ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSITUTE OF TECHNOLOGY
DEPARTMENT OF CHEMICAL ENGINEERING

Effect of adding urea on biogas production potentials of selected fruit wastes in Addis Ababa, Ethiopia

By
Getachew Dagnew Gebreeyssus

November, 2012
Addis Ababa, Ethiopia

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSITUTE OF TECHNOLOGY
DEPARTMENT OF CHEMICAL ENGINEERING

Effect of adding urea on biogas production potentials of selected fruit wastes in Addis Ababa, Ethiopia

A thesis Submitted to the Research and Graduate School of Addis Ababa University, Addis Ababa Institute of Technology, Department of Chemical Engineering in partial fulfillment of the requirements for the attainment of Degree of Masters of Science in Environmental Engineering under Chemical Engineering

By
Getachew Dagnew Gebreeyssus

Advisor: Dr.-Ing Berhanu Assefa
(Associate Professor of chemical engineering)

October, 2012
Addis Ababa, Ethiopia

Effect of adding urea on biogas production potentials of selected fruit wastes in Addis Ababa, Ethiopia

A Thesis Submitted to the Research and Graduate School of Addis Ababa
University, Addis Ababa Institute of Technology, Department of Chemical
Engineering in Partial Fulfillment of the Requirements for the Attainment of
Degree of Masters of Science in Environmental
Engineering under Chemical Engineering

By
Getachew Dagnew Gebreeyssus

Approved by the Examining Board	Signature
Dr-Ing Birhanu Assefa	
Chairman, Department's Graduate committee	
Dr-Ing Birhanu Assefa	
Advisor	
Dr-Ing Belay Woldeyes	
Internal Examiner	
Mr. Lelisa Daba	
External Examiner	

Acknowledgement

First of all, I would like to thank GOD for who did everything beautifully in time.

I want to express my acknowledgment and appreciation to Dr.-Ing Berhanu Assefa, my advisor; for his wisdom, strategic guidance, smart comments and easy approachability as well as good decision in times of uncertainties.

I also extend my appreciation to Chemical Engineering Laboratory Staffs; Mr. Yosan Teshome, Mr. Hintsa-Selassie Seifu, Mr. Alemayehu Mengiste, Mr.Biruk Tefera, Mr. Biruk Yohannes, Mr. Mehtem and Mr. Nebiyu Getachew for their unreserved support to my laboratory work.

I am also happy to thank the Department of Chemical Engineering in general and some staff in particular; -Ing. Gizachew Shiferaw and Dr-Ing. Shemelis Admasu for their encouragements, Mr. Habtamu, the assisting manager of the department and Mr. Mehiretu Jaleta for their support as well.

I would also like to thank Addis Ababa University College of Natural and Computational Sciences, Environmental Science Program; Dr. Mekuria Argaw, Mr. Temesgen and Mr. Andualem Mekonen for their unreserved collaboration during part of my laboratory experiment and equipment provision at the center’s premises.

My thanks also go to my family especially to Mrs. Alem Alemayehu and Ms. Birtukan Dagnew for their encouragement and support in times of ups and downs during my thesis and academic career.

Last, but not least, I would to acknowledge those people who provided me information during the situational analysis period and prediction works

Table of contents

Content	**Page Nº**
Acknowledge	I
Contents	II
List of figures	IV
List of tables	V
Acronyms	VI
Abstract	VII
1. Introduction	1
1.1 Background	1
1.2 The statement of the problem	2
1.3 Objective	4
1.4 Significance of the study	4
2. Literature review	5
2.1 Fruit waste management and environmental implication	5
2.2 Potential of fruit waste for biogas and compost	8
2.3 Anaerobic digestion	10
2.4 Anaerobic process microbiology	11
2.5 Factors controlling anaerobic digestion	13
2.6 C0-digestion, chemical addition and digester stability	16
3. Materials and methods	19
3.1 Study area description	19
3.2 Materials	19

3.3 Methods 21

3.4 Experimental procedure 22

3.5 Experimental design 23

3.6 Experimental set up 24

3.7 Analysis 24

4. Results and discussions 25

4.1 Fruit wastes characterization 25

4.2 The biogas potential experiment 29

4.2.1 Urea dosing 29

4.2.2 Prepared slurry characterization 30

4.2.3 Biogas (methane) yield 32

4.3 Prediction for biogas 37

4.4 Process stability and control 42

4.5 Further on importance of anaerobic digestion 45

4.6 The biogas manure characterization 46

4.7 Biogas manure prediction 49

5. Conclusions 50

6. Recommendations 51

References 52

Annexes 57

List of figures:

Figure2.1 Stages in the methane fermentation of complex wastes. Percentages represent

Figure3.1 Experimental set-up; shaking water bath loaded with anaerobic digesters

Figure4.1 Physical parameters test result for sampled FWs

Figure4.2 Off-site pH determination for the selected sampled FWs

Figure4.3 Biogas production on anaerobic mesophilic digestion of avocado FW with urea (A_1) and without urea (A_0)

Figure4.4 Biogas production on anaerobic mesophilic digestion of banana FW with urea (B_1) and without urea (B_0)

Figure4.5 Biogas production on anaerobic mesophilic digestion of mango FW with urea (M_1) and without urea (M_0)

Figure4.6 Ultimate biogas yield on anaerobic mesophilic digestion of avocado (A_0), banana (B_0) and mango (M_0) FWs without urea and A_1, B_1, $M_{1,}$ with urea

Figure4.7 Ultimate methane yield on anaerobic mesophilic digestion of avocado (A_0), banana (B_0) and mango (M_0) FWs without urea and A_1, B_1, M_1 with ure

List of tables

Table2.1. General sources of MSW

Table2.2. Characteristics of fruits and vegetable wastes and food wastes from a northern china city.

Table2.3. Proximate composition (%) of ripened banana and mango fruits

Table4.1 Average results of characterization for row avocado, banana and mango FW from “Atiklet tera”

Table4.2. Summary of substrate-urea mix determination of slurry

Table4.3. Average results of slurry characterization for avocado, banana and mango FWs

Table4.4 Summary of the biogas yield and the methane content on anaerobic digestion of avocado, banana, and mango fruit wastes with and without urea on average

Table4.5 Mean value of TS (g/l), VS (g/l) removal, and biogas productivity and average methane for the various conditions evaluated in batch experiment of 35 days HRT

Table4.6 Total biogas and corresponding methane yield among studied systems

Table4.7 Summary of fruit and vegetable juice and supermarkets by sub city in Addis Ababa city (Data are up to the year 2010)

Table4.8 Summary of generation rate (in tons/day) for the selected FWs by the identified contributors

Table4.9 Summary of important information and prediction values for biogas (methane) per day.

Table4.10 Summary of substrate-lime mix determination of digesters

Table4.11 Summary of VFA/ TA analysis result for the different batch anaerobic digesters with and without liming

Table4.12 Results of content characterization for avocado, banana and mango FW from “Atiklet tera” after anaerobic digestion on average

Table4.13 Results of parametric tests (soil fertility) in mg/g TS for avocado, banana and mango FW in “Atiklet tera” after anaerobic digestion/treatment

Table4.14 Summary of the total determinant nutrients quantification on daily basis

List of abbreviation

AD: Anaerobic digestion/anaerobic digester, APHA: American public health

ASTM: American Society for Testing and Materials association

BMP: Biochemical methane potential,

BOD: Biological oxygen demand (g/L)

COD: Chemical oxygen demand (g/L)

FW: Fruits wastes

FVW: Fruits and vegetable wastes

FVM: Fruits and vegetable market

FVSW: Fruits and vegetable solid wastes

FS: Fixed solids (%)

HRT: Hydraulic retention time (d^{-1})

MSWM: Municipal solid waste management

PPM: Parts per million

SWM: solid waste management

TA: Total alkalinity

TKN: Total Kejldahl nitrogen (*m*g/L)

TOC: Total organic carbon (%)

TS: Total solids (%)

VFA: Volatile fatty acid

VS: Volatile solids (Kg m^{-3})

Operational definitions

$\mathbf{A_0}$= avocado fruit waste without urea,

$\mathbf{A_1}$= avocado fruit waste with urea,

$\mathbf{B_0}$= banana fruit waste without urea,

$\mathbf{B_1}$= banana fruit waste with urea,

$\mathbf{M_0}$= mango fruit waste without urea,

$\mathbf{M_1}$= mango fruit waste with urea, and

I= Innoculum

S=substrat

Abstract

Fruit wastes are ideal candidates for anaerobic digestion because they contain high levels of easily biodegradable materials. These wastes from the central and biggest fruits, fish & vegetables retail and distribution market in Addis Ababa City, Ethiopia are poorly managed. Again problems such as low biogas/methane yield and process instability are often encountered in anaerobic digestion of these wastes, challenging its reliability and efficiency. This study evaluated the effect of adding urea on biogas (methane) potential of selected fruit wastes following characterization. A laboratory scale experiment on batch anaerobic mesophilic digestion was carried out. Selected and pretreated fruit wastes were fed to digesters using standard procedures. Analytical equipments, simple tools and statistical software were used for data analysis. The ultimate biogas yield from using avocado, banana, and mango fruit wastes as substrate is; 0.48, 0.57, 0.53 l/g VS without adding urea and 0.76, 0.82, 0.82 l/g VS adding urea with a statistically significant difference (*p-value*; 0.006 for avocado, 0.029 for banana, and 0.007 for mango FW at 95% Confidence Interval respectively). Thus urea addition significantly improved biogas yield. In relation to this, ultimate CH_4 yield didn't show difference in response to the treatment and gave 0.27, 0.33, 0.27 l/g VS without adding urea and 0.44, 0.46, 0.43 l/g VS for avocado, banana, & mango fruit wastes with adding urea where the later yield is above average yield reported for fruits and vegetables wastes. Further, the biogas manure contains nutrients in their useful form and better than the row waste for plant growth signifying the advantages of anaerobic digestion. Prediction of biogas and biogas manure obtainable from the city's fruit wastes is also made.

Keywords: ***fruit waste; urea; biogas; methane; volatile acids; and plant nutrient***

1. Introduction

1.1 Background

Solid waste management is a present challenge to large cities like Addis Ababa. The city inhabiting closer to four million people generates solid waste at a rate of 0.4kg/head/day. The largest share of the generation is contributed from households (76%). 60% of the municipal solid waste is organic in nature. The existing solid waste collection coverage of the city of Addis Ababa is inadequate, 60% of the total generated waste, due to lack of transportation facilities and financial matters as well as geographic inconvenience for collection signifying the unreliability of the system for waste items like easily decaying FVW (Tesema, 2010; Regassa et al., 2011).

In Ethiopia, horticulture has become one of big cash crop. As per the country's Central Statistics Agency estimation for 2008/09, the production of fruit and vegetables, including root crops, was 2.16 million tones. The total fruit and vegetable production in 2008/2009 for the season comprises about 351 thousand tones of fruits (16%), 600 thousand tons of vegetables (28%), and 1.2 million tons of root crops (56%), (Ethiopian Horticultural Development Agency, 2011). Tesema (2010) estimated that the city of Addis Ababa generates 23.1 tones of fruits and vegetable waste daily. These figures could increase with the growth of the horticulture industry year by year.

These wastes holdup significant energy (Hawkins and Rains, 2008) and manure resource. However, these wastes are left to decompose in vain where a related problem arises in other areas also (Gustavsson et al., 2011). As a result of decomposition the wastes emit huge amount of CH_4 and CO_2 (green house gasses) to the atmosphere together with NH_3 and H_2S-noxious gases, causing environmental and health problems. Moreover the wastes affect aquatic systems by depleting dissolved oxygen due to the biochemical strength of the wastes if washed with flood water.

The reason for considering environment and methane gas in treatments of solid wastes can be explained (Esposito et al., 2012) considering mainly three factors. First, the need to apply a process to dispose of organic solid wastes in a more environmentally friendly manner, along with useful soil conditioner, Secondly, the opportunity to obtain from this process a renewable fuel called biogas alternative to fossil fuel. Thirdly, the advantage of relatively low costs in starting up and managing this process as it mainly does not require oxygen supply as well as its feasibility of being even commercialized.

However, the nitrogen and in some regions of farming the phosphorus in FVW very low, and the carbon: nitrogen ratio is very much higher than the optimum for stable anaerobic digestion. For this reason the FVWs have been used in co-digestions with other wastes for better biogas/methane yield and process stability, for example, chicken manure and cow dung (Diamantis et al., 2003; Gunaseelan, 1977).

It is important that the BMP of FWs is determined and improved to recover valuable resource. These sorts of studies have been made under different conditions. However there is no significant work done on typical FWs in Ethiopia. This paper, therefore, evaluates the effect of adding urea on biogas/biochemical methane yield and digesters pH control using laboratory scale anaerobic digestion in the context of Addis Ababa city's FVM to predict the recoverable resource from FWs.

1.2 The statement of the problem

Vegetable and fruits market wastes contribute to a great amount of pollution because of its high fraction of readily decaying organic matter that cause serious environmental and health risks. Indiscriminate disposal of these wastes when decomposed produces noxious gases such as hydrogen sulfide and ammonia, which pose serious environmental hazards (Khan et al., 2009). The emission of GHG is also a major issue; the anaerobic decomposition emits CH_4 and CO_2 to atmosphere where the former is 23 worse than the later.

These wastes also result in fish suffocation as it depletes dissolved oxygen in aquatic systems due to its high biochemical oxygen demand. Disposal of such wastes in landfills fill space sooner and adds to leached quantity. In the city of Addis Ababa the wastes are contributed from different groups; market places, fruit and vegetable shops, juice houses, supermarkets, mobile fruit sellers, and consumer households.

“Atikilet tera”, the biggest market for fruits and vegetable in Ethiopia, can be described best by its unsightly accumulation of FVWs which are discarded indiscriminately from transporters, whole sellers, retailers and stores. The existing MSWM is not efficient in managing the FV and other MSWs. The over flooded and leaching waste containers closely spaced along the road sides and in alleys there confined the wastes to a given place but is also annoying.

“Atikilt tera” can also be characterized by its nasty odor easily, even for a passerby; surrounded by ‘waste picking’ people and flies as well as vermin that indicate the poor management of FVWs. The problem is exacerbated during rainy times. Nevertheless, by controlling the decomposition process in systems called anaerobic digesters, the methane can be captured and used for alternative energy sources with accompanying stabilized sludge for soil conditioning. In this regard, however, FVWs in general and FWs in particular are found to have very low nitrogen content in supporting anaerobic digestion. In addition process instability due to lowering of pH is limiting application of such technology (Gunaseelan, 1977).

In this study, effect of adding urea on the anaerobic digestion process is determined in order to exploit the BMP of avocado, banana and mango FWs. The potential of sludge after digestion for its soil fertilizing quality will be analyzed. So, it also reduces the environmental degradation problem that would have occurred to atmosphere, water bodies and soil had these wastes been improperly dumped.

1.3 Objective

General objective

The general objective of this paper is to investigate the effect of adding urea on improving the biogas and hence methane yield through control of lowering of pH and supplement of nutrient demand along with determination of the biochemical methane and biogas manure potential of typical FWs.

Specific objectives

- To determine the characteristics of selected FW with respect to biogas potential.
- To determine biogas (methane) production by anaerobic mesophilic digestion of selected FW without addition of urea.
- To evaluate the effect on anaerobic mesophilic digestion for biogas (methane) production by mixing of the selected FW with urea.
- To make prediction for biogas that can be produced from FW generated in Addis Ababa city.
- To characterize the biogas manure after anaerobic digestion and evaluate its plant nutritive value.
- To make prediction of biogas manure that can be produced from FW generated by Addis Ababa city.

1.4 Significance of the study

This study would contribute to efforts on avoiding environmental and health problems arising FVW sector. The study gives analysis of the physical and chemical composition of the FWs selected. It determines the renewable energy potential of the waste sector, as an alternative renewable and clean energy source after observing the effect of urea addition on biogas yield. Further it also shows the soil fertilizing value of the stabilized sludge. The result could also serve as input to further related investigations. Therefore the finding could be an input to many stakeholders interested in an integrated SWM activity.

2 Literature review

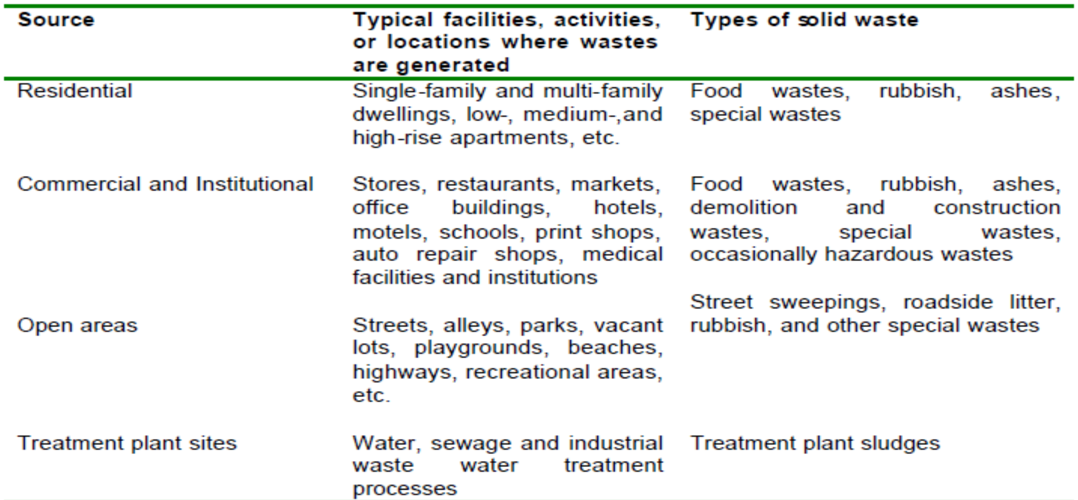
2.1 Fruit waste management practices and its environmental implication

2.1.1 General

Management of MSW is challenging to existing and emerging cities in Ethiopia. The Addis Ababa municipality, for instance, spends large proportion of its budget on collection, transport, and disposal of solid waste though inefficient. Recently the city's economic activity accompanied by the construction and demolition works may have impacted the solid waste composition significantly. However a previous study noted that 60% of MSW generated is organic where it can be managed and changed to useful item using anaerobic digesters as an attractive option for both energy generation as well as waste disposal (Tesema, 2010).

From what I observe the residents of the city are less aware of the impact of refuse while disposing it. Most area of the city are less clean expressed by indiscriminate disposals; to road sides, adjoining streams, poorly managed solid waste containers. There are however approaches by the state to handle the matter; involvement of assigned people to collect rubbish house to house and small enterprises could be mentioned. The geographical condition of the city can be mentioned as challenge to collection operation. Generally the sources and c composition of MSW can be summarized in table 2.1 below.

Table2.1. General sources of MSW



Source	Typical facilities, activities, or locations where wastes are generated	Types of solid waste
Residential	Single-family and multi-family dwellings, low-, medium-,and high-rise apartments, etc.	Food wastes, rubbish, ashes, special wastes
Commercial and Institutional	Stores, restaurants, markets, office buildings, hotels, motels, schools, print shops, auto repair shops, medical facilities and institutions	Food wastes, rubbish, ashes, demolition and construction wastes, special wastes, occasionally hazardous wastes
Open areas	Streets, alleys, parks, vacant lots, playgrounds, beaches, highways, recreational areas, etc.	Street sweepings, roadside litter, rubbish, and other special wastes
Treatment plant sites	Water, sewage and industrial waste water treatment processes	Treatment plant sludges

Source: adapted from Peavy, Rowe and Tchobanoglous, 1985.

2.1.2 Fruit and vegetable wastes

In a study by Gustavsson et al., (2011) roughly one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year. This inevitably also means that huge amounts of the resources used in food production are lost in vain, and that the greenhouse gas emissions caused by production of food that gets lost or wasted are also emissions in vain.

This loss occurs throughout the supply chain, from initial agricultural production down to final household consumption. The causes of food losses and waste in low-income countries are mainly connected to financial, managerial and technical limitations in harvesting techniques, storage and cooling facilities in difficult climatic conditions, infrastructure, packaging and marketing systems including distributions, at e.g. wholesale markets, supermarkets, retailers and wet markets.

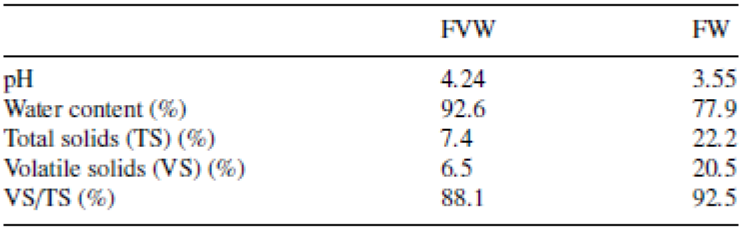
FVWs account in the total food waste varies with spatial and socioeconomic conditions. Fresh fruits, vegetables, and salads were found to make up the largest category of food waste (Kosseva, 2011), according to the UK's Waste and Resources Action Program report, amounting to 1.4 million ton per year. In the city of Addis Ababa over 23.1 tones of FVWs are discarded daily in a report by (Tesema, 2010), that in fact underestimated the current and likely actual amount. Because the harvested FV are less processes due to absence of the technology and are exchanged only on fresh basis in the country, wastage is expected to maximize.

The FVWs in city emanate from general store, open markets, FV markets, transporters, supermarkets, fruit juice houses, mobile fruit sellers and consumer households. These wastes join unnecessarily the municipal general waste mostly at waste containers to be picked and transported to a local dump site.

The biggest FV or food supply market, "Atikilet tera", in Ethiopia is located between piazza and the largest market area, Merkato within Arada sub city of Addis Ababa city. The site there is not designed for the function it undergoes, operationally nasty described by its poor appearance and offensive odor etc. The onsite waste collection system is shared between informal sector and the municipality. Within the informal sector, which holds the greater share, there are different groups; commercial unions, private merchants, recyclers, and neighboring FV shop owners. The recyclers mention uses of FVW for cattle fed, poultry feed and even to kitchen for human consumption in some way. Disposal of the flooded containers is executed based on fee collected from waste generators and is at a cost of 80 Ethiopian birr≈(4.5USD based on current value/exchange) per m^3 where the involvement of the state is very low in this regard. Apart from this, the site is located at the center of the capital and is well accessible to transportation in any direction.

Had FWs been collected as it is mostly contained at the outset, the operation further would have been easy to manage. FVWs known to contain biodegradable compounds and moisture strongly supporting their application to anaerobic biogas digesters' input and are to food wastes (Table2.2).

Table2.2. Characteristics of fruits and vegetable wastes and food wastes from a northern china city.



	FVW	FW
pH	4.24	3.55
Water content (%)	92.6	77.9
Total solids (TS) (%)	7.4	22.2
Volatile solids (VS) (%)	6.5	20.5
VS/TS (%)	88.1	92.5

Source: Jia Lin et al., 2011.

2.1.3 Environmental implication of fruit and vegetable wastes

The issue of climate change is given attention following the Kyoto protocol. FVWs are implicated for environmental degradation, emission of potent green house gases to atmosphere, emission of noxious gases, and pollution of water bodies, attraction of insect and vermin, as well as disgusting appearance.

In some developed countries like Australia and the USA food waste, where FVW are the top two available wastes, accounts 3% (Morgan,2010) and 2% (Venkat, 2011) of the national GHG emission in CO_2 equivalent. The report also noted the cost implication of the waste management based on life cycle assessment methodology. These effects are there even though the nations are having the necessary food process technology at their disposal.

Bringing the scenario to developing nations like Ethiopia could have probably worsened the situation. The issue can be exemplified, based on my perception while making situational observation, indiscriminate disposals, open dumping of the flooded containers, disposal to adjoining town rivers and along roads sides.

Because these wastes hold organic matter, entry of the wastes to water system depletes the dissolved oxygen resulting in imbalance therein. The related beneath anaerobic decomposition also releases noxious gases creating a challenge to aquatic ecosystem including fish killing.

Nevertheless, these wastes are resources if managed properly and converted to useful products. The interest of this study lies here, obtaining clean energy and soil nutrient.

2.2 Potential of fruit waste for biogas and compost

2.2.1 Composting potential

Composting involves the collection of organic residues / wastes, treatment of this organic material in such a way that it decomposes to humus and the utilization of the co-product as a soil amendment.

Anything that is naturally degradable can be thrown into a compost bin. These include food and organic waste created by food processing plants, kitchens, galleys, animal feedlots, yard work, and municipal sewage treatment plants etc. Paper, leaves and grass clippings can also be decomposed in this process and the end product can be used as manure.

It has been estimated that up to 50% (Harilal, kumar and Ravindran, 2007) of all domestic solid waste is kitchen waste, which in principal could be used for the home manufacture of compost. It is therefore highly desirable that the public be encouraged, wherever possible, to set up their own compost heap at home. The use of kitchen waste in compost heaps will certainly have a positive impact on the quanta of solid waste, which though limited could well be significant.

Composting of FVWs is not an excellent method of recycling biodegradable waste from an ecological point of view. Many large and small composting schemes have failed because composting is regarded as a disposal process and not a production process. Moreover the transport cost for FVWs to compost sites could discourage its application. In a related fact, again the microorganisms utilize the organic mass due to its high moisture content to grow much as a result little humus is obtained from FW composting.

However, by application of biogas technology is possible to obtain soil fertilizer from such wastes better than even the waste would have been applied in its row form as manure.

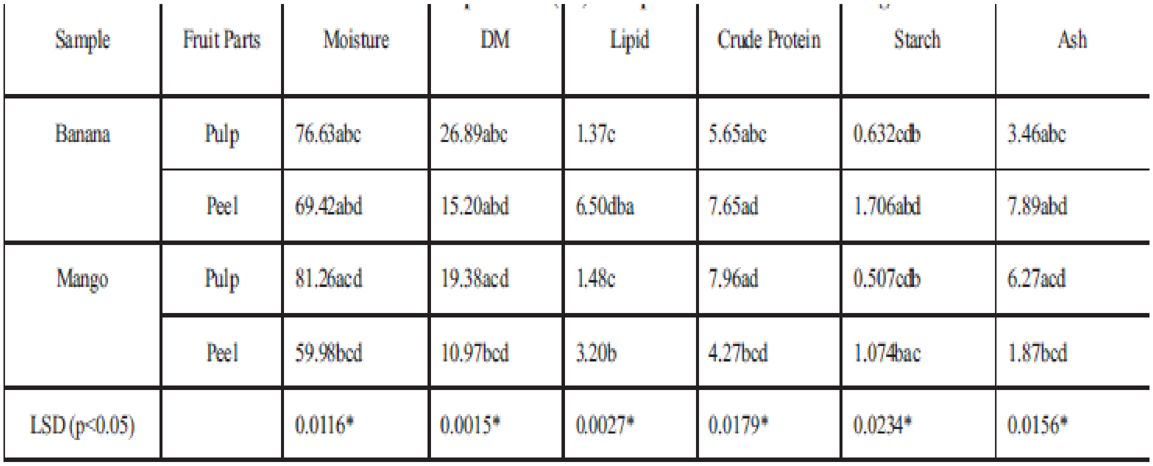
2.2.2 Biogas potential

When sufficient data on the biogas potential of FVWs is available, forecasting the digestibility is not the only advantage but also the values will be used to design pilot scale systems. Further it can be used to secure funding to design an operating plant for converting the waste to methane.

Studies showed that FWs do have better bio-methane potential compared to other biomass wastes including vegetables wastes (Arvanitoyannis and Varzakas, 2008).

According to a study on the chemical characteristics of selected FWs; on banana and mango, by Arumugam and Manikandan in order to determine the fermentation potential of the wastes variability has been reported. The proximate compositions for mango were more watery but more lipid and protein and yet a slightly higher starch and ash for banana (Table2.3).

Table2.3. Proximate composition (%) of ripened banana and mango fruits



Sample	Fruit Parts	Moisture	DM	Lipid	Crude Protein	Starch	Ash
Banana	Pulp	76.63abc	26.89abc	1.37c	5.65abc	0.632cdb	3.46abc
	Peel	69.42abd	15.20abd	6.50dba	7.65ad	1.706abd	7.89abd
Mango	Pulp	81.26acd	19.38acd	1.48c	7.96ad	0.507cdb	6.27acd
	Peel	59.98bcd	10.97bcd	3.20b	4.27bcd	1.074bac	1.87bcd
LSD ($p<0.05$)		0.0116*	0.0015*	0.0027*	0.0179*	0.0234*	0.0156*

Source: Arumugam and Manikandan (2011)

The biogas potential of a given substrate, FVWs in this case, can be estimated on the VS/TS content determined following some procedure. The highly organic and moist wastes showed to have enough potential. Despite this fact FWs are found to be process unstable in anaerobic decomposition due to much higher C:N ratios and acidification problem.

In a more recent study on the feasibility of methane production from FVW using anaerobic digestion based on process and microbial ecology study, batch systems showed that pH control and nitrogen addition had significant effects on biogas production, methane yield, and VS removal from the FVW. The subject of this research is therefore approaching the nutrient imbalance and pH lowering using Urea.

2.3 Anaerobic digestion

By anaerobic digestion, biomass waste is converted to biogas (by bacteria in the absence of oxygen) and compost. The biogas is mainly a mixture of CO_2 and CH_4 (Arvanitoyannis and Varzakas, 2008). This biogas contains about 90 % of the energy of decomposition and has a calorific value of approximately 9000 kcal/m^3. The biogas has been exploited for centuries as an inexpensive source of energy. Today, millions of small-scale plants operate worldwide and produce heat and light. The biogas yield can also be improved by lysing bio-solids microorganisms as well (Bitton, 2005).

The techniques used for the conversion of organic materials to biogas have been in existence for many years. Methane generation has been applied to meeting the energy needs in rural areas. In England, India, and Taiwan, for example, methane generating units as well as plants using cow manure and municipal waste has been in operation for years.

In the United States there has been considerable interest in the process of anaerobic digestion as an approach to generating a safe clean fuel as well as source of fertilizer. The use of rural wastes for biogas generation, rather than direct use of them as fuel or fertilizer, offers several benefits such as, the production of energy resource that can be stored and used more efficiently, the production of stabilized residue (sludge) that retains the fertilizer value of original material and the saving of energy required to produce equivalent amount of nitrogen-containing fertilizer by synthetic process.

Indirect benefits of biogas generation include the potential for partial sterilization of waste during decomposition with subsequent reduction of the public health hazard of pathogens and reduction of fungal and other plant pathogens from one year's crop residue to the next (Sagagi, Garba and Usman, 2009).

Anaerobic systems are best optimized if the feed rate of organic material into the digester is as constant as possible (Hawkins and Rains, 2008).The digestion is easily performed in a biological reactor where mixers and heat exchangers could be the only technological and power consuming equipments needed. Moreover this process can result in gains of money by disposing of organic solid wastes as well as selling the biogas or the power generated by its combustion and, when possible, the digestate as fertilizer in agriculture. This process has therefore opened up interesting perspectives not only for the treatment of the organic solid wastes, but also for the production of a renewable source of power, that is cheap and easy to obtain (Esposito et al., 2012).

2.4 Anaerobic process microbiology

Four categories of microorganisms discussed below are involved in the transformation of complex organic materials into simple molecules such as methane and carbon dioxide (Velmurugan and Ramanujam, 2011; Bitton, 2005). These microbial groups operate in a synergistic relationship. Despite the linearity according to which the anaerobic digestion of organic solid wastes evolves, this process is commonly prone to drops in performance due to the occurrence of dysfunctions or failures that make it strongly dependable on the choice of the substrates as well as on the environmental and operational conditions. This last aspect can be reasonably considered the only drawback of this process in treating organic solid wastes.

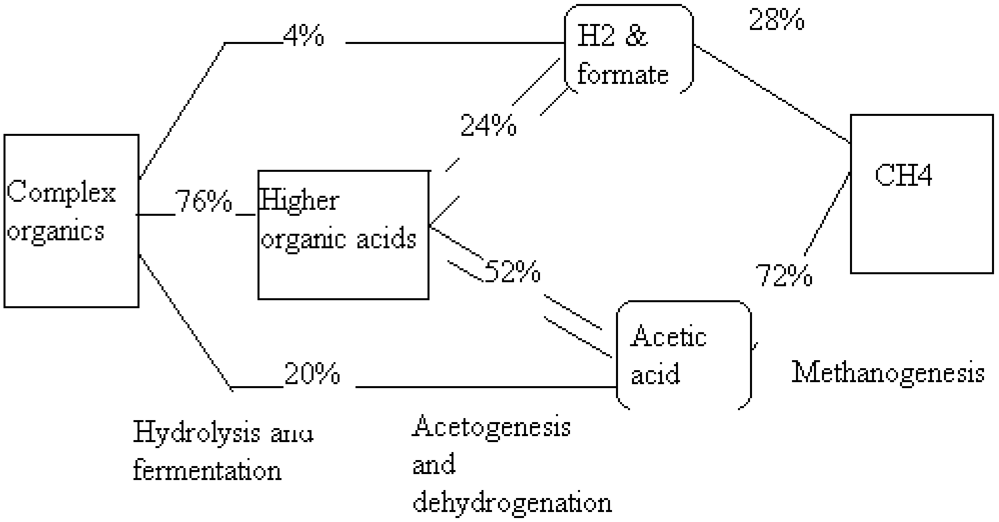


Figure2.1 Stages in the methane fermentation of complex wastes. Percentages represent conversion of waste COD by various routes. (Sawyer, Mc carthy and Parkin, 2003)

Consortia of microorganisms, mostly bacteria and methanogens, are involved in the transformation of complex high-molecular-weight organic compounds to methane.

The overall reaction for anaerobic digestion is shown as:

$$\text{Organic matter} \longrightarrow CH_4 + CO_2 + H_2 + NH_3 + H_2S \qquad (1)$$

2.3.1 Hydrolytic bacteria

Consortia of anaerobic bacteria break down complex organic molecules (example, proteins, cellulose, lignin, lipids) in to soluble monomer molecules such as amino acids, glucose, fatty acids, and glycerol. The monomers are directly available to the next group of bacteria. Hydrolysis of the complex molecules is catalyzed by extracellular enzymes such as cellulases, proteases, and lipases. However, the hydrolytic phase is relatively slow and can be limiting in anaerobic digestion of wastes such as raw cellulolytic wastes that contain lignin.

2.3.2 Fermentative acidogenic bacteria

Acidogenic (acid-forming) bacteria (example, Clostridium) convert sugars, amino acids, and fatty acids to organic acids (e.g., acetic, propionic, formic, lactic, butyric, or succinic acids), alcohols and ketones (e.g., ethanol, methanol, glycerol, and acetone), acetate, CO_2, and H_2. Acetate is the main product of carbohydrate fermentation. The products formed vary with the bacterial type as well as with culture conditions (temperature, pH, redox potential).

2.3.3 Acetogenic bacteria

Ethanol, propionic acid, and butyric acid are converted to acetic acid by acetogenic bacteria according to the following three reactions:

CH_3CH_2OH (ethanol) $+H_2O \longrightarrow CH_3COOH$ (acetic acid) $+ 2H_2$ {I}

CH_3CH_2COOH (propionic acid) $+ 2H_2O \longrightarrow CH_3COOH + CO_2 + 3H_2$ {II}

$CH_3CH_2CH_2COOH$ (butyric acid) $+ 2H_2O \longrightarrow 2CH_3COOH + 2H_2$ {III}

2.3.4 Methanogens

Methanogens are subdivided (G abriel Bitton, 2005) into two subcategories:

1. Hydrogenotrophic methanogens (i.e., hydrogen-using chemolithotrophs) convert hydrogen and carbon dioxide into methane:

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O \qquad (2)$$

Most of the methanococcales and methanobacteriales use H_2 and CO_2

2. Acetotrophic methanogens, also called acetoclastic or acetate-splitting methanogens, convert acetate into methane and CO_2:

$$CH_3COOH \longrightarrow CH_4 + CO_2 \qquad (3)$$

2.5 Factors controlling anaerobic digestion

The rate of biogas production depends on the nature of the substrate, temperature, pH, loading rate, toxicity, stirring, nutrients, slurry concentration, digester construction and size, carbon to nitrogen ratio, retention time, alkalinity, initial feeding, total volatile acids, chemical oxygen demand (COD), TS, volatile liquids etc (Sagagi, Garba and Usman, 2010).

2.5.1 Substrate concentration and hydraulic retention time

Anaerobic digesters for FVW largely depend on the type, consistence as well as concentration of substrate fed for a given HRT. HRT in turn depends on the temperature of digester; decreases with temperature. Generally degradation in mesophilic digesters decline after a couple of weeks. Studies showed inhibition of methanogenic bacteria at HRT below 12 days.

Digesters type (based on attached or suspended growth) effect as well on HRT; lower (1–10days) for attached type than those based on dispersed culture which takes about 10–60 days. The retention times of mesophilic and thermophilic digesters range between 25 and 35days, but can be lower (Bouallagui et al., 2003).

The overall performance of the reactor was depressed by changing the feed concentration from 8% to 10% TS (dry weight). By applying a feed concentration of 6% and HRT of 20 days in the tubular digester, 75% conversion efficiency of FVW into biogas with a methane content of 64% was achieved.

The extent of biogas production increased when feed concentration was increased from 4% TS to 6%. However, the researcher also showed the significant decrease in conversion of the substrate in to biogas when the feed concentration increased from 6% to 8%. At 10%, plugging of the digester has been observed after 1 week of operation.. This fact leads to adjustment of this inhibitory condition by some treatment and hence this study assumed use of urea as natural means of pH stabilizer and reasonable %TS as feed (Bouallagui et al., 2003).

2.5.2 Effects of temperature and pH on anaerobic digestion

Temperature affects the bio-methanation rate and usually higher temperatures imply greater methane yields in a shorter digestion time. Nevertheless sharp increases of temperature should be avoided because they can cause a decrease in bio-methane production due to the death of specific bacteria strains, particularly sensitive to temperature changes (Esposito et al., 2012).

Investigators also compared the performance of anaerobic digestion of FVW in the thermophilic (55^{O}C) process with those under psychrophilic (20^{O}C) and mesophilic (35 ^{O}C) conditions in a given digester on a laboratory scale. Biogas production from the experimental thermophilic digester was higher on average than from psychrophilic and mesophilic digesters by (Arvanitoyannis and Varzakas, 2008).

Because the methanogenesis are inhibited due to a pH decrease from 7.4 down, as the substrate rapidly degraded to VFA by the fermentation process from saprophytes, methanation is subject to maintaining optimum pH of 7-7.2 (Bitton, 2005). This environmental variable is determinant in anaerobic digestion of FWs. Thus putting a device in place to monitor pH and taking correction measures are prominent.

Thus in this study the addition of chemical urea is supposed to impact lowering of pH. However, VFA/TA analysis preferred to the traditional pH checking will be involved in monitoring of digesters.

2.5.3 Effects of nitrogen sources on anaerobic digestion

The effects of nitrogen sources on anaerobic digestion process of wheat straw were investigated by batch model at 35 ± 1^{0}C by (Yin et al., 2011). The results indicated that, the biogas productivity of wheat straw without nitrogen recourse was slow and the biogas yield was 323.97mL/g VS with 64.38% of methane content. Various forms of nitrogen and total nitrogen increased dramatically and ammonium nitrogen and organic nitrogen were dominant after anaerobic digestion. Addition of nitrogen sources improved the biodegradability of wheat straw and the biogas yield by 35.37%-50.20%, but didn't affect the methane content. Compared with control, ***ammonium nitrogen*** was the mainly form in the fermentation liquid of all treatments after anaerobic digestion and the ratio of ammonium nitrogen to total nitrogen were up to 70% except potassium nitrate (only 54.60%). There was no significant difference of nitrate nitrogen content of fermentation liquid between nitrogen sources added and control. With nitrogen sources added, the decomposition of cellulose and semi-cellulose was improved, but didn't affect the destruction of crystalline of cellulose. The best efficacy to anaerobic digestion of wheat straw was obtained by adding urea (Yin et al., 2011).

2.5.4 Influence of trace elements and toxicants on biogas production

The influence of trace elements (Co^{2+}, Ni^{2+} and Fe^{3+}) in varying concentrations and combination was studied by Raju, Devi and Nand for biogas generation from mango peel. Addition of these trace metals enhanced the biogas yield and methane content moderately, the maximum being with the iron fed digester. The digesters were always found to be stable without much variation in total VFA, pH, total alkalinity and other parameters (Raju, Devi and Nand, 1991).

Phosphorus limitation results in a reversible decrease in methanogenic activity. Moreover, trace elements such as iron, cobalt, molybdenum, and nickel are also necessary. Nickel, at concentrations as low as 10 µg, significantly increases methane production in laboratory digesters. A wide range of toxicants are responsible for the occasional failure of anaerobic digesters, those to methanogens include; oxygen, ammonia, chlorinated hydrocarbons, cyanide, volatile acids, and benzene ring compounds etc (Bitton, 2005).

2.6 Co- digestion, chemical addition and anaerobic digester stability

2.6.1 Co-digestion

The high biodegradability of the FVW promotes the rapid production of VFAs resulting in a rapid decrease in pH, which in turn could inhibit the methanogenic activity (Mata-Alvarez et al., 1992; Bouallagui et al., 2003, 2009). An interesting option to avoid the acidification of the system when FVW is used is the addition of co-substrates with high nitrogen contents, which could result in a natural pH regulation and also constitute a source of nitrogen (Agdag and Sponza, 2005).

The co-digestion of FVWs with various substrates has been evaluated for BMP. BMP of FVWs has been improved by co-digesting it with food waste and the total COD removal efficiency of anaerobic digesters has been improved (Jia Lin et al., 2011). The rationale behind is the far carbon to nitrogen ratio of FVWs (farther for FWs) as well as acidic nature of the wastes. Similar studies reported that the co-digestion of FVWs with waste items like cow and chicken manure improved the BMP of those waste. In a related study mixture of fruit wastes was co-digested and with cow dung in four different proportions.

The 3:1 mix gave the highest cumulative biogas yield (Narayani and Priya, 2012) informing advantage of using co-substrate in anaerobic digestion of FWs.

Co-digestion also presents economic advantages, such as minimizing equipment needs by sharing the same equipment for different residues and easier handling of mixed waste (Mata-Alvarez et al., 2000). Habiba et al., (2009) studied co-digestion as a novel solution to adjust unbalanced nutrient constituents and reported that the anaerobic digestion of activated sludge with substrates containing high levels of C: N, such as FVW, overcame the difficulties of digesting activated sludge. The addition of high nitrogen content co-substrates to adjust the nutrient content of FVW was recently evaluated by Bouallagui et al., (2009), and a methane yield of approximately 0.35 L/g VS was obtained without the addition of chemical alkali (Garcia-Peña et al., 2005).

In a laboratory scale experiments, these nitrogen source co-substrates are substituted by chemicals like urea.

2.6.2 Chemical adjustment

The chemical substrate, urea, has been used to supplement ammonia nitrogen deficient in FVWs and other biomass wastes. It has also been considered as a natural means of pH control. In a related study urea has been involved in maintaining the C:N ratio 30:1 using starch-rich tubers of cassava plant at ambient temperature (Anunputtikul and Rodtong, 2004) and brought improved biogas yield.

In a related study wheat straw was evaluated for biogas productivity with and without addition of urea and it was reported that addition of urea improved degradation of cellulose and hence productivity (GuangYin et al., 2011).

62.6.3 Anaerobic digester stability: pH, volatile acids and alkalinity

Operation of ADs is not a simple process. But in view of the potential value of the methane generated and the opportunities to produce additional methane through a fully optimized digester, it is worth ensuring that strategies are in place to achieve this. Many options are available but analysis of the composition of the VFAs in the digester provides a sophisticated approach that permits fine tuning of digester performance. Food and

FVWs are high in carbon and lack nitrogen and phosphorus and so cannot generate a higher yield during digestion. This requires careful operation to ensure the reactions of acid production do not exceed the reduction of these acids to methane, with a resultant digester failure (Horan, Smyth and May, 2011).

VFAs, called so because these acids could be distilled at atmospheric pressure (Sawyer, McCarthy and Parkin, 2003), are present in environmental systems, for instance natural waters contain in the range of 1 to 5,000 ppm and different methods have been reported for their determination. Low-molecular mass carboxylic acids, (C_2-C_7) monocarboxylic aliphatic acids, are important intermediates and metabolites in biological processes. These carboxylic acids are known as VFAs or short-chain fatty acids (SCFAs). The presence of VFAs in a sample matrix is often indicative of bacterial activity. VFA analysis is significant in studies of health and disease in the intestinal tract. In some foods VFA content is an index to quality assurance.

VFA originate from anaerobic biodegradation of organic matter. Therefore, they are widely present in activated sludge, waste and landfill leachates, and wastewater. Recently, the determination of VFAs has become of increasing interest since it has been found that they are involved in different processes, for example in biological removal of phosphorus from water or nitrification-denitrification in activated sludge (Siedlecka, et al., 2008).

Acetic acid is usually present in higher concentrations; the reason for seeding digesters is associated to seeking larger methanogens (Sawyer, Mc carthy and Parkin, 2003) than other VFAs are during AD processes. Buffer capacity is often referred to as alkalinity in AD, which is the equilibrium of carbon dioxide and bicarbonate ions that provides resistance to significant and rapid changes in pH, and the buffering capacity is therefore proportional to the concentration of bicarbonate. Buffer capacity is a reliable method of measuring digester imbalance. Increasing a low buffering capacity is best accomplished by reducing the organic loading rate, although a more rapid approach is the addition of strong bases or carbonate salts to remove carbon dioxide from the gas space and convert it to bicarbonate, or alternatively bicarbonate can be added directly.

The aim of this study is therefore to evaluate the potential use of FW as a substrate for biogas (methane) production and to examine effect of urea addition which could allow for anaerobic systems the optimal performance. Thus selected FW (Avocado, Mango and Banana) from the biggest FV market in Ethiopia were characterized to assess its potential as a feedstock for an anaerobic digestion process.

3 Materials and methods

3.1 Study area description

The city of Addis Ababa is the center and main consumer of FV products in the country. The horticulture products are brought in to the city from four directions and different group of producers. “Atikilt tera”. “Atikilt tera” is the central and biggest FV distribution market in the country. It distributes to whole sellers and retailers in other cities and towns of the country, mainly northern and other elements within the city. The FV shops, fruit juice houses and supermarkets as well as mobile FV sellers all buy it at “Atikilt tera”. By implication, the FVWs in the city emanate from fruit shops (could be legal/licensed or informal), open markets, mobile FV sellers, supermarkets, fruit juice houses, mobile FV sellers etc. Thus, three of the major fruits wastes are used for the study.

3.2 Materials

3.2.1 Instruments

Regarding feed making for anaerobic digestion following characterization, various equipments have been involved ranging from simple containers and hand tools to analytical instruments in the Environmental Engineering Laboratory of the Chemical Engineering Department of Addis Ababa Institute of Technology, Addis Ababa University.

A. Fruit waste characterization

Plastic buckets were used for collecting FW samples from the central FV market. During characterization of the selected FW samples, equipments including; blade for slicing the FWs, air-dryer to remove moisture have been used. There after samples have been stored with moisture content lower enough for safe storage.

Grinder was applied to powder the dried FWs and sieving has been made using an 850μm mesh size, chosen to faster degradability of organic matter. Spoon for grabbing some amount wanted out of the entire sample, analytical balance (SARTORIUS AG, BP110, Germany) to weigh sample in different stages of analysis, drying oven (Beschickung, loading model 100-800, “MEMMERT”, Germany) to drive off moisture were used. Desiccators, to cool crucibles and their content, and muffle furnace to drive off organic matter were also used.

In order to determine pH of sample offsite, additionally flasks, graduated cylinders to measure analyzing solvent, shaker (EXCELLA E-24 incubator shaker, Pb-international) to make uniform concentration, pH meter (3510, JENWAY, UK), thermometers, wash bottle as well as analytical balance have been involved. All the equipments were obtained from three different laboratories (Food, Environmental, and Analytical) of the Chemical Engineering Department of Addis Ababa Institute of Technology, Addis Ababa University.

Total nitrogen apparatus, including the Kjeldahl distillation unit made of Germany, Gerhardt VAP20 has been used to determine nitrogen content of sample. The COD of composed FW was determined before and after anaerobic digestion using Hatch spectrophotometer (DR 5000), all at the laboratory of the Environmental Protection Authority of the Addis Ababa City.

B. Biogas potential experiment

The anaerobic digestion has been processed using different materials and most are mentioned here. Water bath, (SBS40, UK), was used to keep optimum mesophilic condition chosen at 35 $\pm 1^0$C and also to shake vessels and content set at 50 revolutions per minute together with daily manual shaking. Plastic vessels of 500ml and fittings; rubber stopper, fluid valves, hoses, rubber borers for fitting super structures to each digester, wax to smoothen fitting, cutters and plastering materials were central.

Plastic gas bags to collect biogas, gas suction graduated syringe, and biogas analyzer (BIOGAS, GA2000, S/N BM14068) Geotech, England, to check methane content, has also been used.

The anaerobic digestion and monitoring of gas activities were made at the Environmental Engineering Laboratory of the Department of Chemical Engineering of Addis Ababa Institute of Technology and the Environmental Laboratory of the Center for Environmental Science, College of Natural and Computational Science of the Addis Ababa University.

C. Biogas manure characterization

Following completion of AD, based on ceasing of gas formation, analysis of the sludge has been made. At the premises of the Federal Environmental Protection Authority Quality Laboratory, Addis Ababa, Ethiopia analysis was made regarding determination of the fertilizing potential. The parameters; total phosphorus (PO_4^{3-}), total nitrogen have been determined by spectrophotometer (DR 2010) and potassium (K) using atomic absorption spectrophotometer (NOVAA 400, Analytic Jena, USA).

Other characteristics of manure mainly TS, VS and FS were determined using same equipments used for feed characterization.

3.2.2 Chemicals

Extra pure and analytical grade urea (46%-N) was used in order to maintain the optimum C:N ratio to digestion of FWs. Urea is used to investigate chemical amendment role to control nitrogen deficiency in fruit waste. In the determination and stabilization of digesters acidity; solutions of NaOH, H_2SO_4, distilled water to dissolve sample, and lime have also been also used for pH stabilization.

3.3 Methods

3.3.1 Sampling

This paper is aimed to determine the biogas potential (BMP) of selected FWs in “Atikilt tera”. Sufficient random and composite samples of banana, mango and avocado FWs were sorted manually in different days of two weeks duration (May 25-June 9) at the central FVM. The samples were collected in an inert plastic bucket of sufficient volume and were preserved at 4 ^{0}C for subsequent treatment.

In addition data of relevant types especially for prediction have been obtained from focal peoples' discussion, government control agencies, observations, and using letter communications.

3.3.2 Inoculum

The inoculum used in the study was a digestate from a well functioning anaerobic digester working on a pilot scale at the Addis Ababa Institute of Technology, Addis Ababa University. It is known to contain all the required microbes (hydrolyzing, fermentative, acetogenic and methanogenic bacterial consortium) essential for anaerobic digestion process.

3.3.3 Feedstock preparation

Characterized FWs (banana, mango, and avocado) were collected; sliced, dried, ground and sieved. The wastes have been chopped and ground using a kitchen blender as well as sieved to 0.85mm diameter sieve in order to obtain powdered samples. Samples were then stored in a separate black polyethylene bags. Following characterization of the sample, the urea and fruit mixes and the fruit waste alone were made to slurry using tap water and fed to mesophilic anaerobic digesters.

3.4 Procedure

Determination of moisture content, TS, VS, FS, and organic matter were made using standard procedure set by American Public Health Association- APHA, 2005.

As per the standard procedure sample aliquots of 25-50g were dried at 103^0C to 105^0C to drive off water in the sample. The residues were then cooled, weighed, and dried again at 550^0C (450^0C for organic matter) to drive off VS in the sample. The TS, FS, and VS were determined by comparing the mass of the sample before and after each treatment step (METHOD 1684).

The TKN, K, and P contents determined were made at the Quality Laboratory of the Addis Ababa Environmental Protection Authority. The pH of waste sample was made using the procedure document at Environmental Engineering Laboratory of the Department of Chemical Engineering of Addis Ababa Institute of Technology, Addis Ababa University.

Regarding the anaerobic digestion experiment, samples of 3g TS were taken in plastic vessels (500ml) following characterization. Tap water has been added together with inoculum to the level and leaving space above. Rubber stopper was fitted to vessel and those anaerobic batch digesters were connected to gas bags using biogas valves and plastic hoses. Loaded vessels were then put to a shaking water bath set at 50 revolutions per minute and at a temperature of 35 ± 1^0C. Mixing was also made manually every day by tilted shaking of vessel.

Flasks containing water and inoculum and water and substrate were also loaded to water bath as blank tests. Gas production was monitored weekly as digestion proceeds. Digesters were manually mixed thoroughly before measuring biogas production. Biogas produced was measured by suction method using graduated air tight syringes and the methane content has been monitored using biogas analyzer.

The VFA and alkalinity has also been determined during digestion using combination of potentiometric titration methods for acidity (Method 2310B) and alkalinity (Method 2320B).

Up on completion of the anaerobic digestion, judged based on ceasing of gas production, standard method for determination TS, VS and FS has been used as it has been used for feed characterization.

The soil nutritive value of the biogas manure has been determined using digestion method for total nitrogen (TNT Persulphate Digestion Method). Digestion test with acid persulphate for phosphorus (Phos Ver 3, ^{6}N Tube Method), digestion method for COD and flame standard method for potassium have also been applied.

3.5 Experimental design

The study variables in this work are Selected FWs (avocado **{A_O/ A_1**}, banana **{B_O/ B_1}** and mango **{M_O/ M_1}**) without and with commercial urea. The response variable was the biogas/biochemical methane produced per unit of VS fed to digester **{bM / bG}**. Blank run **{I}** was also made for inoculums and the substrate **{S}** each.

Each test was run at two levels (with or without urea) resulting in 6 runs for the three FW types. All the runs were made in replica resulting in a total of 12 runs excluding the blank.

Set ups were tested for proper functionality before beginning the actual experiment. The response variable, biochemical methane/biogas yield was recorded throughout till 35 days of HRT is completed.

3.6 Experimental setup

The BMP of FW was determined using laboratory scale batch anaerobic digestion tests. The characterized and pretreated 3g each; avocado, banana, and mango FWs were placed into the six 500ml volume plastic bottles. Each digester was sealed with butyl rubber stoper bored and fitted to super structures for gas collection. 50mL inoculum was inoculated to each digester. The calculated average optimum nitrogen as urea has been added, having the natural nitrogen content of each FW considered. All digesters were contained in a thermostat (Figure3.1). The systems were incubated at a temperature of 35 ± 1^0C for 35 days.

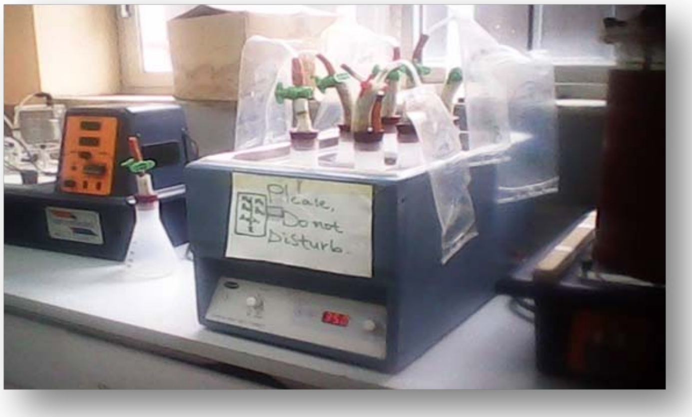


Figure3.1 Experimental set-up; shaking water bath loaded with anaerobic digesters

3.7 Analysis

The samples were oven dried at 105^0C and ashed at 550^0C according to the standard procedures to determine moisture content, TS, VS, and FS. Sample ashing at 450^0C has been made to determine the organic content of each FW. Nitrogen by Kjeldahl method (wet method). The biogas has been determined volumetrically using suction method by a graduated cylinder and the methane content instrumentally using biogas analyzer, Biogas, UK. In order to analyze and interpret results SPSS ver. 15 (software) as well as standard books and journals have also been utilized.

4. Results and discussions

The aim of this study is to examine effect of adding urea that renders anaerobic systems better performance using selected FW. In order to visualize the potential use of FW from such waste sectors like central distribution FV markets, as a substrate for biogas production, along with characterization as well as plant nutritive effect determinations on biogas manure, this sort of study is important.

Avocado, banana and mango FWs have been selected to be studied because of their relative abundance (in quantity and seasonality) in the study site. Again component study provides a better understanding of the total waste in the area, and component study could be useful in any way if selection decision is to be made under different scenarios.

4.1 Characterization of selected fruit wastes

The physical and chemical characteristics of the organic wastes are important for designing and operating ADs because they have an effect on biogas production and process stability during anaerobic digestion (Garcia-Peña et al., 2005). In a similar manner to other studies (Bouallagui et al., 2009), discarded avocado, banana and mango fruits were brought from the biggest FVM in Ethiopia. The waste brought has been characterized with respect to biogas potential in order to determine dosage as a feedstock for an anaerobic digestion process and making subsequent quantitative descriptions.

The FWs brought from “Atiklt tera” were prepared by slicing them using kitchen utensils; knifes and plates and were dried in oven at a temperature of 104^0C before grinding and storage.

Before evaluating the effects of urea (nitrogen) addition, to enhance performance in batch systems; the TS, moisture content, FS and VS (Figure4.1.) as well as pH of pulp of the FWs have been determined using standard procedure (APHA Standard Methods and ASTM standard). Close attention has been given to each sample during desiccation after drying along with keeping uniform temperature and specified retention time followed by subsequent calculations.

The TS is the ***residue left*** in the crucibles after evaporation of liquid from FW samples and subsequent drying in an oven (Beschickung, loading model 100-800, “MEMMERT”, Germany) at 103^0C to 105^0C for 18 hours. Thus it has been determined using equation 1;

%total solid (TS) = $\{(W_{total} - W_{dish}) \div (W_{sample}-W_{dish})\} \times 100$ (Eq.1)

Where: W_{dish}=Weight of dish (mg), W_{sample}=Weight of wet sample and dish (mg)

$W_{total:}$ Weight of dried residue and dish (mg)

Fixed solids (FS) is the ***residue left*** in the vessel after a sample is ignited (heated to dryness at 550^0C). Thus equation 2 has been used for this.

% fixed solids = $\{(W_{res} – W_{dish}) \div (W_{total} -W_{dish})\} \times 100$ (Eq.2)

Where:

W_{dish} = weight of dish (mg)
W_{total}= weight of dried residue and dish (mg)
W_{res} = weight of residue and dish after ignition (mg)

The VS is the ***weight loss*** after a sample is ignited (heated to dryness at 550^0C) for 2hrs. It was then determined from use of equation 3.

% volatile solids = $\{(W_{total} – W_{res}) \div (W_{total} -W_{dish})\} \times 100$ (Eq.3)

Where:

W_{dish} = weight of dish (mg)
W_{total}= weight of dried residue and dish (mg)
W_{res} = weight of residue and dish after ignition (mg)

Table4.1 Average results of characterization for avocado, banana and mango FW from “Atiklet tera”

Fruit Waste	Moisture content, %	Total solid, %	Fixed solid, %	Volatile solid, %	TOC (%, dry basis)	TKN (%)	pH (initial)
Avocado	76.6	23.4	19.4	80.6	38	1.15	5.8
Banana	78.6	21.4	20.2	79.8	57	0.65	5.5
Mango	84.3	15.7	24.5	75.5	64	0.51	4.3

The moisture content in this study is found to be highest for mango FW followed by banana and avocado (Table4.1). These results are closer to others' finding (Arumugam and Manikandan, 2011). The TS measured for the selected FWs are high especially for that of avocado and even banana as can be implied from the moisture content; 23.4% and 21.4%, respectively. Lowest TS, as frequently determined by many researchers, was determined for mango (Figure4.1). Generally TS results are above the range of what is seen in most studies, 10-18%, studied on FVWs (Bouallagui et al., 2005; Bouallagui et al., 2003). This could be due to the impact of exclusion of the vegetable wastes in general and the variability among FWs could be due to peculiar nature of the selected fruit types and their variety in addition to their maturation stage when reaching market.

In other words, relative elevation in TS, especially for avocado, seems unique and can be ascribed to; variety, maturity and ripening stage of the FWs sampled.

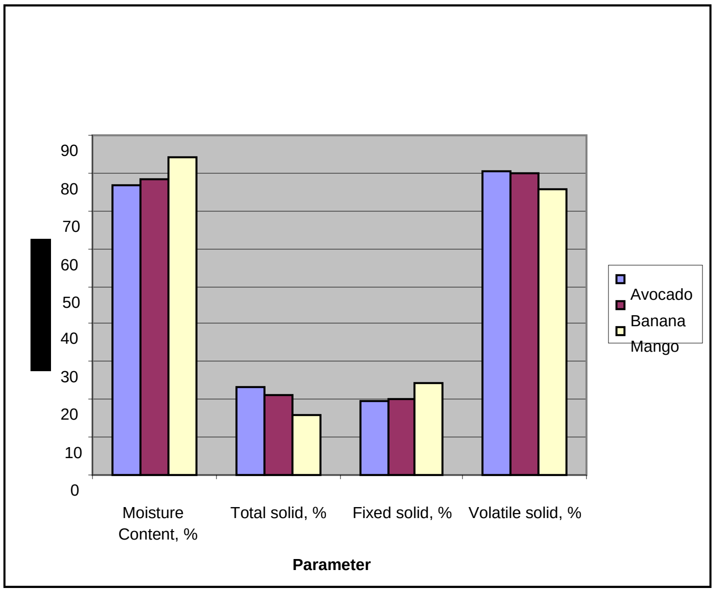


Figure4.1 Physical parameters test result for sampled FWs

The ash/fixed solid component are agreeable to prior related findings except the deviation for mango FWs which is found to be higher in this study, 24.5%. Contrary to TS, the VS of the samples analyzed were found to be slightly lower than those reported by Bouallagui et al., (2005). In a related test the "ashing" method for determination of organic matter has been conducted and the lowest percent was recorded for avocado which still could be due to variety and the ripening stage of the fruits coming to the market early (Table 4.1).

Along with study of those physical parameters mentioned, pH and other chemical properties of the wastes have also been determined. The acidic nature of mango has been noticed as its pH was 4.3 upon analysis using standard procedure and materials; incubator shaker for mixing, distilled water for dilution and using a pH meter (Figure 4.2).

FW solution **automated shaker** **pH testing**

Figure4.2 Off-site pH determination for the selected sampled FWs

The pH test result indicated that those FWs are still more acidic than organic fraction of municipal solid waste as reported by unpublished thesis work (Assefa, 2011). This accompanied by the wastes' rapid decomposition and hence production of those VFAs, could result in fast lowering of pH in anaerobic digesters. The phenomenon is known to be worsening during the hydrolysis and acidogenesis stages of the process negatively impacting the methanogenesis phase. Obviously, pH is desired to be in the range of 7-7.2 for methanogens (Gabriel Biton, 2005). The pH lowering effect is determinant in batch anaerobic digesters (E.I. Garcia-Peña et al., 2005) which are feasible for application to developing countries like Ethiopia. Thus it is imperative to make the pH up with some sort of treatment, vis-à-vis this study evaluates effect of adding urea.

The far lower average natural carbon-to-nitrogen ratio of the avocado, banana and mango FWs are 86:1, 153:1, and 195:1 respectively which are very different ratios compared to the optimum ratios ranging 20-30:1 for the maximum biogas generation (Bitton, 2005; Viswanath, Devi, and Nand, 1992). In a related analysis, the nitrogen content was relatively lower for all the FWs than those studies made combining fruits and vegetables which are reported to be up to 2.3% but the total organic carbon found is almost related (Table 4.1), (Bouallagui, et al., 2003).

4.2 The biogas (methane) potential experiment

Anaerobic digestion is one of the most common chemical processes in nature. The process is similar to fermentation as the transformation is brought about by micro-organisms (bacteria) called anaerobes. A laboratory scale experiment on AD has been run after setting fitting works have been done on digesters as the process involves an air tight engineered environment. The process involves use of valve and house as well as other super structure to collect gas and subsequent analysis and measurement arrangements.

The anaerobic digestion process for the FWs have been made as planned and coded in the method section of the document in order to evaluate the potential use of FW as a substrate for biogas (methane) production. Mainly this study is aimed to examine effect of urea addition which could allow for anaerobic systems the optimal performance based on a lab scale set up for AD and yield analysis.

The ADs were those containing typical FWs (avocado **{A_O/ A_1**}, banana **{B_O/ B_1}** and mango **{M_O/ M_1}**) without and with commercial urea as coded. Each run were made in replica following a test run made for quality assurance of the setup/system resulting in 12 runs for the three FWs excluding the control. The response variables are the biogas/biochemical methane produced per unit of TS/VS fed to digester **{bM / bG}** recorded throughout till 35 days of HRT. Blank run **{I}** and control was also made for inoculums and the substrate alone **{S}**.

It is known long ago that, the anaerobic digestion process concerned with methanation is impacted by various factors; mainly environmental effects including temperature, pH, and toxicants. Generally, anaerobic digestion process is operated under ambient, mesophilic or thermophilic condition, in which thermophilic digestion is reported to be the more efficient method. Under adjusted elevation of temperature gas production increase with temperature, however rapid increase is reported to be unhealthy. Because ambient temperature of 25 ^{0}C up to 37^{0}C is common in Ethiopia, this study applied mesophilic condition.

4.2.1 Urea dosing

The carbon to nitrogen ratio for FVW is found to be out of range of what is optimum for microbial degradation usually in the ratio of 100:4.8 w/w (Bouallagui, et al., 2003). The activity of methanogens is usually inhibited due to a pH lowering from 7.2 to 5.3 because the substrate would rapidly degrade to VFA. This fact leads to correction of this inhibitory condition by some treatment and hence this study assumed use of urea as natural means of pH stabilizer and constitutes a source of nutrient.

In this respect, tracking the dosage of urea addition during the process of digestion was difficult as a matter of management. Therefore the determination of dosage of urea to be added to treatment digesters has been made on slurry preparation stage. Consequently, in this study the average optimum ratio of C: N has been sought for studying effect of adding urea (Table4.2) as source of nitrogen on biogas yield considering their inherent content.

Table4.2. Summary of substrate-urea mix determination of slurry

TS	Natural TKN (% TS)	Desired, optimum C:N	'Inherent-N' (g/g TS)	Urea(g), 46%-N
Avocado	1.15	25:1	0.0115	0.1989
Banana	0.65	25:1	0.0065	0.2084
Mango	0.51	25:1	0.0051	0.2175

4.2.2 Prepared slurry characteristics

Accordingly, 3g TS of each type of FW was fed to six digesters, one containing urea and the other not, altogether with 10% (v/v of solution to be digested) inoculum and 450ml tap water in 500ml volume vessels (Figure4.4). Before start of the digesters, the slurry has been again characterized (Table4.3) to consider effect of adding inoculum on TS concentration that showed an increase by up to 0.9g in overall TS amount. However, the TS increment due to the innoculum is not meant substrate rather it constitutes the cell mass necessary in the degradation of the food mass fed to digesters.

Table4.3 Average results of slurry characterization for avocado, banana and mango FWs

Fruit Waste	Moisture content, %	Total solid, %	Fixed solid, (% TS)	Volatile solid, (%TS)	Total solid (g/l)	Volatile solid, (g/l)	pH (initial)
A_0	99.23	0.77	19.4	80.6	7.7	6.20	6.4
B_0	99.24	0.76	20.2	79.8	7.6	6.06	6.47
M_0	99.22	0.78	24.5	76.5	7.8	5.96	5.9
A_1	99.21	0.79	19.4	80.6	7.9	6.36	6.3
B_1	99.22	0.78	20.2	79.8	7.8	6.22	6.8
M_1	99.21	0.79	23.4	76.6	7.9	6.05	6.01

Because equal weights of the dried FWs have been applied to slurry preparation, the moisture and TS content showed resemblance among systems. However, there still remain slight variations in VS and FS content of those systems mainly due to nature of a particular feed or substrate and urea as well as inoculums additions (Table4.3).

All the pH of slurry measured showed improvement from the pH result of the fresh FWs that may be brought by removal of volatile acids during pretreatment, dilution of the substrate, and addition of inoculums and urea (Table4.3).

After all the slurry characterization has been made, the ADs were fitted and sealed to a level of possible anaerobic system and have been loaded to thermostat, a shaking water bath, set at a temperature of 35 ± 1^0C. The water bath has been set to shake its load at about 50 revolutions per minute; however, the digesters were being manually shaken at least daily during the 35 days of HRT in order to create good substrate-feed contact.

The inoculum and substrate have separately been fed in vessels for system control. The substrate containing vessel was the only one that didn’t give any gas at all.

The inoculum fed bottle, however, gave 3mL of biogas during first run and 4mL during replication period resulting in an average of 3.5mL biogas volume. The gas from this innoculum was subtracted from biogas yield of each experimental digester as tabulated.

4.2.3 Biogas yield

4.2.3.1 General

Gas yield has been followed using a suction method applying a graduated plunger of 500ml volume that suck after gas has been collected in the fitted bag with a rubber port and valve for appropriate suction. Before taking gas by suction the cylinder gets empty of any air in its closed system. Following that a needle is fitted to the hard plastic cylinder system in order to prick the rubber port fitted to the gas collecting bags of the digesters. The air tight rubber port occupies the space soon after the needle is pulled off following suction and gas volume measurement has been made weekly.

Table4.4 Summary of the biogas yield and the methane content on anaerobic digestion of avocado, banana, and mango FWs with and without urea on average

HRT (wks)	Volume of biogas and methane content												
	Biogas (ml)							Methane/ **bM** (%v/v)					
	A_O	**B_O**	**M_O**	**I**	**A_1**	**B_1**	**M_1**	**A_O**	**B_O**	**M_O**	**A_1**	**B_1**	**M_1**
1	230	415	407	2	410	475	350	50	53	48	51	54	47
2	357.5	83	75	1.5	657	545	455	53	54	51	53.2	53	49.5
3	350	515	520	0	509	620	687	57.7	57.5	51.7	53	54.9	52.4
4	165	265	165	0	308	235	318	58	62.8	52.5	58	60	53.8
5	70	85	55	0	75	95	75	59.1	63.5	55	58.2	60	58

Based on the amount of biogas formed from the biodegradation of the organic matter fed to each digester under anaerobic condition, pattern differences; rate and amount of generation have also been observed among treatments. The yield for avocado FW showed its largest volume measured in the second week of HRT. Despite the irregularity in the biogas generation the methane yield revealed consistent improvement by composition along with the HRT.

Looking in to the yield during the last two weeks, there appeared a steep lowering in quantity brought by the degradation of food mass in those anaerobic systems. Furthermore, perhaps unique to FWs, the sag in biogas production during the second week of AD by B_0 and M_0 informs instability in the process (Table 4.4).

Because the food mass that was fed to digesters is assumed to have been consumed, simply based on the ceasing of gas generation, the amount of biogas and methane produced is expressed based on all the VS/TS added. That is expressed in unit of mass (Table4.5) while the gas-hereafter expressed as yield, is matched in unit of volume.

Table4.5. Mean value of TS (g/l), VS (g/l) removal, and biogas productivity and average methane for the various conditions evaluated in batch experiment of 35 days HRT

System (Digester)	TS Initial	VS Initial	TS Final	VS final	VS (%) removal	Biogas (m^3/kg VS)	Average CH_4 (%)
A_0	7.7	6.2	4.1	3.157	49	0.48	55.56
B_0	7.6	6.06	3.8	2.998	50.5	0.57	58.16
M_0	7.8	5.96	3.6	2.495	58.1	0.53	51.64
A_1	7.9	6.36	3.1	2.3	63.8	0.76	54.68
B_1	7.8	6.22	3.2	2.32	62.7	0.82	56.38
M_1	7.9	6.05	3.2	2.22	63.3	0.82	52.14

The ultimate biogas yield for banana and mango showed similarity in the treatment group; however banana is better in yield without urea. In both groups banana is found to be best substrate to biogas production (Table4.5).

4.2.3.2 Biogas yield and variability

The totaled volume of biogas produced showed differences of up to 60ml/g VS within the treatment line (those containing urea added) and more difference among without urea digesters in 90ml/g VS. The figures show the larger degree of instability among untreated systems. In both conditions banana FW showed the highest yield followed by mango FW for the treatment condition and by the avocado FW without urea addition because banana FW is relatively less cellulosic and was amenable during pretreatment operations and was best dissolved (Table4.5).

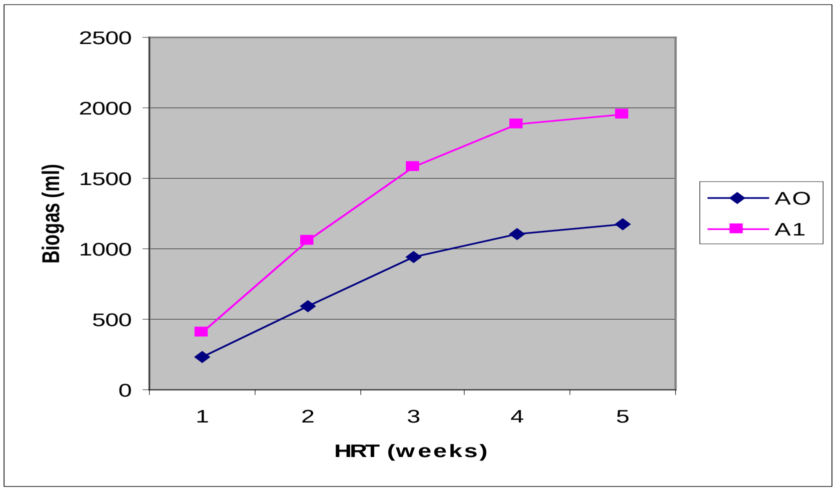


Figure4.3 Biogas production on anaerobic mesophilic digestion of avocado FW with urea (A_1) and without urea (A_0)

Generally, those vessels containing urea added exhibited a significant difference in ultimate biogas volume (p-value; 0.006 for avocado, 0.029 for banana, and 0.007 for mango FW at 95% confidence interval) as can be seen from table 4.5 and figures 4.3-4.5, 4.8. Thus it is possible, at this juncture, to say that urea addition resulted in a more efficient process. However, use of commercial analytical grade urea could be replaced with other natural sources of nitrogen as co-substrate including, but not limited to, poultry manure and cow dung. The co-digestion of other organic fraction of municipal solid waste may also be sorted and used as feed to AD with the FWs.

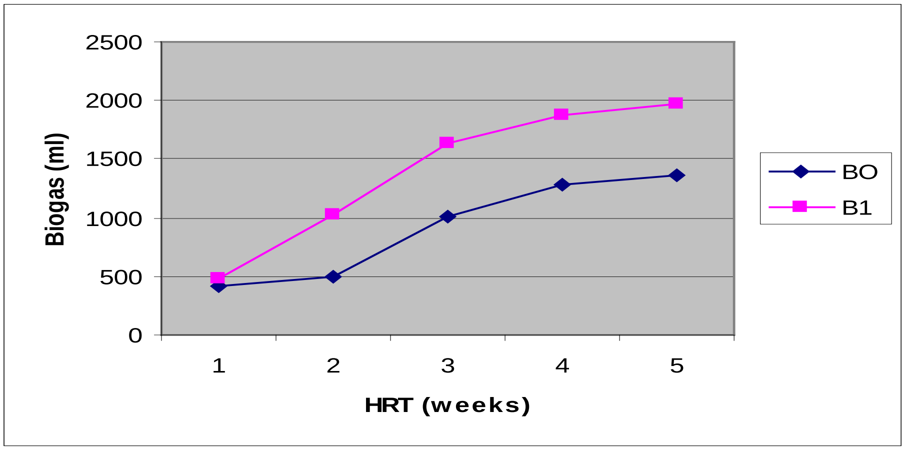


Figure4.4 biogas production on anaerobic mesophilic digestion of banana FW with urea (B_1) and without urea (B_0)

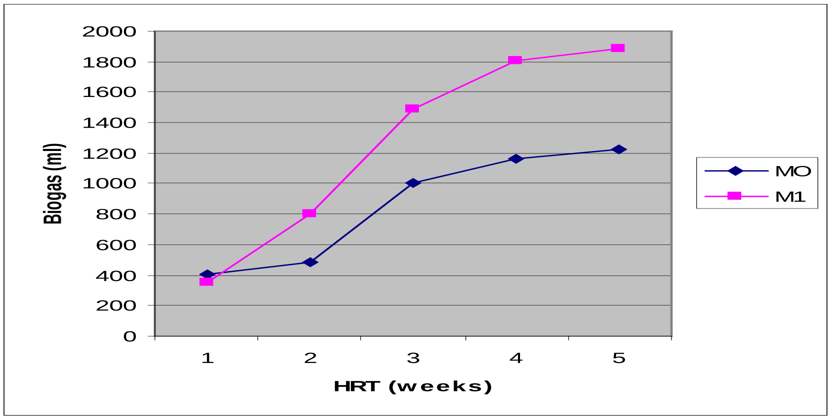


Figure4.5 Biogas production on anaerobic mesophilic digestion of mango FW with urea (M_1) and without urea (M_0)

From observation of Figures 4.4, 4.5, and4.6, the difference in slope due to treatment is approximately 175 for mango, 150 for banana and 175 for avocado FWs. That implies the degree of effect of urea addition was relatively least for banana FW which can also be implied from the p-value calculated.

To add more addition of urea as ammonium nitrogen has scientific background to improve decomposition of cellulose and semi-cellulose compounds (Yin et al., 2011). However, mineralized ammonia/ ammonium during degradation inhibit methanogens, as is a case during degradation of protein substrates, negatively affecting biogas activity. Generally, it is recommended that the concentration of ammonium-nitrogen not to exceed 3g/L in order to maintain a stable and optimized process.

Thus, having controlled addition of urea as treatment, the increment in biogas volume due to treatment showed evidencing magnitude in this study from digestion of selected FW type (Figures4.3-4.5). That remarkably demonstrated the effect of co-substrate addition and hence good manipulation of their natural content. Avocado FW showed addition due to treatment by 67% v/v and mango by about 54% v/v which is far better than what is reported best by Guang Yin et al., 2011 tested on other carbon source substrate. Banana also showed improvement due to treatment by about 44.5% v/v. However, in this regard, the methane content showed no change due to treatment.

The biogas yield as well as methane content for mango FW, in fact following liming, showed interesting improvement because of treatment as it has resulted in 0.825l/g VS and above 55.9% CH_4 that can be compared to study report on AD of mango peel and ensilage with a biogas result of 0.68l/g VS and methane of about 52% by Madhukara et al., (1993).

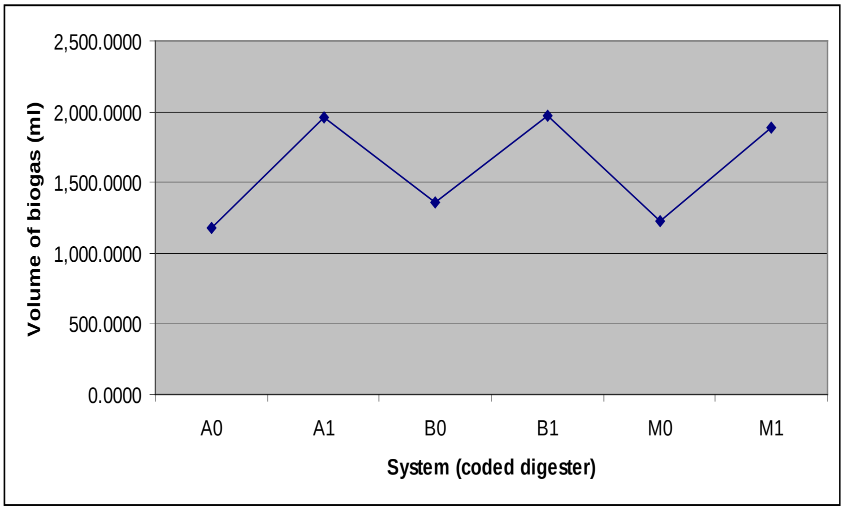


Figure4.6 Total biogas yield on anaerobic mesophilic digestion of avocado (A_0), banana (B_0) and mango (M_0) FWs without urea and A_1, B_1, M_1, with urea

The figure on ultimate biogas yield of those systems studied shows the difference mainly brought by treatment and the difference among FW types (Figure4.6).

4.2.4 Total methane

The variation in ultimate methane yield is more associated to amount of biogas generated with and without urea addition. However, liming improved percent methane converted out of each system, particularly for M_0 and M_1. Looking in to the variability in time with in the same reactor and among reactors, it is hardly possible to associate the methane content with the effect of treatment. However, it is slightly higher in methane composition of the biogas on average for the digesters treated with urea than without (Table4.6). The ultimate methane yield from banana FW is reported to give 0.367 m^3 kg^{-1}VS (Khan et al., 2009). Upon addition of urea, however, the yield increased to 0.46 m^3 kg^{-1}VS.

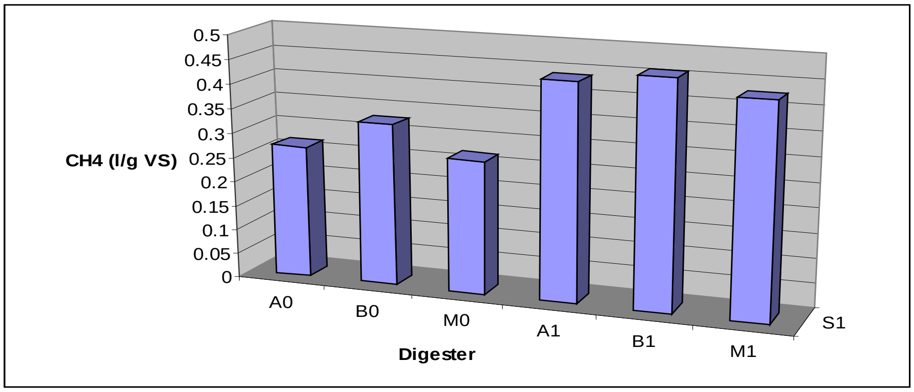


Figure4.7 Ultimate methane yield on anaerobic mesophilic digestion of avocado (A_0), banana (B_0) and mango (M_0) FWs without urea and A_1, B_1, M_1 with urea

Generally speaking, the cumulative methane yield is highest for banana FW and least recorded is for mango FW in both groups, however, avocado FW is same to mango in the untreated group (Table4.5; Figure4.7). The ultimate methane yield by the treatment group is found to be above average yield reported to be 0.42l/g VS for FVW (Bouallagui, et al, 2005).

Table4.6. Total biogas and corresponding methane yield among studied systems

System	Biogas (ml)	CH_4 (%v/v)	CH_4 (ml)	CH_4 (l/g VS)
A_0	1172.5	55.56	651.4	0.27
B_0	1363	58.16	792.7	0.33
M_0	1222	51.64	631	0.27
A_1	1959	54.68	1071.2	0.44
B_1	1970	56.38	1110.7	0.46
M_1	1885	52.14	982.9	0.43

4.3 Prediction for biogas

4.3.1 General

In a report by Tesema (2010), the city of Addis Ababa generates 23.1tones of fruits and vegetable waste daily. The quantity estimated by the author is certainly very much underestimated this could be due to the generality of the report and the interest was on socioeconomic dimension of MSW and was done on household basis, missing major FV sector. Therefore, it could be added to what ‘point sources’ discharge the same waste.

This paper thus predicted the possible potential of biogas obtainable from these FWs by using stratified and judgmental approaches to obtain first line data. This could be possible by identifying the role players from import of FV into the city to export out of the city and consumption within the city.

Approaches have been made to government agencies, fruit juice house owners, fruit retailers and wholesalers for retrieval of data. The possible sources for FWs in the city includes mainly; the stores, distributors and whole sellers concentrated within “Atikilt tera”, fruit juice houses, FV seller open markets, fruit shops, supermarkets and mobile fruit sellers involving cars and carts as well as baskets.

The huge quantity, based on personal observation, is contributed by “Atikilt tera”, followed by fruit juice houses. The fruit business is not only run by licensed owners but also those informal people too. The government’s agency in control of registering this group is also operating behind the existing distribution of the sector. The distribution of the fruit juice houses in the city is uneven (Table4.7) ranging between 2 and 24 among sub cities from data behind 2 years.

Table4.7 Summary of fruit and vegetable juice and supermarkets by sub city in Addis Ababa city (Data are up to the year 2010)

Trade field	Sub city								
	Addis ketema	Akaki	Arada	Bole	Gulele	Kirkos	Kolfe	Lideta	Yeka and N/silk
FV juice	14	6	16	13	15	9	15	24	2
Supermarkets	157	19	54	114	23	121	94	37	87
Sub-total	171	25	60	117	28	130	109	41	89

Source: Extracted from Addis Ababa Trade and Industry Bureau (2010).

In a related fact, the operation and waste generation is variable as well. The reasons for variability are mainly the seasonality of supply of fruits in the market and the consumers factor-massive in fasting days than others as well as location of the houses. In general, auditing of input versus wasted (locally called “marsh”) is almost uncontrolled by the private business makers unlike the state owned ones (etfruit).

4.3.2 Quantification of FWs from major contributors

Rough estimation of the total FWs can be made based on the number of involved parties in this trade field (registered or not), the response of the focal persons on the quantity of input and wastes and the approximate weight of the wastes in a given volume as well as approximate composition the wastes. However it should be considered that supply and discharge are variable within days of a week and seasons as well.

The grand share of FVWs in general and FWs generation in particular is made by the central FVM-“Atikilt tera” partly due to physical damage, rotten fruits and improper heating to ripen the row. There divisions of private and share FV companies are made based on types of FV commodities; for banana, mango and avocado, vegetables and root crops mainly. The tomato dominated section disposes nearly 1500kgs of waste daily. Regarding banana waste, there are 12 compounds in two areas; one in “Atikilt tera” and the other to the north in front of “Atikilt tera” commonly called “Talian sefer”. The hugest amount of FWs contributed is banana, including its holding stem and little rolling leaf $8m^3$ of FW is discharged every day from each store totaled to 12 containers.

Within “Atikilt tera” the mango FW discharge is also comparable to banana, however mango is more seasonal available for around 8 months in a year. It is estimated that 4-7 $8m^3$ container mango wastes are discarded daily from “Atikilt tera”.

The avocado FW is more contributed by juice houses and retailers than in “Atikilt tera”. In fact over 4 $8m^3$ waste containers are discharged to waste dump site daily, more during the supply season.

According to the Ethiopian Fruits and Vegetables Market Share Company (etfruit), there are over 60 Fruit shops relatively evenly distributed within the city. These fruit shops receive 60kgs of fruits daily on average. These shops unlike the private shops have to return almost 20kgs of FWs each daily on average back to storage center due to inventory. In all contributors, except “Atikilt tera” and mobile fruit sellers, the primary FWs discharged are avocado and mango followed by banana all accounting to 2/3 of total. Roughly the over 144 fruit, vegetable and juice houses discard $0.3m^3$ FVWs daily dominated by mango and avocado (2/3) in the city.

Giving observatory guess to those informal mobile sellers, 100-200 in number, in the city 5-11kg of banana waste is discarded daily by each seller. In addition to that the low rate of discard is by those supermarkets, 706 in number, due to the better facilities they involve for storage (3kgs of FWs per day each).

The amount of selected FWs reported in unit of volume can be expressed in unit of weight using the average respective densities of the selected FWs for subsequent calculations. The weight per day and the contributors for the selected FWs is summarized in Table4.8.

Table4.8 Summary of generation rate (in tons/day) for the selected FWs by the identified contributors

Fruit waste	Contributor				
	Atikilt tera	Etfruit	FV Juice	supermarket	Mobile
Avocado	43	0.3	30.	0.8	-
Banana	110	0.4	8	0.1	1
Mango	62	0.2	18	0.6	-

The total quantity of these selected FWs when added gives to 164.51 tons/day. Even this amount is excluding the same discharge from households and the other portion of FVWs. Thus this huge resource though may be underestimated should not be lost in vain. And the other objective of this paper is therefore to predict possible recoverable biogas out of this resources thereby support decision makers and further studies from applying such recovery technologies in efficient manner.

4.3.2 Estimation of possible biogas from these FWs

Given the limitation in data, rough estimate of the possible clean energy obtained had the selected FWs in the city been managed in a way this paper went through can be made. The necessary information to predict is those FWs characterization variable (Moisture, TS and VS), total biogas as well as methane yield from the experimental work (Table4.9).

Table4.9 Summary of important information and prediction values for biogas (methane) per day.

Total FWs (kg)	TS average (%)	VS average (%)	VS total (kg)	Average biogas (m^3/kg VS)	Total biogas (m^3)	Average CH_4 (m^3/kg VS)	Total CH_4 (m^3/kg VS
164510	20.2	78.6	26120	0.8	20896	0.44	11493

The TS and VS values are average values for the selected FWs combined and are calculated the same way as it has been made in the characterization section of this document. The biogas volume retrievable by proper management of these wastes in the city is about 20896m^3/day. This, with average methane content of 54.4%, gives a total of 11496m^3/day methane gas.

It is reported that the fuel value of 0.24m^3 biogas with 40% CH_4 content is equivalent to 0.1litter of diesels fuel (Department of Environment and Resource Management, Australia, 2011). This implies the city of Addis Ababa is wasting an equivalent fuel value of 8707litter of diesel fuel which is about 6792 US dollar. In other terms of comparison, the same amount of daily biogas yield could have been converted to 11.2megawat of electricity was it managed using the anaerobic digesters.

The issue is does not end with only loose of resource but also the accompanying environmental stress the wastes bring in; emission to atmosphere and water sources pollution mainly. On the other hand, our dependence on fossil fuel and synthetic fertilizer production adds much green house gas emissions. Inevitably, the collection and transport to dump site is not free, based on the information from “Atikilt tera” merchants, 4.5 US dollar for 1m^3 wastes. However collection and transport of the wastes to gas centers will also be not free. To add more, if such wastes are simply dumped to soils, it will give little humus as the contents are consumed by microbes for their growth. However, as an indirect benefit the biogas manure interrupts succession of plant parasites from year to year in addition to the best nutritive value it gives. Therefore it is imperative to bring the issue in to attention for action not only to meet environmental demands but also for our economic advantage too.

4.4 Process stability and control

In relation to AD there has been a difference in methane value between the two runs as liming has been done based on the unstable acid condition in those ADs determined by the VFA/TA ratio measurements taken by acid base titration that will be discussed later.

4.4.1 VFA/TA versus pH

A more sensitive parameter for monitoring digesters and measuring process stability is the VFA/alkalinity ratio: when this ratio is less than 0.35–0.40 (equiv. acetic acid/equiv. $CaCO_3$), the process is considered to be operating favorably without acidification risk (Borja, 2011).

The volatile acids/alkalinity test is an important digester control test, much better than pH monitoring alone. Volatile acids/alkalinity tests will give more warning of approaching digester problems, while pH testing may not indicate a problem until it is too late.

The alkalinity or buffering capacity, of the system has to be balanced with the acids being produced in some ratio of 0.05-0.15 of volatile acids to alkalinity. Methane formers have a much narrower optimum range for pH and temperature and are slower in reproducing than the saprophytes which release short chain fatty acids such as acetic, propionic and butyric acids as waste product during conversion of complex organics. While the two groups of organisms do not compete with each other, any condition which are favorable to the saprophytes and not to methanogens result in a shift towards a sour digester.

Table4.10 Summary of substrate-lime mix determination of digesters

Digesters	TS (g) of FW	Desired (0.25%, w-TS/v-sol)	Digesters	TS (g) of FW	Desired (0.25%, w-TS/v-sol)
A_0	3	1.25g	A_1	3	1.25g
B_0	3	1.25g	B_1	3	1.25g
M_0	3	1.25g	M_1	3	1.25g

By monitoring the VFAs/alkalinity relationship, this shift can be seen in an increase in VFAs and a decrease in alkalinity. The traditional method of digester control is monitoring the pH of digesters. This method is not sufficient because a shift downward in pH has been preceded by the loss of the system’s alkalinity. At this point, it could be too late to bring the digester back. A shift in the VFAs/alkalinity relationship may occur days before the pH shift. Therefore it is better to strive to maintain the desired ratio mentioned above as a shift over 0.15 warns of approaching trouble and liming is indicated to bring the digester back into control. Thus, the determination of VFAs/alkalinity relationship in this study was made by analyzing samples from all ADs after mixing.

4.4.2 VFA/TA results

Upon analysis, a ratio of VFA/TA up to 0.9 (Table4.8) for mango FW digester has been observed and the digester was instable which led to correction by liming the content in the second run and has of course significantly improved the methane content. Though there emerges other options to treat acidity of digesters, thermal more recently, liming and two stage digestion are most common. In this research adding uniform amount of lime has been applied to two digesters and evidently improved the methane content.

Table4.11 Summary of VFA/ TA analysis result for the different batch ADs with and without liming

FW fed to digester	VFA/TA Ratio Before liming		VFA/TA Ratio After liming	
	With urea	Without	With urea	Without
Avocado	0.6	0.65	0.124	0.123
Banana	0.86	0.8	0.15	0.18
Mango	0.89	0.9	0.185	0.14

The elevation in the ratio of VFA/TA and hence the instability especially in mango and banana fed digesters (Table4.7) witnessed from reduced % CH_4 yield particularly the mango FW digesters including the urea added system.

For stabilizing pH of FW slurry during the anaerobic digestion, the addition of calcium oxide (Table4.7) was considered to lower the volatile fatty acids-to-alkalinity ratio from greater than 0.8 to down 0.18 and the CH_4 yield of mango and banana FWs elevated to 55.9% and 62% respectively.

In a related scenario, the innoculum size employed in this study is about 10%v/v. Because inoculum size and consortia of anaerobic organisms contained affects the methanation potential and hence process stability inoculum could be possible reason for lower methane yield. In relation to this, the inoculum size and microbial composition to be used in an anaerobic digestion has to be given attention. Therefore increasing the inoculums size and cultivating methanogens may also be able to help manage the problem.

4.5 Further importance from using anaerobic digestion

4.5.1 COD implications

The chemical oxygen demand (COD) values are a measure of the amount of oxygen required to completely convert organic compound into carbon dioxide and water. The COD measurement is also a means to characterize the strength of a waste, in this case the FWs. The VS and COD values are directly used in determining the amount of material that can be fed into an anaerobic digester on a daily basis, in this instance.

It is thus relevant as well to emphasize the spectrum of advantage from using anaerobic digestion as waste management option for easily decaying wastes of such kind by not only looking on the useful product of the system (renewable energy or plant nutrition) but also on the avoided negative impacts we could have encountered in terms of public and environmental health had such wastes been discarded indiscriminately, dumped openly, or sent to land fill even.

Because these wastes do posses characteristic organic strength, expressed in either BOD or COD values that goes to the larger environment like aquatic systems in the end would have brought depleting dissolved oxygen concentration in their natural course of degradation. This phenomenon subsequently brings undesirable effects to aquatic ecosystems, depleted dissolved oxygen and suffocation on user fauna, which naturally supports the system to keep its balance. Thus by applying anaerobic digestion to such wastes it is possible to reduce the COD by over 80% (Benis et al., 2010).

4.5.2 Biogas compared to biomass fuel

Further related is the issue of energy demand and the environment. The region Africa uses biomass energy which accounting for 60% of its energy source, the largest share in the world as 90% of the biomass energy use is in the developing world. This figure is showing growth recently attributed primarily to population growth in developing countries. Balancing this trend along with accompanying population needs, technological advances, and the environmental concern is important which involves; policy makers, increasing energy efficiency and use of improved cooking stoves.

Several of the poorest countries including Ethiopia rely on this source for 80-90% of their energy use. In developing countries, reliance on traditional biomass energy traps people in poverty by saddling woman and children with burdensome time commitment for fuel wood gathering.

Adversely, cooking with biomass also releases suspended particulates, carbon monoxide, methane, and organic compounds; extended exposure to these can result in respiratory infections, lung cancer, and blindness, and can endanger pregnancies. These hazards can be minimized by using cleaner fuels as best option. Interests for biomass conversion are evident in the developing countries, the use of solid waste and animal manure for biogas digesters-for example (Brown, Renner, and Halweil, 1999). Therefore to reduce the negative impacts on our environment from using non renewable energy, use of anaerobic digestion as source of renewable energy is very much attractive in addition to avoiding the improper disposal of waste.

4.6 The biogas manure characterization

4.6.1 Biogas manure solids

Following conclusion of the anaerobic digestion, 40ml equalized/homogenized sample from each digester was taken to determine the amount of TS, VS, FS, and moisture (Table 4.9) at the laboratory of the Chemical Engineering Department.

Table4.12 Results of content characterization for avocado, banana and mango FWs from "Atiklet tera" after anaerobic digestion on average

Digester Code	Moisture (%)	TS (%)	Volatile solid, % TS	Fixed solid, % TS	Total solid (g/l)	Volatile solid, (g/l)	pH
A_0	99.59	0.41	77	13	4.1	3.157	6.8
B_0	99.62	0.38	70.89	9.11	3.8	2.998	6.74
M_0	99.64	0.36	69.3	20.68	3.6	2.495	7.46
A_1	99.48	0.31	74.21	15.79	3.1	2.3	7.6
B_1	99.68	0.32	72.5	18.81	3.2	2.32	6.87
M_1	99.68	0.32	69.38	20.61	3.2	2.22	7.07

The post-anaerobic digestion characteristics were compared to slurry content for related variables. From Table4.9 it can be noticed that despite the slight increase in % VS by banana FW, the rest of the FWs maintained their %VS as it was before anaerobic digestion, but within the very much reduced TS. The pH after digestion was found to be different and increased from that of the former characterization.

4.6.2 Nutritive value of the biogas manure

After anaerobic digestion, determination of the plant nutrient content of the stabilized sludge is important for possible application of it to agriculture (Table4.10). Fertile soils are those that have enough nitrogen (N), phosphorus (P), and potassium (K), along with other nutrients that plants take up (Brady and Weil, 1996).

Classification of natural fertility levels in soils is expressed based on the content of nitrate-N, cation exchange capacity and individual exchangeable cations. Thus N (%) ranges from less than 0.1 of lowest value to greater than 1 highest value and K^+ from less than 0.12 of lowest value to greater than 1.2 highest value in (milli-equivalent) me/100g soil. The classification in phosphorus happens to be difficult and is pH dependent; in neutral and basic soils the critical level is at 5ppm and for acid soils this level is between 15 and 20ppm (Verhege, 2004).

In this regard, further examination of the residue from AD for soil nutrition effect has showed the additional usefulness of the waste treatment method for nutrient recycling (Table 4.10). These nutrients are parameters of soil fertility for agriculture and the biomass is finally set in to sludge. Thus stabilized sludge retains the fertilizer value of original material and the saving of energy required to produce equivalent amount of nitrogen containing fertilizer from using synthetic process. Studies also showed that the biogas manure contains those nutrients in useful form to plants contrary to the original waste material.

During digestion of animal manure, for instance, a large part of the organically-bound nitrogen is converted (mineralized) to ammonium nitrogen, which is more easily absorbed by plants. Using the end product after anaerobic digestion of the manure, therefore results in a reduced risk of leaching of nitrogen from agricultural land (Schnurer and Jarvis, 2010).

Table4.13 Results of parametric tests (soil fertility) in mg/g TS for avocado, banana and mango FW in "Atiklet tera" after anaerobic digestion/treatment

Parameter analysed	Type of sample sludge of FW					
	Avocado		Banana		Mango	
	A_0	A_1	B_0	B_1	M_0	M_1
Total Phosphorus (PO_4^{3-})	13	13.47	10.47	10.99	9.98	10.61
Total Nitrogen	17	17.79	40.9	41.88	12.17	12.4
Potassium	14.43	15.74	24.64	24.5	10.99	10.82

The NPK content of banana is seen to be high for its NP content and low for its K content as compared to other similar study report that showed the NPK of banana waste to be 27.3, 2.3, and 51 g/kg respectively (Memon et al., 2012) which could be associated with the soil-plant nature and hence the variety of the specific fruit. Relatively, the NPK content of mango is lowest. The whole fruits however showed elevated amount compared to the undigested FWs (Table4.10).

4.7 Biogas manure prediction

The advantage of applying biogas technology for management of such wastes is farther than obtaining the clean and renewable energy. It can also provide opportunity to soil nutrient recycle far better than applying the row waste to farm and more.

Based on the daily total solid amount which is 33, 231kg and the amount of the major soil fertility indicators determined in the laboratory, the maximum obtainable nutrient can be projected (Table4.).

Table4.14 Summary of the total determinant nutrients quantification on daily basis

Nutrient	Average gm/kg TS	Total amount (kg)
Total phosphorus	11	366
Total nitrogen	24	798
Potassium	17	565

Given the variability in the nutrient content among the different FWs, the average biogas manure could contain this useful amount of nutrient for soil supplements. Had these nutrients been synthesized artificially the cost and environmental implication would be huge. Undoubtedly, this amount is obtainable excluding other components of FVWs. The content of nutrient by the other vegetable wastes would probably be higher in this regard. Therefore this prediction also adds on the need to recover such nutrients from the waste resources in addition to t he clean energy.

5. Conclusions

Analyzing the physical and chemical characteristics of FW allows the anaerobic digestion analyzer to decide on the food load and co-substrate determination before going in to the digestion process with the required treatment. It is also useful in estimating the potential for biodegradation and evaluation of yield from determination of the organic fraction contained and also to estimate the changes in content before and after digestion. Characterization of the selected FWs in this study showed that all FWs could be substrates for anaerobic digestion and hence showed good biogas potential as can be read from its VS (over 80%w/w TS on average) content. However, the C:N ratios are far from balance for optimum degradation of the organic content and therefore these wastes need co-substrate addition mainly to supplement the nitrogen deficit.

A biogas yield from anaerobic digestion with urea addition on selected FWs was 0.8 m^3/kg VS with 54.4% CH_4 content in biogas. The co-digestion, achieved using urea addition resulted in a statistically significant difference in biogas yield. An increase in biogas volume, over 54.7% on average, has been achieved from using urea addition than without urea addition on anaerobic digestion of selected FWs. Therefore, FWs can be preferred to other wastes as substrates for biogas production having controlled the acidification matter.

However, use of commercial analytical grade urea could be replaced with other natural sources of nitrogen as co-substrate including, but not limited to, poultry manure and cow dung. The co-digestion of other organic fraction of municipal solid waste may also be sorted and used as feed to AD with the FWs. Along with this, it is also necessary to take the intra difference in yield among those selected FWs into consideration because elemental analysis is the building block of larger systems.

It is also possible to reduce COD of this wastes by over 80% and avoid associated environmental stresses by this anaerobic digestion while producing the clean and renewable energy-biogas with up to 62% CH_4 (v/v) content.

Associated with production of biogas from such waste sector, use of the stabilized sludge from the AD process need to be encouraged as it is a good source of plant nutrient has an associated nutrient recycling role for the agricultural activities along with the reduction in sludge volume for convenient transport to arable lands. The phosphorus content of all the

FWs is generally high compared to others' reports. These soil nutrient facts therefore, leads to the conclusion on further usefulness of sludge after digestion for land application.

The prediction on biogas and biogas manure indicates that the city is wasting huge recoverable resource which needs attention.

6. Recommendations

Before extending the use of FWs on anaerobic digestion for supply of biogas to the community or commercialization of service, pilot scale study has to be made towards controlling the lowering of pH and hence stabilization of such systems and energy supply. In addition, in view of improving the methane yield and the process stability, further work on co-digestion of FWs with vegetable wastes need to be done

The existing disposal practice on FW has to be given attention by those stakeholders in the city so that the negative impact from such practice could be avoided while the recovery of resources associated could be succeeded.

Further study is also recommended on the feasibility and commercialization of digestate for farm applications.

References

Ahmad Abdalqader and Jehad Hamad. (2012). Municipal solid waste composition determination supporting the integrated solid waste management in Gaza strip, international. *journal of environmental science and development* , 3:2.

Anna Schnurer and Asa Jarvis. (2010). *Microbiological hand book for biogas plants.* Swedish: Gas Center report.

Anthony Manoni Mshandete and Wilson Parawira. (2009). Biogas technology research in selected sub-Saharan, African countries – a review. *African journal of biotechnology* , 8:116-125.

Arumugam, R. and Manikandan, M. (2011). Fermentation of pretreated hydrolyzates of banana and mango fruit wastes for ethanol production. *Asian Journal of experimental biological science*, 2:246-256.

Arvanitoyannis, I.S., and Theodoros, H.V. (2008). Vegetable waste treatment: comparison and critical presentation of methodologies. *critical reviews in food science and nutrition* , 48:205–247.

Azadeh Babaee and Jalal Shayegan, Anaerobic digestion of vegetable waste, web paper, Italian association of chemical engineering, (Www.Aidic.It/Icheap) 02 May, 2011.

Bitton, G. (2005.). *Waste water microbiology, 3rd ed.* UK: Wiley.

Borja, R., Biogas production, instituto de la grasa (csic), Seville, Spain, 2011, Elsevier B.V.

Bouallagui, H., Ben Cheikh, R., Marouani, L. Hamdi, M. (2003). Mesophilic biogas production from fruit and vegetable waste in a tubular digester. *bio-resource technology* , 86:85–89.

Bouallagui, H., Touhami, Y., Ben Cheikh, R., and Hamdi, M. (2005). Review: bioreactor Performance in anaerobic digestion of fruit and vegetable wastes. *process biochemistry* , 40:989–995.

Burak Demirel, Paul Scherer, Orhan Yenigun, and Turgut T. Onay,. (2006). Production of methane and hydrogen from biomass through conventional and high-rate anaerobic digestion processes. *critical reviews in environmental science and technology* , 40:116–146.

Chen Guangyin, Zheng Zheng, Chang Zhizhou, Ye Xiaomei, and Luo Yan. (2011). Effects of nitrogen sources on anaerobic digestion process of wheat straw. *China environmental science* , 31:73-77.

Clair, N. Sawyer, P.L. McCarthy, and G.F. Parkin. (2003). *Chemistry for environmental engineering and science, 5th ed* . India: Tata Mcgraw Hill.

Dhanalakshmi S.V. and Ramanujam, R.A.,. (2012). Biogas generation in a vegetable waste anaerobic digester: an analytical approach. *research journal of recent sciences* , 1:41-47.

Diamantis, V.I. et al. (2003). Anaerobic/aerobic treatment of peach canning waste water. *8th international conference on environmental science and technology*. Greece: www.

Document by GTZ, project information and advisory service on appropriate technology (ISAT- Website), biogas digest: biogas basics, volume I.

Emily Morgan, Fruit and vegetable consumption and waste in Australia, 2010.

Esposito, G.E. (2012). Bio-methane potential tests to measure the biogas production from the digestion and co-digestion of complex organic substrates,. *the open environmental engineering journal* , 5:1-8.

Ethiopian Horticultural Development Agency, assessment of development potentials and investment options in the export-oriented fruit and vegetable sector, 15/March 2011 online document, (http://www.africa-do-business)

Garcia-Peña E.I., Parameswaran P., Kang D.W., Canul-Chan M., and Krajmalnik-Brown R. (2011). Anaerobic digestion and co-digestion Processes of vegetable and fruit residues: process and microbial ecology. *bioresource technology* , 102: 9447–9455.

Gary, L. Hawkins and Glen Rains,. (2008.). Assessing the physical and chemical properties of fruit and vegetable waste for use in anaerobic digestion. *ASABE, annual international meeting.* USA.

Ghaniyari-Benisa, S., Borjab, R., Bagheria M., Ali Monemianc, S., Goodarzic, V., and Tooyserkani Z. (2010). Effect of adding nitrate on the performance of a multistage biofilter used for anaerobic treatment of high-strength wastewater. *Chemical Engineering Journal* , 156:250-256.

Harilal, C.C., Pradeep, G., kumar, and Ravindran, C.P., Quantification, characterization and management of solid waste from mahe, union territory of pondicherry, september 2007.

Horan, N.J., Smyth, M. and May, A. (2011.). Optimization of digester performance and gas yield through analysis of VFA speciation. *16th European bio-solids and organic resources conference.* UK.

Horan, N.J., Smyth, M. and May, A., . (,16th European bio-solids and organic resources conference, 2011.). Optimization of digester performance and gas yield through analysis of VFA speciation.

Jenny Gustavsson, Christel Cederberg, Ulf Sonesson, Robert Van Otterdijk, and Alexandre Meybeck, Global food loss and food waste: extent, causes and prevention, Food and Agriculture Organization of the United Nations, Rome, 2011.

Jia Lin, Jiane Zuo, Lili Gan, Peng Li, Fenglin Liu, Kaijun Wang, Lei Chen, and Hainan Gan. (2011). Effects of mixture ratio on anaerobic co-digestion with fruit and vegetable waste and food waste of China,. *journal of environmental sciences*, , 23(8):1403–1408.

Kirtane, R.D et al., . (2009). Optimization of organic loading rate for different fruit wastes during biomethanation. *journal of scientific and industrial research* , 68:252-255 .

Lester, R. Brown, Michael Renner, and Brian Halweil. (1999). *Vital Signs: the environmental trends that are shaping our future.* USA: world watch institute, vital sign series.

Letter communication with Trade and Industry bureau of Addis Ababa City, Ethiopia, 2012

K osseva, M.R. (2011). Management and processing of food wastes. *PUBLMED.GOV* , 5.

Madhukara, K. Krishna Nand, Raju, N.R., and Srilatha, H.R. (1993). Ensilage of mango peel for methane generation . *process biochemistry* , 28:119–123.

Memon, M., et al. (2012). Comparative evaluation of organic wastes for improving maize growth and NPK Content. *African journal of biotechnology,* , 11 (39):9343-9349 .

Metcalf and Eddy. (1991). *Waste water engineering:treatment and reuse.* India: Tata McGraw Hill.

Method 1684, total, fixed, and volatile solids in water, solids, and bio-solids, U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology Engineering and Analysis Division (4303) 1200 Pennsylvania Ave. NW, Washington, D.C. 20460, January 2001.

Muhammad Tahir Khan, Claudia Maurer, Dimitrios Argyropoulos, Mathieu Brule, and Joachim Mueller, anaerobic digestion of banana waste, a potential source of energy in Uganda, Tropentag, October 6-8, 2009, Hamburg , "biophysical and socio-economic frame conditions for the sustainable management of natural resources".

Nallathambi, V. Gunaseelan. (1997). Anaerobic digestion of biomass for methane production: A review. *biomass and bio-energy* , 13:83-114.

Narayani, T. G., and P Gomathi Priya. (2012). biogas production through mixed fruit wastes biodegradation . *journal of scientific and industrial research* , 71:217-220.

Nigatu Regassa, Rajan D.Sundaraa and Bizunesh Bogale Seboka,. (2011). Challenges and opportunities in municipal solid waste management: The case of Addis Ababa city, central Ethiopia. *journal of human ecology* , 33(3):179-190.

Nirmala Bardiya, Deepak Somayaji and Sunil Khanna,. (1996). Bio-methanation of banana peel and pineapple waste . *bioresource technology* , 58:73-76.

Nyle, C. Brady and Ray, R. Weil. (1996). *The nature and properties of soil,11th ed.* USA: Prentice Hall, inc.

Office of Environment and Resource Management, Queen's land Government, use of banana waste as fuel source-online document, August 2011, Australia.

Tumutegyereize, P. Muranga, F.I. Kawongolo, J. and Nabugoomu, F. (2011). Optimization of biogas Production from banana peels: effect of particle size on methane yield. *African journal of biotechnology* , 10(79):18243-18251.

Personal communication with Ethiopian Fruit and Vegetable Market Share Company (etfruit), Addis Ababa, Ethiopia, 2012.

Raju, N. R., Devi Sumithra, S. and Krishna Nand. (1991). Influence of trace elements on biogas production from mango processing waste. *biomedical and life sciences* , 13: 461-464.

Sagagi, B. S., Garba, B., and Usman, N. S.,. (2009). Studies on biogas production from fruits and vegetable waste. *bayero journal of pure and applied sciences* , 2 (1):115 – 118.

Siedlecka, E.M., Kumirska, J., Ossowski, T., Glamowski, P., Gołębiowski, M., Gajdus, J., Kaczyński, Z., and Stepnowski, P. (2008). Determination of volatile fatty acids in environmental aqueous samples. *Polish journal of environmental studies*, 17: 351-356.

Tesema Haile, Overview of Addis Ababa city solid waste management system, Division for Sustainable Development, Department of Economic and Social Affairs, United Nations, February/ 2010, Addis Ababa, Ethiopia

Velmurugan, B., and Alwar, R. Ramanujam,. (2011). Anaerobic digestion of vegetable wastes for biogas production in a fed-batch reactor, . *international journal of emergerging Sciences*, 1(3):478-486.

Venkat, K. (2011). The climate change and economic impacts of food waste in the United States, . *international journalof food system dynamics* , 2 (4):431-446.

Verhege, W. (2004). Management of agricultural land: chemical and fertility aspects. *land use, land cover, and soil sciences* , 4.

Viswanath, P., Devi, S.S., and Nand, K.,. (1992). Anaerobic digestion of fruit and vegetable processing wastes for biogas production. *Journal of bioresource technology* , 40:43-48.

Wantanee Anunputtikul and Sureelak Rodtong,. (2004). Laboratory scale experiments for biogas production from cassava tubers. *the joint international conference on "sustainable energy and environment (SEE)"* , (pp. 238-243). Hua Hin, Thailand.

Annexes:

Annex-I: Lab analysis method and procedure

The method of “ashing” received from the environmental protection authority of Ethiopia has been put to determination of the organic matter content of selected FWs.

1. Predetermined amount of sample, 10g, was prepared and added to crucibles.
2. The crucible and content was heated in a low flame till the organic mater begins to burn.
3. The crucibles and content are ignited for 8 hours at a temperature of 450 ^{0}C.
4. The crucibles and content are cooled and weighed.
5. The residue represents the ash. The loss in weight represents the moisture and organic matter.

The procedure has also a straight forward method for calculation.

Annex-II: Lab analysis results

Table II.1 Measurements taken for moisture, TS, and VS determination for avocado, banana and mango fruit wastes in “Atiklet tera”

Fruit Waste	W_{dish}	W_{sample}	W_{total}	W_{res}
Avocado	38.960	70.850	63.15	39.413
Banana	39.974	70.67	62.90	40.367
Mango	39.211	72.150	62.38	39.364

TableII-2 Results of characterization for avocado, banana and mango FW from “Atiklet tera”, first run

Fruit Waste	Moisture content, %	Total solid, %	Fixed solid, %	Volatile solid, %	TOC (%, dry basis)	TKN (%)	pH (initial)
Avocado	78.9	21.1	19.6	80.4	39.8	1.23	5.81
Banana	79.6	20.4	20.09	79.9	58.4	0.67	5.56
Mango	84.7	15.3	25.6	74.4	66.3	0.51	4.3

TableII.3 Results of characterization for avocado, banana and mango FW from “Atiklet tera”, second run

Fruit Waste	Moisture content, %	Total solid, %	Fixed solid, %	Volatile solid, %	TOC (%, dry basis)	TKN (%)	pH (initial)
Avocado	74.3	25.7	19.2	80.8	36.2	1.07	5.79
Banana	77.6	22.4	20.31	79.7	55.6	0.63	5.44
Mango	83.9	16.1	23.3	76.7	61.7	0.51	4.3

TableII-4 Slurry characterization before digestion first run

Digester (System)	Measurements					
	Crucibles (gm)	Sample Solution (ml)	Crucible and sample after drying in (g) (104^0C)	pH (initial)	TS (% sample)	Remarks
A_0	54.68	50	55.05	6.4	0.75	
B_0	49.9	50	50.27	6.47	0.75	
M_0	40.15	50	40.51	5.9	0.73	
A_1	35.73	50	36.12	6.3	0.78	
B_1	38.31	50	38.69	6.8	0.76	
M_1	35.17	50	35.55	6.01	0.77	

TableII-5 Slurry characterization before digestion, second run

Digester (System)	Measurements					
	Crucibles (gm)	Sample Solution (ml)	Crucible and sample after Drying in gm (104^0C)	pH (initial)	TS (% sample)	Remarks
A_0	54.68	50	55.07	6.4	0.79	
B_0	49.9	50	50.28	6.47	0.77	
M_0	40.15	50	40.56	5.9	0.83	

A_1	35.73	50	36.13	6.3	0.8	
B_1	38.31	50	38.7	6.8	0.8	
M_1	35.17	50	35.6	6.01	0.81	

TableII.6 Results of slurry characterization for avocado, banana and mango FW from "Atiklet tera" first run.

Fruit Waste	Moisture content, %	Total solid, %	Fixed solid, (% TS)	Volatile solid, (%TS)	Total solid (g/l)	Volatile solid, (g/l)	pH (initial)
A_0	99.25	0.75	19.1	80.9	7.7	6.20	6.4
B_0	99.25	0.75	20.2	79.8	7.6	6.06	6.47
M_0	99.27	0.73	24.2	75.8	7.8	5.96	5.9
A_1	99.22	0.78	19.2	80.8	7.9	6.36	6.3
B_1	99.24	0.76	20.1	79.9	7.8	6.22	6.8
M_1	99.23	0.77	23.2	76.8	7.9	6.05	6.01

TableII.7 Results of slurry characterization for avocado, banana and mango FW from "Atiklet tera", second run

Fruit Waste	Moisture content, %	Total solid, %	Fixed solid, (% TS)	Volatile solid, (%TS)	Total solid (g/l)	Volatile solid, (g/l)	pH (initial)
A_0	99.21	0.79	19.7	80.3	7.7	6.20	6.4
B_0	99.23	0.77	20.2	79.8	7.6	6.06	6.47
M_0	99.17	0.83	24.8	75.2	7.8	5.96	5.9
A_1	99.20	0.8	19.6	80.4	7.9	6.36	6.3
B_1	99.20	0.8	20.3	79.7	7.8	6.22	6.8
M_1	99.19	0.81	23.6	76.4	7.9	6.05	6.01

Table II.8 Result of biogas and methane measurements taken during the first run

HRT (Wks)	Volume of biogas and methane content													
	Biogas (mL)							Methane/ **bM** (%v/v)						
	A_O	**B_O**	**M_O**	**I**	**A_1**	**B_1**	**M_1**	**A_O**	**B_O**	**M_O**	**I**	**A_1**	**B_1**	**M_1**
1	220	420	415	3	410	500	400	50	53	48	0	51	54	45
2	355	60	50	0	664	520	430	53	55	50	0	53.2	53	48
3	330	520	520	0	518	610	670	55.4	58	50.2	0	53	54.9	48.9
4	180	260	150	0	307	220	300	55	61.7	52	0	58	60	51
5	70	90	80	0	50	80	70	57	62	55	0	58.2	60	55.9

Table II.9 Result of biogas and methane measurements taken during the second run

HRT (Wks)	Volume of biogas and methane content													
	Biogas (mL)							Methane/ **bM** (%v/v)						
	A_O	**B_O**	**M_O**	**I**	**A_1**	**B_1**	**M_1**	**A_O**	**B_O**	**M_O**	**I**	**A_1**	**B_1**	**M_1**
1	240	410	400	4	410	450	300	50	53	48	0	51	54	49
2	360	105	100	0	650	570	480	53	53	52	0	53.2	53	51
3	370	510	520	0	500	630	705	60	57	53.2	0	53	54.9	56
4	150	270	180	0	310	250	335	61	64	53	0	58	60	56.6
5	70	80	30	0	100	110	80	61.3	65	55	0	58.2	60	60

TableII.10 Cumulative biogas yield for all systems studied

HRT (wks)	Biogas volume (ml)					
	A_O	**B_O**	**M_O**	**A_1**	**B_1**	**M_1**
1	230	415	407	410	475	350
2	587.5	498	482	1057	1020	805
3	937.5	1013	1002	1576	1640	1492
4	1102.5	1278	1167	1884	1875	1810
5	1172.5	1363	1222	1959	1970	1885

TableII.11 Statistical analysis of the effect of treatment of the three FWs

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Upper	Lower			
Pair 1	A0 - A1	-787.00000	9.89949	7.00000	-875.94343	-698.05657	-112.429	1	0.006
Pair 2	B0 - B1	-607.50000	38.89087	27.50000	-956.92063	-258.07937	-22.091	1	0.029
Pair 3	M0 - M1	-662.50000	10.60660	7.50000	-757.79654	-567.20346	-88.333	1	0.007

TableII.12 Statistical analysis of the effect of treatment of the three FWs

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	A0	1,172.5000	2	24.74874	17.50000
	A1	1,959.5000	2	14.84924	10.50000
Pair 2	B0	1,362.5000	2	17.67767	12.50000
	B1	1,970.0000	2	56.56854	40.00000
Pair 3	M0	1,222.5000	2	10.60660	7.50000
	M1	1,885.0000	2	21.21320	15.00000

TableII-13 Content characterization after digestion of FW

Digester (System)	Measurements					
	Crucibles (g)	Sample As solution (ml)	Crucible and sample after drying	Moisture (%)	TS (%)	Remark
A_0	37.21	50	37.415	99.59	0.41	
B_0	40.07	50	40.26	99.62	0.38	
M_0	40.15	50	40.33	99.64	0.36	
A_1	35.73	50	35.885	99.48	0.31	
B_1	38.31	50	38.47	99.68	0.32	
M_1	35.17	50	35.33	99.68	0.32	

Table II.14 Results of parametric tests in mg/L for avocado, banana and mango FW in "Atiklet tera" after anaerobic treatment

Parameter analysed	Type of sample sludge					
	Avocado		Banana		Mango	
	A_0	A_1	B_0	B_1	M_0	M_1
Total Phosphorus (PO_4^{3-})	716	740	602	602	537	540
Total Nitrogen	990	1005	2300	2350	690	682
Potassium	845.5	851	1300	1320	634	634

Table II.15 Fertilization potential test for digestate from first run

Parameter analysed	Type of sample sludge of FW					
	Avocado		Banana		Mango	
	A_0	A_1	B_0	B_1	M_0	M_1
Total Phosphorus (PO_4^{3-})	12.7	13.15	11.04	11.0	9.76	9.82
Total Nitrogen	18	18.27	41.82	42.73	12.54	12.4
Potassium	15.37	15.47	23.64	24	11.53	11.53

Table II.16 Fertilization potential test for digestate from second run

Parameter analysed	Type of sample sludge of FW					
	Avocado		Banana		Mango	
	A_0	A_1	B_0	B_1	M_0	M_1
Total Phosphorus (PO_4^{3-})	13.3	13.8	9.9	10.9	10.2	11.4
Total Nitrogen	16	17.32	40.0	41.03	11.8	12.4
Potassium	13.5	16.02	25.64	25	10.45	10.11