MAURITIUS RESEARCH COUNCIL

SAFE AND SUSTAINABLE UTILISATION OF COAL/BAGASSE ASH IN AGROECOSYSTEMS AS SOIL AMENDMENT AND FOR CROP PROTECTION

Final Report

December 2013

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UNIVERSITY OF MAURITIUS

Safe and sustainable utilisation of coal/bagasse ash in agroecosystems as soil amendment and for crop protection

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Final Report

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Executive summary

This project attempted to evaluate the agronomic and environmental characteristics of ash, which is a waste product generated during energy production from coal and bagasse (coal ash and bagasse ash, respectively). Ash is produced in large amounts and its injudicious disposal into the environment can have adverse consequences for human, plant, and animal health (Kumar et al, 1998). The best strategy would be to convert this waste into a resource that can be utilised, for instance in agriculture (Munbodh, 1995; Lalljee, 2000; Bhantoo, 2002; Lalljee, 2006) and construction.

This project will investigated and developed the optimum rate and frequency of ash application to soil to improve soil properties, control pests, and enhance crop growth and yield. The study will also investigated the effect on soil biodiversity. Scientific data from the experimental work was statistically analysed .

Many soils in Mauritius are acidic, and under such conditions, plants are able to take up very small amounts of nitrogenous, phosphatic and potassic nutrients, and hence, even large scale additions of fertilizers and compost can fail to provide the essential nutrients to the crop. On the other hand, high alkalinity too can have a similar effect (although the reason for the unavailability of the nutrients is not the same). Moreover, Mauritian soils are deficient in silicon (Lalljee, 2008). Ash has the potential to reduce soil acidity and serve as a soil amendment and conditioner. Ash can also help in pest control by its abrasive effect on soft-bodied pests such as molluscs and insect larvae. However, it is necessary to investigate the appropriate rate, frequency and mode of application to ensure that the effects of ash are optimized, and that there is no toxicity to the plant or soil resulting from excessive application.

This project will help (i) reduce the amount of ash that would need to be disposed of into the environment, (ii) provide a locally-produced, easily available, soil amendment and crop control product which can be used in conventional and organic agriculture, the latter in itself being a high value-added activity envisaged by the 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 ash, (v) increase the income of flexi-factories, and State-owned

and Independent Power Producers through the sale of this by-product, and create business opportunities for Small and Medium Enterprises (SMEs).

I. Introduction

Ia. Background

The Africa Adaptation Programme (AAP), funded by the Government of Japan, has as its main objective the integration and mainstreaming of climate change adaptation into the institutional framework and into core development policies, strategies and plans for the Republic of Mauritius. One aspect of the programme involved research in the area of Climate Change adaptation in Mauritius, coordinated by the Mauritius Research Council (MRC).

One key aspect of climate change mitigation is reduction in use of fossil fuels and therefore green house gas emissions and increase in renewable energy sources. Mauritius has a long history in the use of sugarcane bagasse as a source of energy.

The Ministry of Environment and Sustainable Development (MoESD), the main coordinating body at Government level, has solicited ~~the~~ an apex body under the Ministry of Tertiary Education, Science & Technology to promote Research and Development in Mauritius, to coordinate the research part of the AAP Program.

In this context the MRC under its Unsolicited Research Grant Scheme (URGS) has funded 11 research projects; eight (8) of which deal with climate change adaptation and three (3) of which focus on coal ash management.

Ib. Rationale

In spite of the increasing move towards renewable energy sources, coal remains the major source of energy in many countries, including the US, Brazil, Russia, India, China and South Africa. Coal is abundant on the African continent and is expected to last for another 300 years. All fuels produce wastes; coal and biofuels produce ash. Around 70,500 tonnes of coal ash is generated annually in Mauritius. The technology and management of the polluting side-effects of coal-based production of energy are continuously improving.

Mauritius is already classified as a middle-income country and is aspiring to be among the high-income countries. For this to happen, all the key sectors of the economy must develop and progress concomitantly. The Government of Mauritius, has responded to the triple economic shocks (reduction in export price of sugar to the European Union, erosion of the preferential trade agreement, increase in the prices of petroleum and food) by promulgating bold policies for

re-engineering the sugar industry into a sugarcane industry, with the help of processes such as clustering, flexi-factories, and value addition of sugarcane, its by-products, ethanol, special sugars, and waste products. Bagasse ash is one such waste/by-product that needs to be revalorized and utilised to reduce the amount disposed in the environment. The attention and importance given by Government to the physical environment and to the health of its people is evidenced by Government's efforts to decrease the proportion of fossil fuel in the country's energy mix, and to reduce the environmental impacts of the waste products resulting from the use of fossil fuel, e.g. ash.

Any development is driven by energy. In line with the principles of sustainable development encompassed in the Maurice Ile Durable vision of the Prime Minister, the Government is focused *inter alia* on diversifying the country's energy profile, and addressing environmental and climate changes. The energy strategy has been given top national priority as a means of addressing the development and environmental challenges ahead, and meeting the Millennium Development Goal 7 of Environmental Sustainability. While Mauritius has done very well on most of the other goals, this is one area where the need for a more concentrated effort is necessary. The heart of the energy plan rests on innovation through science driven development of new technologies, particularly for resolving and supporting a future of cleaner energy through an array of resources that include renewable sources, and traditional fossil fuels linked with new technologies that reduce their environmental impact (Long Term Energy Strategy, 2009).

About 40% of the country's total power requirement is produced by the Central Electricity Board from its four thermal power stations and eight hydroelectric plants, while the remaining 60% is purchased from Independent Power Producers, who produce electricity from sugarcane bagasse and coal. Presently the energy mix comprises about 17% from renewable sources (solar, biofuel, wind and hydro), and the rest from fossil fuels such as coal and heavy oil. Of these renewable sources, bagasse alone accounts for 93.2% and fuel wood 2.9%, while the rest is from hydro (3.5%) and wind (0.4%). Overall, the total fuel inputs are composed of 50.4% coal, 27.7% bagasse and 21.4 % fuel oil (Long Term Energy Strategy, 2009).

Government strategy is to increase the proportion of the renewables to 35% by 2025 for the country's electrical supply, and increase the contribution of bagasse based electricity in the medium-term from the present level of 350 GWh to 600 GWh annually (Long Term Energy Strategy, 2009). This will increase the amount of bagasse ash produced. Post-2025, 65% of the energy will still come from coal and oil. If the 20MW Waste-to-Energy plant at La Chaumiere and the setting up of a coal plant of 110 MW at Pointe aux Caves will be implemented, this further increase the tonnage of coal ash that will need to be disposed.

The disposal of this quantity of ash represents a potential environmental problem that needs to be addressed as a matter of priority. The imperative to maintain the health of the population, and the ecosystems and natural beauty of the country as a tourist destination, makes it necessary to adopt a proactive approach, and develop means of disposing this potential hazard. Fortunately, it is possible to adopt technologies and techniques that permit valorization of this waste/by-product into wealth in a number of ways, such as in agriculture and construction.

This project investigates the potential of using coal/bagasse ash for improving the physical, chemical and biological properties of agricultural soils, for contributing to crop protection and crop growth, thereby enhancing qualitative and/or quantitative yields. Mauritian soils are acidic, and given its ability to increase the pH of soils, ash can be a potentially good soil amendment. The physical abrasiveness of ash can also enable its use for controlling soft-bodied, crawling agricultural pests, such as snails, slugs, millipedes, insects and insect larvae. Ash is composed of a large number of minerals, including the essential ones needed for crop growth (trace elements), namely iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), and molybdenum (Mo) (Lalljee, 2006).

Ic. Literature review

Ash is characterized by physical (lightweight, small spherical particles, hardness) and chemical (cement-like) properties that provide it with an economic value as a raw material in many applications. The ash also contains unburned carbon residue that gives it its dark color. The carbon content commonly found in coal ash is in the range of 3% - 6%. Ash is rich in minerals, and can contribute Fe, Zn, Cu, Mn, Mo (five of the seven essential micronutrients), to the crop

(Anguissola *et al.*, 1999). This property enables the use of ash as a soil conditioner which can contribute to increased crop yields (Basu et al, 2009). Arivazhagan et al (2011) reported that coal ash increased yields of cereal crops by upto 20%, sugarcane by 30%, maize by 40%, red gram by 50%, potato by 25%, mustard by 30% and vegetables by 10% through the effects of improved physical soil structure, better soil health, and increase in nutrient uptake by the plants. Bagasse ash does not contain N, and although it contains significant concentrations of K and P (Page *et al.*, 1979), the P is not bio-available. However, the latest coal-based energy production units often add ammonia as a flue gas conditioner to limit NOX emissions; this may lead to some plant-available N. Its use in agriculture can therefore be beneficial. Jamil et al (2004) demonstrated the impact of various rates of bagasse ash on wheat (*Triticum aestivum*) applied with and without a basal application of NPK. Wheat yield and yield components were shown to increase significantly with various rates of bagasse ash as compared to unamended soil, but maximum plant height, spike length, number of productive tillers, and grain yield were obtained at 2% application rate, while number of tillers and straw yield was significantly higher at 10% application rate. Lalljee (2000, 2002, 2006) and Lalljee and Facknath (2006a, 2006b) demonstrated that ash, composted with other sugar industry wastes, namely vinasse, scum and bagasse, could provide a good compost for soil health improvement, and yield increases in beans, maize, and cabbages. However, the direct application of ash alone to vegetable cultivations has not been scientifically investigated in Mauritius so far.

The cementing ability of coal ash and its high calcium content was shown to lower the dispersivity of certain loessial soils and the swelling capacity of sodium-rich soils (Fine et al, 2009). Furthermore, the addition of ash to sandy soils increased water retention eight-fold and reduced susceptibility to wind erosion (Fine et al, 2009). Ash addition improved water infiltration up to 2.5 fold in loessial soils by inhibiting the formation of crust. The albedo measurements confirmed the inhibitory effect of ash addition on crust formation. Weakening the crust, on the other hand, increased the susceptibility of the loess to wind erosion. Addition of fly-ash to sodium-rich soils reduced swelling to such a degree that the treated soil did not display any cracks, while the untreated soil cracked severely upon drying (Fine et al, 2009).

The acid-reducing effect of ash is of particular importance, given that the usual practice of lime to correct soil acidity has been implicated in global warming and climate change (IPPC, 2007) due to the release into the atmosphere of all the carbon in the lime in the form of CO_2.
Ash modifies the soil biochemistry variably, for instance it gives positive increases in urease and dehydrogenase activities and reduction in the β-glucosidase and alkaline phosphatase activities. It has been reported that coal ash can be added up to a dosage of 35% in some types of soil without any deleterious effects on the processes of nutrient recycling in the soil (Fine et al, 2009). However, the appropriate dosage of ash to be applied needs to be carefully studied since excessive amounts of ash to soil may cause P deficiency, even when the ash contains adequate amounts of P, because soil P forms insoluble complexes with the Fe and Al in more acidic ashes (Adriano et al., 1980) and similarly insoluble Ca-P complexes with Class C ashes. Amendment of K-deficient soil with fly ash increases plant K uptake, but the K in fly ash is apparently not as available as fertilizer K, possibly because the Ca and Mg in the fly ash inhibit K absorption by plants (Page et al., 1979).

Furthermore, ash contains radioactive elements in small quantities, and their concentration in ash is relatively larger than their concentrations in most natural rocks and soil. Since the source of coal is an agglomeration of organisms and minerals accumulated over extended geological time periods, it contains most of the natural elements at concentrations that are characteristic of the environment of the deposit from which it was mined, including heavy metals and radioactive elements. In the combustion of coal, some of the elements evaporate and others concentrate in the mineral residue in the form of ash. The ash is composed mainly of the inorganic constituents of the coal: oxides of silicon, aluminum, iron and calcium, and also of some trace elements which are hazardous to the environment. However, in general, the availability of the hazardous materials is quite low, both because of their level of solubility that is limited as a result of chemical bonds that are created in the ash at high temperatures of the combustion compartment and the glassy structure of the particles, and because of their low concentration in the ash as trace elements. This is the reason that coal ash itself is defined as "a returnable by-product of the energy production that requires environmental supervision for its uses". In the USA, coal ash is used extensively in the construction of roads and bridges and is classified as a non-hazardous waste by the American Coal Ash Association (ACAA, 2011).

The major attribute, which makes ash suitable for agriculture, is its texture and the fact that it contains almost all the essential plant nutrients, except organic carbon and nitrogen. Although ash cannot substitute the need of chemical fertilizers/ manure, it can be used in combination with these to get additional benefits in terms of improvement in soil physical characteristics, crop protection, and increased yields. As in the case with fertilizers and any other agriculture input, the amount and method of ash application would vary with the type of soil, the crop to be grown, the prevailing agroclimatic condition and also the type of ash available, and must be determined through site-specific investigations.

The microbial community structure can be studied in a new dimension by using Density Gradient Gel Electrophoresis (DGGE) (Roesti et al., 2006). The molecular approach to understanding the relationship between environment and microbial community includes DNA extraction from the rhizosphere followed by DNA purification and amplification of bacterial 16S rRNA gene using polymerase chain rection (PCR) and then run the PCR product on DGGE. The data collected will be in the form of DGGE fingerprints and banding patterns representing bacterial populations. Normalization of banding patterns and their conversion to numeric format will result in better understanding of the change in bacterial population structure with respect to coal ash amendment at different time intervals. The data will be run through Principal Component Analysis (PCA) which will reduce the number of variables in the data matrix (Li *et al*, 2010). Total analysis will help us to track the changes in bacterial community structure during the experiment duration.

Sequencing studies of the DGGE bands excised from the gel will aid in comparing with the public DNA database sequence using BLAST. There is a possibility of identifying some microbial populations specific to the region and environment, which can be identified as a new strain/species and can be researched further. Other partial 16s rRNA gene sequences generated during the experiment can be deposited in the genebank under a new accession number.
Soil microorganisms are the most promising and valuable source of natural products, including antibiotics. Only 1% of the total 10, 000 predicted bacterial species are culturable in laboratory. The rest of the 99% is uncultivable and hold a vast potential of gene pool with capacity to produce natural products e.g. secondary metabolites. Gene mining based on construction and screening of complex libraries derived from the soil metagenome provides new opportunities to

explore and utilize the enormous genetic and metabolic diversity of soil microorganisms Spı´z˘ek *et al* (2010). Since all the genes required for the biosynthesis of bacterial natural products reside on bacterial chromosome, the metagenomic library construction from the environmental DNA is the best choice to functionally assess the secondary metabolites in the uncultivable microbial community. Metagenomic approach (Kim, Simmons and Brady, 2009) contributes to the development of valuable information about microbial community structures and array of natural products that can be tapped. This will, in turn, lead to advancement in agriculture, environmental remediation and human health.

Unlike many other wastes, coal and bagasse ash could be utilised as, and turned into, important economic inputs in agriculture. However, the direct and indirect economic value that coal and bagasse ash represents, especially to flexi-factories, farms and SMEs, has not been systematically studied in Mauritius. Investigating how ash can result in cost savings to firms, industries and the general economy will not only help promote the economic bottom-line of economic agents but also help build the long-term sustainability of the economy. Methodologies that have been used to assess the economic impacts of coal ash include partial and general equilibrium analysis (Veritas, 2011), cost-benefit analysis and net present value models (Carlin, 2009). Atkinson and Mourato's (2008) comprehensive approach to environmental cost-benefit analysis and Jorge and de Rus' (2004) practical approach to cost-benefit analysis would form the basic framework of cost-benefit analysis in the current study.

Many soils in Mauritius are acidic due to the climate (namely high precipitation) and also due to unsustainable agricultural practices such as heavy use of nitrogenous chemical fertiliser, Both these leach soluble nutrients and make the soil acidic to very acidic with pH values of 3-6. Acidic soils are degraded soils and have low productivity. At low pH, the plant availability of nitrogenous, phosphatic and potassic nutrients is low, as a consequence of which the large amounts of fertilizers and compost added by farmers do not achieve the expected result of increased plant growth and development. Worse still, the unutilised fertilisers and nutrients leach into nearby water bodies, causing eutrophication and other environmental hazards. On the other hand, high alkalinity too makes nutrients unavailable to the plants, and both these phenomena translate into reduced crop yields at very low and very high pH values.

The best amendments for these kinds of soils are lime and coral sand. However, extraction of coral sand and use of corals for lime manufacture, are both not allowed in Mauritius. Cement can also be used in controlled amounts, but cement is quite expensive for use as a soil amendment. Ash has the potential to serve as an alternative soil amendment.

Ash is being used in agriculture in several countries, either as a direct soil amendment to improve the physical, chemical, biological, biochemical properties of the soil, for pest control (Facknath and Lalljee, 2005), and also as a source of minerals for plant growth (Arivazhagan et al., 2011; Fine et al., 2009; Jamil et al., 2004). However, it is not possible to adopt a transfer-of-technology approach, since the rate and frequency of application depends on a number of factors, such as composition of the ash, soil type, soil biodiversity, climatic conditions, and land use. This project investigated and developped the optimum rate and frequency of ash application to soil to improve soil properties, control pests, and enhance crop growth and yield. The study will also investigate the effect on soil biodiversity, and also the economics of coal and bagasse ash use by conducting a cost-benefit analysis and economic impact assessments, sensitivity and risk analysis. Scientific data from the experimental work, and economic data through surveys and established sources, will be statistically analysed to develop predictive economic models on the use of ash.

Under the acidic conditions of most Mauritian soils, plants are able to take up only very small amounts of nitrogenous, phosphatic and potassic nutrients, and hence, even large scale additions of fertilizers and compost can fail to provide the essential nutrients to the crop. On the other hand, high alkalinity too can have a similar effect (although the reason for the unavailability of the nutrients is not the same). Moreover, Mauritian soils are deficient in silicon (Lalljee, 2008). Ash has the potential to reduce soil acidity and serve as a soil amendment and conditioner. Ash can also help in pest control by its abrasive effect on soft-bodied pests such as molluscs and insect larvae. However, it is necessary to investigate the appropriate rate, frequency and mode of application to ensure that the effects of ash are optimized, and that there is no toxicity to the plant or soil resulting from excessive application.

Coal and bagasse ash are mineral products containing large amounts of calcium oxides (CaO), aluminum oxides (AlO), oxides of silica (SiO), etc., and all these, when dissolved in water, produce solutions of high alkalinity. Application of ash in a controlled manner therefore can prove to be a good agricultural practice for increasing soil pH, and at the same time, finding a use for this 'waste'. The normally low levels of Si in Mauritian soils can also be amended by ash, which contains high amounts of Si (Lalljee, 2008). However, it is necessary to investigate the appropriate rate, frequency and mode of application to ensure that the effects of ash are optimized, and that there is no toxicity to the plant or soil resulting from excessive application.
Plants are unable to take up nitrogen, phosphorous or sulphur. Micro-organisms in soil convert nitrogen into nitrates, phosphorous into phosphates and sulphur into sulphates, which can be taken up by plants. Nitrifying bacteria of the *Nitrobacter* genus convert nitrogen into ammonia, which is, in turn, converted into nitrites and then nitrates by *Nitrosomonas* bacteria. At low pH, the population of the micro-organisms is insufficient, and there can be accumulation of ammonia which cannot be taken up by plants. Ammonia can be toxic to plants.

Vesicular Arbuscular mycorrhyza (VAM) fungi convert phosphorous into phosphates. *Frankia* spp and *Berinkia* spp are other soil micro-organisms that play an important role in soil reactions that have implications for soil fertility and productivity. Soil microorganisms are natural factories which help in bio-availability of soil nutrients, enhance root health, provide biological control against pathogens, increase nutrient uptake in roots, better soil structure, water stress resistance.

The multivalency of the mineral content of ash can also have an impact on the soil structure through its property to attract and hold several soil particles at a time. This can result in a strong soil structure that has numerous contiguous pores for air and water, leading to improved pore size distribution, improved soil architecture, better water holding capacity, better aeration, and better percolation, all of which are key factors impacting on sol fertility and productivity. Such soils also have better Erosion Resistance.

Coal ash can affect the soil microbial community and crop growth and health in positive or negative ways depending on the amount of coal ash amended in the fields. There could be

changes in soil microbial community structure in association with the plant rhizosphere. To understand the flow of change, it is necessary to first study the functional diversity and community structure of microorganisms associated with the subject agroecosystem before and after coal ash amendment and over a period of time. To tap the metabolic activity of the soil microbial community it is also important to study the carbon source utilisation patterns of soil microorganisms from the ash-amended and unamended soils, and develop community-level physiological profiles (CLPP) for a series of carbon sources.

The use of ash as an abrasive to control soft-bodied insect larvae, snails and slugs is an old traditional practice (Indigenous/Traditional Knowledge) (Facknath and Lalljee, 2005). The ash abrades the soft exo-cuticle of the organism, in particular the hydrophobic-lipophillic principles in the cuticular layers. This results in increased moisture loss from the skin, resulting in dehydration and eventual death of the organism. However, this practice has been lost since decades due to the easy availability of synthetic insecticides. However, the environmental and health hazards to humans and animals of such synthetic insecticides are increasing causes of concern, and are the main reason for the renewed interest in alternative methods for pest control in many parts of the world.

To assess the nature of microbial life is in soil ecosystems, fatty acid lipid profiling along with Density Gradient Gel Electrophoresis (DGGE) will be used to develop a comparative study on microbial community structures and to discriminate between individual microbial groups. Fatty acid lipid profiling is a proven technology for analyzing any shifts in population structure. The nature of microbial life will be explored in terms of population shift due to coal ash amendment. Whole Phospholipid Fatty Acids (PLFA) pattern analysis as per Zaady *et al* (2010) which provides for active living membrane fraction (as opposed to fatty acid methyl ester (FAME) analysis which provides for dead and inactive components) will be carried out. Data generated by PLFA profiling will be used for building taxonomic database and physiological activity biomarker identification using proven technology for analyzing any shifts in population structure. The nature of microbial life will be explored in terms of population shift due to coal ash amendment. Whole PLFA pattern analysis as per Zaady *et al* (2010) which provides for active living membrane fraction (as opposed to Fatty Acid Methyl Ester (FAME) analysis which

provides for dead and inactive components) will be carried out. Data generated by PLFA profiling will be used for building taxonomic database and physiological activity biomarker identification

Id. Objectives of the project

The main objectives of this research project are to:

(i) Determine the effect of ash addition to soil physical, chemical, biological, microbiological and biochemical properties.

(ii) Determine the effect of ash addition on snails, slugs, and soft-bodied crawling insects, insect larvae and millipedes, and the consequent role in crop protection.

(iii) Determine the effect of ash addition on crop growth and crop yield through its effects on soil properties and pest control.

2. An evidence-based report which will include the following information :

- The effects of various levels of ash amendment in one season on soil physical, chemical and biological properties;
- The effects of various levels of ash amendment in one season on the growth and yield of Maize and Potato;

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2. Methodology

The work consisted of both laboratory and field work to investigate the effect of addition of different levels of ash in soil and plant properties, and on yield and quality of produce.

Work Package 1.

Ash collected regularly from the flexi-factories was analysed for pH, particle size, P, K, Zn, Cu, Fe, Mn, Mo, B, Cl, Al, Bo, B, C, Be, Hg, Cr, Cd.

Work Package 2.

Various doses (0%, 5%, 10%, 20%, 30%, 40%) of ash will be added to soil in potted and field experiments on the University of Mauritius Farm. Cabbage (*Brassica oleracea*) will be planted in a Randomised Block Design, with three replicates.

Effect of ash addition on following parameters will be analysed :

(a) Soil chemical properties: pH, EC, redox potential, total and available N, total and available P, total and available K, total and extractable Cu, Zn, Fe, Mn, Cr, Cd, Pb, Be, Al, Hg, etc.

(b) Soil physical properties: Bulk Density, Particle Density, Porosity, Water holding capacity, infiltration rate, aggregate size index, aggregate stability (dry and wet), colour, texture and structure.

(c) Soil biological, microbiological and biochemical properties: microbial biomass, C-mineralisation, N-mineralisation, respiration rate, and soil biodiversity, (earthworms, snails, mites, nematodes, and Collembola, total bacterial and fungal counts, N-fixing bacteria, P-solubilising bacteria, and P-solubilising fungi).

The above parameters were analysed before, during and at the end of the crop cycle.

Experimental Design

1.1 Field experiment

The field experiment was carried out at the University of Mauritius farm and coal/bagasse ash was collected from FUEL Sugar Estate. A plot of size 21m × 51 m was identified and potato (*Solanum tuberosum*) and maize (*Zea mays*) were planted under various ash treatments. Prior to planting, beds of size 5 m × 5 m were raised and the soil was leveled. Ash was then added and mixed throughout the bed.

The various treatments were as follows:

A. Untreated Control
B. Fertiliser + 0 t/ha ash
C. Fertiliser + 10 t/ha ash
D. Fertiliser + 20 t/ha ash
E. Fertiliser + 40 t/ha ash

A randomised block design was chosen for the experiment and the plot layout is represented in the diagram below.

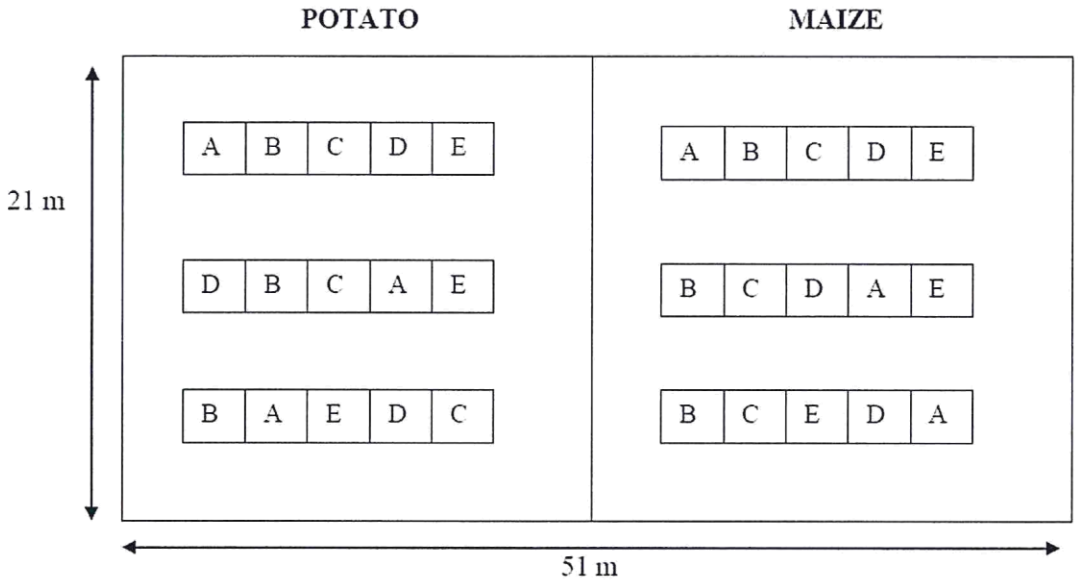


Fig 1. Plot Layout

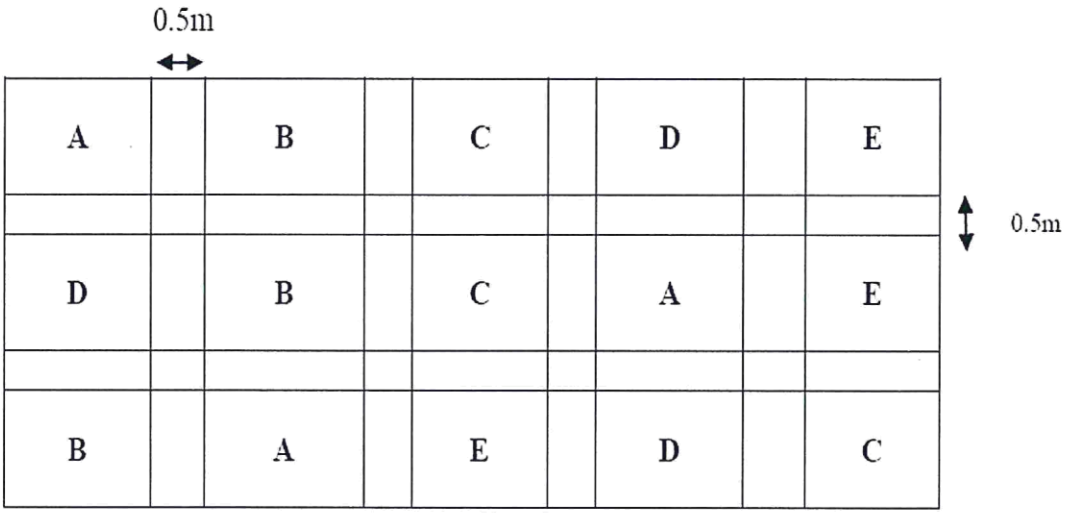


Fig 2. Details of A Plot

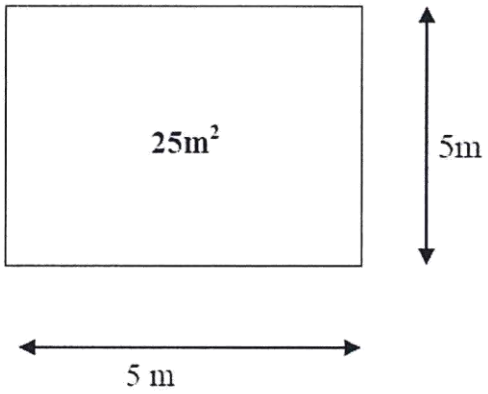


Fig 3. An Individual Subplot

Potato and maize were planted according to "Guide Agricole" and germination and growth of the crops were monitored.

1.2 Analysis of soil/ash chemical properties

Ash used on field were analysed and the following tests were carried out: pH, P, K, Zn, Cu, Fe, B, C, Cr, Cd, Pb and Ni. Soil sampling was carried out before addition of ash in soil that is at the start of the experiment. In each plot, five independent soil samples were collected by walking in a zigzag pattern in the sampled area. At each pit, soil was collected at a depth of 0-15 cm (root zone). Prior to analysis, the soil samples were allowed to air dry to remove excess moisture. After drying, the soils were screened through a 2 mm sieve. Soil analysis was done with five replicates of each sample and the various tests were carried out.

1.2.1Determination of pH (Rowell, 1993)

20 g of fresh soil samples was transferred into plastic bottles followed by the addition of 50ml of distilled water. The soil and water mixture, in a ratio of 1:2.5 was shaken for 30 minutes on an automatic shaker (125 revolutions per min). The pH was then read using a pH meter (Mettler Delta 320) which was calibrated with buffer solutions of pH 7 and pH 4.

1.2.2 Determination of electrical conductivity (Rowell, 1993)

Soil and water were mixed in a ratio of 1:2.5 for 30 mins after which the suspension was filtered and the filtrate was retained in test tubes. The electrode of the EC meter was dipped into the filtrate and the reading was recorded. The EC meter was calibrated using 0.02 M KCl Rdg 2.77 Ms at 27^0C.

1.2.3 Determination of total nitrogen (Rowell, 1993)

A. Digestion

2g of air dry soil was added into digestion tubes, followed by the addition of 15 ml concentrated sulphuric acid and Kjedahl catalyst. The samples were digested under a temperature of 3800C for 3 hours.

B. Distillation

Markham distillatory was used. A 250 ml conical flask containing 5% boric acid was positioned under the condenser followed by the addition of 5ml of digest into the Markham funnel and 5 ml of 40% NaOH solution.

C. Titration

The distillate was collected until the colour changes from red to green. The distillate was then titrated with 0.02 M HCl.

1.2.4 Determination of available potassium (Rowell, 1993)

Available potassium was extracted from 10 g of soil sample using 50 ml ammonium nitrate. The mixture was shaken for 30 mins and then filtered. The amount of K was determined using the flame photometer. Prior to analysing soil samples, standards were prepared and analysed. A standard curve was obtained from which the K concentration was read.

1.2.4 Determination of available phosphorous (Rowell, 1993)

All glasswares: pipettes, volumetric flasks, other tools used were acid washed overnight prior to preparation of reagents, extraction and analysis.

A. Preparation of Soil Extract

5g of soil and 50 ml of 0.1 M sulphuric acid solution were shaken in plastic bottles for 30 minutes and filtered. The filtrates were retained for analysis.

B. Preparation of Ammonium molybdate

12g of powdered ammonium molybdate and 0.3g of antimony potassium tartrate were dissolved in 600ml distilled water followed by the addition of 148ml conc. Sulphuric acid and was diluted to 1L. 125 ml of this solution was diluted to 1L.

C. Preparation of Standards

5g of Potassium dihydrogen orthophosphate was dried at 105^0C for 1 hour and cooled in a desiccator. 1.099g was then dissolved in distilled water; 1 ml of concentrated hydrochloric acid was added and made up to 250ml. This was the stock solution containing 1mg Pml-1. 10ml of this solution was pipette into a 100ml volumetric flask and diluted to 100ml. this solution contained 100µg Pml-1. 10 ml of this solution was pipette and diluted to 1L to obtain 1 µg Pml-1 . Into six 100ml volumetric flasks, 0, 5, 10, 15, 20 and 30 ml of this solution was pipette and dilute to 50 ml of distilled water. 8ml of ammonium molybdate solution was added followed by 8ml 1.5% ascorbic acid. Freshly made ascorbic acid was used. The mixtures were made up to the mark and allowed to stand for 20minutes for colour development.

D. Preparation of Samples

5ml of soil extract was pipette into 100 ml volumetric flasks followed by adding 50ml water. The same procedures were applied as in standards preparation above for colour development.

Both the standards and samples were measured at an absorbance of 880 nm using the spectrophotometer.

1.2.5 Determination of % organic carbon: Colorimetric method (Baker, 1976)

A. Preparation of Standards

15g of sucrose was dried at 1050C for 2hours and cooled in a desiccator.11.886 g was then dissolved and made up to 100ml in a volumetric flask and labeled as the stock solution which

contained 50mg/ml C. 0, 5, 10, 15, 20 and 25 ml of that stock solution was pipetted into 100ml volumetric flasks and made up to the mark with distilled water and mixed well. These were working solutions containing 0, 2.5, 5.0, 7.5, 10.0, 12.5 mg/ml C. 2 ml of each of these working solutions were pipetted into 250 ml conical flasks and dried at 1050C. They contained 0, 5, 10, 15, 20 and 25mg C.

B. Wet oxidation of samples and standards

0.1g of soil/ash was measured and transferred into 250 ml conical flasks. 10 ml of 5% potassium dichromate solution was added to both standards and samples and swirled to wet the soil or dissolve the standards. 20 ml of concentrated sulphuric acid was added from a fast burette and the mixture was swirled and allowed to cool. 50 ml of barium chloride was added. The mixture was then allowed to stand overnight to leave a supernatant solution.

An aliquot of the supernatant solution was transferred into a colorimeter cuvette and was measured at an absorbance of 600 nm.

1.2.6 Determination of available heavy metals (Rowell, 1993)

Ammonium-EDTA (0.05 M) was prepared and the pH was adjusted to 7.0 by using ammonia solution. 10 g of soil/ash was measured using a measuring cup into a bottle. 50 ml of ammonium – EDTA was added into the bottle and the mixture was shaken for 1 hour. The mixture was then filtered and the filtrate was retained for analysis.

1.2.6 Determination of bulk density (Brady and Weil, 2008)

Metal core ring of a known volume were hammered into the soil until it was filled. The soil was then transferred into weighed envelopes. The weight of both the soil and envelope was recorded before and after placing them in oven at 1050C until a constant weight was reached. A mean of 4 samples were recorded per plot.

1.2.7 Determination of particle density (Brady and Weil, 2008)

A 50ml specific gravity bottle was weighed (M1). 10g of soil were weighed in a 50ml specific gravity bottle and the weight was recorded as (M2). The bottles were half filled with de-aired water and were then placed in a water bath for approximately 15 minutes to remove any air bubbles. The bottles were then allowed to cool and the moisture on them was wiped. The bottles were filled completely with water and the weights were taken as (M3). The same procedure was repeated but this time without soil and the weights were recorded as (M4). A mean of 4 samples was recorded.

5. Results

Table 1 : Properties of Bagasse Ash

Parameter	**Level**
pH	9.6 ± 0.1
Potassium	197 ± 3.0 µg/ml
Phosphorus	81.5 ± 2.5 µg/ml
Organic Carbon	2.6 ± 0.2 %
Zinc	180 ± 0.5 µg/ml
Copper	25.5 ± 0.5 µg/ml
Iron	15.36 ± 1.0 µg/ml
Chromium	24.0±.05 µg/ml
Cadmium	traces
Nickel	0.207 ± 0.8 µg/ml
Lead	78.4± 0.5 µg/ml

Table 2. Effect of ash addition on soil physical and chemical properties (potato plot)

	Untreated Control	**Fertiliser + 0t/ha Ash**	**Fertiliser + 10t/ha Ash**	**Fertiliser + 20t/ha Ash**	**Fertiliser + 40t/ha Ash**
Soil Physical Properties					
Bulk density, g/cm^3	0.833 ± 0.06	0.913 ± 0.18	0.793 ± 0.08	0.721 ± 0.2	0.677 ± 0.15
Particle density, g/cm^3	2.12 ± 0.09	2.15 ± 0.2	2.16 ± 0.09	2.1 ± 0.06	2.07 ± 0.11
Soil Chemical Properties					
pH	5.64 ± 0.72	5.64 ± 0.48	7.53 ± 0.68	6.72 ± 0.51	7.5± 0.72
Electrical conductivity, µS	158.1 ± 2.8	168.4 ± 3.5	176.2 ± 2.6	183.3 ± 11.8	191.7 ± 9.8
Total nitrogen, %	0.129 ± 0.002	0.179 ± 0.07	0.168 ± 0.112	0.159 ± 0.112	0.164 ± 0.1
Available phosphorous, µg/g	22.9 ± 2.1	24.6 ± 3.8	24.2 ± 5.3	25.5 ± 4.0	25.1 ± 3.6
Available potassium, µg/g	20 ± 6.8	22.8 ± 4.8	31.3 ± 2.2	33.6 ± 3.6	34.7 ± 0.6
Iron, µg/g	29.8 ± 3.6	29.6 ± 3.3	31.2 ± 7.1	39.6 ± 1.9	42.5 ± 1.0
Zinc, µg/g	3.8 ± 0.2	3.61 ± 0.27	3.99 ± 0.06	4.69 ± 0.36	5.52 ± 0.06
Copper, µg/g	3.61 ± 0.43	3.38 ± 0.23	3.49 ± 0.06	3.69 ± 0.36	3.52 ± 0.06
Lead, µg/g	0.777 ± 0.37	0.613 ± 0.07	0.757 ± 0.35	0.79 ± 0.32	0.793 ± 0.36

Table 3. Effect of ash addition to soil on growth and development of potato plants (30 DAP)

Parameter	Untreated Control	Fertiliser + 0t/ha Ash	Fertiliser + 10t/ha Ash	Fertiliser + 20t/ha Ash	Fertiliser + 40t/ha Ash
Shoot length, cm	19 ± 1.0	40 ± 1.0	38.7 ± 2.0	43 ± 1.0	49 ± 1.0
Root length, cm	18 ± 1.0	22 ± 1.0	24.7 ± 2.0	25 ± 2.5	25 ± 1.0
Fresh weight, g	106.2 ± 5.5	224.1 ± 8.0	193.6 ± 10.0	252.7 ± 6.6	376.5 ± 9.2
Dry weight, g	12 ± 3.0	34.4 ± 4.6	21.3 ± 3.0	28.1 ± 3.5	38.9 ± 4.0

DAP=Days after sowing

Table 4. Effect of ash addition on soil physical and chemical properties of soil

	Untreated Control	Fertiliser + 0t/ha Ash	Fertiliser + 10t/ha Ash	Fertiliser + 20t/ha Ash	Fertiliser + 40t/ha Ash
Soil Physical Properties					
Bulk density, g/cm^3	0.993 ± 0.07	0.923 ± 0.2	0.913 ± 0.09	0.891 ± 0.2	0.827 ± 0.17
Particle density, g/cm^3	2.14 ± 0.08	2.15 ± 0.3	2.15 ± 0.1	2.2 ± 0.02	2.17 ± 0.19
Soil Chemical Properties					
pH	5.52 ± 0.56	5.31 ± 0.63	6.99 ± 0.68	7.20 ± 0.54	7.79 ± 0.69
Electrical conductivity, µS	240 ± 5.4	250 ± 9.6	263.2 ± 3.4	270.5 ± 2.9	281 ± 10.2
Total nitrogen, %	0.224 ± 0.003	0.252 ± 0.115	0.262 ± 0.08	0.266 ± 0.13	0.284 ± 0.117
Available phosphorous, µg/ml	21.8 ± 3.4	25.7 ± 3.9	26.8 ± 4.2	27.7 ± 5.3	28.5 ± 3.1
Exchangeable potassium, µg/ml	24.4 ± 3.3	27.7 ± 6.5	28.9 ± 3.8	31.2 ± 4.3	33.8 ± 2.8
Iron, µg/ml	26.9 ± 4.1	27.7 ± 3.2	28.3 ± 3.7	29.8 ± 2.5	31.2 ± 2.1
Zinc, µg/ml	3.67 ± 0.1	3.92 ± 0.06	3.99 ± 0.23	4.49 ± 0.05	5.55 ± 0.34
Copper, µg/ml	3.51 ± 0.38	3.82 ± 0.25	3.91 ± 0.32	4.19 ± 0.06	4.86 ± 0.08

Lead, µg/ml	0.877 ± 0.4	0.745 ± 0.05	0.723 ± 0.04	0.82 ± 0.32	0.956 ± 0.45

Table 5. Effect of ash addition to soil on growth and development of maize plants (30 DAP)

Parameter	Untreated Control	Fertiliser + 0t/ha Ash	Fertiliser + 10t/ha Ash	Fertiliser + 20t/ha Ash	Fertiliser + 40t/ha Ash
Shoot length, cm	34.2 ± 1.5	33.5 ± 1.0	36.3 ± 1.0	38.4 ± 1.0	40.6 ± 1.7
Fresh weight, g	12.7 ± 4.3	14.6 ± 6.2	15.2 ± 5.5	17.9 ± 4.1	23.7 ± 4.2
Dry weight, g	5.19 ± 3.9	6.33 ± 4.5	8.99 ± 3.5	10.12 ± 4.0	13.16 ± 3.6

DAP= Days after planting

Table 6. Effect of ash on potato tuber yield

Treatments	Tuber length/cm	Yield/Tons/ Ha
Control	7.0 ± 4.2	7.2 ±1.1
Fertiliser + 0t/ha	8.7 ± 3.0	9.1 ±1.7
Fertiliser + 10 t/ha	9.3 ± 3.5	10.2 ±1.9
Fertiliser + 20 t/ha	9.5. ± 4.5	11.2 ±1.3
Fertiliser + 40 t/ha	10.3 ± 4.5	11.1 ±1.6

6. Discussion

The soil on the university farm (Low Humic Latosol,Typic Haplustox, Humic Nitosol) used in this experiment was acidic with a pH of 5.52 (Table 2)

Addition of ash at all levels of application improved the soil physical, chemical , biological and microbiological properties of the soil (Table 3) and consequently the growth characteristics and yield of both test crops i.e Maize and Potato (Table 5 and 6). Potato tuber yield increased by 61% by the highest application of ash as compared to the control. These results are the means of two crop cycles. Dry maize yields showed erratic trend because they were attached by birds. However the dry matter yield at 30 DAP showed that there was a significant increase in total dry matter production of maize (153%).

Table 1 above gives the composition of the ash that was used for this experiment. Ash was collected from FUEL.

The results of different ash from different sources are not all comparable because they depend on the geological origin and original composition of the coal used. The results also depend on the methods of combustion of the coal and the types of furnace used and the curing process that the ash has undergone. In the present case, the ash was low in the major nutrients like Nitrogen, Phosphorus and Potassium. This is expected because at the high temperature of the incineration all these elements are volatilized.

The organic carbon was found to be 2.6 % which is on the high side. Some efficient furnaces produce much lower carbon content in the ash. In some places the ash is reignited and this produces lower carbon content ash. The level of heavy metals such as Zinc , Copper nickel and lead are comparable in some published literature ((Rungsun Im-Erb et al. 2004).

The addition of the ash lowered the bulk density of the soil and made it more porous and this resulted in a higher water holding capacity of the soil. This increase was directly correlated with the rate of ash application. The presence of spherical cenosphere in flyash, which have larger specific surface and characteristic hollow structure, resulted in increased water holding capacity and reduction of modulus of rupture of ash amended soil (Shenggao and Zhu, 2006).

Ash amended soils had higher pH values (Table 2) . This is due to the presence of metallic oxides in the ash which turns to hydroxides when mix with water. Therefore ash can be used as an antacid to increase pH of acid soils. Improvement of pH of soils improves the availability of most soil nutrients.

Ash application in soils has also been shown to improve the soil biodiversity, soil enzymes etc. All this in turn improves the soil conditions and make it a more conducive environment for plants and improve crop yields.

This is seen in the growth characteristics and improvement of both test crops i.e maize and potato (Table 5 and 6). The elemental composition of the crops did not show any significant differences among the treatments. However Mishra and Shukla (1986) reported that there was

enhanced absorption of Boron, Copper, Manganese and Zinc but no change in Potassium, Phosphorus and Calcium.

It has also been reported that coal ash can effectively be used in potting mixture for substrates. Even at rates of 20%,the additions did not have a negative effect on tomato (*Lycopersicon esculentum*)

7. Conclusion:

Addition of ash invariably improved all soil characteristics (chemical, physical, biological, microbiological, biochemical).

Ash did not have a direct effect, *per se*, on yield and growth characteristics of maize and potato, but improved them through indirect effects.

Ash does not have substantial amount of plant nutrients like N, P, and K

Ash did not have any adverse characteristics on the quality of Maize and Potato especially in terms of heavy metals, at the rates used in this experiment

In this report only the main findings have been reported. It is proposed that several other results not presented in this report will be made available to MRC, once the scientific papers are ready.

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