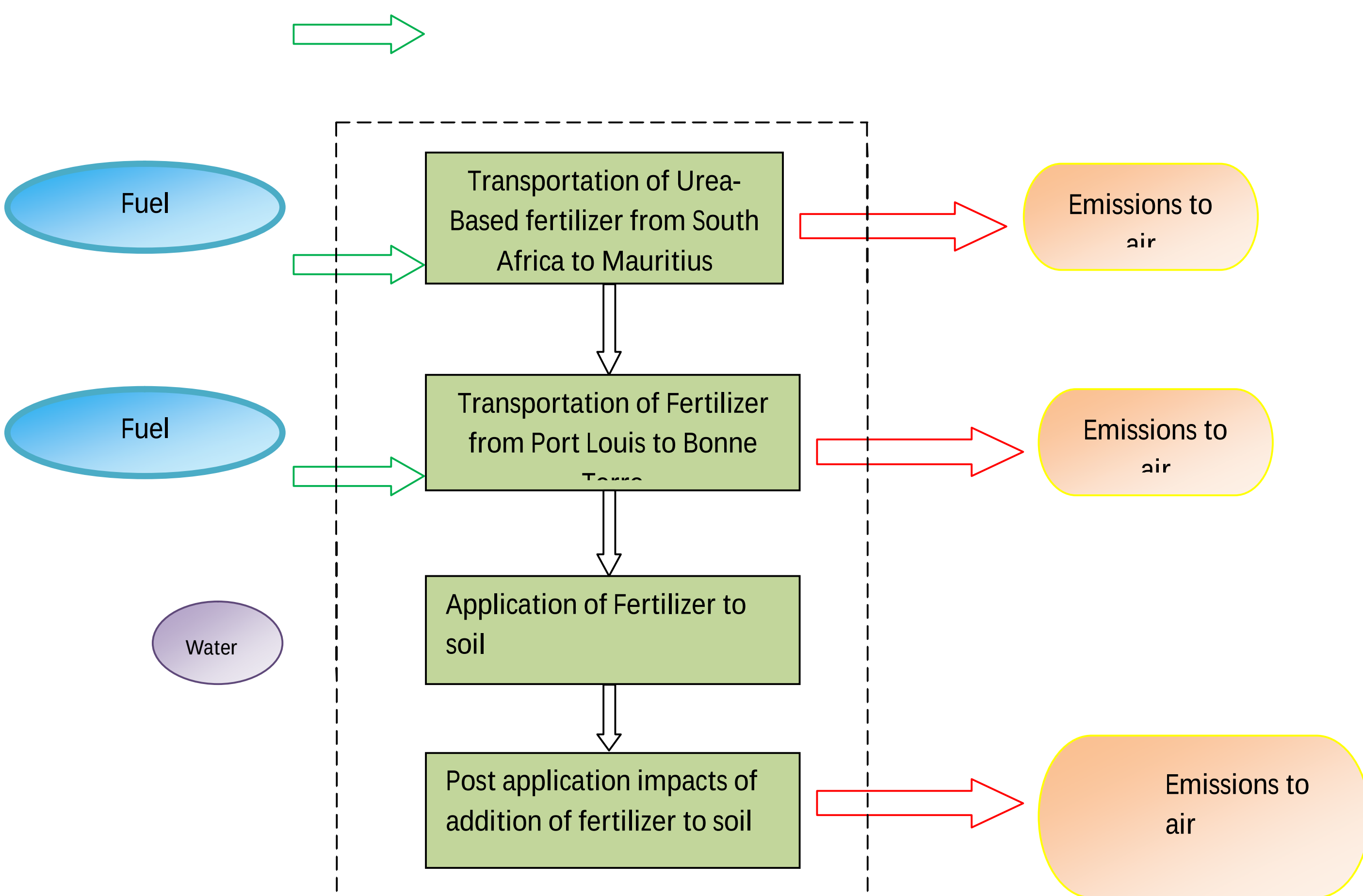
kg N/ha/yr. The functional unit was selected based on the application amount of MSW compost (33 ton/ha). It was also assumed that compost is applied twice, on ayearly basis. This would mean that per year, 1155 kg of Nitrogen is being used on one hectare.

2.6.3 System boundaries

It is not necessarily desirable or possible to include all stages of the life cycle of the systems under analysis in any life cycle study. The aim of this study was to assess the environmental impacts associated with the application of organic and inorganic fertilizers. Thus, to limit the scale of data collection, this study concentrated on the transport, application and post application impacts of the various treatments.

***Scenario 1:* Application of urea-based fertilizer to soil**

Urea-based fertilizers were imported from South Africa (Cape Town). The fertilizer was then transported to Bonne Terre, where it was used for land application.



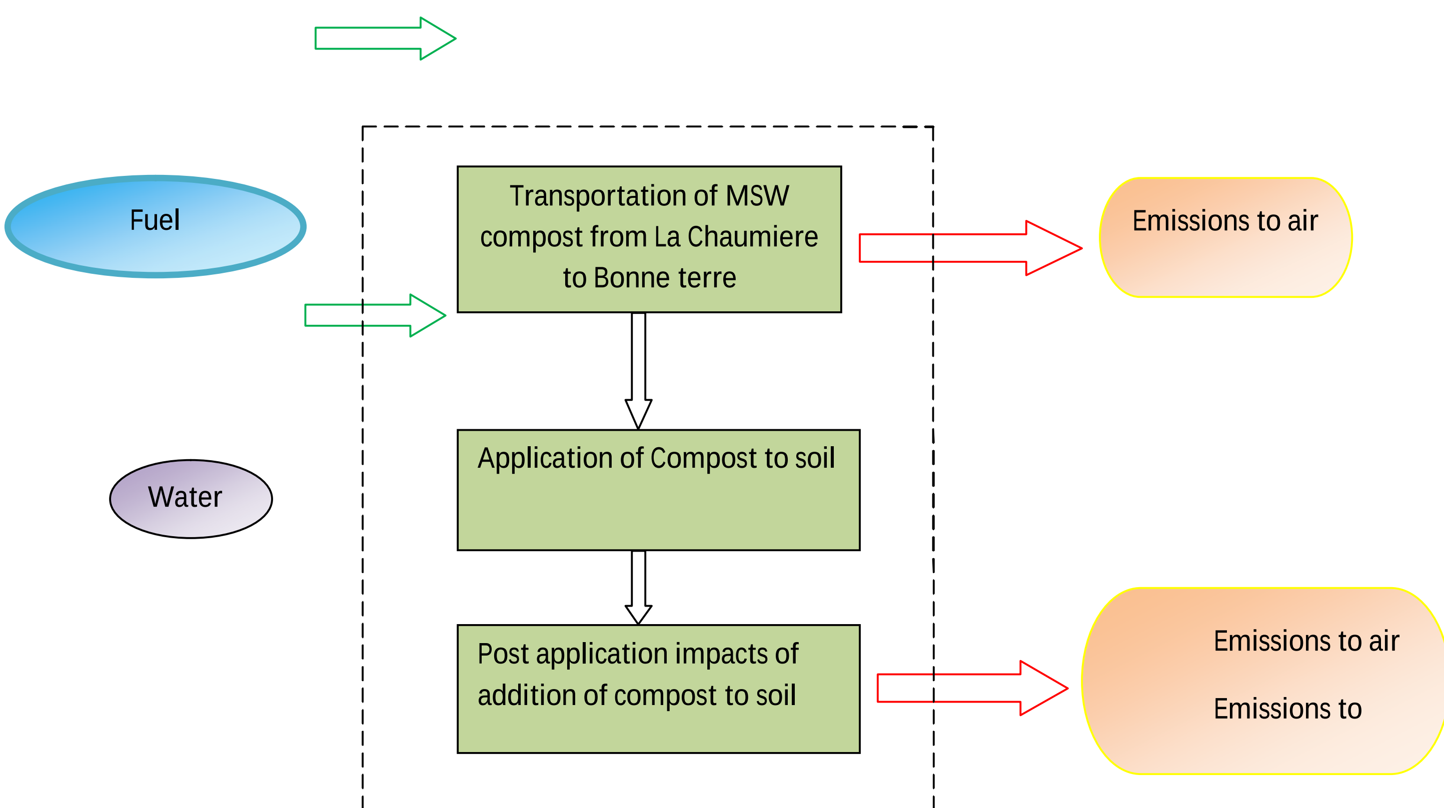
Scenario 1: Application of Fertilizer to soil

Assumptions:

- 7.22 tons of urea-based fertilizer (16-16-23) supplied 1155 kg of Nitrogen.
- 1.80 tons of fertilizer was applied four times a year for the cultivation of lettuce
- The distance from Cape Town to Mauritius was determined to be 2295 nautical miles which is equivalent to 4250 km (Source: Distance Calculator, http://distancecalculator.globefeed.com/mauritius_distance_calculator.asp)
- The travel distance from Port Louis to Bonne terre is 17.75 km.
- 61.25% of water supplied to soil treated with fertilizer is lost as leachate (Unmar at *al.*, 2010)

***Scenario 2:* Application of MSW compost**

Compost produced at La Chaumiere composting site was transported to Bonne terre for cultivation purposes.



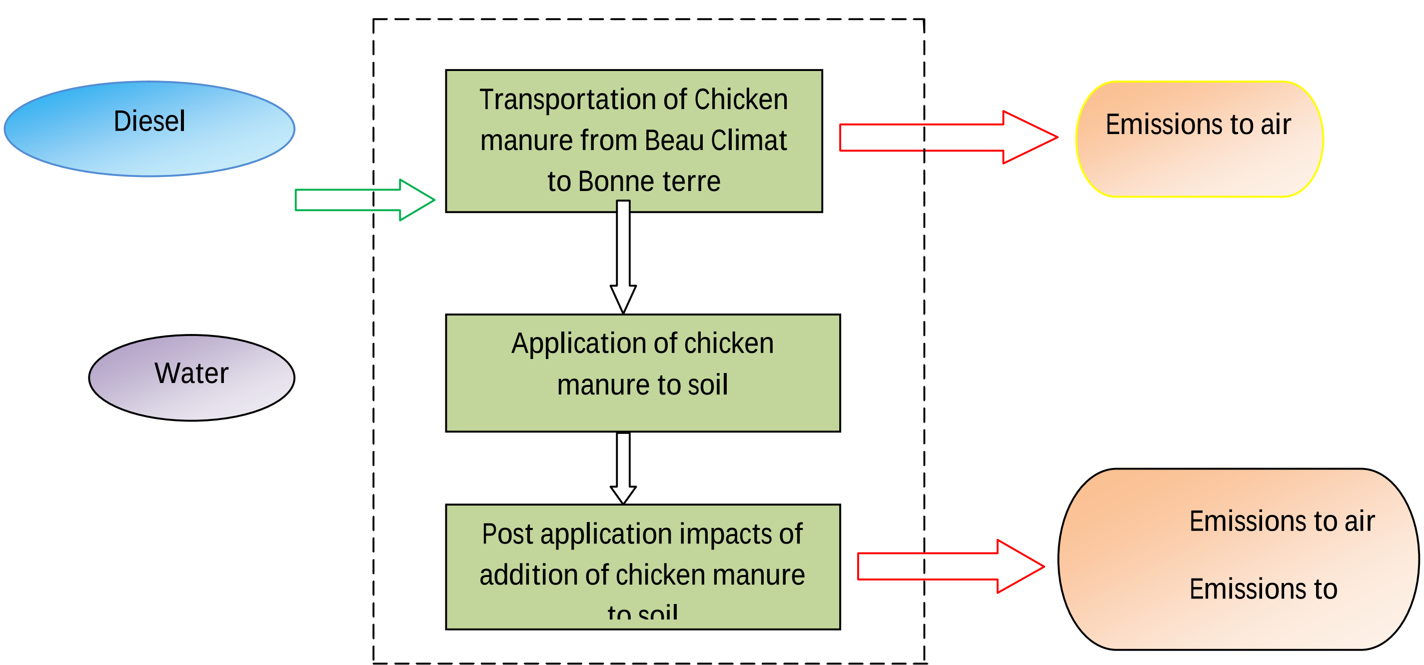
Scenario 2: Application of compost to soil

Assumptions:

- To supply 1155 kg of Nitrogen, 66 tons of MSW fertilizer was required per year.
- Compared to the frequency of fertilizer application, compost was applied twice a year (33 tons each time)
- The travel distance from La Chaumiere to Bonne Terre is 11km. The lorry was assumed to make 2 trips per year. The return journey was not accounted for.
- Based on a study by Unmar *et al* (2010) on Impacts of composts application on properties of a dry soil- a lab scale study it was found that on average 45% of water used for irrigation of soil/compost treatment is leached. Thus, this value was used to account for the amount of leachate formation.

Scenario 3: Application of Chicken Manure to soil

Chicken Manure was transported from Beau Climat (Innodis Ltd) to Bonne terre, where it was used as organic fertilizer.



Scenario 3: Application of chicken manure to soil

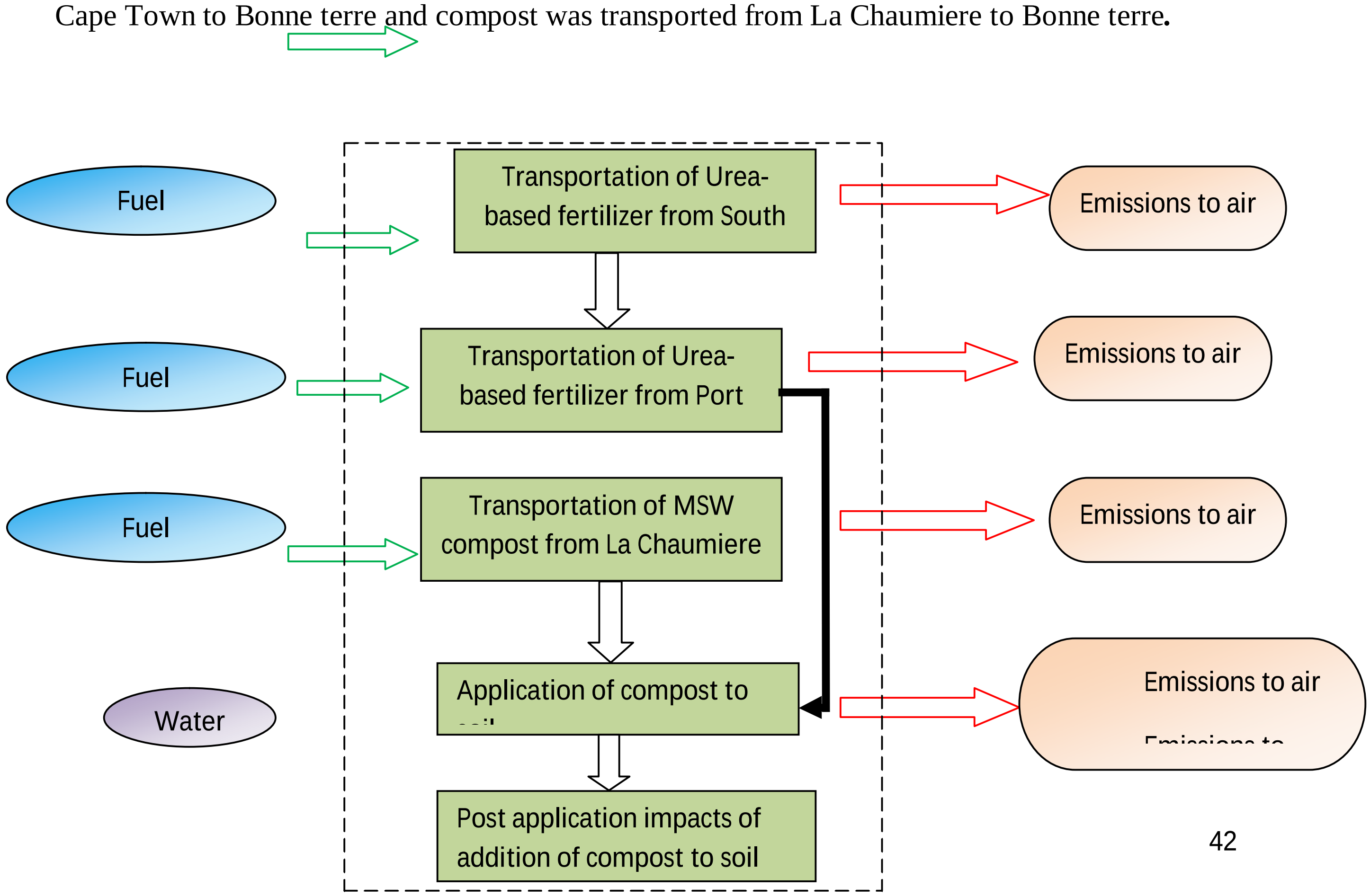
Assumptions:

- The application amount of chicken manure was 58 ton per hectare on a yearly basis. In a year, manure was applied twice to the soil. The same amount of manure was able to supply 1155kg N per year.

- The Distance between Beau Climat (Innodis Ltd) and Bonne terre is 30km. The lorry has to travel twice per year to be able to supply the required amount of manure.

Scenario 4: Application of MSW Compost and Urea-based fertilizer to soil.

Soil was treated with compost and urea based fertilizer. Thus fertlizer was transported from Cape Town to Bonne terre and compost was transported from La Chaumiere to Bonne terre**.**



Scenario 4: Application of Fertilizer and MSW Compost

Assumptions:

- 33 ton of compost and 3.6 ton of fertilizer is applied per hectare on yearly basis to supply 1155kg of N.
- 3.6 tonnes of fertilizer was shipped through a distance of 4250 km from Cape Town to Mauritius
- Finally, 1.2 tonnes of fertilizer was transported over a distance of 17.75 km (from Port Louis to Bonne Terre), thrice a year.
- 11 tonnes of compost was also transferred from La chaumiere to Bonne terre (11km) thrice a year.

2.6.4 SimaPro

SimaPro contains a number of impact assessment methods, which are used to calculate impact assessment results. For instance, CML 2001, Eco-indicator 99, Ecological Scarcity 2006, EDIP 2003, EDP (2008), EPS 2000, Impact 2002+ and ReCipe are examples of European impact assessment methods. The only assessment methods which consist of climate change as a damage category is **Impact 2002+**. Thus, this particular method was selected for the purpose of impact assessment in this study. Impact 2002+ also consists of the following midpoint and damage categories:

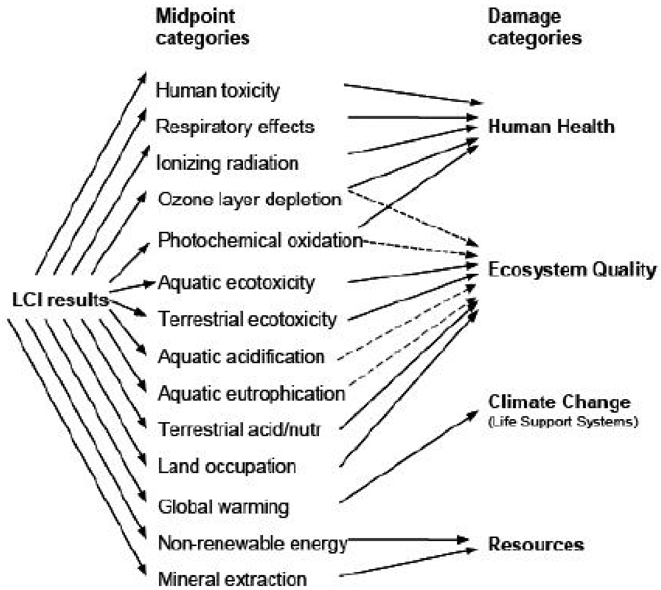


Figure 2.6 : Overall scheme of Impact 2002+, framework, linking LCI results via the midpoint categories. (Source: SimaPro Database Manual Methods, 2010)

Chapter 3

Results and Discussion

3.1 Analysis of Physical & Chemical Properties of the treatments

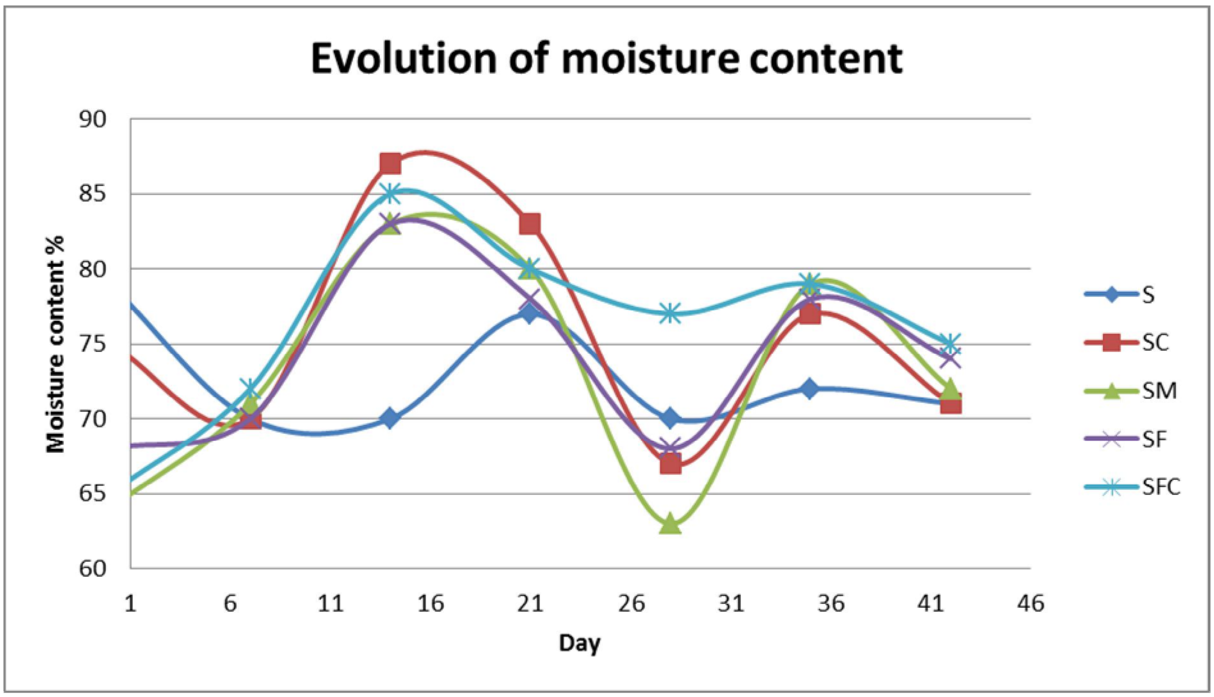


Figure 3.1(a): Moisture content evolution

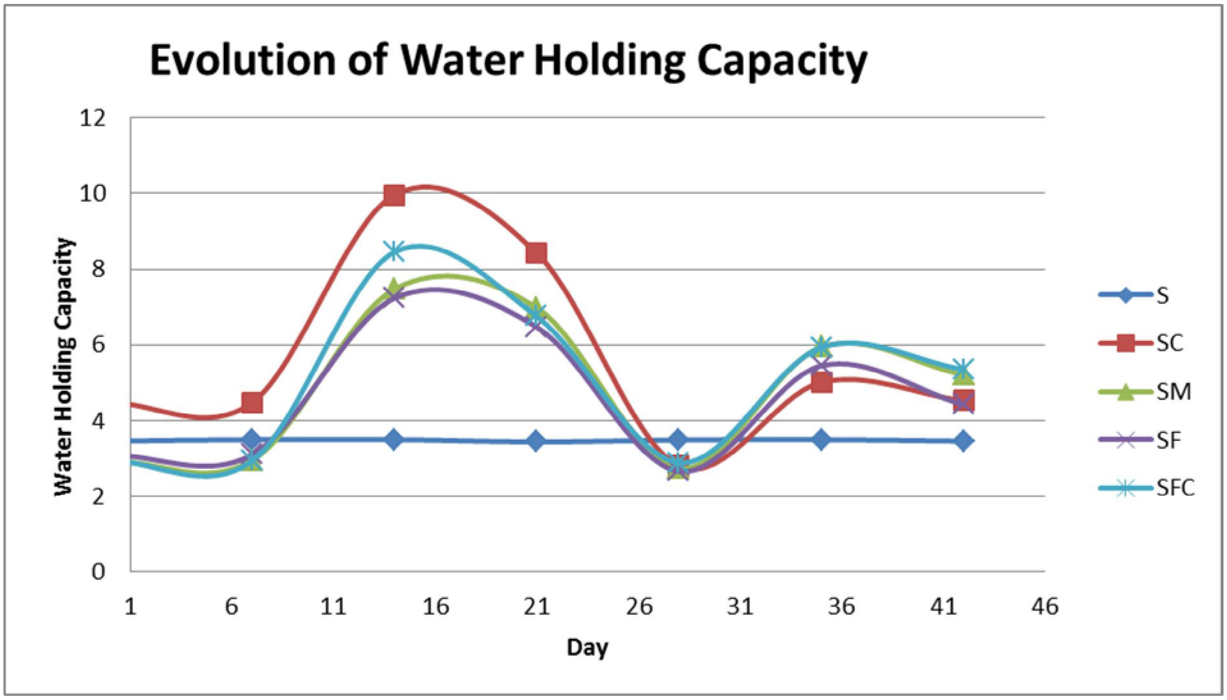


Figure 3.1 (b): Water Holding Capacity evolution

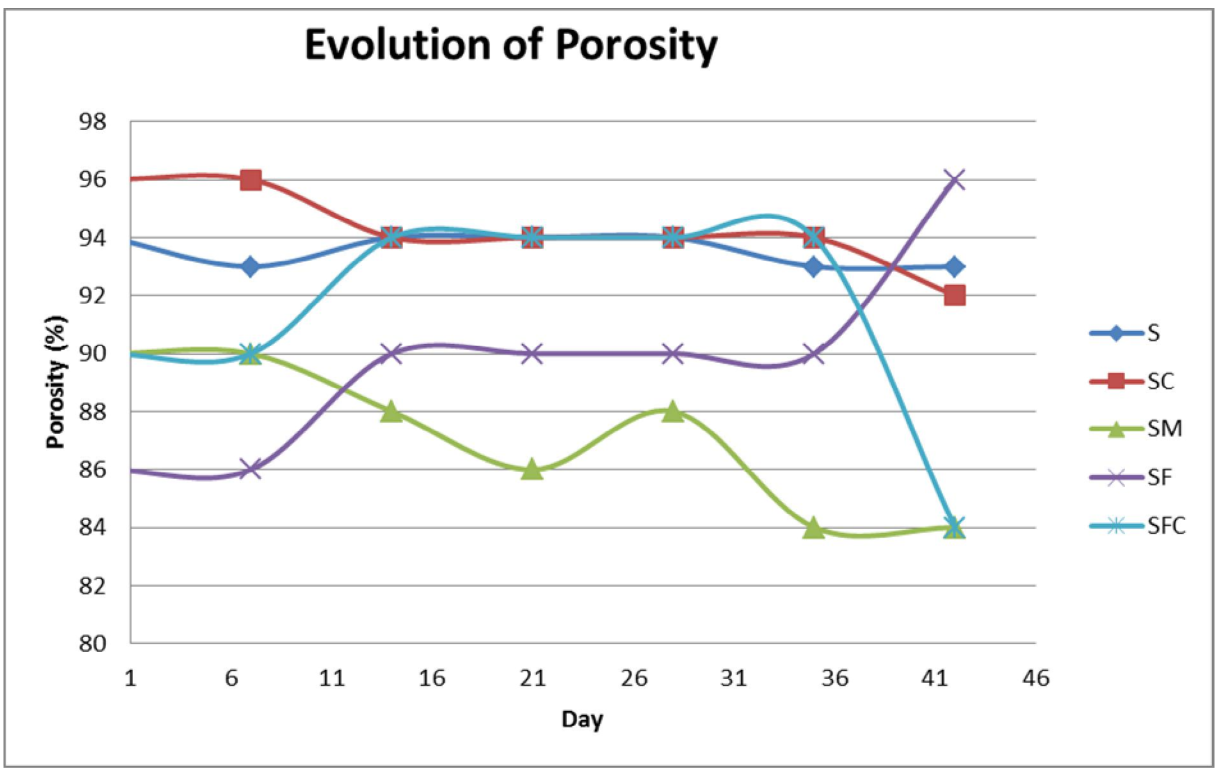


Figure 3.1 (c): Evolution of porosity

Table 3.1(a): Moisture content, Water Holding capacity & Porosity of different treatments

Parameter	S	SC	SM	SF	SFC
	Day 1	Day 42	Day 42	Day 42	Day 42
Moisture content %	74	71	72	74	75
Water Holding Capcity	3.46	4.52	5.21	4.42	5.35
Porosity (%)	93	94	84	96	84

The addition of composts to agricultural soils has been found to increase the water holding capacity of soils (Shiralipour *et al.,* 1992). A convenient amount of water in the soil provides a medium for the transport of nutrients. Thus, the moisture content of the treatments was kept above 50 %. This was ensured by regular irrigation of the treatments. The moisture content of soil treated with compost and that treated with chicken litter followed a similar trend compared to the moisture content of soil treated with fertilizer which was 3 % lower on average. Among all the treatments, compost (SC) was more effective in increasing the water holding capacity by almost 30 % at set up, followed by 44% on day 35. Treatment SFC was also effective in retaining a higher amount of water, in contrast to treatment SF whereby an increase of only 23% was noted on day 28. Treatment SFC, the integrated system which consisted of a mixture of MSW compost and Fertilizer was more effective in retaining a higher amount of moisture and thus the mobility of the ions (Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+ or H^+) were also higher. Foley and Cooperband (2002) found that the application of two paper-based composts increased the amount of water held both at field capacity and permanent wilting point in a loamy sand soil. Since the increase in water held at field capacity increased to a greater extent than at wilting point, it can be inferred that plant available water increases following compost addition to soil. Another study by Mamo *et al.,* (2000) on the growth of maize on a loamy sand soil using MSW composts showed an increase in soil water holding capacity. There is unfortunately a shortage of data on the effects of different compost treatment regimes on plant available water within soils, and further research is required in this area. With future changes in climate and rainfall patterns, this area of research will become increasingly important (Farrell and Jones, 2009).

Porosity provides an estimate on the ability of a soil to store root-zone water and air necessary for plant growth. It helps in maintaining soil organic carbon accumulation, infiltration capacity, movement and storage of water. The rise in CO_2 concentration, temperature and rainfall as a consequent of climate change, may change root development and soil biological activities, soil porosity (D.E. Allen *et al.*, 2011). Moreover, CH_4 emissions and uptake, and N_2O emissions from soil are affected by pore size distribution and aeration between soil particles (D.E. Allen *et al.*, 2011). From Table 3.1 (a), the porosity of SC was 94%, while that for soil and fertilizer (SF) was 96%. It can be observed that the porosity of soil and chicken litter was reduced to 84% as compared to the other treatments which ranged between 90% and 96%.

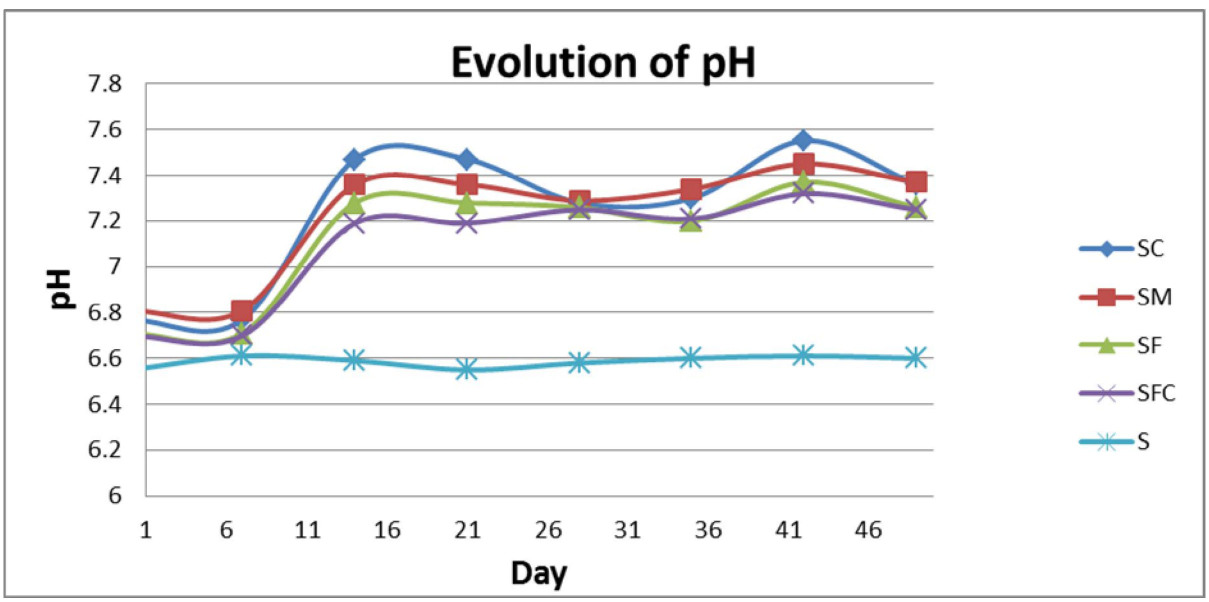


Figure 3.1 (d): Evolution of pH

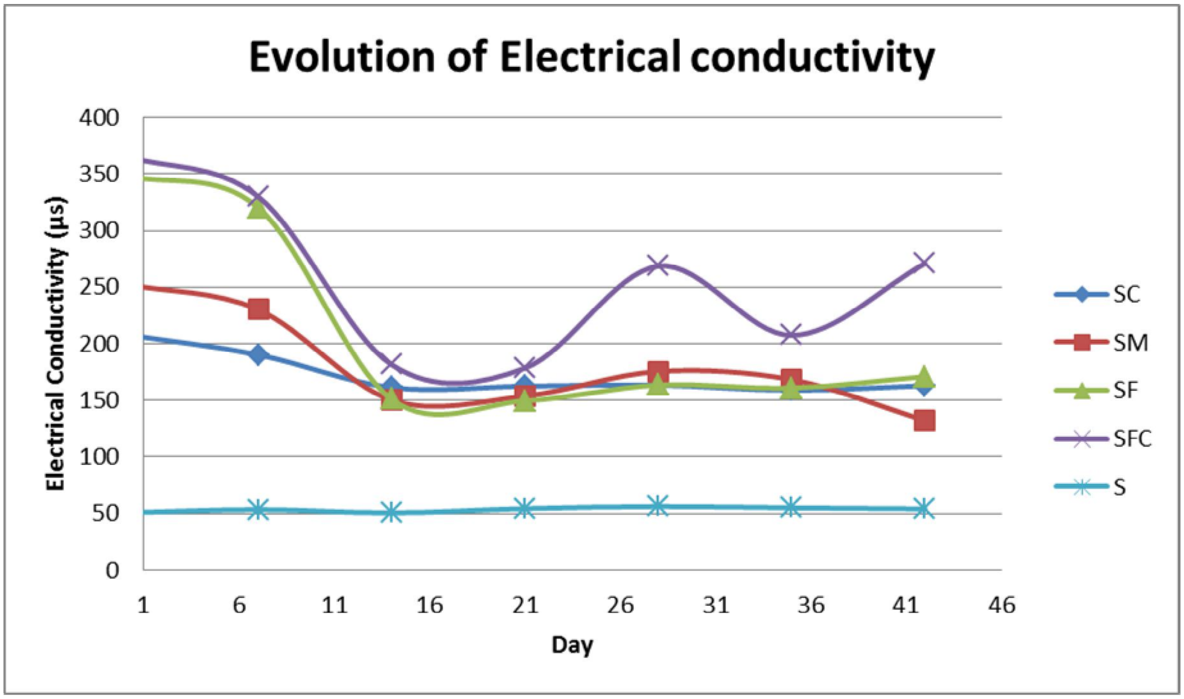


Figure 3.1 (e): Evolution of EC

Table 3.1 (b): pH and Electrical Conductivity of the various treatments

Parameter	S	SC	SM	SF	SFC
	Day 1	Day 42			
pH	6.61	7.55	7.45	7.37	7.32
Electrical Conductivity (µs)	52	162.9	132.1	171	271

Prior to the set up, the pH of bare soil was around 6.6. Incorporation of MSW compost and chicken litter helped to maintain the pH of soil to 7.3-7.5 which is deemed right for vegetation. The pH of untreated soil showed almost no variation during the monitoring period of 42 days. On day 1, the pH of SM was the highest, which is 6.8, followed by the pH of SC which was 6.77.

The electrical conductivity of the urea-based fertilizer was 42 800 µs as compared to chicken litter and MSW compost which was 962 µs and 2858 µs respectively. This explains the variations in initial EC of the different treatments. Initially, the electrical conductivity of SF and SFC was 348.7 µs and 366 µs compared to that of SC and SM which was 208 µs and 252 µs.

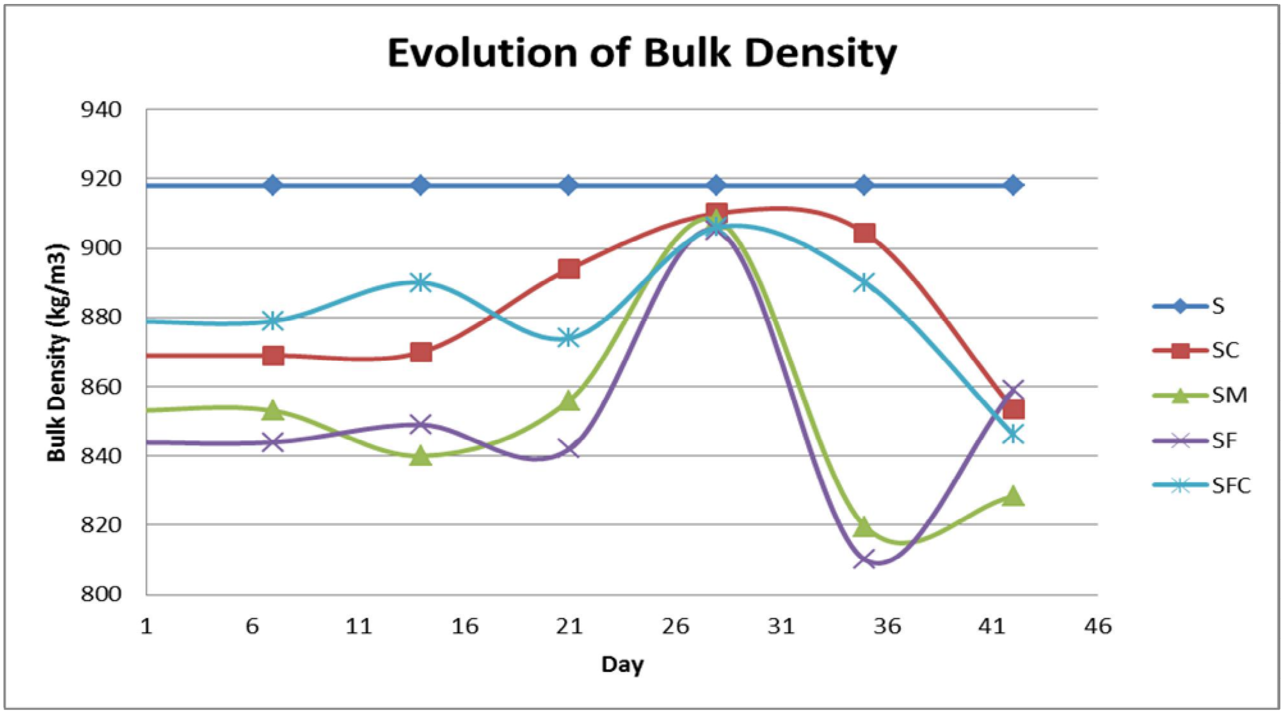


Figure 3.1 (f): Evolution of Bulk density

Table 3.1 (c): Bulk density of the treatments

Parameter	S	SC	SM	SF	SFC
	Day 1	Day 42			
Bulk density(kg/m^3)	918	854	828	859	846

Bulk density provides an indication of the soil compactness as well as aeration and infiltration. Bulk density is negatively correlated with soil organic matter (Weil and Magdoff, 2004, in D.E. Allen *et al.*, 2011). Increased in temperature due to climate change eventually leads to a rise in decomposition and this may result in an increase in bulk density. An increase in bulk density implies more soil compaction that is not favorable for crop cultivation. From the results obtained in this study, it was found that the soil bulk density decreased upon being subjected to the different treatments. There was a steep decrease in the bulk density of SC and SM from day28 onwards. This can be attributed to the fact that application of compost, has the ability to decrease the bulk density of soil and thus plant growths are enhanced. The bulk density of SC, SM, SF and SFC increased significantly during day 14 and 28 as the moisture content of the samples were equally high. This is due to the elevated level of rainfall noted in the region. In general, incorporation of MSW compost and chicken litter caused a decrease of 8 % in the bulk density of the soil.

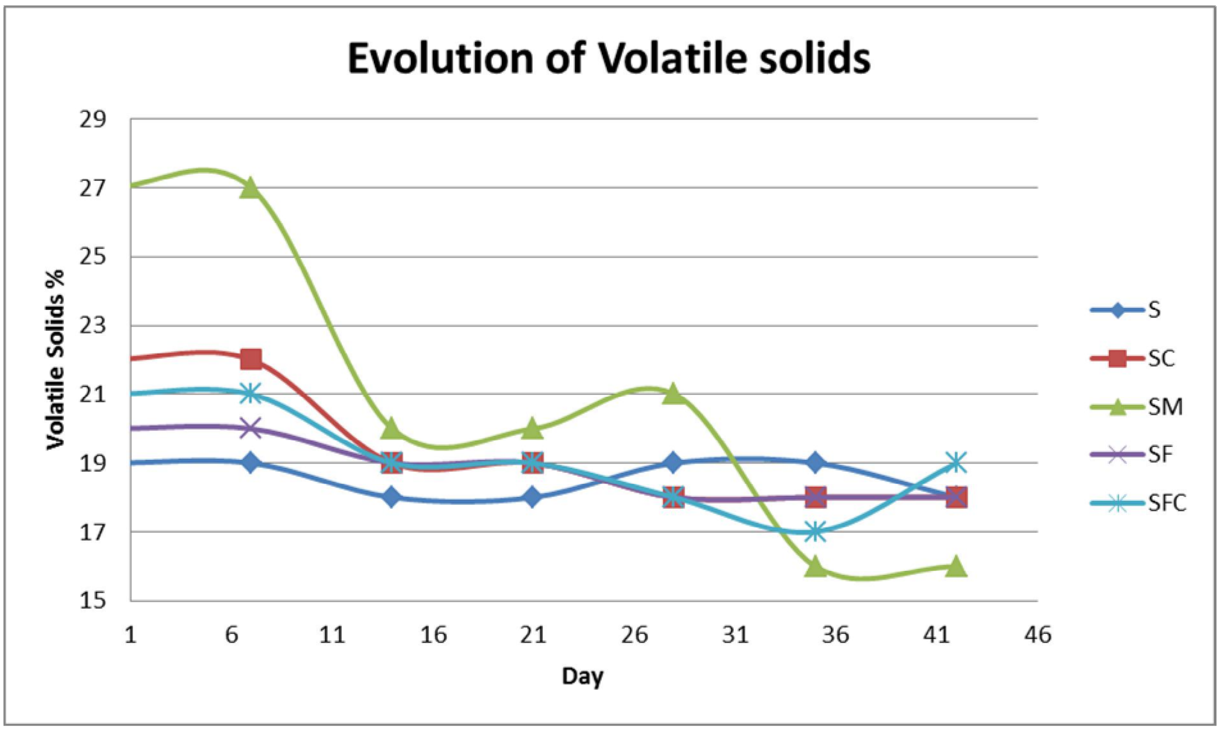


Figure 3.1 (g): Evolution of VS

The soil used in this study consisted of 18.5% of organic substances which is also termed as Volatile solids. Application of MSW compost increased the amount of volatile solids by almost 16 %. Higher values for volatile solids (85%) were noted in soil treated with chicken litter. The amount of organic matter in treatment SC, SM and SFC were higher compared to treatment SF as the latter was treated with inorganic treatment only.

Total Organic Carbon and Organic matter evolution with time.

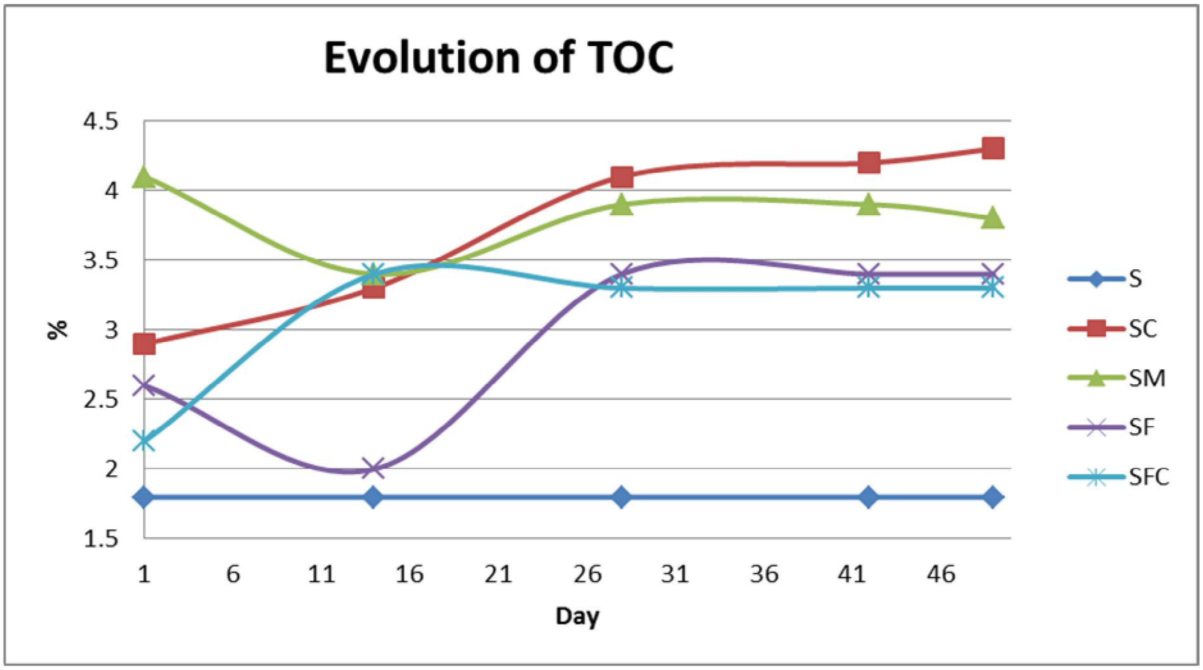


Figure 3.1(h): Evolution of TOC

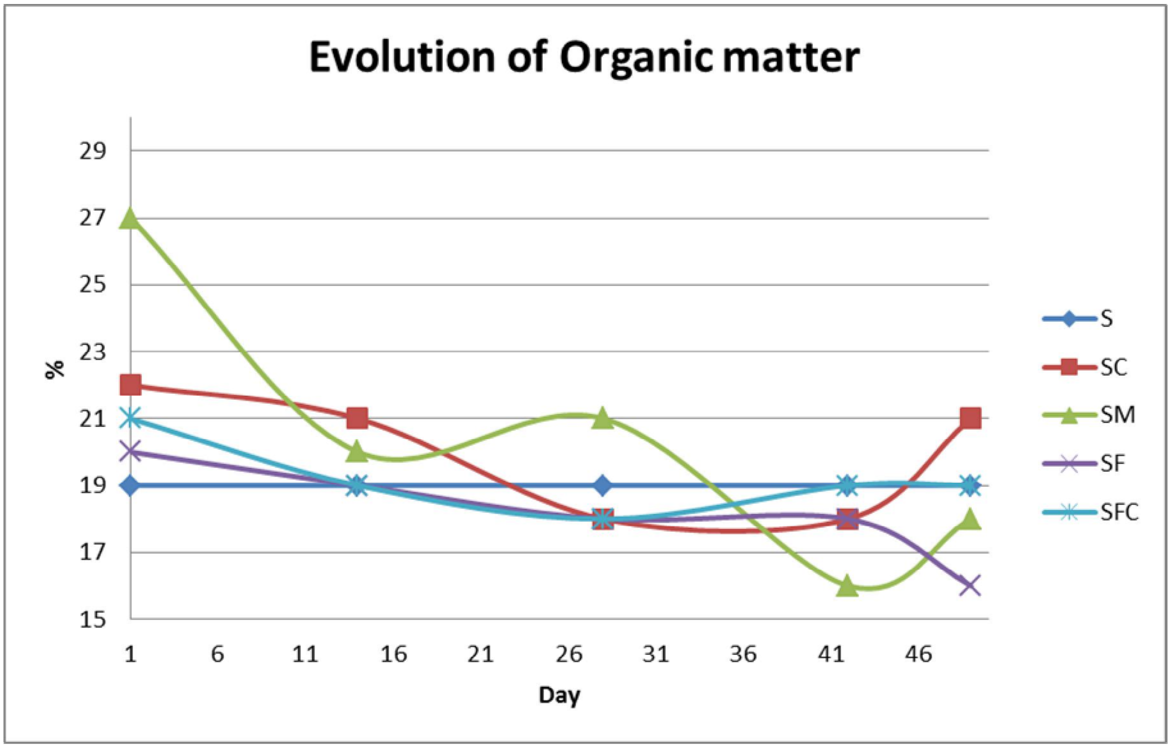


Figure 3.1 (i): Evolution of Organic matter

The Total Organic Carbon (TOC) of soil was 1.841%. Incorporation of MSW compost (SC) to soil triggered an increase of 60% in the TOC content of the soil on day 1. Compared to other treatments, only MSW compost (SC) caused significant increase of TOC in the soil, after more than 40 days (Figure 14). This showed evidence of compost acting as Carbon sink. The TOC of treatment SC was 4.208% while that of SM and SF were 3.92 and 3.44% only on day 42. Soil treated with a mixture of fertilizer and compost (SFC) also showed an overall increment of 81.7% in TOC after 6 weeks.

Soil organic matter (SOM) provides a sink for and a source of carbon and nitrogen as well as regulates phosphorus and sulphur cycling and possesses the ability to complex with multivalent ions and organic compounds (D.E. Allen *et al.*,., 2011). Soil organic carbon comprises of about 50% of SOM (D.E. Allen *et al.*, 2011). Improvements in the organic matter of soil is important as SOM drives a majority of soil functions and a decrease in SOM can lead to a drop in soil fertility, biodiversity, water holding capacity, and a rise in soil erosion and bulk density. Therefore, a buildup of SOM will help in absorbing CO_2 from the atmosphere thus mitigating global warming. Compost application to soil showed a general increase in SOM of 10.5 % after 7 weeks (Figure 14).However, according to Davidson and Janssens (2006), the accessibility and availability of SOM to microorganisms are the determinants of SOM losses rather that the rate-modifying climate factor which is temperature (D.E. Allen *et al.,.,* 2011).

It is to be noted that the total organic carbon and organic matter contents of soil remained unchanged throughout the experimental analysis. However, there has been a general increase in TOC and organic matter (OM) content for soil subjected to compost application as compared to a decline in TOC and OM for application of manure to soil.

3.2 GHG Emissions

Table 3.2 (a): Carbon dioxide and methane %

Day	Treatments	Carbon dioxide (%)	Methane (%)
1	S	0	0
	SC	0.1	0
	SM	0.1	0
	SF	0	0
	SFC	0	0
14	S	0	0
	SC	0	0
	SM	0.2	0
	SF	0	0
	SFC	0	0
28	S	0	0
	SC	0	0
	SM	0.2	0
	SF	0	0
	SFC	0	0
42	S	0	0
	SC	0	0
	SM	0.2	0
	SF	0	0
	SFC	0	0

49	S	0	0
	SC	0	0
	SM	0.3	0.1
	SF	0.1	0
	SFC	0	0

Table 3.2 (b): GHG emissions

Treatments	**SF**	**SC**	**SM**	**SFC**
Application amount	2.4t/ha	33t/ha	29.7 t/ha	16.7t/ha & 1.2 t/ha
Application rate for *Lactuca Sativa* cultivation	Four times a year	Twice a year	Twice a year	Thrice a year
N_2O emissions (kg CO_2eq/yr)	9914	8017	7998	9805
CO2 emissions (kg CO2 eq//yr)	619	301	3404	-
CH4 emissions (kg CO_2eq/yr)	-	-	2356	-
Total GHG emissions (kg CO2 eq/yr)	10533	8318	25160	9805

The CO_2 flux from treatment SC was 15.47g/m^2/day on Day 1 (Table 14). No flux of CO_2 was recorded from treatment SC till day 49. Soil treated with chicken litter produced a flux of 15.47g CO_2g/m^2/day which further increased to 30.95 g/m^2/day (0.2%) on the 7th day. Treatment SM acted as a source rather than a sink of CO_2. Thus, a maximum flux of 46.41g CO_2/m^2/day (0.3%) was measured on day 49 from treatment SM. The carbon dioxide flux from plot SM increased by almost 200% within 7 weeks after incorporation of the organic fertilizer. Treatment SF emitted only 15.47g CO_2/m^2/day (0.1%) one week after incorporation of the urea-based fertilizer to the bare soil. No carbon dioxide flux was detected from the control S and treatment SFC even after 7 weeks (Table 3.2 (b). Treatment SM produced a net flux of 5.61 g CH_4/m^2/day (0.1%) on the 49th day. No methane emissions were detected from the treatments S, SC, SF and SFC.

The GHG emissions were calculated on a yearly basis for *Lactuca Sativa* cultivation. It was assumed that *Lactuca Sativa* would be grown four times a year. Fertilizers were thus applied prior to each crop growing period, that is, four times a year. Based on their availability of nutrients, compost and chicken manure were applied twice a year. With manure, 5% to 20% of applied carbon is retained, while carbon retention for compost ranges between 10% and more than 50%. Hence, it can be assumed that compost is also considerably more effective in sequestering carbon in the long-term than manure (Biala.J., 2008).

The total GHG emissions was found to be highest for treatment SM (25160 kg CO_2 eq/yr), followed by treatment SF (10533 kg CO_2 eq/yr). N2O emissions were the main contributor to GHG emissions for these treatments. Dalal *et al* (2010) measured N_2O emissions of 5.0 kg N_2O ha^{-1}/yr^{-1} from soil treated with urea (applied at 150 kg N ha^{-1}), 5.1 and 5.5 kg N_2O ha^{-1}/yr^{-1} from manure applied at 10 and 20 t ha^{-1} respectively, 2.2 kg N_2O ha^{-1} $/yr^{-1}$ from Green Waste Compost applied at 10 t ha^{-1} and 3.3 kg N^2O ha^{-1}/yr^{-1} from the bare soil (Dalal *et al.,*2010) Fronning *et al.,* (2008) found that for an application amount of both manure and compost of 45 t/ha/yr, manure had the highest flux of 39.0 g N_2O-N ha^{-1} d^{-1} followed by compost, which was 13.7 g N_2O-N ha^{-1} d^{-1}. Lessard *et al.,* (1996) found that about 1 kg N ha^{-1} was lost due to N_2O emission during 185 days from soil that received two applications of cattle manure for 2 years. The effect of long-term manure application on N_2O emission has been largely ignored. Chang *et al.,* (1998) studied the effect of long-term manure application (21 years) on the annual emission of N_2O and whether emission rate was related to various environmental factors. Emission rates ranged from 2 to 4% of total N applied manure. Greater emission rates from the long-term study may be the cumulative effect of repeated manure applications over several years and the mineralization of organic N reserves. The relationship of different combinations of environmental factors only accounted for 30% or less of the variability in N_2O flux. The rate of N_2O emission was greatest during spring season, but flux rates were significant throughout the winter months. Similar to NH_3 emissions, application method can greatly influence N_2O emissions.

CH_4 emissions were only detected in soil treated with manure. As shown by Fronning *at al* (2008), the application of manure resulted in emissions of 1.3 g CH_4–C ha^{-1} d^{-1} compared with bare soil which produced a flux of −0.9 g CH_4–C ha^{-1} d^{-1}. Treatment SC was found to contribute the least to GHG emissions with 8318 kg CO_2 eq/yr while treatment SFC produced of N_2O emissions (98025 kg CO_2 eq/yr).While the percentage decrease in GHG emissions from plot SC was 21% and that from plot SFC was 7%, plot SM caused an increase of 139% in the total GHG emissions compared to plot SF.

NPK analysis

Nitrogen Content

Table 3.2 ©: Nitrogen content of the treatments

Day	SC	SM	SF	SFC
	ppm			
1	0	0	0	0.419
14	0	0.441	0.387	0.4
28	0.525	0.641	0.483	0.394
42	0.548	0.615	0.404	0.521
56	0.464	0.521	0.424	0.401

Phosphorus content (ppm)

Table 3.2 (d): Phosphorus content of the treatments

Day	SC	SM	SF	SFC
	ppm			
1	149.5	164.6	136.5	242.8
14	133.6	86.9	77.2	98.5
28	286	132	116.4	16.7
42	110.9	118.6	104.8	129.6
56	127	115.1	112.9	124.1

Potassium Content

Table 3.2 (e): Potassium content of the treatments

Day	SC	SM	SF	SFC
	ppm			
1	754	1408	1115	1140
14	728.9	784.5	404.8	725.9
28	595.9	1143	716.8	717.9
42	666	819.5	436.6	896
56	618.9	1048	805.4	782.4

The nitrogen contents of compost (SC), manure (SM) and fertilizer (SF) applications increased by 46 %, 52% and 42.4 % respectively. However, a decrease of 30% was obtained for treatment involving the mixture of fertilizer and compost (SFC). Treatments SC and SF showed a decrease in phosphorus contents of 15% and 17% as compared to treatments SM and SFC which have shown the highest drop in P contents. This may be due to P uptake by *Lactuca Sativa*. A decline in Potassium contents were also observed for all the treatments after 56 days. From the results obtained for NPK evolution (Tables 3.2(c-e)), it can clearly be observed that there is a need for comprehensive assessment of the influence of drivers of climate change on soil nutrients contents.

3.3Crop Yield Analysis

Number of plants

Table 3.3 (a): Number of plants harvested per treatment

Treatment	40 days	60 Days (Harvest)
S	19	19
SC	20	20
SM	20	20
SF	19	15
SFC	15	13

Average number of leaves formed in the different treatment

Table 3.3(b): Average number of leaves formed in the different treatment

Treatment	40 days	60 Days (Harvest)
S	8	11
SC	9	17
SM	6	16
SF	5	10
SFC	6	15

Plant Height

Table 3.3 (c): Plant height

Treatment	40 days	60 Days (Harvest)
S	6 cm	10 cm
SC	5 cm	15 cm
SM	6 cm	16 cm
SF	3 cm	12 cm
SFC	4 cm	13 cm

Visual observation of trend in growth of *Lactuca Sativa*

Soil Only

Week 2

Week 3

Week 4

Week 9

Soil and Compost

Week 2 **Week 3** **Week 4** **Week 9**

Soil and Chicken Litter

Week 2 **Week 3** **Week 4** **Week 9**

Soil and Fertilizer

Week 2 **Week 3** **Week 4** **Week 9**

Soil, Fertilizer & Compost

Week 2 **Week 3** **Week 4** **Week 9**

Plate 6: Crop formation in the different treatments

Root Formation

S **SC** **SM** **SF** **SFC**

Plate 7: Root formation

Dry mass of *Lactuca Sativa*

Table 3.3 (d): Dry mass of crop harvested

Treatments	% Growth	Dry mass %
Soil (S)	95 %	10.3
Soil & MSW Compost (SC)	100%	10.9
Soil & Chicken Litter (SM)	100%	10.5

Soil & Fertilizer (SF)	**75%**	**10.1**
Soil, Fertilizer & MSW Compost (SFC)	**65%**	**10.8**

Both treatment SC and SM were successful in sustaining 100% growth of the seedlings. After 40 days, the maximum number of foliage (9 per plant) was formed in the treatment treated with MSW compost. The maximum number of leaves per plant that was formed in treatment SF was 5 only. It can thus be concluded that compared to inorganic treatments, SC has the ability to increase crop yield. Similar conclusion can be drawn after having analyzed the height of *Lactuca Sativa* shoots in each treatment, whereby the tallest leaves were spotted for treatment SC.

The dry mass of *Lactuca Sativa* from plots S, SC, SM, SF and SFC were 10.3, 10.9, 10.5, 10.1, 10.8 % respectively. Plots SC and SM were successful in sustaining 100% growth followed by plots S, SF and SFC, whereby the percentage growths were 95%, 75% and 65% respectively. Magkos *et al* (2009) found that vegeTables (spinach, lettuce, cabbage) cultivated on soils treated with high amounts of organic fertilizers produced higher dry matter. Moreover, Solid Waste Recycling LTD demonstrated a crop yield of more than 25% for compost use as compared to chemical fertilizers (Defi Plus, 28 September 2012).

3.4 LCA Analysis

Contribution of substances to Climate Change

Scenario 1: Application of Fertilizer

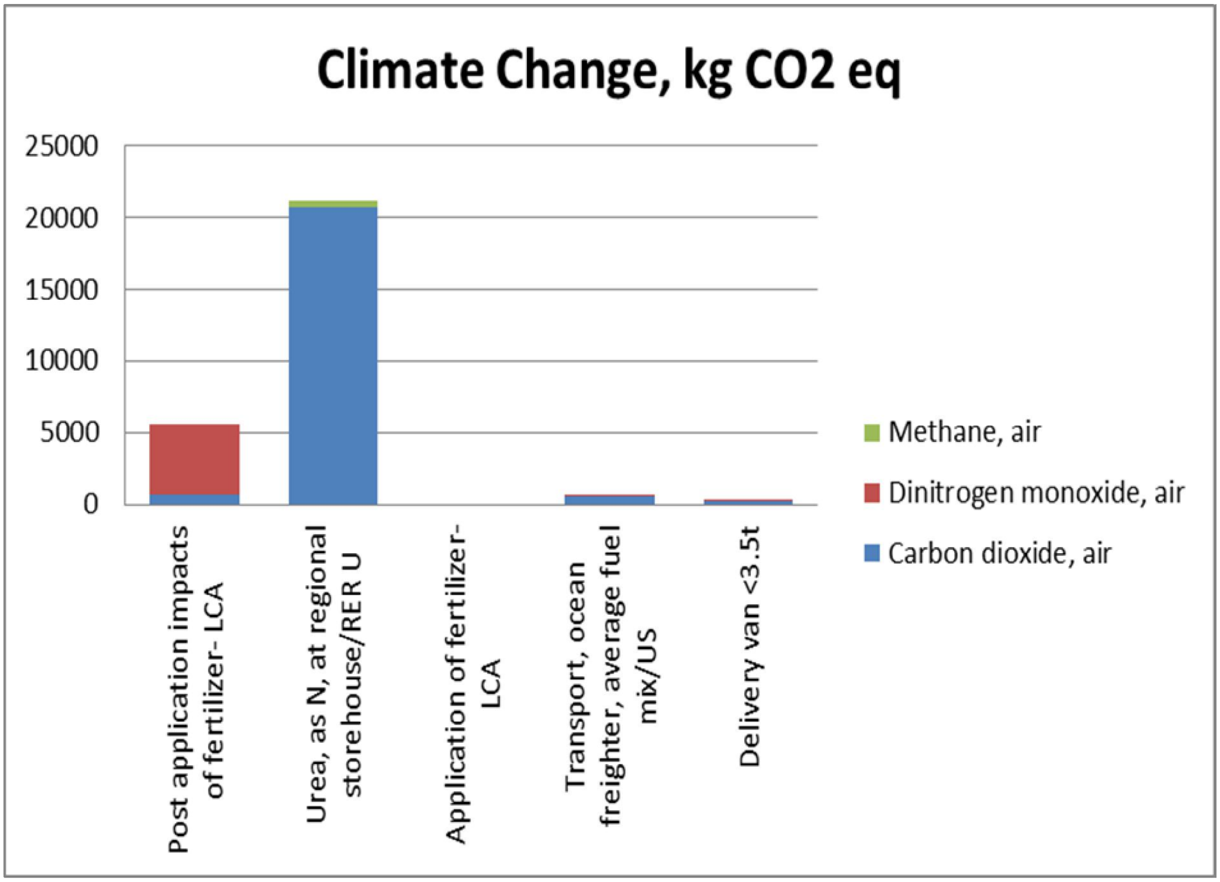


Figure 3.4 (a): Contribution of substances to Climate Change- Scenario 1

From Figure 3.4 (a), it can be deduced that the production of the urea-based fertilizer contributed the most to emission of Carbon dioxide, followed post application impacts of fertilizer to soil.

Scenario 2: Application of MSW Compost

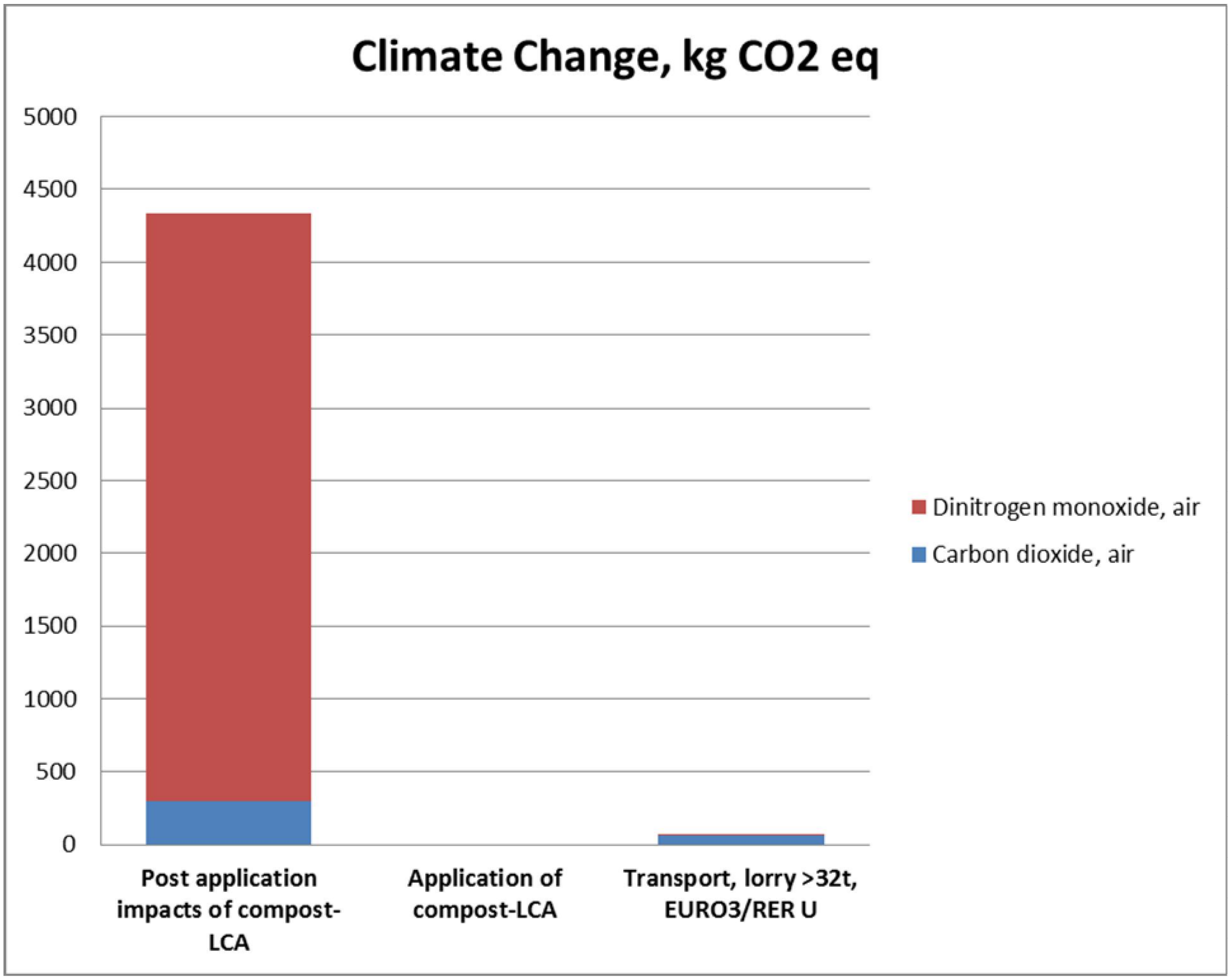


Figure 3.4 (b): Contribution of substances to Climate Change- Scenario 2

Figure 3.4 (b) shows that the post application impacts of compost led to an increase in Nitrous Oxide emission.

Scenario 3: Application of Chicken Manure

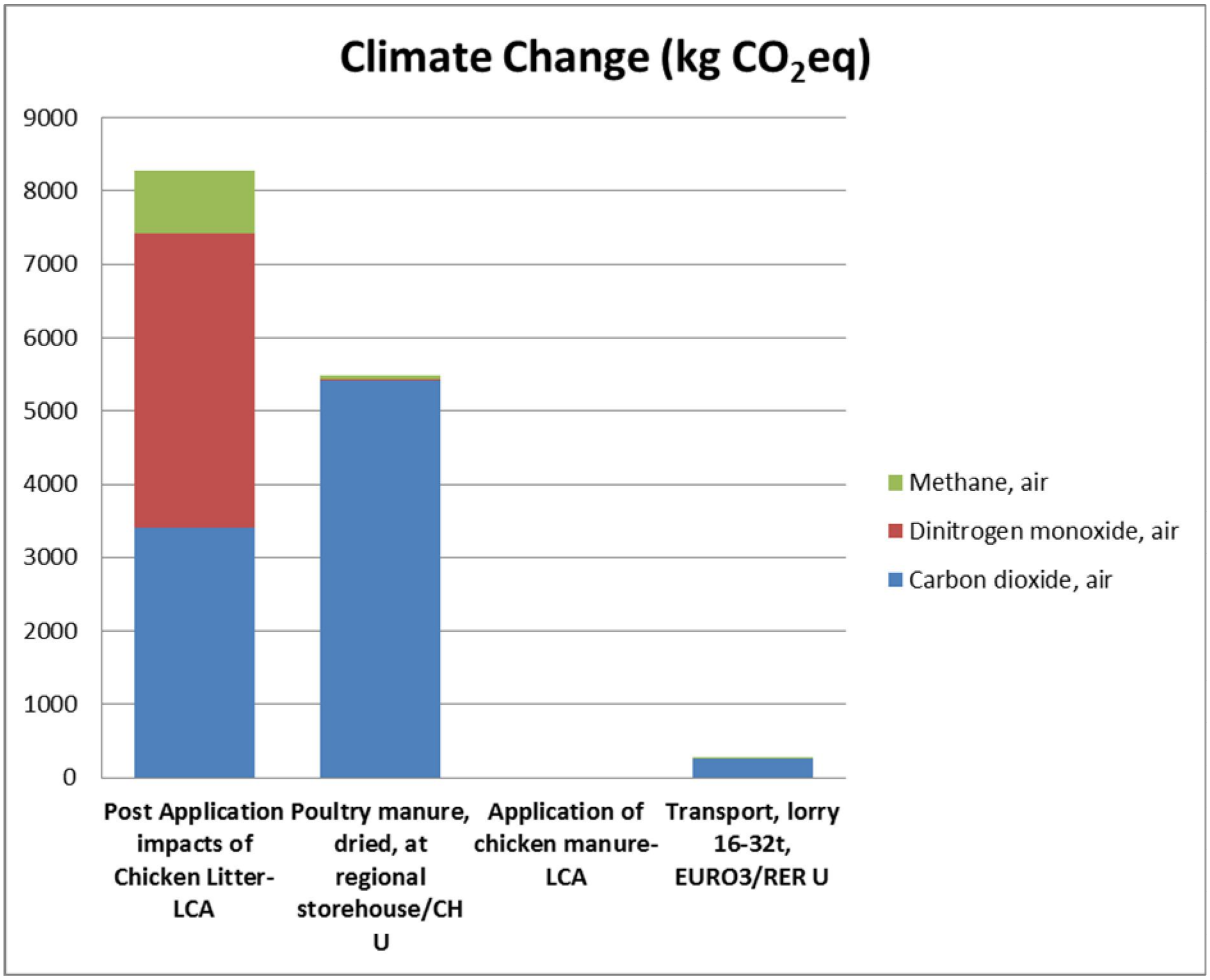


Figure 3.4 ©: Contribution of substances to Climate Change- Scenario 3

Post application impacts of chicken manure contributed significantly to methane emissions. Also, handling and storage of poultry manure caused high emission of Carbon dioxide (5400 kg CO_2 eq).

Scenario 4: Application of MSW compost and fertilizer

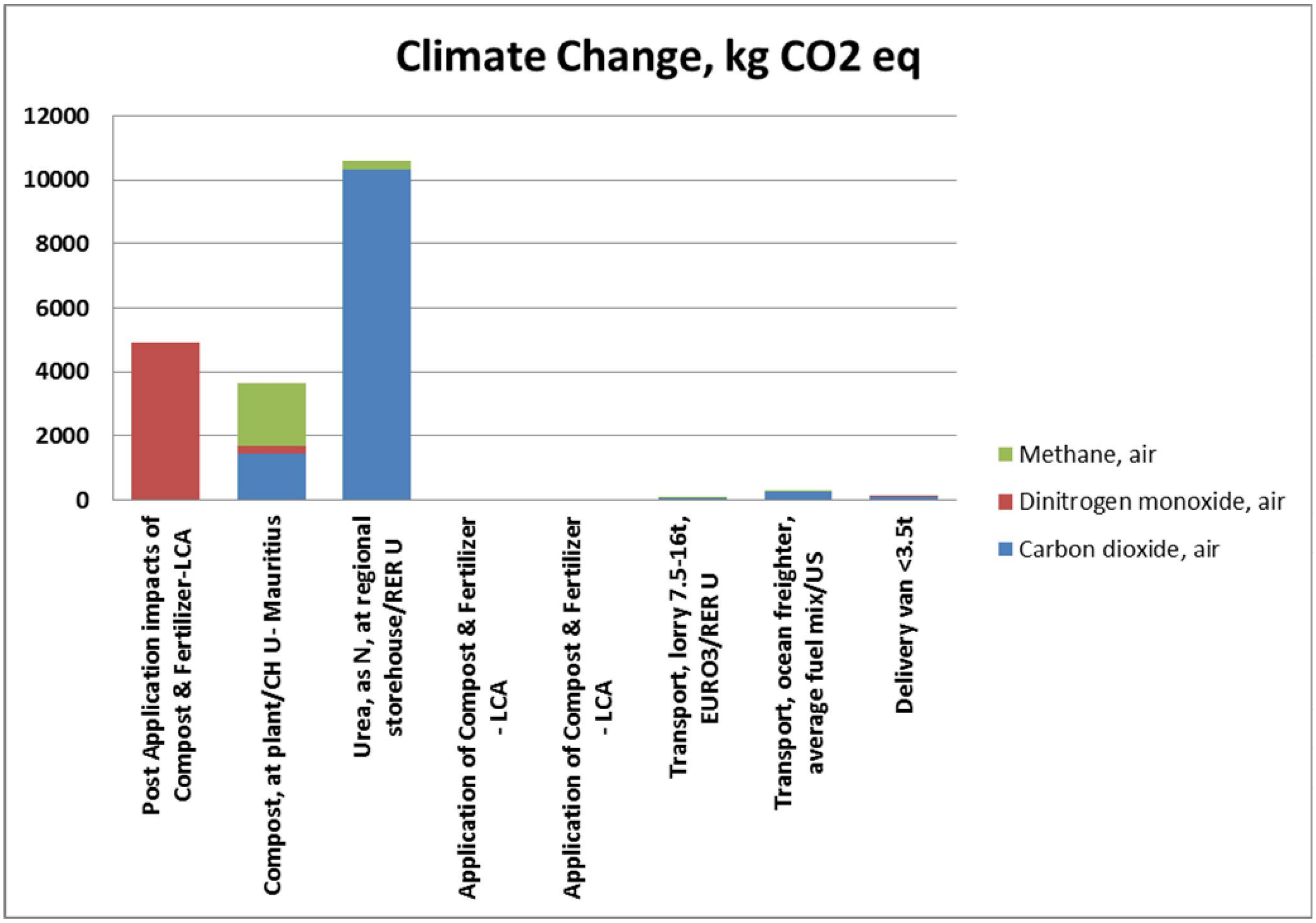


Figure 3.4 (d): Contribution of substances to Climate Change- Scenario 4

Among all the processes involved in scenario 4, production of fertilizer caused the highest emission of Carbon dioxide (10 300 kg CO_2), followed by application of compost and fertilizer.

Carbon footprint of the scenarios

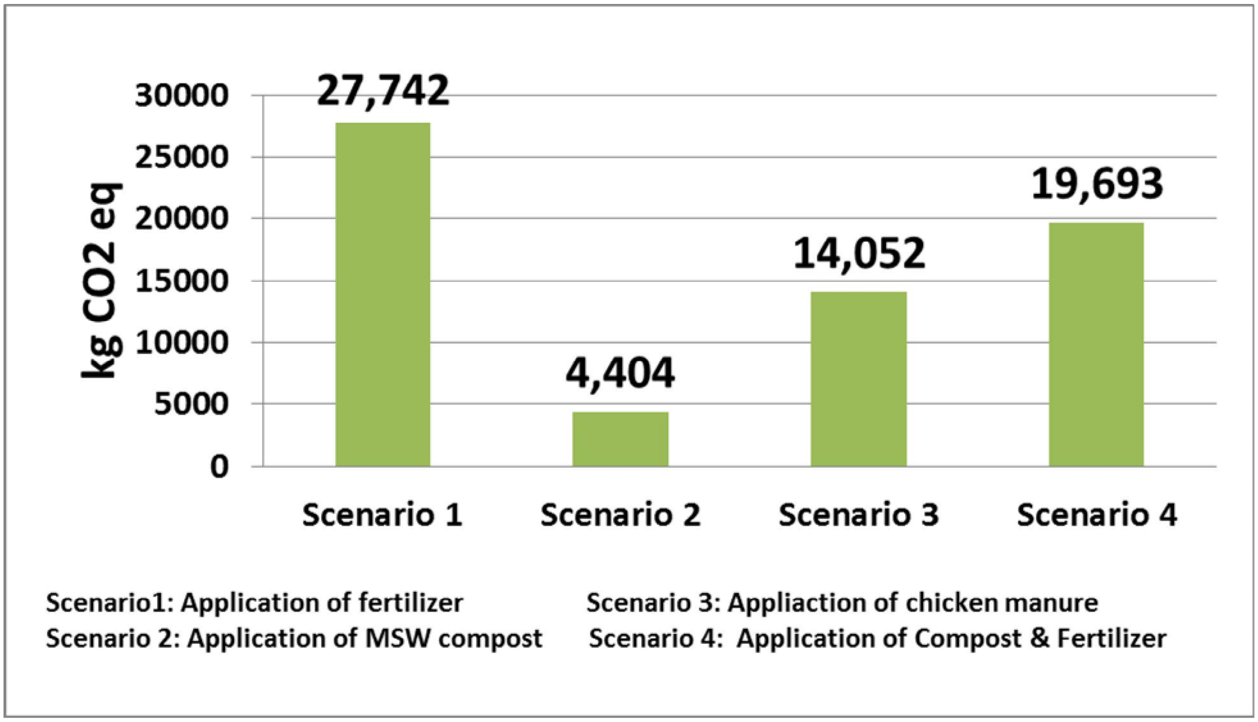


Figure 3.4 (e): Carbon footprint of the various scenarios

From Figure 3.4 (e), it can be deduced that scenario 2 had the lowest carbon footprint (4,404 kg CO_2 eq). Scenario 1 produced the highest contribution to kg CO_2 equivalent, thus has the highest carbon footprint. The carbon footprint from scenario 1 was 84 % higher than that of scenario 2. Also, application of compost and fertilizer increased the carbon footprint by almost 78%, compared to the application of compost only (Scenario 2).

Other damage categories (Human Health, Ecosystem Quality and Resources) were analyzed for each scenario. The findings are in Appendix 2.

Chapter 5

Conclusion

5.0 Conclusion

From the results obtained in this study, the following conclusions can be drawn:

- Among all the treatments, compost was more effective in increasing the water holding capacity of soil. The water holding capacity of soil incorporated with MSW compost increased by 44 % after 35 days. An increase in the water holding capacity of soil ensures sufficient amount of available water for the plant. Thus, plant growth can be sustained without regular irrigation. Compared to inorganic treatments, compost has the ability to retain a convenient moisture content of the soil.

- It can be deduced that incorporation of organic fertilizers such as MSW compost and chicken litter helped to maintain the optimum pH (7.3-7.5) and electrical conductivity required for the proper functioning of soil mechanisms. Compost can thus be used to adjust pH of the soil instead of more costly methods such as addition of cement to soil.

- A reduction in bulk density of soil is equally important if the soil is to promote growth of plants. Compost has the ability to decrease the bulk density of soil, once it has been incorporated with the soil. Based on the results obtained, it can be deduced that both compost and chicken litter were successful in reducing the bulk density of the soil by at least 8 %. This consequent decrease in bulk density ensures better transfer of water and nutrients to the root systems of plants under cultivation. "Compost acts as a sink for Carbon dioxide". This statement was supported with the results obtained for the Total Organic Carbon (TOC) in this study. While treatments such as chicken litter and fertilizer were ineffective in both conserving and increasing the TOC of soil, incorporation of compost triggered an increase of 60% in the TOC content of soil. Hence, the net Carbon dioxide and Methane fluxes from treatment SC were zero, as compared to the remaining treatments.

- Among all the treatments, chicken litter contributed the most to greenhouse gas emissions. A maximum flux of 46.41 g/m^2/day of carbon dioxide flux was measured from treatment SM on the 49th day. Thus, treatment SM acted as a source of Carbon dioxide rather than a sink. On the other hand, treatment SC acted as a sink for Carbon dioxide, since the net fluxes of both CO_2 and CH_4 was zero. A net flux of 5.61g/m^2/day of methane was also noted from treatment SM on the 49th day.

- Based on the IPCC guidelines for N_2O emissions from managed soils, and CO_2 emissions from lime and urea application, production and application of fertilizer results in high N_2O emissions (31.98 kg N_2O/yr) compared to compost application(25.86 kg N_2O/yr) and chicken litter application (25.80 kg N_2O/yr). While compost and chicken litter was applied twice a year, fertilizer was applied four times a year for cultivation of *Lactuca Sativa*.

- The number of leaves formed and height of shoots per plant were the highest in treatment SC and SM. The urea-based fertilizer was ineffective in increasing the yield of the crops as probably the fertilizer was leached due to the rainy season in July- August.

- Application of compost resulted in the highest crop yield and lowest greenhouse gas emissions. Presently, Mauritius is importing around 50 000 tonnes of inorganic fertilizers which cost Rs 850 million (Defi Plus, 28th September 2011). The use of compost in farming will cause a significant decrease in the cost of production for cultivation of vegeTables, fruits and even sugarcane. The increased demand of compost will thus further reduce the load of organic waste going to the Mare Chicose landfill. As application of compost increases, the water holding capacity of soil, less water will be needed for the irrigation of crops.

- Usage of compost instead of chemical fertilizers will help Mauritius decrease its Carbon footprint in the agricultural sector as production and application of inorganic fertilizers entail high resources input and thus increase the amount of greenhouse gas emissions.

- Good soil health can moderate climate disruptions through reducing emission of CO_2 and other GHGs, sequestering CO_2 and oxidizing CH_4.

- Carbon footprint reduction of 84 % for compost application with regards to chemical fertilizer application.

- Carbon footprint reduction of 68 % and 78% were obtained for treatments SC and SM respectively.

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Appendix 1

Moisture content

100g ($W_{1)}$ of fresh soil/treatment sample was spread on an aluminium plate. The latter's weight was also noted. The above procedure was done in triplicates. The plates were then placed in the oven at 55^{o}C for a period of 24 hours, until a constant mass was obtained. Thus, the mass, W_2 of the dried sample was recorded. The moisture content was calculated as shown below:

$$\text{Moisture content on wet basis} = \frac{W_1 - W_2}{W_1} * 100$$

Where W_1=weight of sample before drying

W_2=weight of sample after drying

Volatile solids % and Organic carbon

Volatile solids % is also referred to as loss on ignition. It supplies a measure for the content of the organic substances in soil/treatments mixtures. The volatile and fixed components in the total, suspended and dissolved solids is determined by igniting the solids at 550°C. Thus, organic matter at this temperature is converted to CO_2. The amount of solids remaining after ignition is termed the fixed portion of the solids and represents the inorganic fraction or ash %.

The moisture free sample was grinded and passed through a < 2.50 mm sieve. Three porcelain crucibles were each weighed and between 1-5 g of the dried and ground sample were placed in each crucible. The weights of the crucibles were recorded before they were placed in the muffle furnace at a temperature of 550°C for two hours, period after which the porcelain crucibles were allowed to cool down after being transferred to a dessicator. Finally, the weights of the crucibles were recorded.

VS % was calculated as follows:

$$VS \% = \{[M_{S1} - M_S] / [M_{S1} - M_c]\} * 100$$

Where, M_c= mass of empty crucible (g)

M_{S1}= mass of sample + mass of empty crucible (g), before burning.

M_S = mass of sample + mass of empty crucible (g), after burning.

Ash % = 100 – VS%

pH

pH is a measure of how acidic or alkaline a solution in water is. pH level greatly affects the productivity of soil and quality of plant growth. Nutrients dissolve gradually in acidic soil, which cause essential plant nutrients to be locked up in insoluble mineral compound. Even the addition of fertilizer is not effective as the latter cannot be absorbed in the soil. Adding well-decomposed organic matter, such as compost can help correct soil with a high pH. A pH of 6.5-7.0 is deemed right for the cultivation of lettuce.

200 ml of 0.01 molar calcium chloride was added to 20g of the sample (after sieving the sample to <10mm). The mixture was continuously stirred for 2 hours, time after which the sample was passed through a filter paper and the pH of the filtrate is recorded.

Electrical Conductivity (EC)

Electrical conductivity is a measure of total concentration of dissolved salts in water. When salts dissolve in water, they give off electrically charged ions that conduct electricity. The more ions in the water, the greater is the electrical conductivity.

200ml of distilled water was added to about 20g of dried and ground sample (<10 mm). The mixture was stirred continuously for two hours. The suspension was then filtered and the conductivity of the filtrate was determined using a calibrated electrical conductivity meter.

Bulk Density

Bulk density is defined as the weight per unit volume of material. Bulk density of the soil sample is determined by filling and weighing a container of known volume with the component.

Bulk density = $\underline{W_1 - W_2}$* 100

V

Where W_1= weight of container after filling, g

W_2 = Weight of container after filling, g

V = Volume occupied by sample

Water holding capacity

Water holding capacity of a soil, compost or soil/compost sample is used to determine the ability of the sample to retain moisture against drainage due to the force of gravity. The water holding capacity of a soil sample determines its aptitude to maintain plant life during dry periods. The pores between soil particles and the thin films surrounding the particles held water. Thus, depending on the types of soil, Different types of soil retain different amounts of water, depending on the particle size and the amount of organic matter. Organic matter adds to a soil's water holding capacity because humus particles absorb water.

To measure the water holding capacity, a glass cylinder, height 120mm and having an internal diameter of 35.7mm with a close-meshed plastic net bottom was used. That side of the cylinder was wrapped with a moist filter paper. The weight of the empty cylinder, m_o was thus noted. The cylinder was then filled with the sample and the new weight, m_c was recorded. The former was then placed in a beaker, to which water was added until the sample floated as mulch. The set up was allowed to stand for 24hrs.

The cylinder was then taken out of the water, dried from the outside and placed on a water-saturated cellulose base covered with a watch glass. After 2 hours, the glass cylinder was weighed back m_{moist}, then allowed to drain again and finally weighed back until a constant weight was reached.

The water holding capacity is calculated as follows:

Max. Water capacity WK max is given in %

WK max = (E moist-E dry) / Edry – 100%

Mass of the dry sample, E dry = $(m_c - m_o)(1\text{-}WC / 100)$

Mass of the wet sample, E moist = $(m_{moist} - m_o)$

WC: water content of the fresh sample (naturally moist)

m_o= mass of cylinder + wet filter paper

m_c = mass of cylinder + weighed-in-sample

m_{moist}= mass of cylinder + wet sample

Porosity

Porosity is used to determine the volume of pore space in a compost or soil sample. In other words, porosity measures the proportion of a given volume of soil occupied by pores containing air and water. It gives an indication whether the soil is loose or compacted, as drainage and aeration are both affected. It is to be noted that addition of organic matter increases a soil's porosity.

A 100 ml glass cylinder was half filled with compost, soil, or soil/compost mixture. The cylinder was tapped firmly several times, to settle the sample. The volume occupied by the sample was then recorded. The component was poured out and saved and the cylinder was filled with water up to the 70 ml mark. Ultimately, the saved sample was slowly added, while breaking the clumps simultaneously. The set up was allowed to stand for five minutes, before the total volume occupied by the sample/water mixture was recorded.

Porosity is calculated by:

vol. of solids (ml) in the compost or soil = vol. of compost/water mix (ml) – 70 ml water

vol. of pore space (ml) = vol. of packed soil (ml) – vol. of solids (ml)

$$\% \text{ pore space (porosity)} = \frac{\text{vol.of pore space}}{\text{Vol. of packed soil}} * 100$$

Phytotoxicity bioassay

The phytotoxicity bioassay is used to determine whether a soil, compost, or soil/compost mixture contains substances that inhibit seed germination or growth of the radicle (the embryo root). Immature compost may contain substances such as methane, ammonia, or acetic acid that are harmful to plant growth. Created during the composting process, these elements are later broken down during the curing phase. However, even mature compost may contain substances that inhibit plant growth. Examples of such substances are, heavy metals, salts, pesticide residues, or other toxic compounds contained in the original compost ingredients. Compost quality may be tested chemically; however, the trouble with this approach is that it is not feasible to test for every compound that might possibly be present. On the contrary, bioassays, in which test organisms are grown in a water extract of compost, provide a means of measuring the combined toxicity of whatever contaminants may be present. However, they will not identify what specific contaminants are causing the observed toxicity.

In order, to standardize the dilution form one compost to another, the water content of the compost need to be corrected by measuring the moisture content of the compost sample. The next step is to calculate how much of the wet sample equivalent to 100g dry weight is. This is given by;

$$\_\_ \text{ g wet compost} = \frac{\text{100g dry compost}}{(W_W - W_d)/W_w}$$

As Moisture content varies from one compost type to another, this needs to be accounted for, while determining how much more water is to be used for the extraction.

__ g (or ml) distilled water = 850 g total – __ g wet compost

The mixture was stirred and was allowed to settle for approximately 20 minutes. The first 200ml of the mixture was skipped off and the rest was filtered through a double layer of cheese cloth and the filtrate obtained was the extract.

The pH of the distil water was measured and adjusted to neutral if it was not so, by the addition of a small amount of baking soda. X2 dilution of the extract was made. In each of the 15. 9 cm Petri dishes, a 7.5 cm filter paper was placed. Five dishes were labeled control, X2, and the remaining five “full strength”. To each of the Petri dish, 1 ml of the appropriate test solution was added. Eight “brède de chine” seeds were placed in each dish; the dishes were covered and incubated in dark, at steady room temperature for 48 hours. The length of the radicles formed in each of the Petri dishes were then measured, using a verniercalliper.

For each treatment, the percent germination is given by,

$$\% G = G_t / G_c * 100$$

in which:

%G = percent germination

Gt= mean germination for treatment

Gc= mean germination for distilled water control

% radical length for each treatment ;

$$\%L = L_t / L_c * 100$$

in which:

%L = percent radicle length

Lt = mean radicle length for treatment

Lc= mean radicle length for distilled water control

Germination Index:

$$GL = \frac{\% G * \% L}{10000}$$

Germination Rating Index

1.0–0.8	No inhibition of plant growth
0.8–0.6	Mild inhibition
0.6–0.4	Strong inhibition
<0.4	Severe inhibition

Total Organic Carbon- Walkey Black Method

In soils and sediments, Total Carbon includes Inorganic Carbon and Organic Carbon. TOC content can be measured directly or can be determined by difference if the total carbon content and inorganic carbon contents are measured. For soils and sediments where no inorganic carbon forms are present, Total Carbon is equivalent to Organic Carbon only.

Typically this is the case so methods described as quantifying total or organic carbon should produce the same result. However, in geographic areas where the parent material/geology is limestone, dolomite, or another carbonate-bearing mineral, inorganic forms of carbon may be present in the samples. In arid regions, soils and sediments may have greater concentrations of carbon being derived from inorganic carbonates than from organic carbon sources. The basic principle for the quantification of total organic carbon relies on the destruction of organic matter present in the soil or sediment. The destruction of the organic matter can be performed chemically or via heat at elevated temperatures. All carbon forms in the sample are converted to CO_2 which is then measured directly or indirectly and converted to total organic carbon or total carbon content, based on the presence of inorganic carbonates.

The total Organic carbon (Organic and Inorganic) is determined using the Walkey Black method which includes a wet oxidation of samples using dichromate followed by titration with Ferrous Ammonium Sulphate. Oxidisable matter in the soil is oxidized by 1N $K_2Cr_2O_7$ solution. The reaction is assisted by the heat generated when two volumes of H_2SO_4 are mixed with one volume of dichromate. The remaining dichromate is titrated with ferrous sulphate. The titre is inversely related to the amount of C present in the soil sample.

$$2Cr_2O_7^{2-} + 3C + 16H^+ \longrightarrow 4Cr^{3+} + 8H_2O + 3CO_2$$

Based on the above equation, 1 ml of 1 N Dichromate solution is equivalent to 3 mg of carbon.

$$\text{Organic Carbon (\%)} = \frac{0.0003g \times N \times 10ml \times (1-T/s) \times 100}{ODW}$$

$$= \frac{3(1-T/S)}{W}$$

Where:

N = Normality of $K_2Cr_2O_7$ solution

T = Volume of $FeSO_4$ used in sample titration (mL)

S = Volume of $FeSO_4$ used in blank titration (mL)

ODW = Oven-dry sample weight (g)

NPK Nutrients

The total Nitrogen, Potassium and Phosphorus content of the different soil samples were tested on a bi-monthly basis so as to analyse the evolution of the nutrients in soil treated differently.

Appendix 2

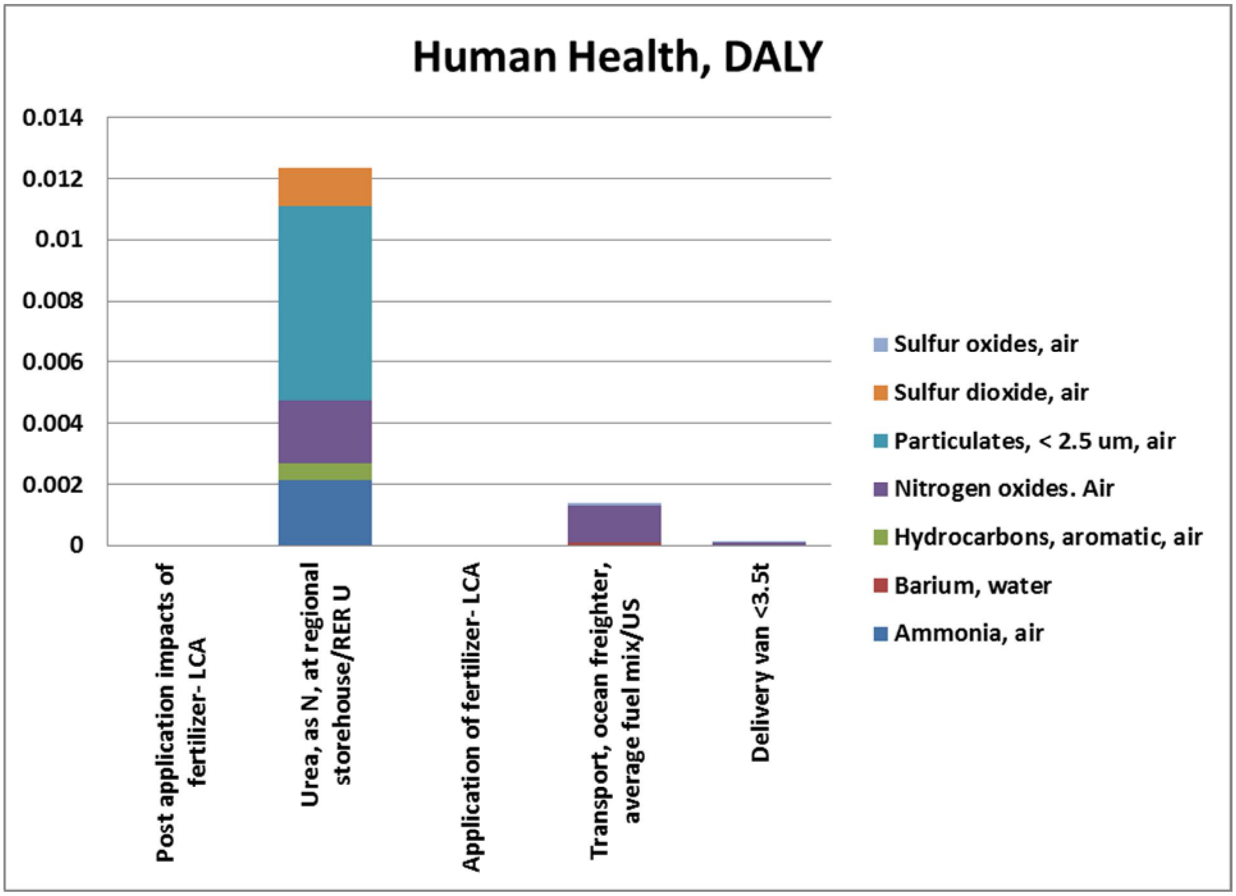


Figure A1: Contribution of substances to Human Health- Scenario1

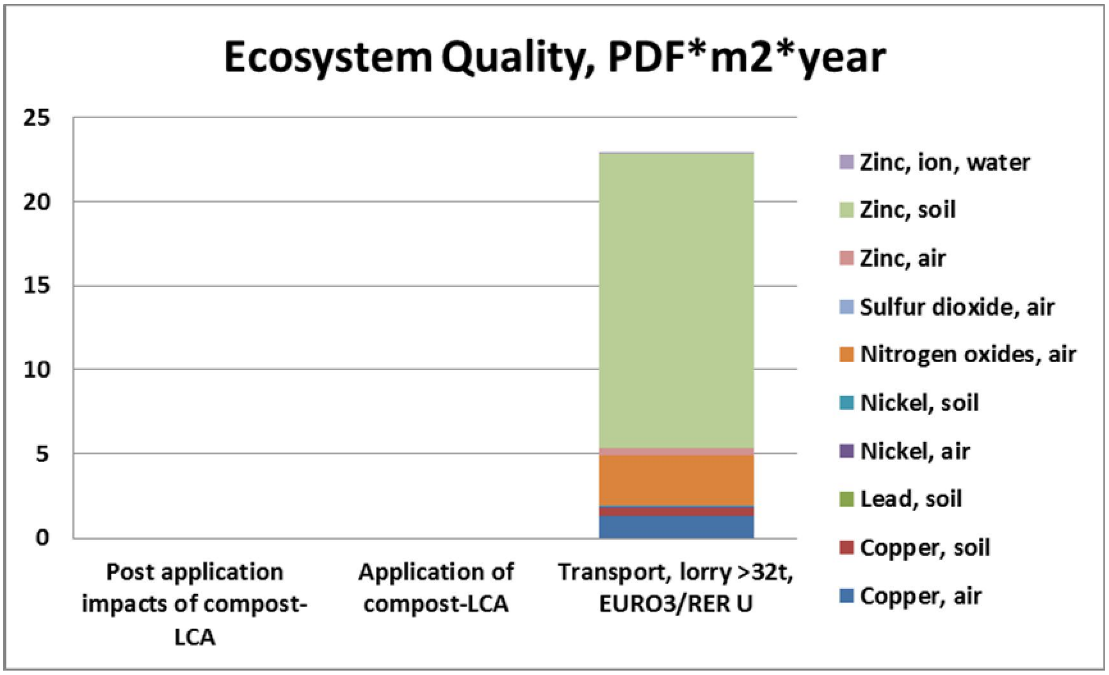
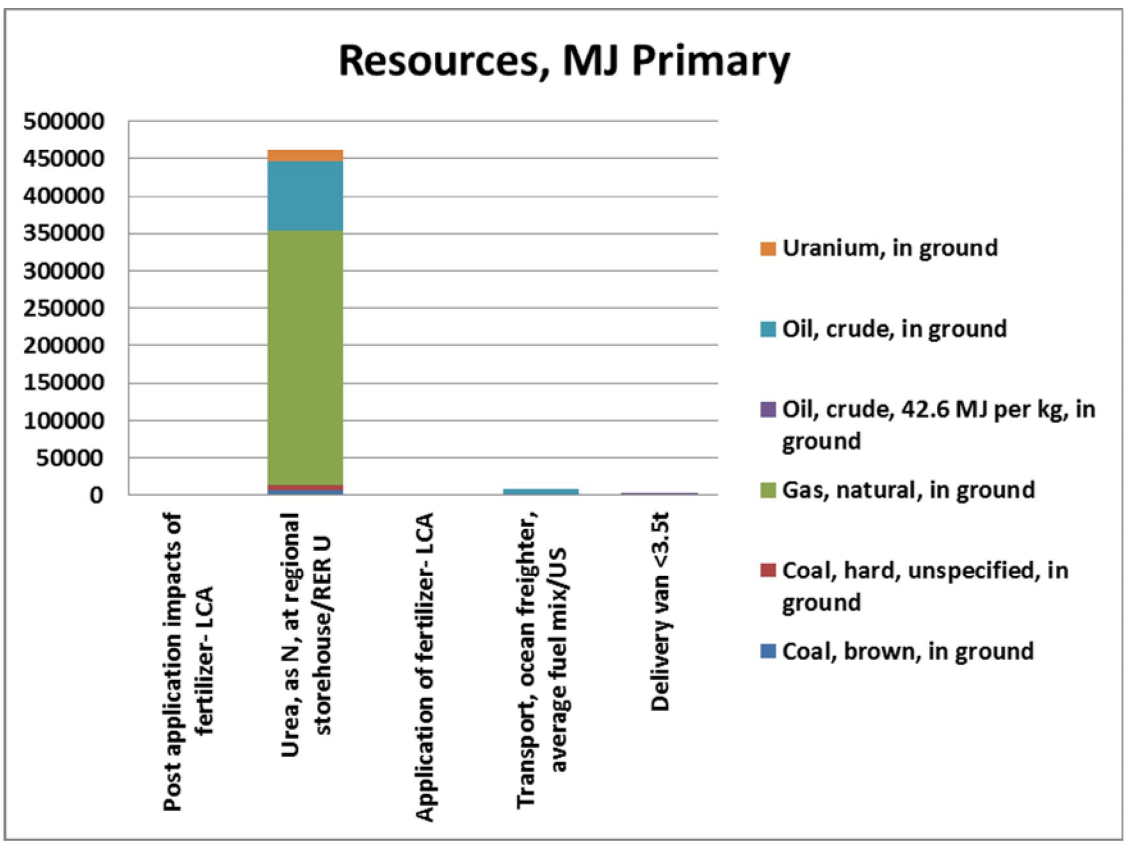


Figure A2: Contribution of substances to Ecosystem Quality- Scenario 1



FigureA3: Contribution of substances to Resources- Scenario 1

Scenario 2

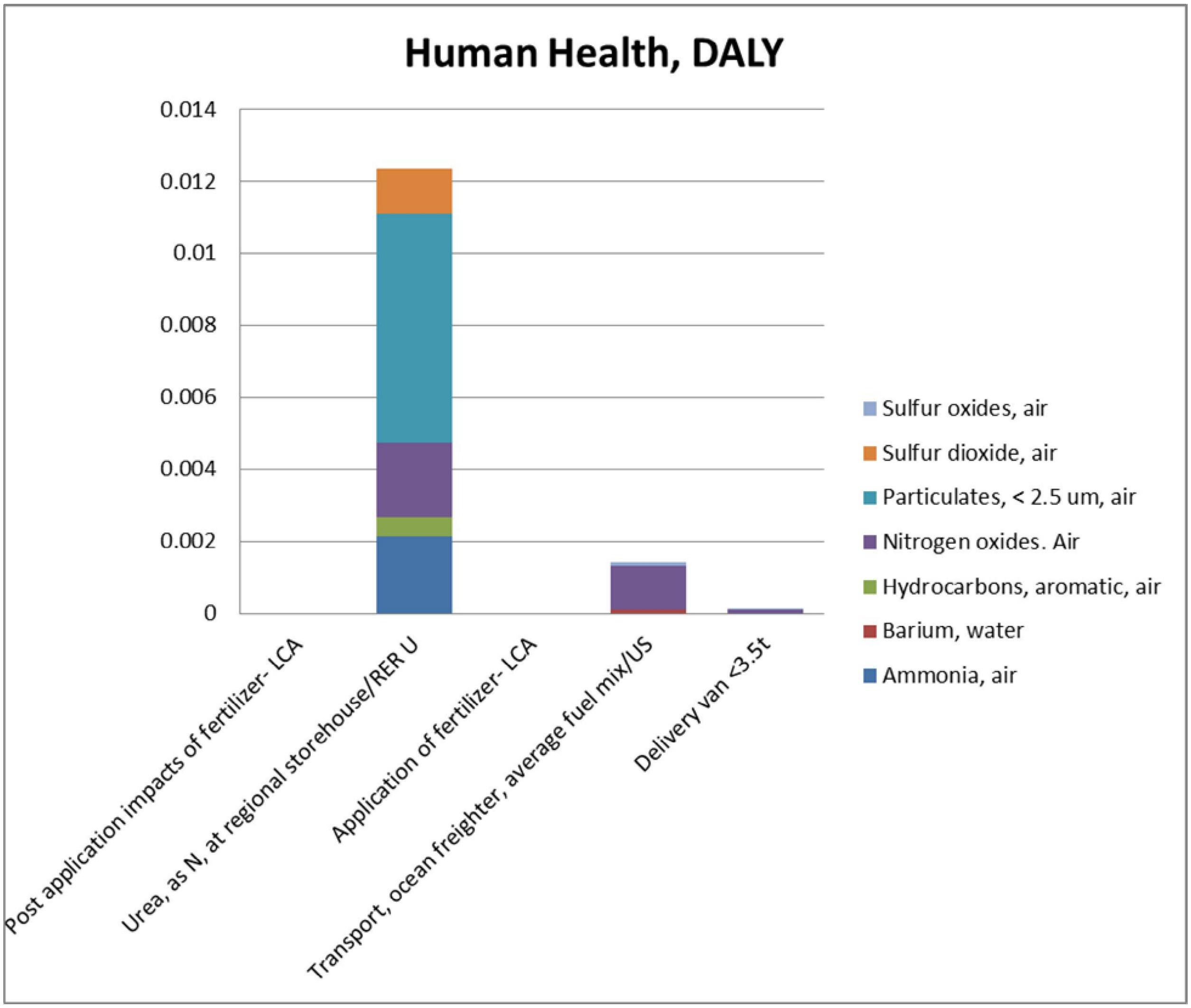


Figure A4: Contribution of substances to Human Health- Scenario2

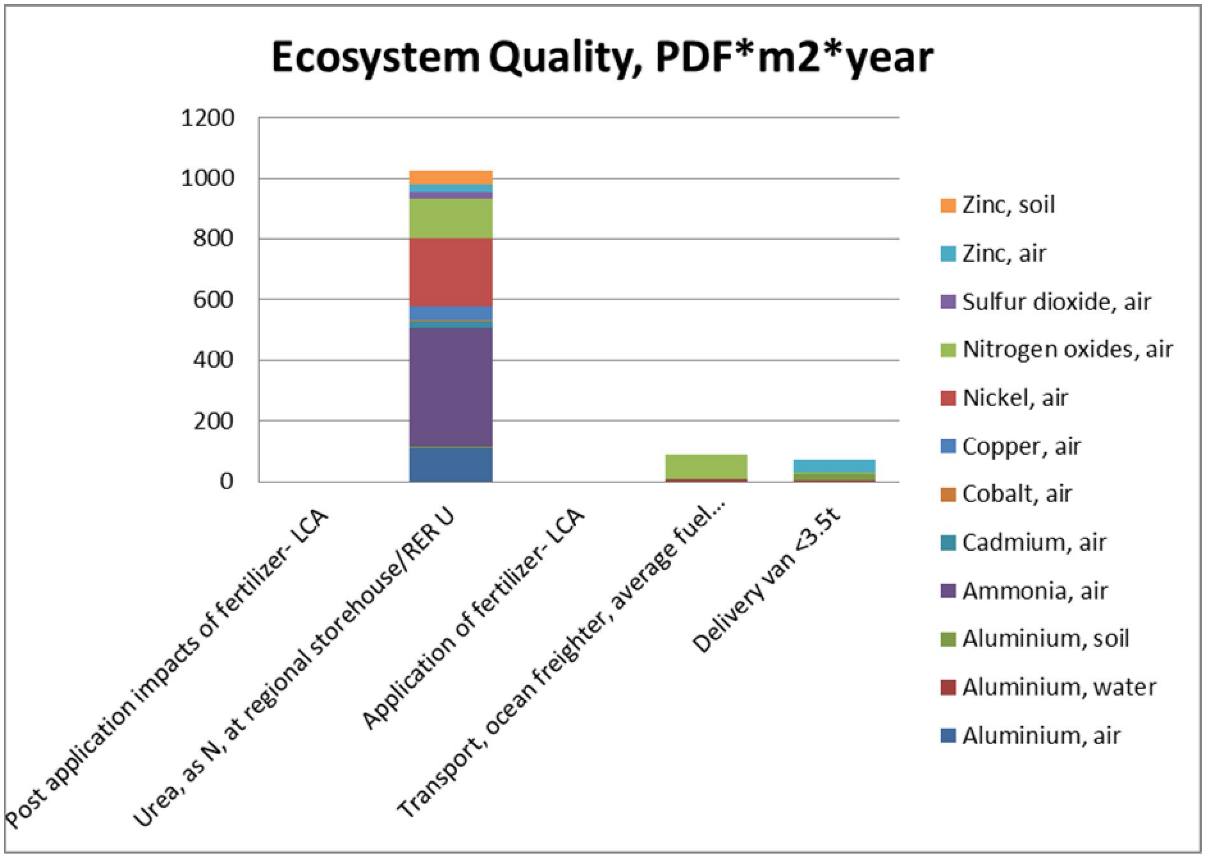


Figure A5: Contribution of substances to Ecosystem Quality- Scenario2

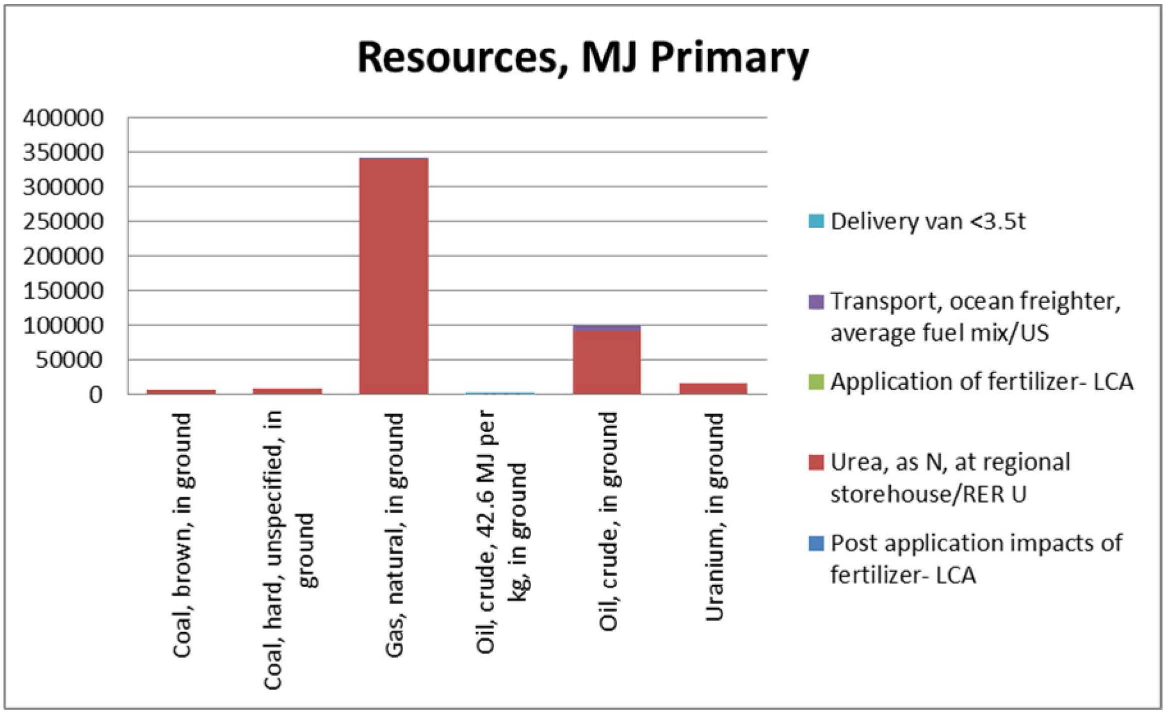


Figure A6: Contribution of substances to Ecosystem Quality- Scenario2

Scenario 2

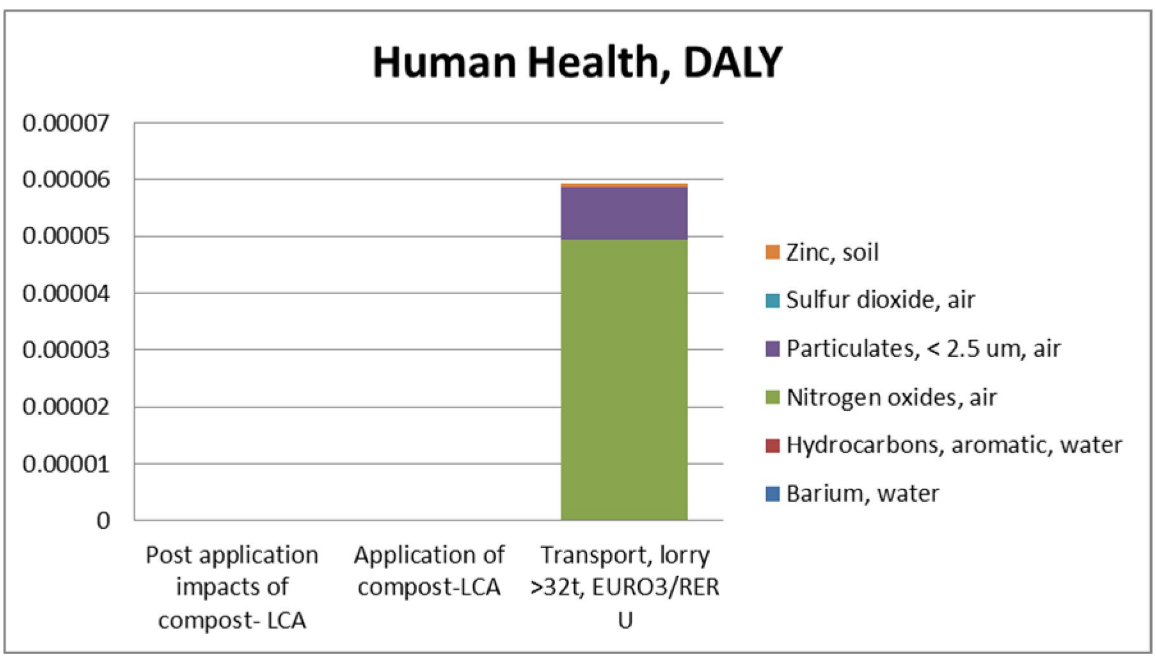


Figure A7: Contribution of substances to Ecosystem Quality- Scenario2

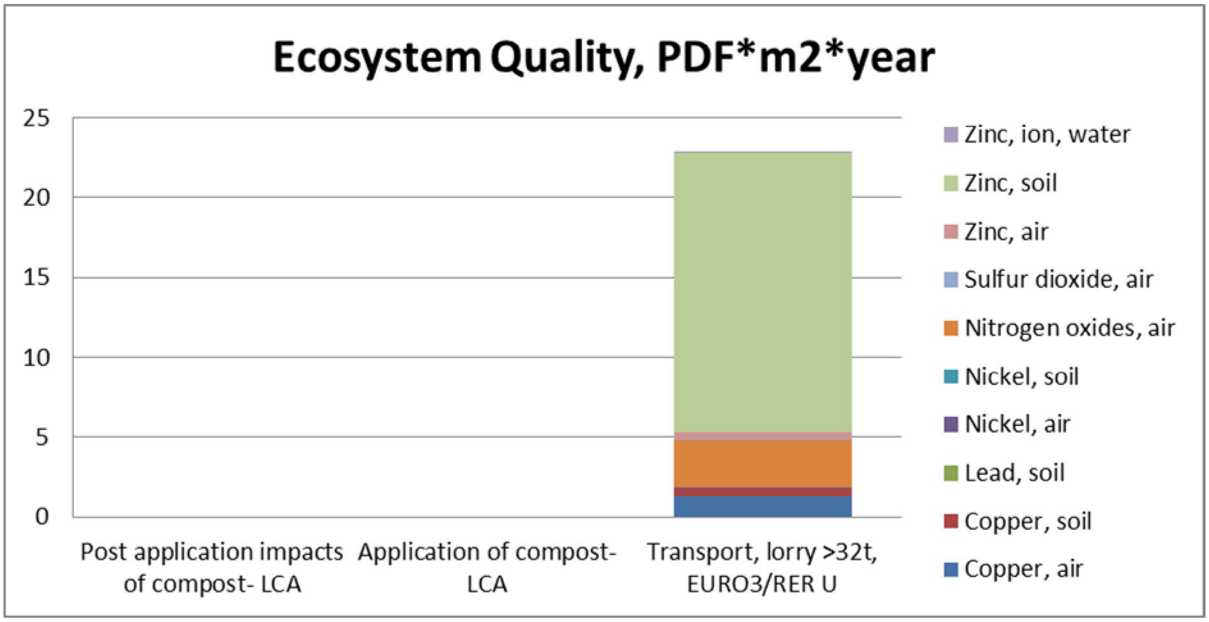


Figure A8: Contribution of substances to Ecosystem Quality- Scenario 2

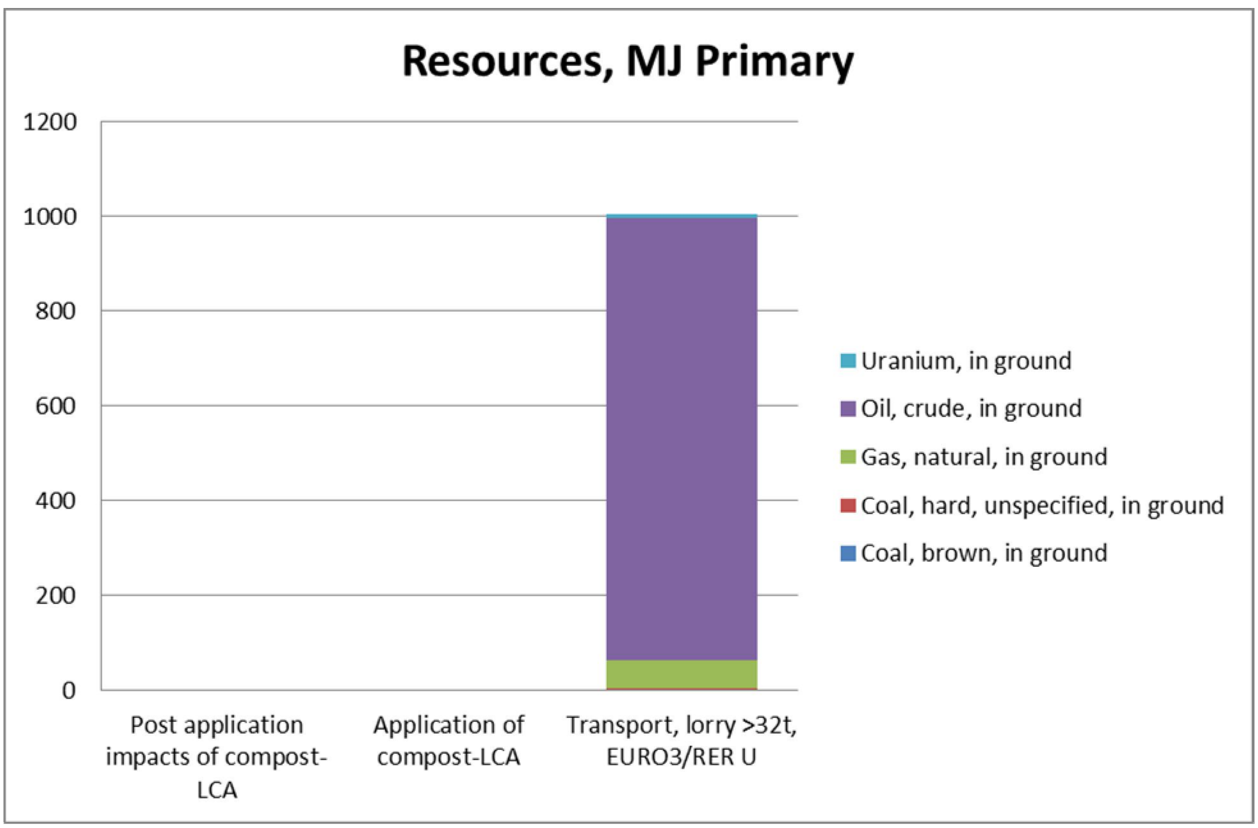


Figure A9: Contribution of substances to Resources- Scenario 2

Scenario 3

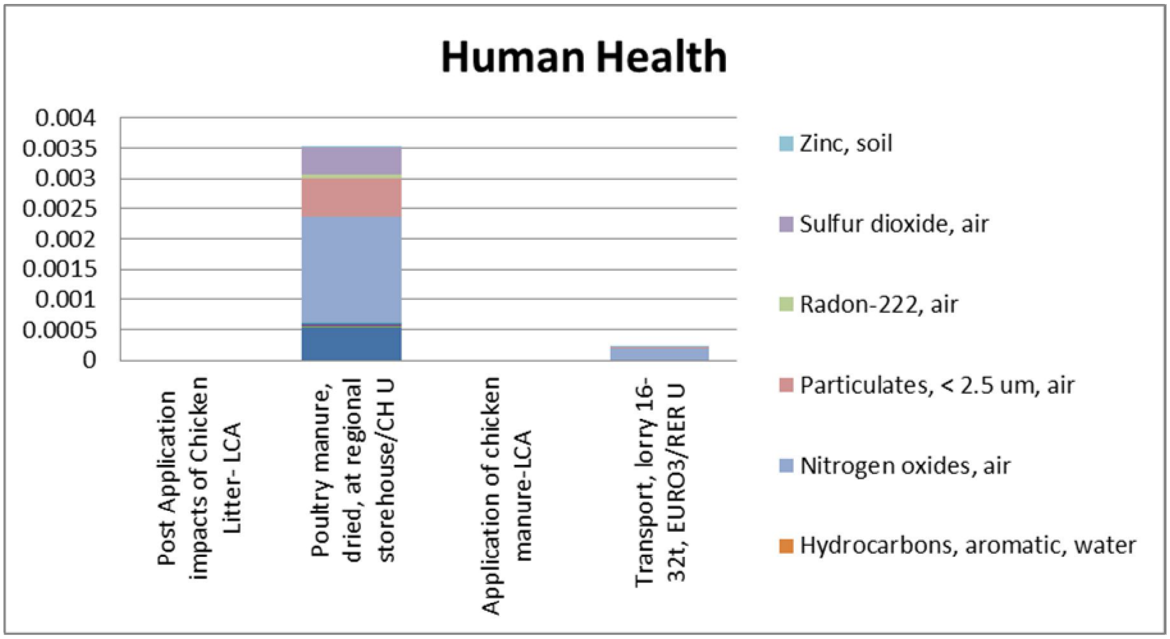


Figure A10: Contribution of substances to Human Health- Scenario 3

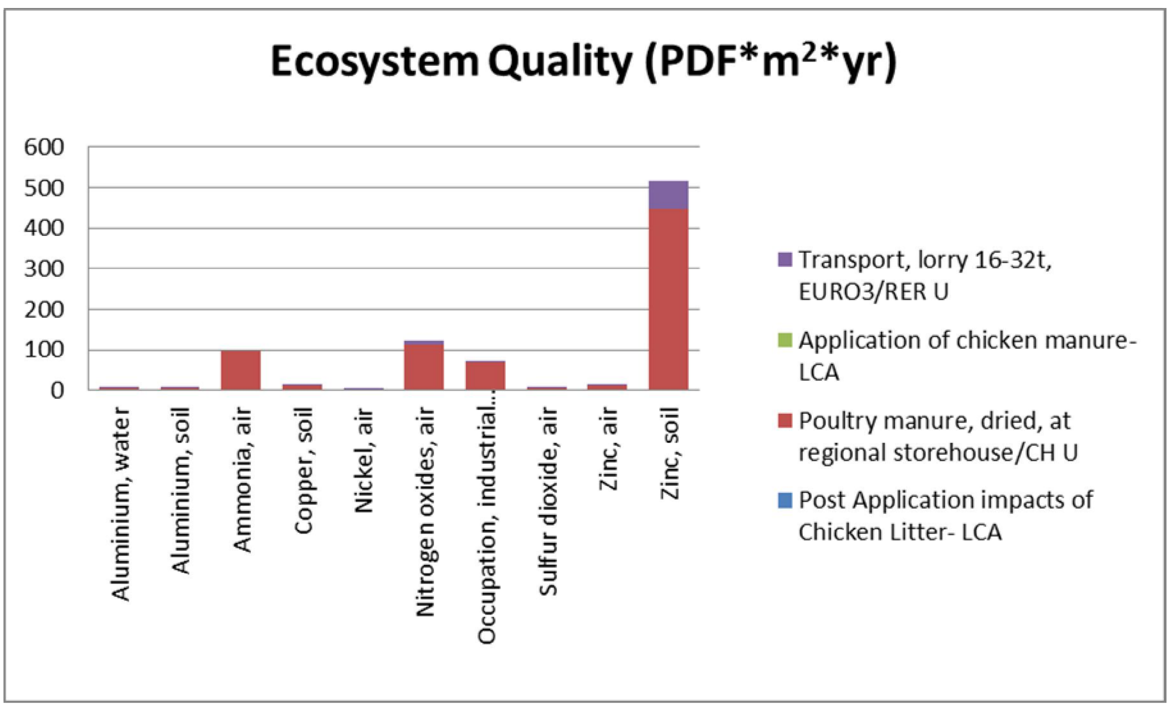


Figure A11: Contribution of substances to Ecosystem quality- Scenario 3

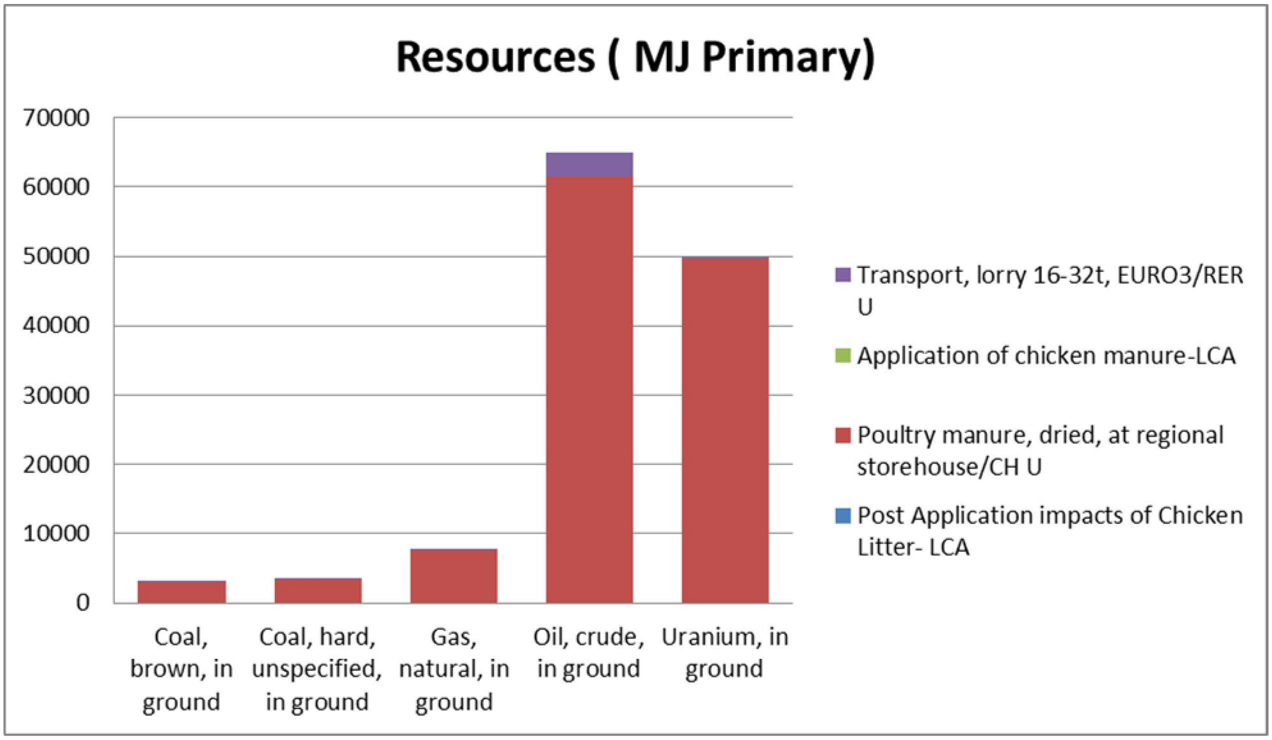


Figure A12: Contribution of substances to Resources- Scenario 3

Scenario 4

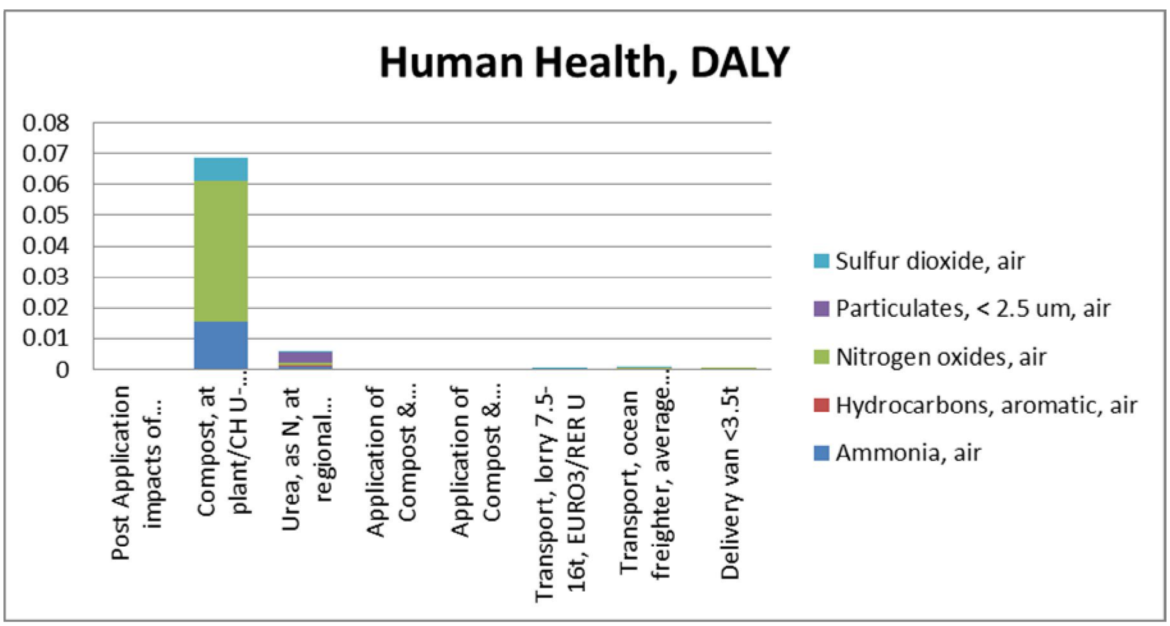


Figure A13: Contribution of substances to Human health- Scenario 4

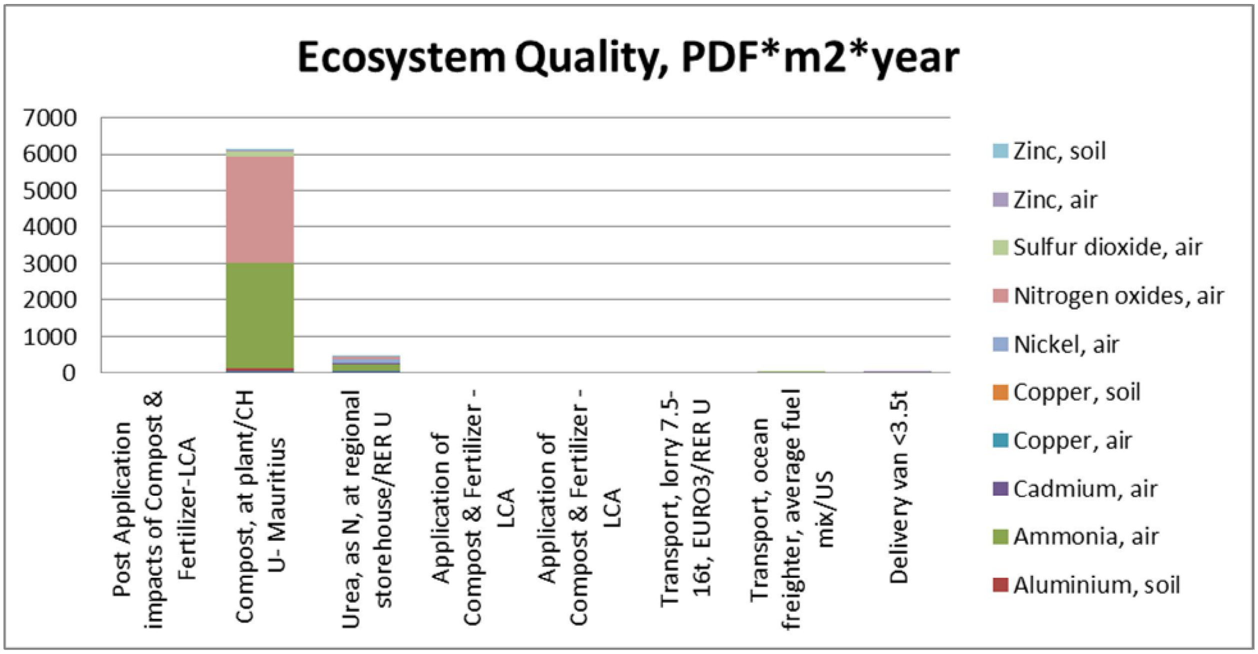


Figure A14: Contribution of substances to Ecosystem quality- Scenario 4

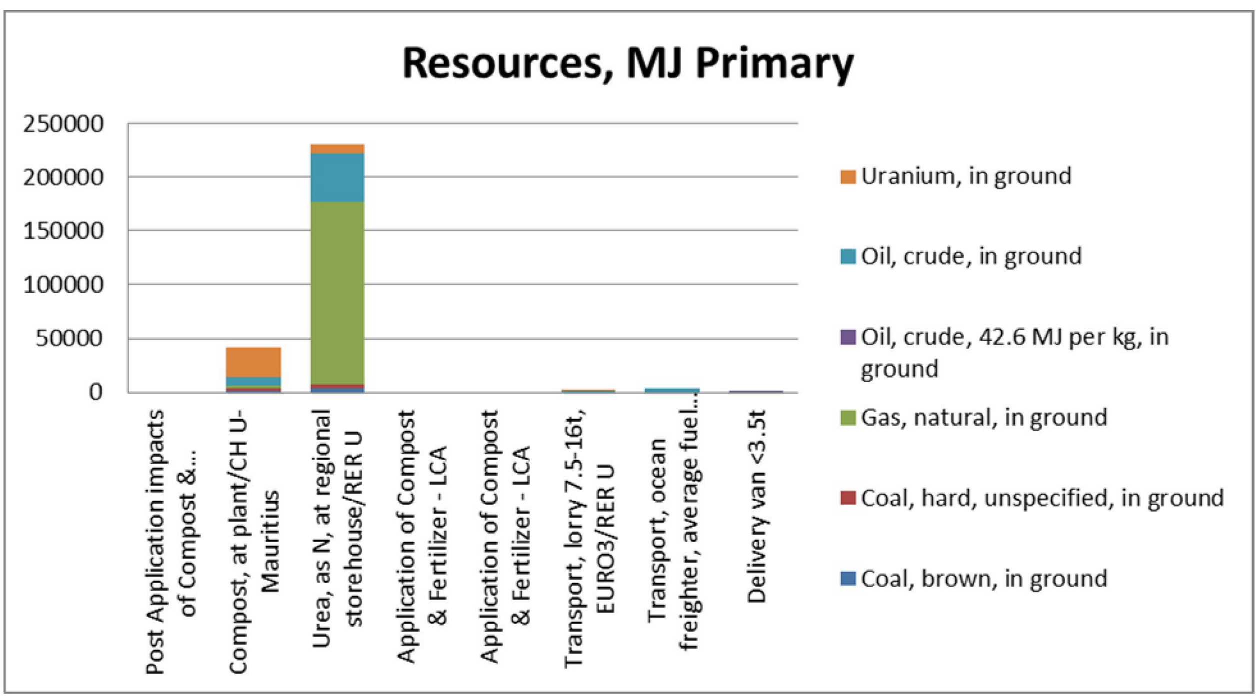


Figure A14: Contribution of substances to Ecosystem quality- Scenario 4

Scenario 1: Application of Fertilizer

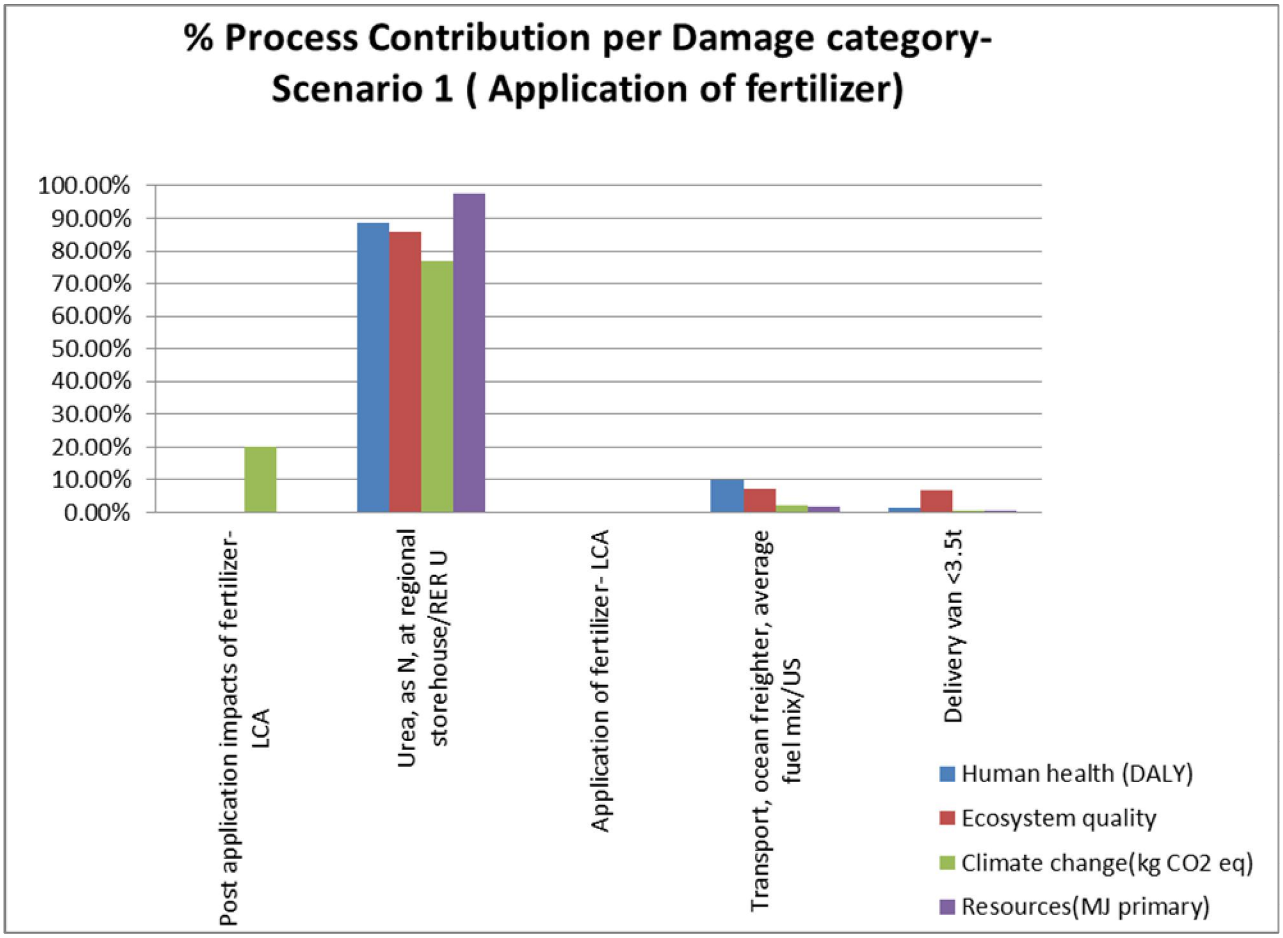


Figure A16: Percentage Process contribution per Damage category for scenario (application of fertilizer)

The main contributor to the damage categories was the production of Urea- based fertilizer, followed by transportation of the fertilizer by sea and road.

Emissions associated to the Damage categories for all the scenarios

Human health

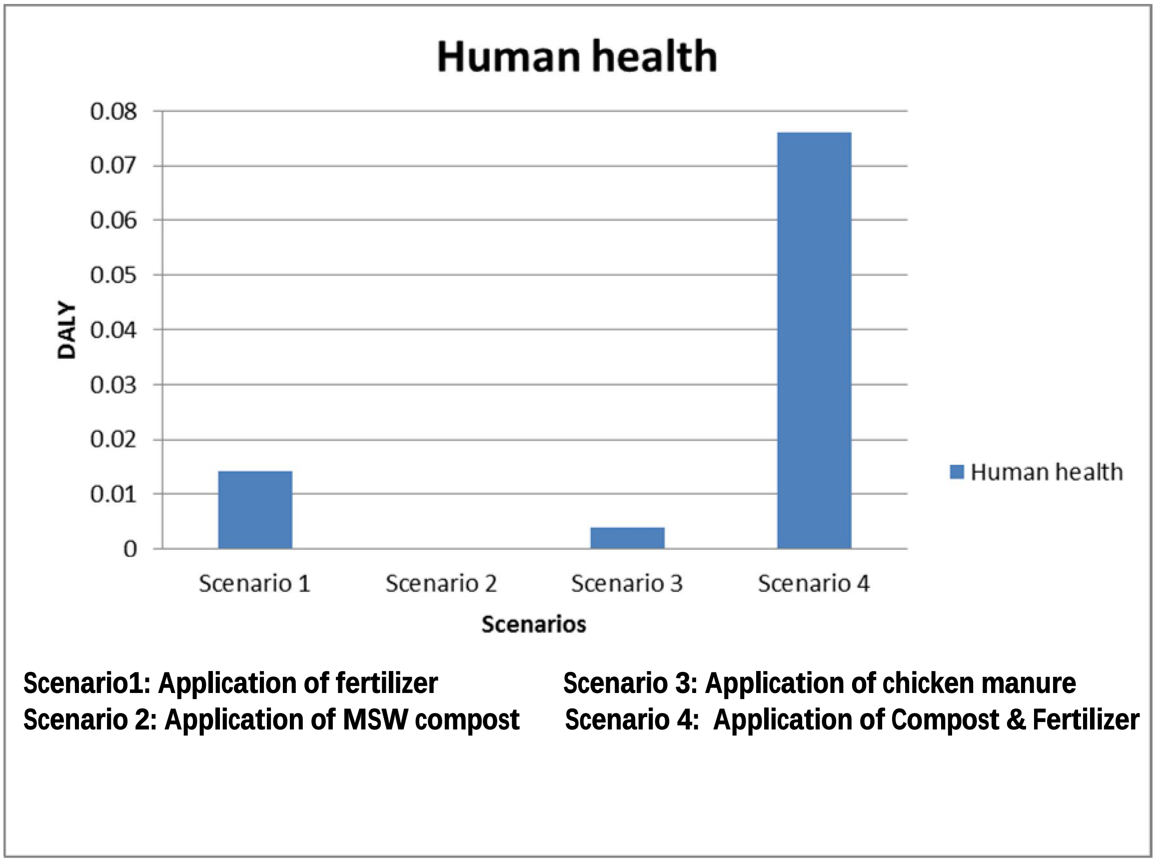


Figure A17: Emissions associated to Human Health for all the scenarios

From Figure A17 it can be concluded that Scenario 4, that is the application of compost and fertilizer contributed the most (almost 80%) to Human health damage impact. The contribution of Scenario 2 to Human Health was almost zero, followed by that of scenario 3 and scenario 1 respectively.

Ecosystem quality

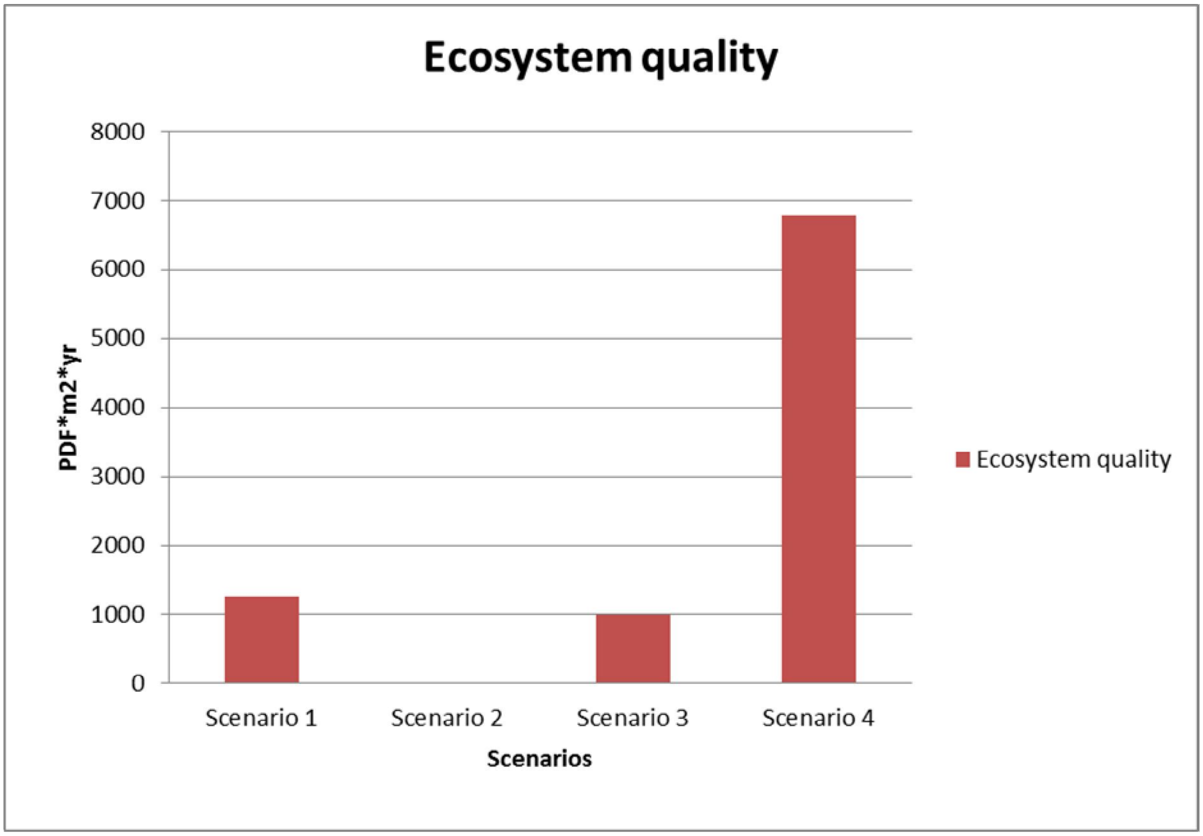


Figure A18: Emissions associated to Ecosystem quality for all the scenarios

The damage to Ecosystem quality was the highest (75%) due to application of fertilizer and compost to soil. This due to the increased number of input and emissions related to the production of fertilizer and even compost. It is to be noted that application of compost (Scenario 2) contributed insignificantly to the damage related to the Ecosystem Quality.

Climate Change

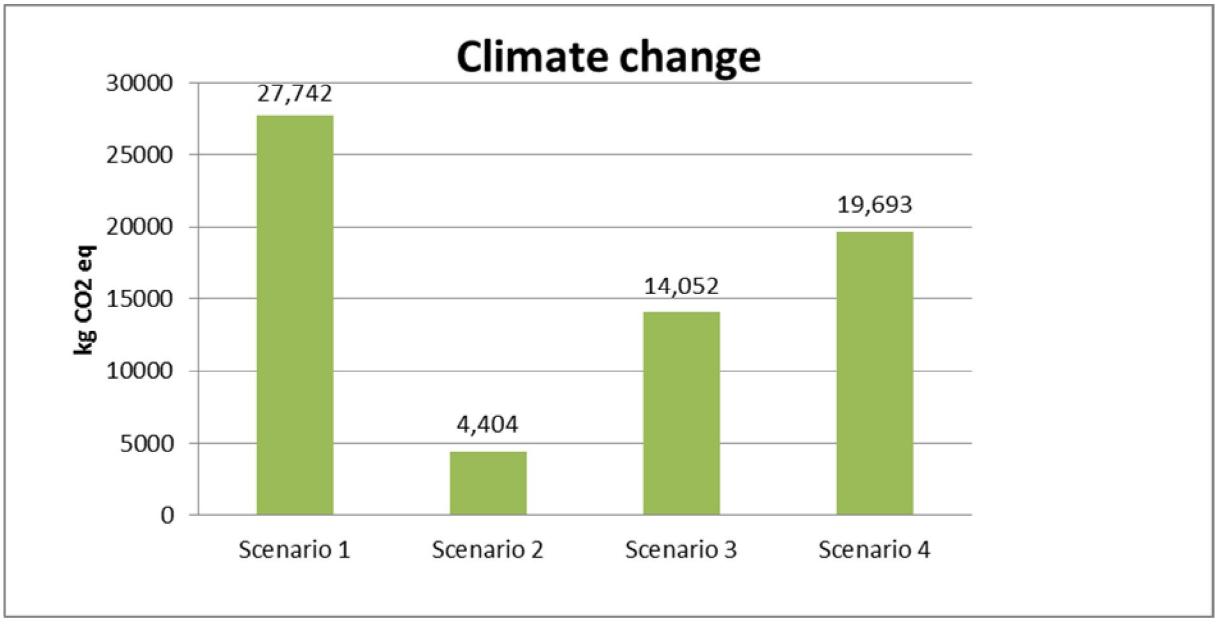


Figure A19 Emissions associated to Climate Change for all the scenarios

Compared to the other damage categories discussed above, Scenario 1 lead to an increase in the Climate Change damage category. Production of fertilizers necessitate huge amount of resources such as nutrients and energy. Since fertilizers are imported from South Africa, transportation is another process that leads to an increase in the climate change impact category. The scenario which contributed the least in this category of damage is the application of compost as the latter is being produced in Mauritius itself and thus, emissions related to transportation is little.

Resources

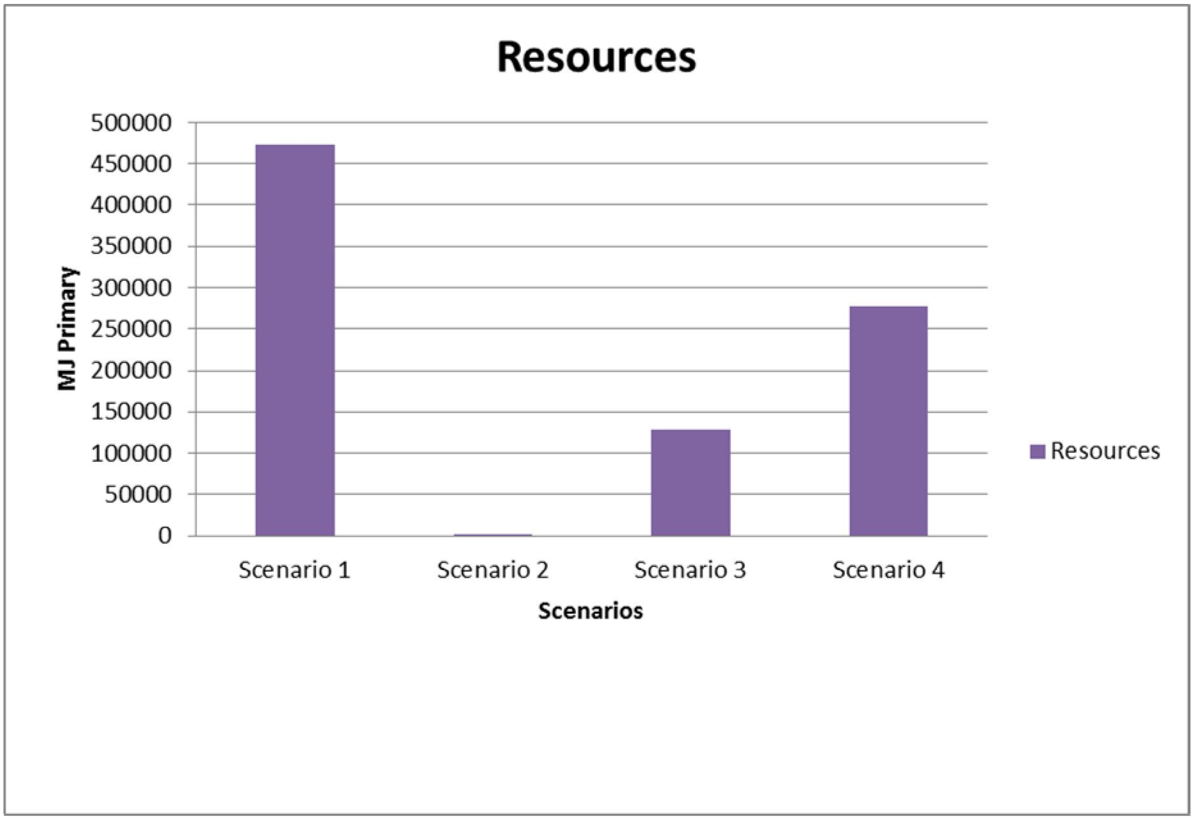


Figure A20 Emissions associated to Resources for all the scenarios

Production of fertilizer causes depletion of resources, since it requires the use of non- renewable forms of energy. Thus, application of fertilizer contributed the most to resources depletion, compared to the other scenarios. Among all the scenarios studied, scenario 2 contributed the least to the damage categories. Another reason that can be attributed for this positive benefit is that production and application of compost requires less energy intensive properties.

Table A1: Process contribution to impact category for scenario 1(application of fertilizer)

Impact category	Unit	Post application impacts of fertilizer-LCA	Urea, as N, at regional storehouse/RER U	Application of fertilizer-LCA	Transport, ocean freighter, average fuel mix/US	Delivery van <3.5t
Carcinogens	DALY	0	0.000593063	0	4.94641E-07	1.49218E-05
Non-carcinogens	DALY	0	9.92125E-05	0	0.000100499	8.82748E-06
Respiratory inorganics	DALY	0	0.01188353	0	0.001330475	0.000152639
Ionizing radiation	DALY	0	3.31385E-05	0	0	6.22732E-07
Ozone layer depletion	DALY	0	3.69358E-06	0	2.20498E-11	3.13955E-07
Respiratory organics	DALY	0	1.03581E-05	0	7.5345E-07	1.52147E-06
Aquatic ecotoxicity	PDF*m2*yr	0	7.7455562	0	11.992728	3.758898
Terrestrial ecotoxicity	PDF*m2*yr	0	521.86635	0	0.20916181	70.483909
Terrestrial acid/nutri	PDF*m2*yr	0	547.53002	0	80.192949	6.852163
Land occupation	PDF*m2*yr	0	1.5175721	0	0	3.173805
Aquatic acidification		-	-	-	-	-
Aquatic eutrophication		-	-	-	-	-
Global warming	kg CO2 eq	5607.88	21368.236	0	554.33614	211.82052
Non-renewable energy	MJ primary	0	461427.73	0	7597.3487	3231.4868
Mineral extraction	MJ primary	0	0.4133627	0	0	4.901212

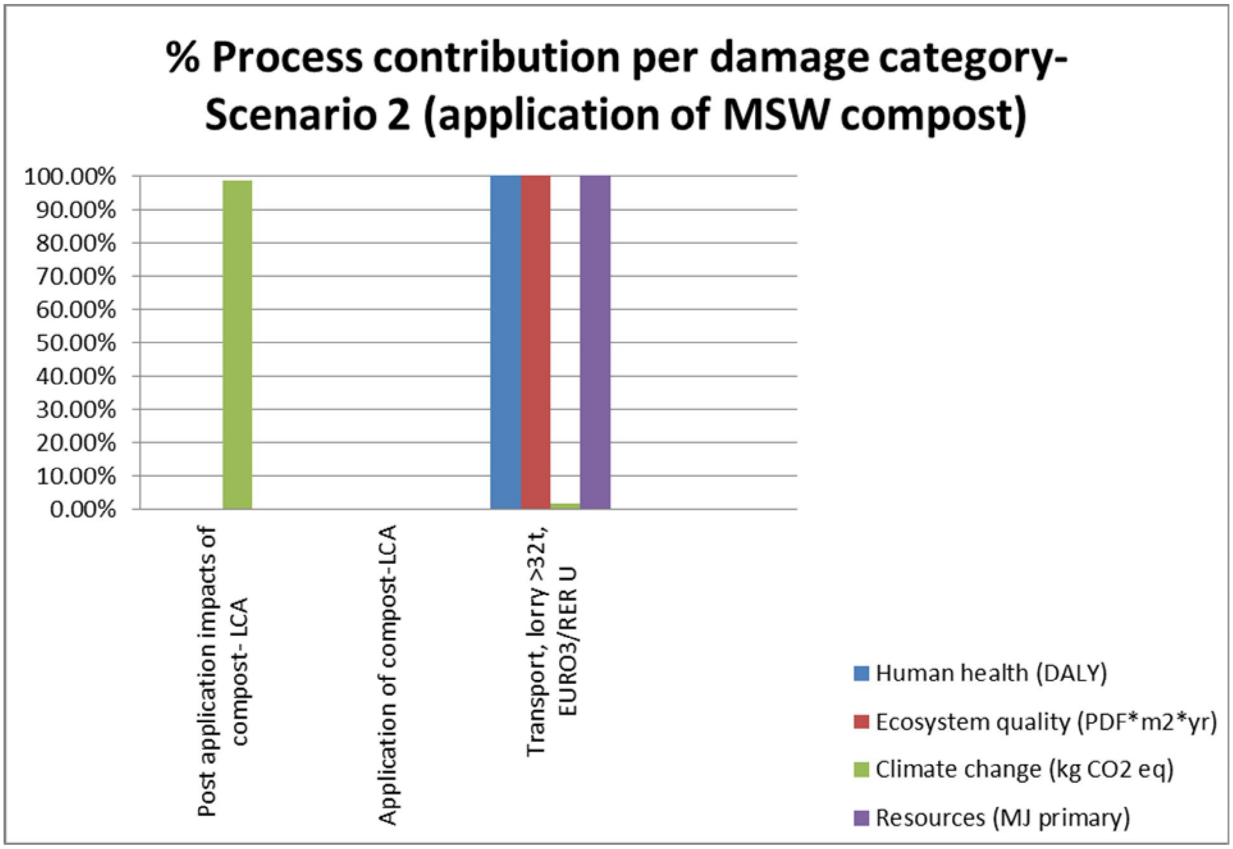


Figure A17: Percentage Process contribution per damage category for scenario 2 (application of compost)

For Scenario 2, the process that contributed the most to the damage categories was transportation, from the composting site (La Chaumiere) to the site of compost application (Bonne Terre

Table A2: Process contribution to impact category for scenario 2(application of compost)

Impact category	Unit	Post application impacts of compost- LCA	Application of compost-LCA	Transport, lorry >32t, EURO3/RER U
Carcinogens	DALY	0	0	2.32E-07
Non-carcinogens	DALY	0	0	9.45E-07
Respiratory inorganics	DALY	0	0	6.23E-05
Ionizing radiation	DALY	0	0	1.83E-08
Ozone layer depletion	DALY	0	0	1.11E-08
Respiratory organics	DALY	0	0	6.26E-08

Aquatic ecotoxicity	PDF*m2*yr	0	0	0.10569298
Terrestrial ecotoxicity	PDF*m2*yr	0	0	19.889014
Terrestrial acid/nutri	PDF*m2*yr	0	0	3.2072555
Land occupation	PDF*m2*yr	0	0	0.001132657
Aquatic acidification		-	-	-
Aquatic eutrophication		-	-	-
Global warming	kg CO2 eq	4335.16	0	68.58134
Non-renewable energy	MJ primary	0	0	1004.2919
Mineral extraction	MJ primary	0	0	0.000335021

Scenario 3: Application of Chicken Manure

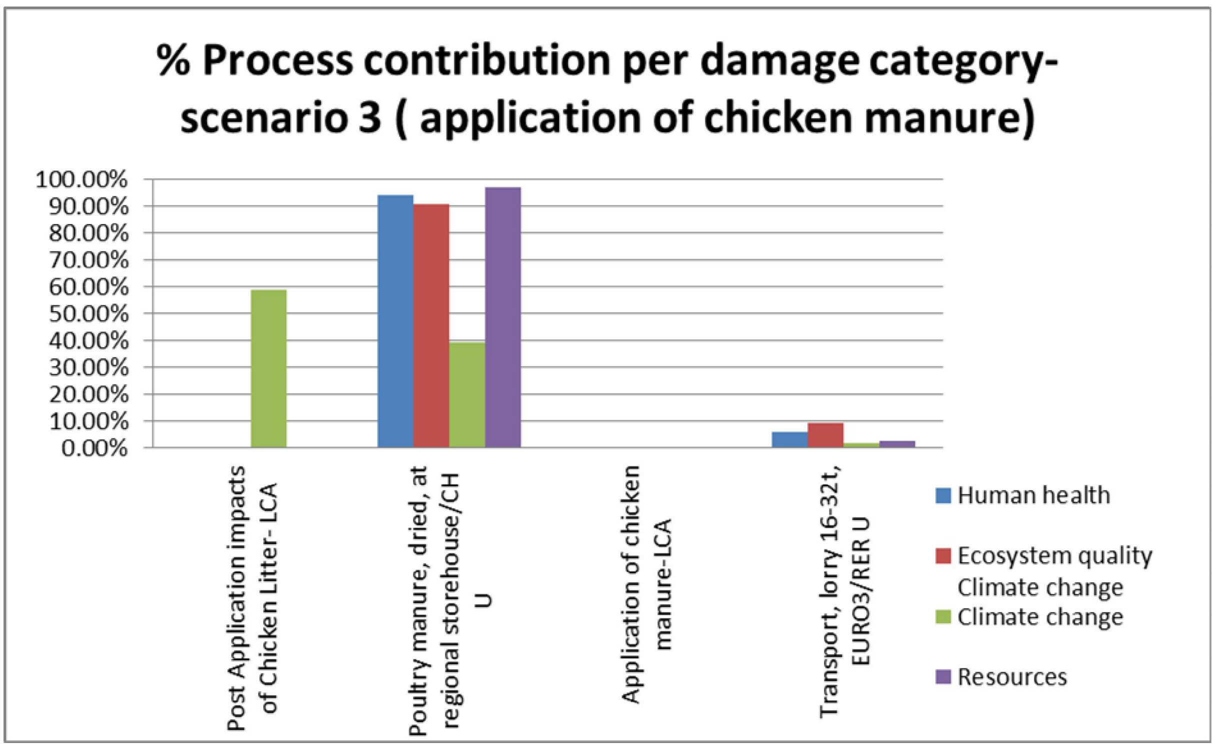


Figure A18: Percentage Process contribution per damage category for scenario 3(application of chicken manure)

Manipulation of Chicken manure contributed the most to the damage categories of scenario 3. Construction and maintenance of poultry farms contribute to large amount of GHG emissions. For instance, Methane was detected from the treatment treated with chicken manure only. This shows that chicken manure is a source for GHG. This justifies the high value obtained for the damage categories due to the contribution of chicken manure handling.

Table A3: Process contribution to impact category for scenario 3(application of chicken manure)

Impact category	Unit	Post Application impacts of Chicken Litter-LCA	Poultry manure, dried, at regional storehouse/CH U	Application of chicken manure-LCA	Transport, lorry 16-32t, EURO3/RER U
Carcinogens	DALY	0	3.56E-05	0	8.79E-07
Non-carcinogens	DALY	0	8.68E-05	0	3.82E-06
Respiratory inorganics	DALY	0	0.003336731	0	0.000225635
Ionizing radiation	DALY	0	0.00010936	0	6.95E-08
Ozone layer depletion	DALY	0	8.26E-07	0	4.19E-08
Respiratory organics	DALY	1.44E-06	4.31E-06	0	2.18E-07
Aquatic ecotoxicity	PDF*m2*yr	0	10.877257	0	0.43714011
Terrestrial ecotoxicity	PDF*m2*yr	0	607.3409	0	81.879246
Terrestrial acid/nutri	PDF*m2*yr	0	216.3704	0	12.064011
Land occupation	PDF*m2*yr	0	68.260213	0	0.004292932
Aquatic acidification		-	-	-	-
Aquatic eutrophication		-	-	-	-
Global warming	kg CO2 eq	8281.444	5510.0638	0	260.39025
Non-renewable energy	MJ primary	0	124822.08	0	3806.4086
Mineral extraction	MJ primary	0	1.0526573	0	0.001269778

Scenario 4: Application of MSW Compost and Fertilizer

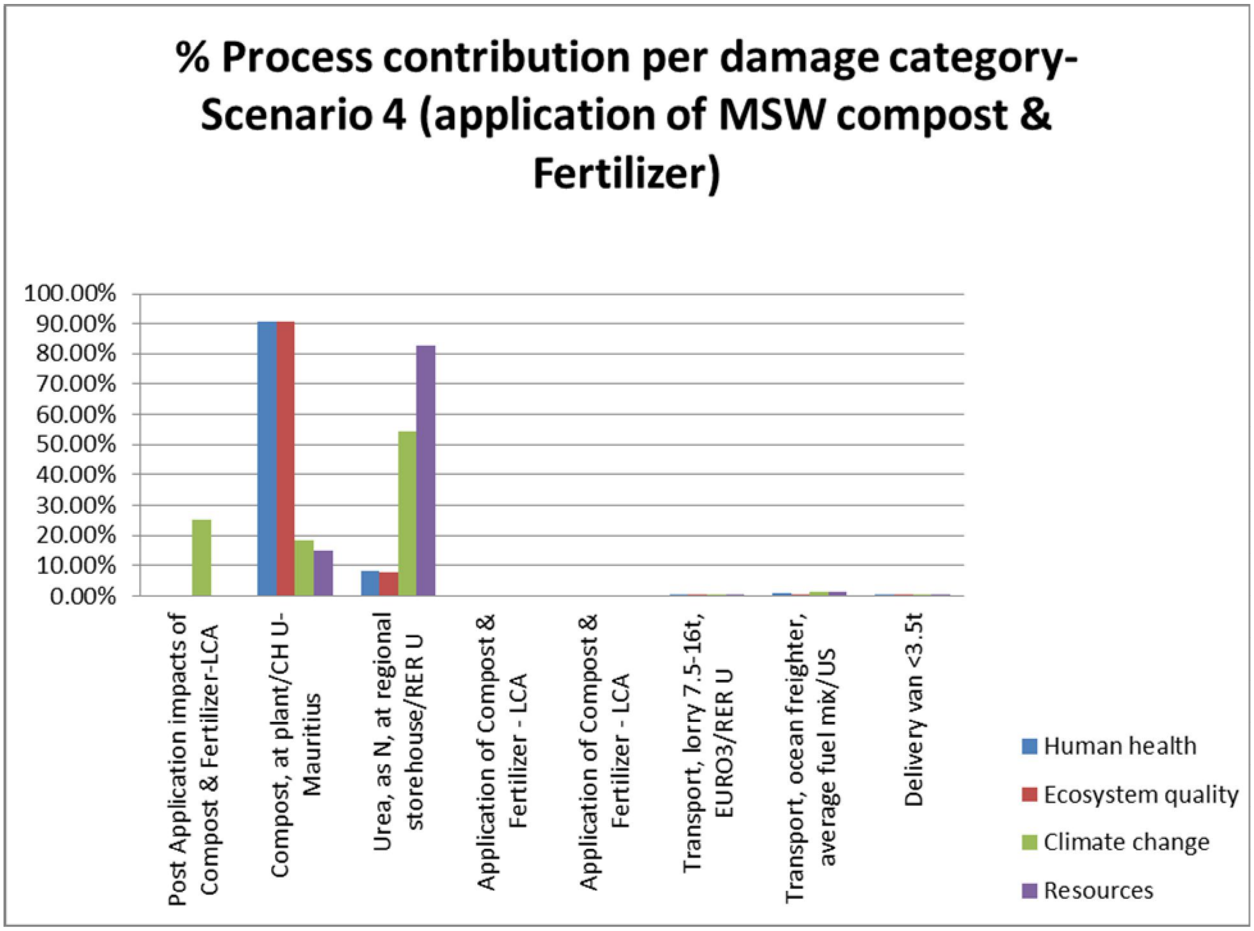


Figure A19: Percentage Process contribution per damage category for scenario 4

Production and handling of MSW compost and urea based fertilizer led to an increase in the damage categories for scenario 4. This can be explained to due the fact that production of both compost and fertilizer utilizes energy intensive processes. However, it is worth noting that application of a mixture of MSW compost and fertilizer did not lead to an increase to the damage impact categories.

Table A4: Process contribution to impact category for scenario 3

Impact category	Unit	Post Application impacts of Compost & Fertilizer -LCA	Compost, at plant/CH U-Mauritius	Urea, as N, at regional storehouse/RER U	Application of Compost & Fertilizer - LCA	Application of Compost & Fertilizer - LCA	Transport, lorry 7.5-16t, EURO3/RER U	Transport, ocean freighter, average fuel mix/US	Delivery van <3.5t
Carcinogens	DALY	0	7.63E-06	0.0003	0	0	2.38E-07	2.47E-07	7.42E-06
Non-carcinogens	DALY	0	7.88E-05	4.95E-05	0	0	7.01E-07	5.01E-05	4.39E-06
Respiratory inorganics	DALY	0	0.068726	0.00593	0	0	6.11E-05	0.000663	7.59E-05
Ionizing radiation	DALY	0	5.95E-05	1.65E-05	0	0	1.88E-08	0	3.10E-07
Ozone layer depletion	DALY	0	1.65E-07	1.84E-06	0	0	1.13E-08	1.10E-11	1.56E-07
Respiratory organics	DALY	0	1.47E-06	5.17E-06	0	0	6.14E-08	3.76E-07	7.57E-07
Aquatic ecotoxicity	PDF*m2*yr	0	8.208402	3.86419	0	0	0.094962	5.979754	1.86907
Terrestrial ecotoxicity	PDF*m2*yr	0	237.9311	260.355	0	0	14.97938	0.104291	35.0472
Terrestrial acid/nutri	PDF*m2*yr	0	5901.247	273.158	0	0	3.258565	39.9854	3.40715
Land occupation	PDF*m2*yr	0	0.530428	0.7571	0	0	0.00116	0	1.57814
Aquatic acidification		-	-	-	-	-	-	-	-
Aquatic eutrophication		-	-	-	-	-	-	-	-
Global warming	kg CO2 eq	4934.28	3646.317	10660.4	0	0	70.50694	276.4003	105.325
Non-renewable energy	MJ primary	0	41521.14	230202	0	0	1028.46	3788.152	1606.82
Mineral extraction	MJ primary	0	0.587805	0.20622	0	0	0.000343	0	2.43707