



MAURITIUS RESEARCH COUNCIL

TURNING A WASTE INTO WEALTH- VINASSE INTO AN ORGANIC FERTILISER

Final Report

October 2008

MAURITIUS RESEARCH COUNCIL

Address:

Level 6, Ebène Heights,
34, Cybercity,
Ebène 72201,
Mauritius.

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

This report is based on work supported by the Mauritius Research Council under award number MRC/RUN-0804. Any opinions, findings, recommendations and conclusions expressed herein are the author's and do not necessarily reflect those of the Council.

UNIVERSITY OF MAURITIUS

Faculty of Agriculture

REPORT OF MRC –FUNDED PROJECT

FINAL REPORT OF PHASE I

November 2007 – October 2008

PI : Dr. B. Lalljee Assoc Professor, UoM	AWARD NO: MRC/RUN- 0804	STARTING DATE: November 2007	COMPLETION DATE: October 2008
TITLE: Turning a waste into wealth - vinasse into an organic fertiliser			

1. INTRODUCTION

1.1. Overall Aim

Vinasse is a waste product of alcohol production from sugarcane juice or molasses, produced in large amounts (13-15 litres of vinasse for every litre of ethanol). It can be a serious environmental liability if not properly disposed of. This project aims at transforming vinasse into a form that is usable by farmers, is safe and easy to store and transport, easy to apply to land, effective, and environmentally-safe. The project aims to revalorize a waste product into a valuable resource, and also resolve the issue of its disposal in the environment.

1. 2. Project Justification

The Republic of Mauritius is presently experiencing three important economic shocks due to globalisation, namely, (i) reduction in the export price of sugar to the European Union (EU); (ii) increase in the price of petroleum products, and (iii) erosion of the preferential trade

agreement on textiles due to the dismantling of the Multifibre Trade Agreement. These three economic shocks are predicted to have serious consequences for the island's economy and its inhabitants. Government has promulgated bold policies to help the country face these serious threats. One of the main policies is the re-engineering of the sugar industry to transform it into a sugarcane industry, with the help of processes such as clustering, flexi-factories, and value addition of sugarcane, its by-products and waste products. One example of this is increased production of ethanol from sugar or molasses. Government's Action Plan envisages the production of about 30 million litres of ethanol. This will result in an estimated 450 million litres of vinasse being produced annually. Its high organic matter content gives vinasse a high Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD), that is almost equivalent to raw sewage. Disposing vinasse into water bodies can have serious adverse consequences, while long term and injudicious application to soil has been shown to have adverse effects on soil quality and yield of crops (Gonzalo et al., 2006). For good environmental stewardship, it is therefore necessary that the vinasse is disposed of in a way that will not pose any hazard to the environment. The best strategy would be to convert this waste into a resource that can be recycled in agriculture as a source of plant nutrients. This is also in line with the recent policy of the Government of Maurice Ile Durable (MID) Concept.

This project aims at finding a potential use for this waste product, by processing it into a form that is safe, effective and easily applicable. The main objective is to revalorize this waste product into a valuable resource by converting it into a good organic fertiliser. Such a strategy will (i) avoid the need to dispose of raw vinasse into the environment, (ii) provide a locally-produced, easily available, organic fertiliser which can be used in organic agriculture, which in itself is another high value added activity envisaged by Government, (iii) reduce consumption of synthetic fertilisers in conventional agriculture, and hence help make it more environment friendly and sustainable, (iv) add value to the vinasse, (v) increase the income of sugar estates as well as small planters through the sale of this organic fertiliser, (vi) create business opportunities for SMEs.

Sugarcane has been playing a multifunctional role in Mauritius; it is a highly efficient, C₄ crop that is well adapted to the island's climate and soil types. The annual sugar production target of Mauritius is about 600,000 tonnes, and under the Sugar Protocol, Mauritius has an annual export quota of 507,000 tonnes. This, coupled with the fact that the price of Mauritian sugar is well above the prevailing world market price, has provided Mauritius with a stable

and predictable foreign exchange earning. The revenue accruing from the export of sugar has been for a long time the lifeblood of the country and has helped the island to diversify its economy into other pillars, such as tourism and textile, which can be considered as offshoots of the sugar industry.

The WTO Framework Agreement on Agriculture calls for an end to all forms of export subsidies in all sectors, including sugar, and a reduction in import taxes, both of which will result in substantial reform in the EU Sugar Protocol, also known as the Cotonou Agreement (2000-2020). This will result in a reduction of 36% in sugar prices by 2008. This economic shock is aggravated by the spiraling prices of petroleum products, which has reached 72 \$ per barrel (Mauritius imports about 350,000 tonnes of diesel and 90,000 tonnes of gasoline annually), and the erosion of our textile markets due to the dismantling of the Multifibre Trade Agreement. The island is no longer under the comfort zone of yesteryears.

Fully conscious of this problem, the Government of Mauritius has already submitted its Multiannual Adaptation Strategy (2006) to the EU for accompanying measures to cushion this shock. The roadmap of the Mauritian sugar industry for the 21st century in a globalised environment proposes, *inter alia*, the following :

- (i) optimisation of the value-addition of sugar and its co-products;
- (ii) optimization of the production of ethanol from sugarcane;
- (iii) preservation and protection of the environment through reduction in the soil and land degradation and increase in carbon sequestration;
- (iv) optimization of the production of environmentally renewable sources of energy from bagasse;
- (v) preservation of the secondary employment created by those who indirectly serve the sugar industry, namely the SMEs.

The way forward to meet the above objectives is a concerted action with the involvement of all stakeholders. The Government of Mauritius' programme for 2005-2010 (Multiannual Adaptation Strategy) envisages strengthening diplomatic endeavors vis-à-vis the EU and the WTO in order to safeguard the islands' economic interest on one hand, and on the other to promote a fast track modernization and diversification to convert the sugar industry into an efficient sugarcane industry geared towards the production of sugar, by-products and energy. By the end of 2016, sugar production is predicted to be 550,000 tonnes, the energy

production from bagasse to be 600 GWh, and ethanol production from molasses to be 30 million litres. The Action Plan of the Government also aims at the development of a sugar cluster that will produce *interalia* a higher amount of electricity from bagasse, a higher quantity of special sugars, and a larger volume of ethanol, through the construction of flexi-factories. As per this Action Plan, the 30 million litres of ethanol envisaged will be used mostly as a 10% additive to petrol for normal cars (this practice has already been approved by the Government). However, if the price of petrol continues to rise, car engines may be modified and/or new engines that can use an increased mix of alcohol (upto 80%), or run totally on alcohol, as in Brazil, may come into the local market. Therefore, the 30 million litres may, in fact, represent only a fraction of the total potential demand for ethanol in the country. Furthermore, the Action Plan also encourages the production and export of rum agricole, a high value added product, which will be in addition to the 30 million litres mentioned above.

Ethanol is made by the fermentation of a dilute solution of cane sugar or cane molasses with yeast for 1-2 days, followed by the distillation of the ferment (beer) to recover the ethanol. The fermentation process begins as the yeast converts the sucrose in the sugar or molasses into equal amounts of glucose and fructose. These in turn are converted into alcohol and carbon dioxide. The resulting fermentation product, known as beer or mash (which contains 8-10% ethanol), is then fed continuously through a multicolumn distillation process to separate the ethanol. The remaining fermentation by-product is known as stillage, spent wash or vinasse.

In the production of rum, the alcohol from the first column is fed to a second distillation column or aldehyde column. However, if the alcohol is to be used as a petrol additive, the aldehyde column is replaced with a dehydrating and benzene-recovery column to obtain anhydrous (100%) alcohol, also known as gasohol. The amount of vinasse per volume of alcohol produced depends on the source of the fermentable material. For sugarcane, be it from molasses or cane juice, the volumetric relationship between alcohol and vinasse is 1 litre of alcohol to about 15 litres of vinasse, hence 30 x 15 million litres of vinasse will be co-generated annually.

Its high organic matter content gives vinasse a high Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD), that is almost equivalent to raw sewage (Sweeney and

Graetz, 1988, 1991). Hence, this product can be a serious environmental pollutant, if not properly disposed of. It is difficult to envisage how such a huge amount of a potentially environment-polluting by-product can be disposed of safely in the relatively small, fragile, island ecosystem, such as exists in Mauritius. Disposing vinasse into streams, rivers, rivulets or other such water bodies can have serious adverse consequences, which include death of aquatic organisms, anaerobic condition, eutrophication, foul smell, etc. This in turn can have major environmental, economic, social as well as political repercussions. In an attempt to reduce the problem of disposal of vinasse, raw diluted vinasse has been applied to sugarcane soils in some countries, such as Brazil and Costa Rica. However, the long-term application of this material has been shown to have adverse effects on the environment, on soil quality and yield of crops (Gonzalo et al., 2006). Although small amounts of raw vinasse have been applied to sugarcane soils in Mauritius, its long-term effects have not been studied in depth. Moreover, the huge amounts that are expected to be generated cannot be absorbed by the sugarcane fields. Another complication of applying raw vinasse to fields is that it requires specialised equipment, such as special tractors fitted with tankers, and also needs proper land preparation. These conditions cannot be met by small planters at present.

Vinasse has the potential to be transformed into an environmentally-friendly usable product, namely an organic fertiliser (Lalljee, 200; Lalljee, 2006a, 2006b; Lalljee and Facknath, 2006). However, in order to achieve this, research needs to be conducted to study and establish the right mix of materials and appropriate processing parameters in order to produce a good quality product locally, which will have maximum soil nutrients (in qualitative and quantitative terms) and minimum levels of toxic components (heavy metals, pathogens, etc). Once the optimum processing conditions have been established, the end-product formed will need to be evaluated for its fertiliser qualities, its toxicity, ease of transport and application.

1. 3. Expected Outcomes of the Project

1. There will be a broadening of scientific and technical knowledge as regards the properties of raw vinasse and other substrates.
2. A new fertilizer material will be available to planters, especially to organic growers.
3. A scientifically studied process for transformation of vinasse into an environmentally safe product having fertiliser properties will be available.

4. It will create an avenue to convert a waste product into a valued product having significant market value.
5. It will provide a potential avenue for increase in revenue of sugarcane planters from the proceeds of sale of vinasse.
6. The problem of vinasse disposal will be addressed.
7. It will contribute towards Government's commitment to satisfy its obligations under the various conventions it is party to, e.g. the Kyoto Protocol, the UNFCCC, UNCCD, etc. as well as towards the MID policy.

1.4. Issues Addressed

- (i) Analyses of the chemical, physical, biological and biochemical properties of raw vinasse;
- (ii) Analyses of the physical, chemical, biological and biochemical parameters of various possible local substrates that would be appropriate for mixing with vinasse in the conversion process. These include market wastes, kitchen wastes, green wastes, sugar industry and other wastes;
- (iii) Optimization of processing parameters, e.g. pH, temperature, water, C:N, C:P, C:S, time and frequency of turning, oxidation, etc. that will give a good quality product in terms of maximum available soil nutrients and minimum toxic elements;
- (iv) Analyses of the chemical, physical, biological and biochemical properties of the processed vinasse;
- (v) Study of the effects of raw and processed vinasse on soil physical, chemical and biological properties, crop pests, and crop yields;
- (vi) Study of the physical properties of the end product for ease of transport, storage, application and acceptability.

These issues will be undertaken in three phases. This report describes the results of Phase I.

2. LITERATURE REVIEW

The sugar industry is by far the most important crop in the Mauritius economy. It is the major net foreign exchange earner and even though in the last few years its contribution to the economy has declined with the increasing development in tourist and manufacturing

industry, it still remains an essential sector for the economic growth and social stability (Deepchand, 2005). In 2006, about 70 801 hectares of island were under sugarcane plantation and a yield of about 550 000 to 625 000 tonnes of sugar are produced annually, most of it (90%) being exported to other countries (Deepchand, 2005; CSO, 2006).

The manufacture of sugar and its by-products also entails the production of secondary products, two important ones being bagasses and molasses, which also contribute to the economy of the island through diversification of revenue basket sources and reduction in industry's vulnerability to sugar price shocks (Deepchand, 2005). Bagasse is the plant fibrous material that remains after all the cane juice has been extracted from the stalks. It is about half water and half dry matter; consisting mainly of stalk fibres, leaves and other biomass components (Baucum *et al.*, 2006) and is used as renewable sources for energy production (Deepchand, 2005). Molasse on the other hand, is what remain after much of the sucrose has been removed as crystals from the boiled cane juice (Baucum *et al.*, 2006). Molasses is mostly used for ethanol production, through fermentation followed by distillation. Up to now, 1/3 of the molasses produced in Mauritius is used for ethanol production with an annual production of 8 million litres per year and is intended to reach 30 million litres in 2015 (Agreco consortium, 2007). This increase is associated with the increase in price of petroleum all around the world. The ethanol produced can be mixed with petroleum and used as fuel, therefore helping to reduce the total gasoline imports (Agreco consortium, 2007). However, the production of ethanol also results in significant production of a polluting distillery effluent known as vinasse (also referred to as slops, dunder, stillage). For every litre of ethanol produced, an average of 12 litre of vinasse is produced. Increasing ethanol production to 30 million litres per year will generate approximately 350,000 m³ of vinasse, which will need to be disposed (Agreco consortium, 2007; CSO, 2006), therefore creating large disposal area. Mauritius, being a small island of 1,860 km² and a population of 1.3 million, (Deepchand, 2005) disposal of such massive amount of vinasse may be possible. However, agriculture can offer a potential solution to this problem by using vinasse as a substitute to inorganic fertilizer (Rosabal *et al.*, 2007).

2.1. Characteristics of Vinasse

Vinasse is an amber or muddy brown liquid with a characteristic odour. It can be characterized physically as an aqueous suspension of organic solids and minerals, whose particle size varies from coarse, dispersed to molecular solution.

Its physical and chemical characteristic varies greatly depending on the raw materials, operating conditions of the fermentation and distillation process (Table 1) (Moreira, 2007). But in general, it is acidic, corrosive in nature, has a high Biology Oxygen Demand and Chemical Oxygen Demand and a high density (Moreira, 2007; Agreoc consortium, 2007). Moreover, vinasse has astringent to nauseating smell, related to the high amount of residual sugar and putrefaction process, which takes place as soon as vinasse is discharged in the environment. Based on its physiological characteristics, vinasse is classified as a Class II solid residue (that is; it is not inert nor dangerous) (Cortez, 2000). However, its physical and chemical composition (high biology oxygen demand, low pH) characterizes it as a pollutant and therefore cannot be disposed easily. Direct application of vinasse to cane field has long been a common practice of handling it. But vinasse increases mobility of metals due to the formation of water-soluble complexes with organic ligands, which favours their transport to lower soil profile and to groundwater (Rosabal *et al.*, 2007). Direct discharge of vinasse in any open water system also has disastrous effect on aquatic life, due to its large demand in oxygen to be stabilized. (Cortez, 2000; Moreira, 2007). The high level of organic load will cause a drop in dissolved oxygen to a level that will not support aquatic life, causing the water to become unsuitable for any other use (Moreira, 2007; Wilkie *et al.*, 2000).

2.2. Vinasse in Agriculture

Many studies have been conducted to determine the characteristics of vinasse in terms of organic strength and nutrients content (Wilkie, *et al.*, 2000). Analysis of results showed that it contains a chemical composition that is well appreciated in agriculture (Courtney, 2005). It has a level high of potassium, calcium and organic matter and moderately high in nitrogen and phosphorus and some micronutrients (Table 1) (Camhi, 1979; Kee Kwong *et al.*, 1997; Gomez *et al.*, 2000). It is normally free from heavy metals and toxic chemicals (Agreco consortium, 2007). Therefore it has a potential for use as organic fertilizer.

Several studies have shown that direct application of vinasse led to an increase in sugarcane yield, cane tonnage, sugar accumulation and promote root development (Rodriguez, 2000; Penatti *et al.*, 2005; Casagrande *et al.*, 2007; Li *et al.*, 2007). However, response to yield varied with rate of applications. Li *et al.* (2007) reported that all three treatments

(45t/hectare, 75t/h and 105t/h) used, showed improvement in cane yield as compared to non-fertilizer control but however highest yield was obtained when vinasse was applied at a rate of 75t/h. Algur *et al.* (1992) also reported that length of shoot, leaf area, biomass and primary productivity increased at concentration up to 2.5% vinasse, but however decreased at higher concentration.

Table 2.1. Vinasse characteristics resulting from different origin

Parameter	Units	Molasses	Cane juice	Mixture of molasses and juice
pH	-	4.2-5.0	3.7-4.6	4.4-4.6
DQO	kg O ₂ /L	65.00	15.00-33.00	45.00
Total solids	kg/L	81.50	23.70	52.70
Volatiles solids	kg/L	60.00	20.00	40.00
Fixed solids	kg/L	21.50	3.70	12.70
Nitrogen	kg N/L	0.45-1.60	0.15-0.70	0.48-0.71
Phosphorous	kg P ₂ O ₅ /L	0.10-0.29	0.01-0.21	0.01-0.20
Potassium	kg K ₂ O/L	3.74-7.83	1.20-2.10	3.34-4.60
Cálcium	kg CaO/L	0.45-5.18	0.13-1.54	1.33-4.57
Magnésium	kg MgO/L	0.42-1.52	0.20-0.49	0.58-0.70
Sulphates	kg SO ₄ /L	6.40	0.60-0.76	3.70-3.73
Carbon	kg C/L	11.20-22.9	5.70-13.40	8.70-12.10
C/N ratio	-	16.00-16.27	19.70-21.07	16.40-16.43
Organic Matter	kg/L	63.40	19.50	38.00
Reducers	kg/L	9.50	7.90	8.30

Source: Camhi, 1979

Because of its composition, vinasse is now treated as a nutrient source rather than a residue in some countries like Brazil (Monteiro, 2007). This is also applicable for Mauritius where two sugar estates; Médine and Beau Plan sugar estate, are now applying vinasse to their cane field. Moreover, Médine also use about 10% of its vinasse for composting with other factory waste such as scum (Agreco consortium, 2007). Some researchers also reported that when

used under controlled conditions vinasse could successfully act as a substitute (either partially or completely) to inorganic fertilizer and therefore contribute to a decrease in cost of production (Gemtos *et al.*, 1999; Rodriguez, 2000; Gonzalo *et al.*, 2006; Rosabal *et al.*, 2007).

Even considered as being a good organic fertilizer, the amount of vinasse added to the soil must be calculated considering the deepness and fertility of the soil, the concentration of potassium in the vinasse and the average extraction of this element to the culture (Durval *et al.*, 2008). Direct and excessive application of liquid vinasse to soil has proved to have detrimental effect on soil physical, chemical and biological, which is probably associated with its high salinity. Aggregates degradation, increase in bulk density, low pH, decrease in microbial biomass and soil enzymatic activities were all observed in treated soil. (Madejon *et al.*, 2001; Tejada *et al.*, 2006a; Tejada *et al.*, 2006b; Rosabal *et al.*, 2007; Tajeda *et al.*, 2007a).

2.3. Management of Vinasse

When the application limit to soil is reached, the application of vinasse is restricted to prevent soil degradation and other means of managing the waste should be considered. Several possible methods exists and these are:

2.3.1. Anaerobic Digestion

Anaerobic digestion seems to be a promising future option for vinasse management for it is economically viable and is an effective means of removal of the organic load as it produces gas, mainly carbon dioxide and methane which can be used for other purposes (Wilkie *et al.*, 2000). However, the volume of stored vinasse in such a process is significant, which may poses significant problems in terms of available space, technical feasibility and risks of possible accidents (Agreco consortium, 2007).

2.3.2. Production of Single Cell Protein

A potentially use of stillage is for the production of single cell protein (SCP) production. An aerobic culture is added to vinasse for removal of residual sugars and soluble proteins. , reduction in Chemical Oxygen Demand and nutrients also takes. The product that is left after the biological treatment could be used as feed materials (Wilkie *et al.*, 2000).

2.3.3. Composting

Composting the waste also seems to be an efficient way for managing vinasse especially for a small agriculture country like Mauritius. This process offers an effective mean to return nutrients to the nutrient cycle of the soil. Moreover, this negative effect of vinasse of soil properties can be overcome when it is co-composted with other agricultural wastes (Madejan *et al.*, 2000; Tejada *et al.*, 2006). In several studies, vinasse has been composted with organic wastes such as scum, cotton gin crushed and red clover (*Trifolium pratense* L.). In all cases, it was reported that application of vinasse compost not only led to increase in yield but also have beneficial effect on soil properties; causing an increasing in soil structural stability, soil respiration, microbial biomass and enzymatic activities (Tejada *et al.*, 2006a; Tejada *et al.*, 2006b; Tejada *et al.*, 2007). The major problem with composting is that it requires large open area, which can be limited in Mauritius. But out the three process composting remain the most feasible method dispose vinasse. Being an agricultural island, the compost so produced can be used in sugarcane field as well as in vegetable production, thereby contributing to decrease in cost of production especially among the small planters.

This project aimed at finding a use for this potentially environment-polluting waste product, by processing it into a form that is safe, effective and easily applied, stored and transported, and thus to revalorize a waste product into a valuable resource, and resolve the issue of its disposal in the environment.

3. METHODOLOGY

3.1. Resources

(a). Following an advertisement made as per the University of Mauritius guidelines, a Research Assistant, in the person of Miss Heidi Noormahomed, was appointed for this work. She is a graduate from the University of Mauritius and successfully completed her BSc. (Hons.) Agriculture with specialisation in Organic Farming.

(b). A review of existing literature was done.

(c). Vinasse was collected from local factories producing ethanol.

(d). Based on preliminary tests, bagasse, ash and scum were identified as being the most appropriate materials for mixing with raw vinasse for the transformation process. These raw materials were obtained from Medine Sugar Estate at several times over the duration of the project, as needed.

(e). Plastic compost bins were manufactured locally.

(f) Equipment required was purchased.

3.2. Analytical work and processing

(a). Each batch of raw vinasse obtained was analysed for the following characteristics :

Organic matter, pH, moisture content, ash, carbon, nitrogen, C:N ratio, total and available ($\text{NO}_3^- + \text{NH}_4^+$)N, mineralisable N, total P, total K, extractable nutrients, Cu, Zn, Fe, Mn, Ni, Co, Cr, Pb.

(b). Each batch of ash, scum, bagasse, and rock dust were also analysed for their chemical properties.

(c). Vinasse was processed by composting in various proportions with the above mentioned materials. Composting bins were of 45 to 50 kg capacity (200 litres). The composting was done twice during the experimental period, with three combinations of raw materials each time, with three replicates for each combination.

The composting material was turned over weekly in order to control temperature, to provide aeration and also to help mix the materials thoroughly. This also helps the microorganisms responsible for the composting process to spread over the substrate evenly and be able to act on all the portions of the mixture.

Samples of this composting mixture were collected at regular intervals for determination of the various parameters.

(d). The following main processing parameters were monitored and optimised :

(i) Temperature, (ii) pH, (iii) moisture, (iv) Electrical Conductivity, (v) Organic matter, (vi) carbon, (vii) ash, (viii) nitrogen, (ix) C: N ratio, and (x) turning frequency.

Other parameters monitored are shown in the Results section.

(e). End product of composting was analysed for :

Compost maturity and quality, organic matter, moisture, carbon, ash, nitrogen, C:N ratio, pH, electrical conductivity, potassium, phosphorus, sodium, magnesium, calcium, iron, manganese, zinc, copper, cadmium, nickel, lead, chromium, particle size.

(f). Data analysis

Results obtained were analyzed using Microsoft Excel and SPSS.

3.3 Analytical Methods Used

All analytical methods used were those that had been established by the PI in his lab and/or by other overseas researchers, as follows :

3.3.1. Determination of Temperature

During composting, temperatures were monitored at 3 to 4 days intervals. Temperatures were taken at 5 different places and at approximately 3 different depths in each of the composting bins.

3.3.2. Determination of Moisture

The moisture content of the mixtures was measured gravimetrically every 3 to 4 days. 100g of samples were dried in an oven at 70 °C for 24 hours. The moisture content was calculated using the values for the weight of the fresh samples and that of the dried samples.

The moisture content of the compost pile was monitored and adjusted to 50 to 60%. If the moisture content dropped to below this value, an appropriate amount of water was sprinkled onto the pile to increase the moisture content. The amount of water needed to increase the moisture content to appropriate levels was calculated as follows:

$$a = \frac{M_b - M}{M - M_a}$$

Where,

a: quantity of water required

M: desired moisture content of 55% (0.55)

Ma: Moisture content of water 100% (1.0)

Mb: Moisture content of compost mix

3.3.3. Determination of pH

pH was determined in water using a sample to water ratio of 1:5 w/w. The samples were shaken in water for 30 minutes and the pH of the solution was determined using a calibrated pH meter.

3.3.4. Determination of Organic Matter

Total organic matter was determined by weight loss on ignition. Five g of oven dry samples were placed in muffle furnace at 500 °C overnight. The total organic matter content was determined according to the appropriate equation.

3.3.5. Determination of Total Carbon Content

The total carbon content was calculated from the total organic matter, using a conversion factor of 1.8.

3.3.6. Determination of Total Nitrogen

Total nitrogen was determined using the Kjeldahl Method. 0.5 g sample was digested in concentrated sulphuric acid and Kjeldahl tablets (as catalyst) at 380 °C until a white precipitate was obtained. When digestion was completed, the digest was poured in a 50 ml volumetric flask and made up to the mark. 10 ml of this digest was pipetted into the steam distillation unit. Steam was passed for a few minutes and distillate was collected in boric acid until the colour of boric acid changed from pink to green. The distillate/boric acid solution was then titrated against 0.05M HCl.

The percentage nitrogen was calculated using the appropriate formula.

3.3.7. Determination of Total Potassium and Phosphorus

5 g of samples were first ashed at 500 °C in a muffle furnace. The ashed samples were digested in nitric-hydrochloric acid mixture (1:3) at first at 50 °C for 30 mins and then increased to 120 °C for 2 hours. The digest was transferred to a 50 ml volumetric flask and

made to the mark with 8.8 % nitric solution. The solution was filtered through Whatman filter paper, and the filtrate used for determination of total potassium and phosphorus.

Total potassium was determined by flame photometer.

Total phosphorus was determined by spectrophotometer.

3.3.8. Determination of Available Potassium

Available potassium was determined using ammonium acetate. 5 g of sample was shaken with 25 ml of ammonium acetate for 30 minutes. The mixture was filtered. The residues were discarded while the filtrate was used for determination of available potassium using flame photometry.

3.3.9. Determination of Total Secondary Macronutrients, Micronutrients and Heavy Metals

- Secondary Macronutrients include: Calcium, Magnesium, Sulphur.
- Micronutrients include: Iron, Zinc, Manganese, Boron, Molybdenum and Copper, Sodium.
- Heavy metals include Cadmium, Lead, Nickel, Chromium.

3.3.10. Determination of Sulphur

25 g of the sample was shaken with 1 g of activated charcoal and 50 ml of calcium chloride. The solution was filtered and the filtrate used for determination of sulphur. 5 ml of the filtrate was mixed with 5 ml of HCl, 10 ml water and 0.25 g barium chloride, and shaken for 30 minutes. Absorbance was measured using spectrophotometer.

3.3.11. Determination of Boron

10 g of the sample was boiled for 5 minutes in calcium chloride solution. The solution was filtered immediately. 1 ml of this solution and 2 ml of buffer masking solution were mixed together. 2 mL of Azomethine-H reagent was added and mixed thoroughly. This solution is allowed to stand for 30 minutes for colour development. Intensity was measured spectrophotometrically at 420 nm.

3.3.12. Determination of Total Calcium, Magnesium, Iron, Zinc, Manganese, Copper, Sodium. Cadmium, Lead, Nickel, Chromium

Level of these elements was determined by digestion of the sample in a mixture of nitric acid and hydrochloric acid after pre-digesting in aqua regia at 50 °C for 30 minutes, and then at 120 °C for 2 hours. The digest was made up to the mark with 8.8 % nitric acid. This solution was filtered, and the filtrates used for analysis.

Concentration of sodium in the filtrates was determined by flame photometry while concentration of the other elements was determined by atomic absorption spectrophotometry using the appropriate cathode lamps.

3.3.13. Determination of Ammonical-N and Nitrate-N

5 g of samples were shaken with 100 ml of 1M KCl for one hour. The suspension was filtered and the filtrates used for the analysis. Ammonical-N and Nitrate-N were determined by steam distillation.

3.3.14. Determination of Ammonical-N

0.5 g of magnesium oxide was added to 50 ml of the extract, and the mixture poured into the steam distillation unit. The distillate was collected in boric acid. The distillate/boric acid solution was then titrated against 0.01M HCl.

3.3.15. Determination of Nitrate-N

0.5 g of Devarda's alloy was added to 50 ml of the extract and the solution poured into the steam distillation unit. The distillate was collected in boric acid and titrated against 0.01M HCl.

4. RESULTS

Results obtained are shown below.

Table 4.1. Mean \pm s.d. of chemical characteristics of vinasse, ash, bagasse and scum (first batch)

	Vinasse	Ash	Bagasse	Scum
pH (1:5)	5.03 \pm 0.01	8.3 \pm 0.2	6.10 \pm 0.58	7.68 \pm 0.11
pH of pure vinasse	4.95 \pm 0.06	—	—	—
Moisture content (%)	90.28 \pm 0.77	35.20 \pm 4.12	57.22 \pm 3.18	57.41 \pm 3.71
Organic matter (%)	66.12 \pm 0.99	11.77 \pm 1.86	92.20 \pm 3.06	68.97 \pm 3.31
Ash (%)	33.88 \pm 0.99	88.23 \pm 1.86	7.80 \pm 3.06	31.03 \pm 3.31
Carbon content (%)	36.73 \pm 0.55	6.54 \pm 1.03	51.22 \pm 1.7	38.31 \pm 1.84
Total Nitrogen (%)	0.24 \pm 0.17	0.1 \pm 0.03	0.24 \pm 0.11	0.98 \pm 0.16
C/N ratio	153	65	204	39
Potassium (%)	10.38 \pm 0.69	1.00 \pm 0.04	0.10 \pm 0.02	0.46 \pm 0.08
Phosphorus (%)	8.35 \pm 1.85	2.56 \pm 0.21	2.30 \pm 0.23	3.14 \pm 0.14
Sodium (%)	11.02 \pm 0.68	0.20 \pm 0.03	0.17 \pm 0.04	0.68 \pm 0.11
Magnesium (%)	1.07 \pm 0.36	3.74 \pm 0.79	0.11 \pm 0.06	1.75 \pm 0.15
Calcium (%)	2.15 \pm 0.21	0.93 \pm 0.03	2.52 \pm 0.07	3.41 \pm 0.31
Manganese (mg/kg)	85.01 \pm 6.93	707.5 \pm 34.0	69.46 \pm 12.59	629.6 \pm 83.83
Copper (mg/kg)	10.0 \pm 2.88	47.21 \pm 2.04	8.38 \pm 0.91	53.67 \pm 6.84
Zinc (mg/kg)	66.04 \pm 4.28	116.0 \pm 8.89	48.35 \pm 4.24	28.63 \pm 0.81
Lead (mg/kg)	8.43 \pm 2.85	0.82 \pm 0.46	2.69 \pm 0.48	3.33 \pm 0.74
Nickel (mg/kg)	1.87 \pm 1.01	97.65 \pm 16.0	5.99 \pm 2.03	79.3 \pm 20.95
Cadmium (mg/kg)	7.82 \pm 0.79	4.14 \pm 0.15	3.54 \pm 0.45	3.57 \pm 0.57
Chromium (mg/kg)	10.43 \pm 0.57	47.77 \pm 2.26	7.13 \pm 1.09	32.37 \pm 3.79
Iron (%)	0.02 \pm 0.01	4.68 \pm 0.61	0.30 \pm 0.07	2.41 \pm 0.49

Table 4.2. Mean \pm s.d. of chemical characteristics of vinasse, ash, bagasse and scum (second batch)

	Vinasse	Ash	Bagasse	Scum
pH (1:5)	4.96 \pm 0.03	8.3 \pm 0.2	6.10 \pm 0.58	8.37 \pm 0.03
Moisture content (%)	90.28 \pm 0.77	19.93 \pm 1.21	13.48 \pm 1.18	48.08 \pm 1.14
Organic matter (%)	66.12 \pm 0.99	11.77 \pm 1.86	92.20 \pm 3.06	54.08 \pm 1.61
Ash (%)	33.88 \pm 0.99	88.23 \pm 1.86	7.80 \pm 3.06	45.92 \pm 1.61
Carbon (%)	36.73 \pm 0.55	6.54 \pm 1.03	51.22 \pm 1.7	30.04 \pm 0.89
Nitrogen (%)	0.97 \pm 0.24	0.1 \pm 0.03	0.24 \pm 0.11	1.12 \pm 0.08
C:N ratio	38	65	204	27
Phosphorus (%)	10.00 \pm 2.56	2.56 \pm 0.21	2.30 \pm 0.23	4.24 \pm 0.14
Potassium (%)	10.48 \pm 2.56	1.00 \pm 0.04	0.10 \pm 0.02	0.84 \pm 0.16
Sodium (%)	11.96 \pm 0.15	0.20 \pm 0.03	0.17 \pm 0.04	0.49 \pm 0.07
Magnesium (%)	1.10 \pm 0.15	3.74 \pm 0.79	0.11 \pm 0.06	1.02 \pm 0.12
Calcium (%)	1.85 \pm 0.27	0.93 \pm 0.03	2.52 \pm 0.07	2.66 \pm 0.07
Iron	579.52 \pm 103 mg/kg	4.68 \pm 0.61	0.30 \pm 0.07	3.22 \pm 0.16 %
Manganese (mg/kg)	85.14 \pm 7.14	707.5 \pm 34.0	69.46 \pm 12.59	592.50 \pm 54.10
Copper (mg/kg)	6.56 \pm 1.12	47.21 \pm 2.04	8.38 \pm 0.91	59.31 \pm 3.18
Chromium (mg/kg)	70.99 \pm 6.01	47.77 \pm 2.26	7.13 \pm 1.09	20.00 \pm 3.5
Nickel (mg/kg)	2.14 \pm 2.28	97.65 \pm 16.0	5.99 \pm 2.03	67.19 \pm 5.38
Lead (mg/kg)	4.66 \pm 3.41	0.82 \pm 0.46	2.69 \pm 0.48	3.04 \pm 0.75
Cadmium (mg/kg)	2.05 \pm 0.36	4.14 \pm 0.15	3.54 \pm 0.45	0.17 \pm 0.08

Table 4.3. C: N ratios of composting mixtures used (first batch)

	Compost A	Compost B	Compost C
Ash	6	3	4
Scum	12	10	6
Bagasse	1	1	2
Vinasse	4	12	10
C:N Ratio	48	51	61

Table 4.4. C: N ratios of composting mixtures used (second batch)

Materials	Compost D	Compost E	Compost F
Bagasse	2.75	4	7.5
Scum	1	1	1.5
Ash	2	2	3.25
Vinasse	8	10	12
CN ratio	70	80	90

Table 4.5. Moisture content (%) of composting mixtures (first batch)

Days	Composts A	Compost B	Compost C
0	35.00 (0.44 l/ kg)*	59.00	50.00 (0.11 l/ kg)
5	51.00 (0.1 l/ kg)	56.00	55.00
8	60.00	60.00	56.00
12	55.00	58.00	55.00
15	54.00	56.00	54.00
19	52.24	56.76	50.52 (4.6 l/kg)
22	51.64 (3.4 l/kg)	54.22	53.48
26	52.26	56.68	51.92
29	51.60	53.28	53.34
33	49.60 (5.5 l/kg)	54.32	51.96 (3.1 l/kg)
36	53.30	52.50	52.32

40	52.88	51.96 (3.1 l/kg)	52.52
43	51.50 (3.6 l/kg)	53.00	51.08 (4 l/kg)
47	53.48	52.68	53.88
50	52.34	52.34	52.96

*Values in brackets represent the amount of water added to raise the moisture content to 55%

Table 4.6. Moisture content (%) of composting mixtures (second batch)

Days	Compost D	Compost E	Compost F
0	60.20	67.38	66.91
7	70.68	70.40	68.56
10	67.38	67.86	67.86
14	65.66	67.62	67.50
17	65.1	67.68	68.08
21	63.14	67.66	68.82
24	63.54	68	67.36
28	63.06	66.86	66.40
31	63	65.36	66.74
35	64.04	65.10	68.38
38	63.89	63.10	66.01
42	62.90	62.59	65.40
45	61.11	65.45	65.90
49	65.21	67.88	73.44
52	63.42	67.52	72.01
56	65.40	68.01	71.88
59	63.88	67.56	72.56
63	62.68	66.01	69.89
66	63.01	66.11	68.66
70	62.12	65.60	65.52
73	62.41	65.04	64.85

Table 4.7. Temperatures (°C) of composting mixtures (first batch)

Days	Compost A	Composts B	Compost C
0	23.4	22.9	23.5
5	60.0	440.6	40.3
8	28.8	58.0	56.0
12	26.2	22.2	23.2
15	22.2	20.8	18.8
19	20.00	19.08	18.75
22	20.42	19.17	19.00
26	19.83	19.08	19.50
29	20.00	20.83	20.50
33	21.50	19.58	20.00
36	20.00	19.67	19.25
40	19.92	19.75	19.58
43	20.33	19.25	19.33
47	20.17	19.50	19.42
50	20.25	19.08	19.00

Table 4.8. Temperatures (°C) of composting mixtures (second batch)

Days	Compost D	Compost E	Compost F
0	21.88	22.00	21.75
5	50.0	48.0	49.00
10	22.13	22.00	22.00
14	22.13	22.13	22.00
17	22.19	22.19	22.06
21	22.94	22.13	22.13
24	22.63	22.00	22.00
28	23.00	22.00	22.00
31	22.00	21.94	22.00
35	21.13	21.88	22.00

38	22.13	22.00	22.00
42	22.00	22.00	22.25
45	22.06	22.13	22.31
49	22.00	22.00	22.44
52	22.13	22.38	21.81
56	22.13	22.25	22.00
59	22.00	22.00	22.13
63	22.06	22.19	22.00
66	22.00	22.19	22.06
70	22.00	22.06	22.19
73	22.00	22.00	21.88

Table 4.9. pH of composting mixtures (first batch)

Days	Compost A	Compost B	Compost C
0	8.28	8.36	8.37
5	8.13	8.25	8.66
8	8.05	8.42	8.35
12	8.23	8.62	8.47
15	7.97	8.41	8.37
19	7.71	8.19	8.20
22	7.91	8.39	8.30
26	7.70	8.20	8.23
29	7.67	8.24	8.21
33	7.56	8.26	8.23
36	7.62	8.13	8.07
40	7.55	8.01	7.98
43	7.51	8.15	8.09
47	7.47	8.11	8.12
50	7.44	7.99	8.09

Table 4.10. pH of composting mixtures (second batch)

Days	Compost D	Compost E	Compost F
0	8.04	8.00	7.81
3	8.04	7.83	7.05
7	8.26	8.02	7.95
10	8.29	8.09	7.82
14	8.21	7.99	7.59
17	8.33	7.88	7.81
21	8.42	8.06	7.92
24	8.40	8.04	7.94
28	8.32	8.02	7.91
31	8.33	8.03	7.94
35	8.34	7.99	7.97
38	8.25	8.00	8.15
42	8.20	8.07	8.12
45	8.25	8.08	8.04
49	8.26	8.10	8.13
52	8.22	8.15	8.05
56	8.24	8.16	7.99
59	8.31	8.15	8.32
63	8.26	8.16	8.11
66	8.23	8.15	8.23
70	8.26	8.11	8.19
73	8.21	8.13	8.21

Table 4.11. Electrical conductivity (ds/m) of composting mixtures (first batch)

Days	Compost A	Compost B	Compost C
12	1.89	3.01	2.61
15	1.64	2.11	2.38
19	1.56	1.73	1.67

22	1.58	1.75	1.67
26	1.59	1.75	1.72
29	1.65	1.89	1.86
33	1.71	1.95	1.93
36	1.72	1.80	1.62
40	1.58	1.70	1.53
43	1.68	1.78	1.54
47	1.77	1.96	2.12
50	1.77	1.97	2.16

Table 4.12. Electrical conductivity (ds/m) of composting mixtures (second batch)

Day	Compost D	Compost E	Compost F
0	2.69	3.22	2.18
3	2.89	3.26	1.87
7	2.85	2.97	2.59
10	2.72	2.90	2.43
14	2.70	3.30	2.90
17	2.74	3.18	2.60
21	2.72	3.04	2.71
24	2.73	3.06	2.72
28	2.46	2.93	2.87
31	2.24	2.33	2.21
35	2.07	2.31	2.21
38	2.19	2.24	2.52
42	2.25	2.16	2.59
45	2.26	2.53	2.60
49	2.30	2.47	2.47
52	2.40	2.51	2.47
56	2.31	2.79	2.22

59	2.46	3.19	2.16
63	3.12	3.08	3.11
66	3.08	2.81	2.95
70	3.04	3.01	3.08
73	2.71	3.07	3.01

Table 4.13. Characteristics of the final compost (first batch)

	Compost A	Compost B	Compost C
Moisture content (%)	33 ± 1.34	37.76 ± 3.38	39.02 ± 1.13
Organic matter (%)	41.46 ± 1.48	48.10 ± 1.35	44.08 ± 3.06
Carbon (%)	23.03 ± 0.82	26.72 ± 0.75	24.49 ± 1.70
Ash (%)	58.54 ± 1.48	51.90 ± 1.35	55.92 ± 3.06
CN ratio	19	18	21
pH	7.82 ± 0.04	7.92 ± 0.04	8.12 ± 0.03
EC (ds/m)	0.76 ± 0.02	2.33 ± 0.08	1.76 ± 0.04
Nitrogen (%)	1.22 ± 0.26	1.51 ± 0.10	1.19 ± 0.07
Phosphorus (%)	6.34 ± 2.22	6.78 ± 0.90	6.70 ± 1.41
Potassium (%)	1.09 ± 0.11	2.19 ± 0.18	2.18 ± 0.12
Sodium (%)	0.20 ± 0.03	0.30 ± 0.05	0.33 ± 0.04
Magnesium (%)	1.17 ± 0.14	1.16 ± 0.13	1.29 ± 0.13
Calcium (%)	1.41 ± 0.39	1.80 ± 0.38	1.68 ± 0.19
Iron (%)	3.78 ± 0.71	4.33 ± 0.56	4.95 ± 0.45
Manganese (mg/kg)	555 ± 57.01	642.70 ± 124.76	652.0 ± 171.31
Zinc (mg/kg)	202.85 ± 5.88	217.62 ± 9.34	182.78 ± 9.12
Copper (mg/kg)	54.22 ± 4.85	51.72 ± 5.32	51.01 ± 3.49
Chromium (mg/kg)	32.72 ± 5.17	34.70 ± 3.92	30.25 ± 2.50
Nickel (mg/kg)	67.22 ± 6.58	69.29 ± 8.53	66.24 ± 6.01
Lead (mg/kg)	2.67 ± 0.55	3.24 ± 0.25	3.54 ± 0.67
Cadmium (mg/kg)	0.32 ± 0.44	0.16 ± 0.08	0.14 ± 0.05
Boron (mg/kg)	0.91 ± 0.14	1.01 ± 0.04	1.00 ± 0.07

Nitrate (%)	0.09 ± 0.0000	0.21 ± 0.02	0.08 ± 0.01
Ammonical-Nitrogen (%)	0.014 ± 0.0001	0.021 ± 0.0001	0.019 ± 0.0001
Sulphate (%)	0.06 ± 0.01	0.31 ± 0.04	0.28 ± 0.04
Particle size (<2mm)	90 %	87 %	75%
Germination Lettuce seeds (%)	100	90	100

Table 4.14. Characteristics of the final compost (second batch)

	Compost D	Compost E	Compost F
Moisture content (%)	61.54(1.31)	64.20(0.85)	68.24(1.78)
Organic matter (%)	59.52(1.26)	65.08(0.48)	56.16(4.60)
Carbon (%)	33.07(0.70)	36.16(0.27)	31.20(2.56)
Ash (%)	40.48(1.26)	34.92(0.48)	43.84(4.60)
CN ratio	45	33	47
pH	8.65(0.16)	8.90(0.08)	8.63(0.18)
EC (ds/m)	1.30(0.05)	2.40(0.19)	1.53(0.01)
Nitrogen (%)	0.73(0.03)	1.08(0.22)	0.66(0.05)
Phosphorus (%)	20.04(1.44)	22.04(1.35)	12.90(3.03)
Potassium (%)	2.13(0.10)	3.29(0.11)	2.16(0.16)
Sodium (%)	0.30(0.03)	0.49(0.02)	0.32(0.02)
Magnesium (%)	0.80(0.08)	0.70(0.06)	0.80(0.04)
Calcium (%)	1.15(0.12)	1.15(0.08)	0.86(0.11)
Iron (%)	2.20(0.57)	2.08(0.05)	2.75(0.22)
Manganese (mg/kg)	551.88(53.33)	591.57(21.58)	703.44(54.46)
Zinc (mg/kg)	74.50(7.78)	81.56(4.65)	73.73(5.95)
Copper (mg/kg)	33.88(2.51)	38.41(2.50)	42.31(2.70)
Chromium (mg/kg)	24.51(1.93)	24.32(1.01)	28.80(1.88)
Nickel (mg/kg)	44.87(4.50)	43.62(0.92)	46.25(6.32)
Lead (mg/kg)	1.52(1.24)	2.22(0.74)	2.36(0.59)
Cadmium (mg/kg)	7.08(1.25)	9.63(0.78)	7.79(2.95)

Nitrate-N (%)	0.02(0.01)	0.03(0.01)	0.01(0.00)
Ammonical-N (%)	0.01(0.00)	0.01(0.00)	0.01(0.00)
Sulphate (%)	0.27(0.07)	0.36(0.11)	0.37(0.05)
Boron (mg/kg)	1.23(0.26)	1.82(0.26)	1.01(0.07)
Particle size <2mm (%)	62	58	42
Plant response (%)	90	93	93

5. DISCUSSION

The results of the analyses of the raw materials used for the transformation process, i.e. vinasse, ash, bagasse, and scum are shown in Tables 4.1 (first batch) and 4.2 (second batch). The parameters determined in both the batches did not differ significantly except for total nitrogen. It is also noted that both batches of raw material were collected from the same sugar factory, i.e. Medine. The high moisture content of vinasse (> 90%) is noteworthy. Similarly the high carbon content (66%) of this material is also to be noted as this is what gives it its high BOD, COD and environmental liability. Total nitrogen was high in the scum and low in the ash. This is understandable when we know that all volatile solids are normally absent in ash. The high phosphorus content of scum makes it an ideal fertiliser especially at the time of planting. This is a very popular both among sugar planters as well as vegetable growers. The high level of potassium in vinasse (10.4%) would make it an ideal potash fertiliser, had it not been for its high organic matter content. In effect some small amount of vinasse is used in animal feed to increase the mineral potassium in it. Levels of zinc in vinasse were also high. Bagasse used for the compost also has alternate uses, e.g. in the generation of electricity, in the preparation of animal feed, and also as a substrate for growing flowers, e.g. anthurium. In fact, the waste products not having high economic value are vinasse and ash.

Mixing ratios

The mixing ratios for the 3 trials conducted in the first phase of the project are shown in Table 4.3. These mixing ratios yielded C/N ratios of 48, 51 and 61 for the first batch of raw materials collected. The second batch of materials collected was mixed to produce C/N ratios of 70, 80 and 90. The objective was to use large amounts of vinasse and to follow the composting parameters such as temperature, pH as the C/N ratio increased from 48 to 90. The C/N ratios are higher than the ideal ones (20 : 1 to 40:1). A C/N ratio of less than 20: 1 leads

to underutilization of nitrogen and excess nitrogen may be lost as ammonia and nitrous oxide to the atmosphere and the compost then gives a bad odour. A C/N ratio of higher than 40:1 may slow down the process of composting.

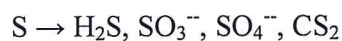
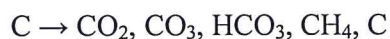
Bioavailability of carbon and nitrogen

Simple sugars such as glucose and simple carbohydrates are more easily degradable by microbes and are degraded first. Complex carbohydrates, cellulose, hemicellulose and lignin decreases biodegradability of substrates. Cellulose is a long chain of glucose molecules linked to one another primarily with beta glycosidic bonds. Hemicellulose are branch polymers of xylose, arabinose, galactose, mannose and glucose. Hemicellulose bonds bundles of cellulose fibres to form microfibrils. They also constitute with lignin a complex web of bonds thereby increasing structure, length and decreasing degradability. Lignins are complex polymer of phenyl propane units which are x-linked to each other. Some fungi have developed enzymes to break lignin. Initial reactions are mediated by extra-cellular lignin and manganese peroxidases. Some Actinomycetes can also degrade lignin.

The order of decomposition of organic molecules in a compost mixture follows the following order :

Simple sugars > starches > simple proteins > crude proteins > hemicellulose > cellulose > lignins > fats > waxes.

It is to be noted that proteins apart from containing C, N, O, H, also contain S, Fe, P, etc. which are released during the composting process. The following products are usually obtained during composting



Other products are H_2O , O_2 , H_2 , H^+ , OH^- , K^+ , Ca^{++} , Mg^{++} , etc.

Particle Size and Bioavailability

The smaller the particles of the substrate, the larger is the specific surface area (m^2/kg). As decomposition starts from the surface, rate of composting is much higher in substrates with small particle size. It has been shown by Gray and Sherman (1970) that grinding the substrate

can increase the rate of decomposition by almost a factor of 2. A theoretical calculation by Haug (1993) demonstrated that particles having size > 1mm may prevent oxygen diffusion.

Volatile solids (VS)

VS are the components (largely C, O, N), which burn off on an already dry sample in a furnace (500-600°C) leaving only ash (largely Ca, Mg, P, K). For most biological materials, the C content is between 45 - 60% of the VS. Assuming 55% is C, the % C is given as :

$$\%C = \%VS / 1.8$$

Moisture

Compost heaps having less than 35-40% moisture have reduced rate of decomposition. In fact, it has been shown that in some cases, if the moisture content is below 30%, the whole composting process stops. Too much moisture leads to anaerobic condition and foul odours (due to release of H₂S). The appropriate moisture must also be considered in relation to particle size and porosity of the substrate. Furthermore, during the composting process, large amount of heat is released with leads to loss of moisture. The moisture of the compost varied from 35% to 70.6%

Temperature

Tables 4.7 and 4.8 give the temperatures recorded during the composting process. For the first batch (Table 4.7), the temperature rose very quickly (in just about 5 days) to 60°C for Compost A. It took 8 days for the temperature to rise to 58°C in Compost B and 8 days for temperature to rise to 56°C in Compost C. Although these compost temperatures are not very high, the end product resulted in appreciable mineralization of plant nutrients. It was found that generally a lower C/N ratio of the original substrate lead to a higher maximum temperature. The C in the substrate is used by the microbes as an energy source as well as to incorporate into body tissues. C from simple organic molecules like glucose are more readily assimilated than C from more complex carbohydrates. It was not in the scope of this project to characterize the different organic molecules in the substrate. The oxidation of C to CO₂ is exothermic and this results in considerable heat being released and an increase in temperature. In the second experiment, Compost D reached a maximum of 50°C in just 5 days, whereas Composts E and F reached maximum temperatures of 48°C and 49°C during

the same period. A high temperature during the thermophilic phase is important to kill pathogens and weed seeds.

Initially, mesophilic organisms (20-35°C) multiply rapidly on the readily available simple sugars and amino acids. Heat is generated by the metabolism and temperature rises. The population of the mesophiles decreases; however, activity of thermophilic bacteria and fungi (optimum temperature 50-70°C) continue the process, raising the temperature of the compost further to the peak temperature. This peak temperature is important to kill pathogen and weed seeds. The active composting process then attains a curing stage where the temperature gradually comes down to the ambient temperature.

pH

pH of the composts showed a gradual decrease (Table 4.9). The decrease in pH was 10% for Compost A, 4.5 % for Compost B and 3.5% for Compost C. During the composting process, acids are released as well as nutrients. Similarly, ammonia is released which can increase the pH. In the second batch the change in pH was negligible. This could be due to neutralization of acids by production of hydroxylamines and some ammonia.

Electrical Conductivity (EC)

This parameter is directly related to the soluble cations and anions and their transport number in the compost extract. EC is related to osmotic pressure and concentration of salts by the following equation :

$$\text{OP (in atmosphere)} = 0.36 \times \text{specific conductance}$$

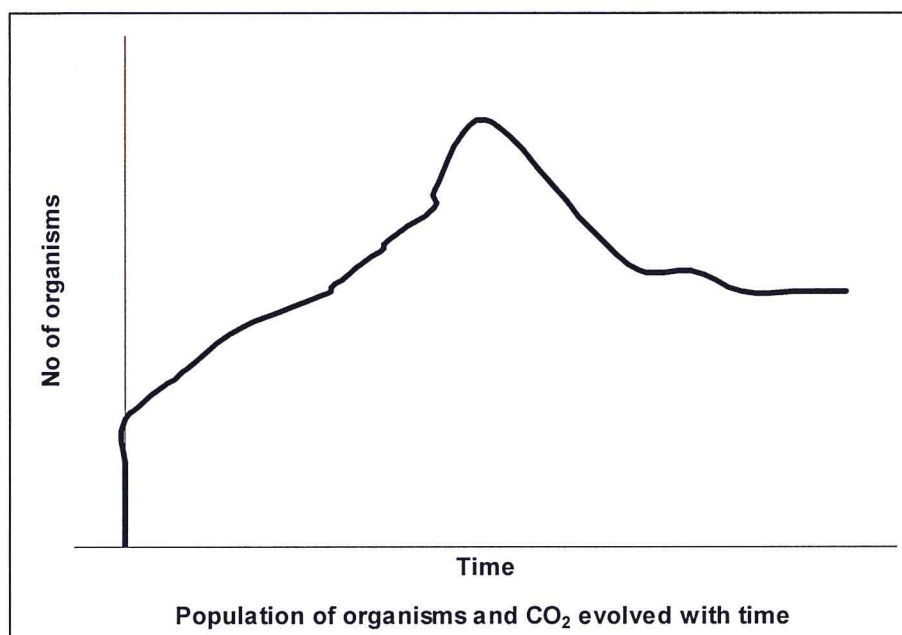
$$\% \text{ of salts in compost extract} = 0.064 \times \text{specific conductance}$$

The EC in both batches did not show significant changes; they were slightly erratic mainly due to mineralization immobilization of nutrients.

Mineralisation (solubilisation of nutrients)

The total nitrogen in the compost from the first batch was greater than the total nitrogen in the raw vinasse by almost 1.3%. The C content reduced by 65% in the first batch and 43% in the second batch. In fact, this was one of the main objectives of the experiment (to decrease the C content of the vinasse since it is essentially this parameter that gives vinasse its high

COD and BOD and makes in an environmental liability). Most of the values of the other nutrients decreased in the compost. However, some of the heavy metals such as Cu increased in the compost, but was still within the acceptable limits.



The graph shows the rate of CO₂ evolution and microbial population with respect to time in a typical compost heap.

Compost Quality

Based on the characteristics of the endproduct (Tables 4.13 and 4.14), it can be stated that the following ratio of substrates gave the best final compost in terms of physical and chemical

Vinasse : Bagasse : Ash : Scum = 4 : 1 : 6 : 12.

Higher proportion of vinasse or ash did not produce a better compost and will increase the composting time and reduce the peak temperature attained. Hence, it is recommended through this study that the above ratio of raw materials be used to obtain compost of optimum characteristics, with a weekly turning frequency.

6. CONSTRAINTS TO THE WORK

Some of the technical problems/ difficulties that arose during analysis of samples, and which contributed to some delay in the work, include :

Working of equipment.

(i). For analyses of nitrogen, only one heating block was available in the Soil Science laboratory. The heating block consists only of 6 cells, indicating that only 6 samples can be heated at a time. For analysis of total nitrogen, for which the digestion process is very long, it takes several days before the analysis can be completed and the nitrogen content of a particular material determined. Given that students and other staff needed to use the heating block as well, there was a bit of delay in completing this analysis.

(ii). Only 2 muffle furnaces (a large one and a small one) are available. The largest can accommodate only 6 to 10 crucibles (depending on the size of the crucibles) while the smaller one can accommodate only 5 medium size crucibles. It takes approximately 2 to 3 days to ash all the 15 samples of a particular material. Since Faculty regulations require that the furnace be switched off every evening, this took some time to ash all the samples and caused delay in the work.

(iii). The oven in the Soil Science lab was out of order for several weeks, which delayed the analyses work.

(iv). The EC apparatus broke down during the analytical work, and there was some delay in getting another one. This also caused some delay in the work.

7. CONCLUSION

The present investigation showed that vinasse, which is an environmentally toxic materials, can be transformed into a more acceptable product by composting it with sugarcane industry by-products, on the six trials conducted, it was found that the following ratio of substrates gave the best final compost in terms of physical and chemical properties.

Vinasse : Bagasse : Ash : Scum = 4 : 1 : 6 : 12.

Higher proportion of vinasse or ash did not produce a better compost and will increase the composting time and reduce the peak temperature attained. Hence, it is recommended

through this study that the above ratio of raw materials be used to obtain compost of optimum characteristics, with a weekly turning frequency.

8. FUTURE WORK PLAN

The Phase II of the project consists of studying the agronomic characteristics of the compost obtained, in particular the effects on soil properties, soil health and fertility, as well as on the growth and health of selected crop species, pests and disease attack, and qualitative and quantitative yield. Based on these parameters, the original composition and/or proportion of the raw materials used for the compost may be modified to improve the desired agronomic characteristics of the end-product. The methodology used will include potted experiments as well as small scale field trials.

9. REFERENCES

- Algur, O.F. and Kadioglu, A. (1992). The effects of vinasse on the growth, biomass and primary productivity in pea (*Pisum sativum*) and sunflower (*Helianthus annuus*). *Agriculture Ecosystems and Environment Netherlands* 39 (34). 139-144.
- Baucum, L.E., Rice, R.W. and T. J. Schueneman, T.J. (2006). An overview of Florida sugarcane. University of Florida, IFAS extension publication. <http://edis.ifas.ufl.edu/SC032>. Date assessed: 01/02/2008.
- Camhi, J.D. (1979). "Tratamento do vinhoto, subproduto da destilação de álcool", *Brasil Açucareiro*, 94 (1). pp 18-23: In: Vinasse: Life cycle analysis and cost assessment of different methods for its disposal. International sugarcane biomass utilization consortium 2007.
- Casagrande, A.A., Buzolin, P.R.S., Mutton, M.A., Mutton, M.J.R. and Compos, M.S. (2007). Effects of trash, vinasse and nitrogen application on ratoon sugarcane. International Society of Sugarcane Technologist 26th Congress, Durban, South Africa.
- Cortez, L.A.B. and Brossard P. L. E. (1997). Experiences on Vinasse Disposal: Combustion of Vinasse 6 Fuel Oil Emulsions. *Brazilian Journal of Chemical Engineering*, 14 (1). 9-18.

Deepchand, K. (2005). Sugar cane bagasse energy cogeneration – Lessons from Mauritius. Parliamentary Forum on Energy Legislation and Sustainable Development, Cape Town, South Africa. 5-7 October 2005.

Durval, R.P.J. and Marcilio N.A.G. (2008). Potentialities of the biodigestion of the vinasse.<http://www.cori.unicamp.br/centenario2008/completos/A09%20%20POTENTIALITIES%20OF%20THE%20BIODIGESTION%20OF%20HE%20VINASSE.pdf>. Date assessed: 28/01/2008.

Gemtos, T.A., Chouliaras, N. and Marakis, S. (1999). Vinasse rate, time of application and compaction effect on soil properties and durum wheat. *Journal of Agricultural Engineering Research* 73 (3). 283-296.

Gonzalo, D.D.P., Casagrande, J., Soares, M. and Mouta, E. (2006). Effect of high levels of vinasse application on soil fertility and potash leaching. Proc. 18th World Congress of Soil Science, Philadelphia, Pennsylvania, USA. 9-15 July 2006.

Kee Kwong, K.F. and Paul, J.P. (1997). Vinasse as a potassium fertilizer for sugarcane. *Revue agricol et sucrière de l'île Maurice*. 76. 34-37.

Lalljee, B. (2000). Fertiliser materials from sugar industry by-products. *Engrais derive de sous-produits de l'industrie de sucre. Sols Africain/African Soils*. 31. 215-232.

Lalljee, B. (2006a). Heavy Metal Content of Sugar Industry Wastes and its Effects on Soil Properties. Proc. 18th World Congress of Soil Science, Philadelphia, USA. 9th to 15th July 2006.

Lalljee, B. (2006b). The use of composted vinasse, a sugar factory waste product, to improve soil quality and crop yield. Proc. International Conference on Agricultural Wastes: Turning Wastes to Wealth, University of Putrajaya, Malaysia. 21st to 23rd March 2006.

Lalljee, B. and Facknath, S. (2006). The use of vinasse, a sugar factory effluent, as an organic fertiliser for improved soil biological properties. Proc. International Conference on

Agricultural Wastes: Turning Wastes to Wealth, University of Putrajaya, Malaysia. 21st to 23rd March 2006.

Li, Y., Zhu, Q. and Solomon, S. (2007). The effect of a novel system of vinasse application on sugarcane growth and yield in China. International Society of Sugarcane Technologists 26th Congress, Durban, South Africa.

Madejon, E., Lopez, R., Murillo, J. and Cabrera, F. (2001). Agricultural use of three (sugar-beet) vinasse composts: effect on crops and chemical properties of a Cambisol soil in the Guadalquivir river valley (SW Spain). *Agriculture Ecosystem and Environment* 84 (1). 55-65.

Moreira, J. R. (2007). Water use and impacts due to ethanol Production in Brazil. http://www.iwmi.cgiar.org/EWMA/files/papers/Jose_Moreira.pdf. Date assessed: 28/01/2008.

Penatti, C.P., De Araujo, J.V., De Souza, S.A.V., Forti, J.A. and Ribeiro, R. (2005). Vinasse: A liquid fertilizer. Proceedings of the xxv congress of International Society of Sugarcane Technologists, Guatemala. 30th January to 4th February 2005 1. 403-412.

Rodriguez, J.G.O. (2000). Effects of vinasse on sugarcane (*Saccharum officinarum*) productivity. *Rev. Fac. Agron. (LUZ)*. 17. 318-326.

Rosabal, A., Morillo, E., Undabeytia, T., Maqueda, C., Justo, A. and Juan, F. (2007). Long-term impacts of wastewater irrigation on Cuban soil. *Soil Science Society of American Journal* 71. 1292-1298.

Sweeney, D.W. and Graetz, D.A. (1988). Chemical and decomposition characteristics of anaerobic digester effluents applied to soil. *J. Env. Quality*, 17. 309-313.

Sweeney, D.W. and Graetz, D.A. (1991). Application of distillery waste anaerobic digester effluent to St. Augustin grass. *Agric. Ecosystems and Environ.* 33 (4). 341-351.

Tejada, M., Garcia, C., Gonzalez, J.L. and Hernandez, M.T. (2006a). Organic amendment

based on fresh and composted beet vinasse: Influence on soil properties and wheat yield. *Soil Science Society American Journal* 70. (900- 908).

Tejada, M. and Gonzalez, J.L. (2006b). Effects of two beet vinasse forms on soil properties and soil loss. *Catena* 68 (1). 41-50.

Tejada, M., Gonzalez, J.L., Garcia-Martinez, A.M. and Parrado, J. (2007). Application of a green manure and green manure composted with beet vinasse on soil restoration: Effects on soil properties. *Bioresource Technology* 22.

Wilkie, A. C., Riedesel, K.J. and Owens, J.M. (2000). Stillage characterization and anaerobic treatment off ethanol stillage from conventional and cellulosic feedstocks. *Biomass and Bioenergy*, 19. 63-102.

I certify that to the best of my knowledge (i) the statements herein (excluding scientific hypotheses and scientific opinions are true and complete (2) the text and graphics in this report as well as any accompanying publications or other documents, unless otherwise indicated are the original work of the signatories or individuals working under their supervision.

PI Name : Assoc Prof Dr B. Lalljee

Signature :

