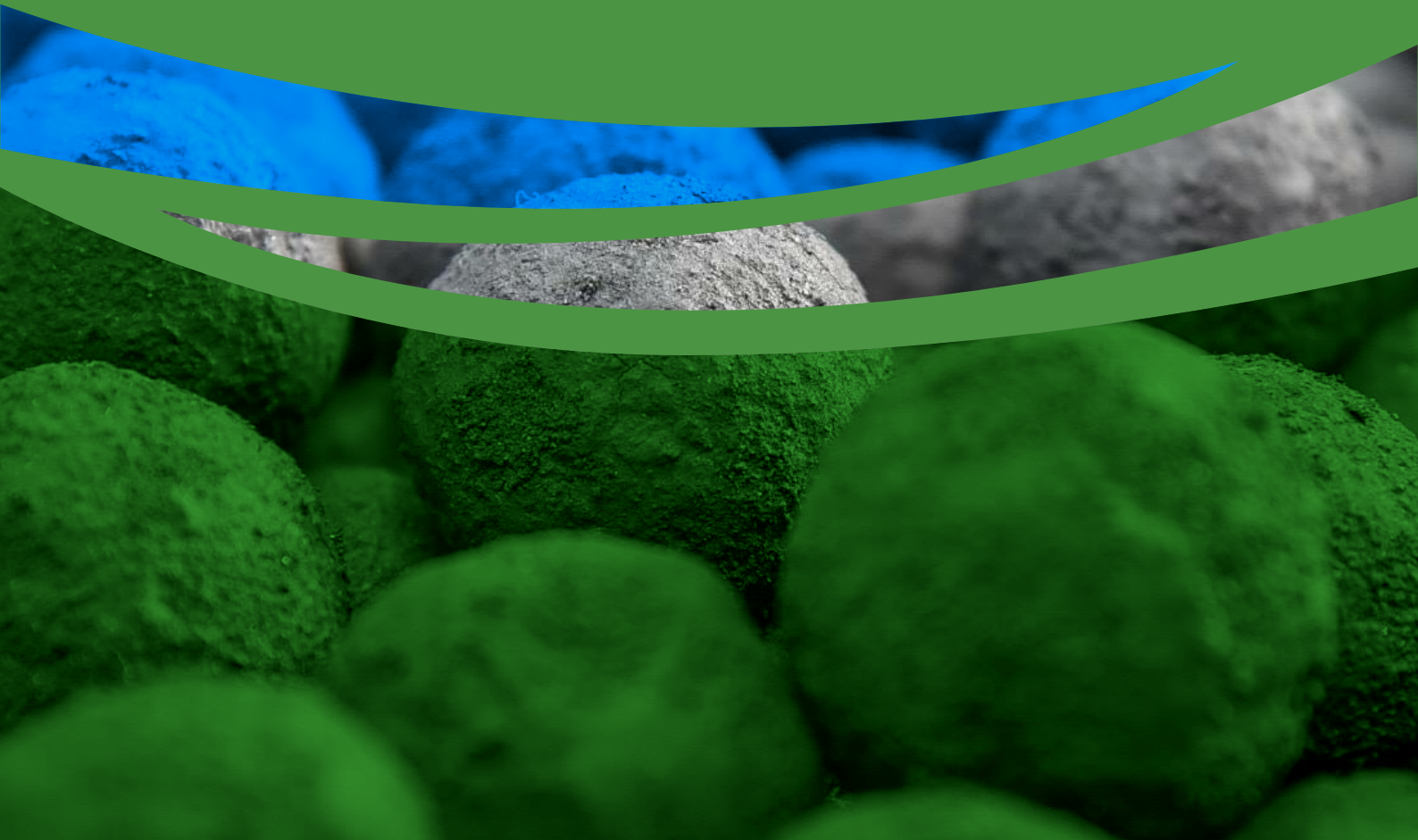


# **SANITATION VALUE CHAIN:** Unlocking Opportunities In Sanitation

Scientific and Popular Publications for Nakuru County Sanitation Programme



## **ABOUT NCSP**

The Nakuru County Sanitation Programme (NCSP) was a five-year programme co-funded by the European Union (EU) and implemented by the Nakuru Water and Sanitation Services Company Ltd (NAWASSCO) in partnership with Nakuru County, Umande Trust, Vitens Evides International (VEI) and SNV Netherlands Development Organisation.

The overall objective of the NCSP was to demonstrate and implement a commercially viable sanitation value chain, benefiting residents of unsewered (peri-)urban low income areas (LIA) in Nakuru County.

More specifically, the action has the following (specific) objectives:

1. Increase hygiene awareness and sanitation coverage in Nakuru Town;
2. Establish collection facilities and transport services for hygienic and sustainable capture and removal of human waste from the LIAs;
3. Controlled and certified production and sales of human waste products on a large scale.

This value chain approach has led to the development of round-shaped carbonised faecal matter-saw dust briquettes currently produced and marketed under the name MakaaDotcom.

## **ACKNOWLEDGEMENTS**

This booklet and its popular and scientific publications are a result of the NCSP and its research partnership with Egerton University. The research benefitted from the Aqua for All managed VIA Water fund. We wish to acknowledge the invaluable contributions of the following institutions and individuals for their daily support, energy, enthusiasm and persistence.

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# **POPULAR PUBLICATIONS**





# REAPING BENEFITS OF HUMAN WASTE ENERGY

(By Caroline Chebet)  
Fri, June 30th 2017

John Njeng'u, a poultry farmer from Kivumbini estate, lights a jiko as he prepares his chicken coop for the night. His 12-day-old chicks require constant warmth throughout the night for proper growth, a situation that demands he lights and keeps the jiko burning overnight to keep the birds warm.

## CARBON MONOXIDE

Incorporating charcoal briquettes made from human waste into his business has instantly cut down the mortality rate of his chicks.

Previously, he would lose many chicks that often suffocated because of high carbon monoxide concentration in regular charcoal.

*"These briquettes have come in handy because I do not have to wake up several times during the night to refill the jiko to keep it burning,"* Mr Njeng'u told The Standard.

Mr Njeng'u now saves Sh1,600 monthly unlike previously when he used to spend Sh2,400 to buy regular charcoal.

*"A sack of charcoal which goes for Sh800 would last 10 days, but currently the same amount of money can get me briquettes which can last a month yet my chicks are not dying,"* he says.

The Sh500 million partnership briquettes-making project from human waste — set up to address sanitation challenges — is a partnership between the county's public health sector, Nakuru Water and Sanitation Services Company (Nawasso) and a Netherlands-based organisation and other local companies.

The project of faecal sludge management through briquettes making is one of a kind in the country.

Apart from addressing sanitation challenges that contributes majorly towards pollution of underground water, the project also seeks to address forest degradation emanating from charcoal burning in the region especially in Mau forest complex.

*"Nakuru County majorly depends on underground water which is highly contaminated due to high fluoride concentration coupled with less sewerage coverage system,"* Leonard Mutai, Nawasso technical superintendent said.

## CRUMBLING TOILETS

The region is also characterised by volcanic soil with very poor load bearing capacity, a situation which contributes to crumbling toilets.

*"This poses difficulty in digging as the walls crumble. The toilet facilities also collapse especially when it rains but with the project, we have managed to construct over 5,000 improved pit latrines,"* said Reinilde Eppinga, sanitation adviser from the Netherlands-based organisation. Human waste, the main raw material for the briquettes, is collected from pit latrines and septic tanks by trucks and transported to a waste water treatment plant where the manufacturing takes place.

Read more at: <https://www.standardmedia.co.ke/business/article/2001245439/reaping-benefits-of-human-waste-energy>

# NAWASSCO VENTURES IN TO PRODUCING FERTILIZER OUT OF HUMAN WASTE

(By Caroline Chebet)  
Thu, September 28th 2017

Nakuru Water and Sanitation Service Company (Nawassco) is producing organic fertiliser from human waste. Through a collaboration with researchers from Egerton University, the firm has produced the newest fertiliser varieties in the market, Struvide and Biochar. Scientists say the venture will address soil degradation as well as sanitation challenges. Struvide is made out of human urine while Biochar is made out of carbonised human faeces.

*"Various studies and tests indicate that the two fertiliser varieties are safe for use. While Struvide is rich in phosphorous compared to other fertilisers in the market, Biochar is rich in nitrates,"* said Kevin Nakitare, a soil research scientist from Egerton University. According to Mr Nakitare, early tests were conducted on different soils in several parts of Nakuru and good results were posted. *"We have conducted several trials in different regions with different soil varieties and the results are positive. The two (fertiliser) varieties are rich in nutrients. Apart from addressing soil degradation, sanitation challenges will also be tackled,"* Nakitare said.

He revealed that producing Struvide was a challenge, especially collecting the raw material as the majority of toilet users often flush after use.

*"It is one of the greatest challenges because not many people are aware that urine can be used economically,"* Nakitare said, adding that the urine was mixed with magnesium oxide to crystallise it.

He also said production was expensive because of having to source magnesium oxide.

*"There should be specialised facilities for the collection of urine. A lot of awareness is also needed,"* he said. Nakitare however revealed that initial tests conducted on maize yielded excellent results. Producing Biochar is not as difficult because sludge is easily obtained from the domestic sewage treatment plant.

*"Nawassco carries out part of the activities in the treatment of sewerage and it is easier to obtain sludge that is then carbonised and made into granules,"* said Mwende Osur from Nawassco. Plans to expand production are underway.

*"The biggest challenge we have is lack of funding,"* said Ms Osur. *"But once resolved, expansion will be achieved."* Once the sludge is collected from exhausters, excess water is allowed to evaporate until the residue is dry, after which it is subjected to very high temperatures through carbonisation and finally granulised. All harmful bacteria is killed during carbonisation.

According to Wilson Ngeno, an agricultural officer, the new fertiliser will help to address leaching problems.

*"Farmers have been battling soil degradation as a result of constant fertiliser use but the organic varieties should address the problem,"* he said.

<https://www.standardmedia.co.ke/business/article/2001255843/nawassco-ventures-in-to-producing-fertilizer-out-of-human-waste>







# HUMAN POO TRANSFORMED INTO CLEAN FUEL FOR KENYA'S URBAN POOR

(Reporting by Benson Rioba)

MAY 12, 2017 at 4:02 PM

Poultry farmer Josephine Mbithe used to get up three times a night to add charcoal to her stove just to keep her newborn chicks warm. But since she started using fuel briquettes made with human waste, the stove burns all night, leaving her to sleep in peace.

Mbithe is one of many Nakuru residents who have embraced the briquettes manufactured from human poo and sawdust collected around the town, northwest of Nairobi, in the Great Rift Valley.

Before the briquettes find their way into Nakuru's poor households, they undergo processes to ensure they are free from harmful pathogens that could cause diseases, and are safe to use.

Human waste - the main raw material for the briquettes - is collected from pit latrines and septic tanks around Nakuru by truck and transported to a waste water treatment plant run by the Nakuru Water and Sanitation Services Company (NAWASSCO), where the manufacturing takes place.

At the plant, the sludge is discharged into drying beds in a greenhouse, and left to dry for two to three weeks. The greenhouse heat reduces the moisture content from around 95 percent to below 20 percent, to prepare it for carbonisation.

The dried-out sludge is then treated at temperatures of about 700 degrees Celsius, with the accompanying sawdust carbonised at 300 degrees Celsius.

Next, the carbonised materials are ground into fine particles using a hammer mill, before being mixed together in an equal ratio using motorised equipment. Molasses is added as a binder, before the mixture is transformed into small, round balls in a rotating drum.

John Irungu, NAWASSCO's site manager, said impurities, harmful pathogens and the foul smell of the waste are removed during the carbonisation process, with the molasses adding a sweet aroma.

Margaret Japaso, a resident of Kaloleni neighbourhood in Nakuru town who uses the briquettes, said they burn longer with less smoke compared to firewood and charcoal. Initially she was worried about the smell, but her fears have been laid to rest.

## WATER CONTAMINATION

Reinilde Eppinga, a sanitation advisor with SNV Netherlands Development Organisation, which is a partner in the briquette project, said only 27 percent of Nakuru residents are connected to the town's sewerage system, highlighting the need for a better way to dispose of the large quantities of human waste generated each day.

*"Most (people) use pit latrines, and when these fill up, they are emptied, but nobody is asking where the human waste is taken to," she said.*

The threat of water contamination in Nakuru is real, she added, as human waste is often dumped in storm drains and rivers, or is buried in low-income areas. In turn, faeces are finding their way into nearby Lake Nakuru, polluting the ecosystem.

Cees Lafeber, who works for Vitens Evides International, a Netherlands-based water operator that is collaborating on the sanitation project with the EU, SNV and NAWASSCO, said the briquette initiative helps protect the environment and forests, while improving sanitation.

It also generates income through sales of the briquettes by NAWASSCO, and reduces health risks from inhalation of smoke, he added.

In addition, the project is supporting households and landlords to construct more than 6,000 special toilets in poorer parts of Nakuru, as well as in schools, to help collect human waste.



*"Unlike normal pit latrines, our latrines are designed not to allow water to seep into the ground," said Lafeber. "The toilets have a lining to contain the waste, and also a place where the waste can be collected with ease."*

### **SANITATION LEVY**

At first, it was hard to convince the local community to use the briquettes due to the taboo associated with human poo, Lafeber admitted. Now the efficiency of the process has sparked interest, not just among Nakuru residents, but further afield in other Kenyan counties and neighbouring countries such as Rwanda.

SNV sanitation advisor Lawrence Kimaru said the country's licensing bodies and the Nakuru County Health Department also had early reservations about the project, raising questions about how the waste would be collected, transported and treated in accordance with local laws and existing practices.

The project partners lobbied the Nakuru County Assembly for a comprehensive public health bill that addresses how to handle human waste, removing the legislative bottlenecks.

The site now produces two tonnes of briquettes each month, but NAWASSCO's Irungu said the plan is to scale up production to 10 tonnes a month, and eventually 10 tonnes per day.

That will require larger-scale equipment, including improved solar drying systems, a machine to remove water from the sludge, and an industrial carbonisation system.

NAWASSCO has proposed a levy on water bills to fund provision of sanitation services as part of the company's core activities, which it expects to be approved this year, Lafeber said.

Under it, Nakuru residents would pay 5 percent on top of their water bill, with which the company would be able to maintain the sludge collection and transportation system.

SNV's Eppinga said the briquette market is huge, with a study indicating it could cover around half of household fuel demand in Nakuru town, suggesting the current production site is unlikely to be able to fully meet demand.

*"Briquette production from human waste is a viable option," she said.*

If more water companies team up with social enterprises and other businesses, as well as the government and development groups, on the activity, *"it may generate income for jobless youths in the country while providing clean and affordable sources of fuel for large populations"*, she added.

1. Briquettes ready for packaging
2. & 3. Roasted meat from Briquettes



# KENYANS TURN HUMAN WASTE INTO HOUSEHOLD FUEL

October 13th 2017

**And before you ask no, it doesn't smell. A Kenyan public company has found a way to manufacture human waste into fuel briquettes that can be used for cooking and heating in the home.**

The poo briquettes actually fulfil two functions: not only are they an efficient and safe source of fuel, but the collection of the waste needed to make the briquettes has also improved sanitation in towns and villages.

The process used by Nakuru Water and Sanitation Services Company (NAWASSCO) starts with human excrement, collected from pit latrines and septic tanks around the region of Nakuru, north west of Nairobi. The waste is then taken to a processing plant, where it is dried out for two to three weeks in drying beds in a greenhouse. The hot temperatures in the greenhouse take out around 70 per cent of moisture from the sludge, which prepares it for carbonisation.

Briquettes being used in fires. Photo: Nakuru Water and Sanitation Services Company

The dried waste is then heated in a kiln at temperatures of about 700 to 800 degrees Celsius, which burns off harmful gases (and the smell). It's ground up finely, before being mixed with sawdust that has also been carbonised. Molasses are also added at this stage to bind the materials, and it is formed into little balls.

The combined materials of milled sawdust and sludge are fed into a rotating drum machine, while molasses (a binding agent) are added gradually until the mixture forms a ball of about 2.5 cm in diameter. Photo: Nakuru Water and Sanitation Services Company

Reuters reported that there was slow uptake of the product at first, because of the stigma of human faeces, but locals are now convinced. France 24 spoke to a local who prefers this new type of fuel, after initial scepticism of the idea.

Isaac Wafula is a tuk-tuk driver who lives in the Nakuru region. He and his wife recently started using the briquettes.

*"When I first heard about the idea, I thought it was really funny – I didn't understand how they are able to transform it. I was one of the people who criticised it and didn't bother testing it because I thought it wouldn't be good. Then I saw them for the first time at a neighbour's house. Now I think these briquettes are better than others. Normally I use kerosene for cooking, but I use these briquettes when food takes a long time to cook. For example, we use it when we cook beans, and my wife uses it to cook French fries that she sells. These briquettes are much easier to light, and they stay lit longer than coal. So they are good but they are a little expensive for me.*

*People have started selling them everywhere in Nakuru; if I want them I can find them easily. One package of them costs 65 Kenyan shillings [0.53 euros]."*

Reinilde Eppinga, an advisor for SNV Netherlands Development Organisation, which partnered with Nakuru Water and Sanitation Services Company for the project, says that they're hoping to increase production of the briquettes from the current two tonnes a month to ten tonnes a month and eventually ten tonnes a day.

**"They're easier to light, and stay lit longer"**

Isaac Wafula, a tuk-tuk driver

*"The product has become popular, and we're creating awareness campaigns so that people know about it. The briquettes are being used in hotels and restaurants for cooking and space heating, in schools, in people's houses, and by poultry farmers who use them to warm breeding houses for hens. The selling price is comparable to that of ordinary charcoal but the benefits surpass charcoal and firewood, in terms of money saved [because they last longer] and also the health benefits [because the poo briquettes produce less smoke."*

*"Collection of human waste is also helping to deal with sanitation problems in Nakuru. In low income areas, the collection of sludge is challenging because of the types of constructions and terrain. Many residents have constructed pit latrines, which are difficult to empty because they have not been lined properly and so there is a danger of them collapsing. Some areas do not have road access for exhauster trucks to get through. But now NAWASSCO, in collaboration with Nakuru County Public Health Department, has an onsite solution: pits in low income areas are manually emptied by certified workers. Now residents can have their pits emptied safely and hygienically, whereas before people would empty their own pits at night, burying the waste anywhere or leaving it in drainage systems."*

*"Only one out of every four residents in Nakuru has access to the town's sewage system, and so poorly disposed of waste was polluting the environment, with harmful pathogens entering Lake Nakuru." Eppinga says that apart from providing solutions to environmental concerns and creating a use for a waste material, the briquettes could also have a direct economic benefit in the future: if the business continues to develop,*

*"it may generate income for jobless youths in the country while providing clean and affordable sources of fuel for large populations."*

<http://observers.france24.com/en/20171013-kenyans-cook-food-fuel-faeces?nocache>







# NAKURU RECYCLES WASTE INTO CHEAP ENERGY SOURCE

(By Magdalene Wanja)  
MONDAY, JULY 17, 2017

**Nakuru Water and Sanitation Services Company (Nawasco) has embarked on a project that turns waste into affordable and sustainable energy.**

The company is making briquettes — a block of compressed charcoal or coal dust used as fuel — from human waste.

Nawasco taps the waste from the sewerage system, which accounts for only 27 per cent of Nakuru's sludge.

However, this is not the only source of materials. Waste from areas not connected to the sewerage system — totalling between 50 tonnes and 80 tonnes every day — is delivered by exhauster trucks.

*"The production of human waste briquettes starts with collection of saw dust from sawmills and faecal sludge from septic tanks and pit latrines from Nakuru Town to the site,"* said Nawasco site manager Mr John Irungu.

Once collected, the sludge is dried in the greenhouses, a process that takes place under intense heat to reduce the waste's water content from around 95 per cent to below 20 per cent.

The next stage is called carbonisation, which involves the sludge being heated further in a drum kiln at 700 degrees celsius.

*"This (carbonisation) kills all pathogens and eliminates bad smell emanating from the sludge,"* he said. "Most of the impurities contained in the raw material can be very poisonous."

Separately, the sawdust is carbonised at 300 degrees celsius. The carbonised materials are then crushed into fine powder using a hammer mill.

Using a batch mixer, the crushed materials are blended together in equal proportion.

The next step of making the briquettes involves adding molasses to the mixture which contains lignin that binds materials.

This is done on a rotating drum that turns the mixture into round-shaped briquettes which are then dried in the sun before being used.

Nawasco currently produces two tonnes of briquettes per month.

"The main beneficiaries of these briquettes are households, schools and chicken farmers," said Ms Reinilde Eppinga, water sanitation and hygiene (WASH) advisor, one of the partners in the project.

"They are among the largest consumers of energy."

The project is helping to reduce pollution related to dirty fuels such as petrol and conventional charcoal.

The initiative, she said also leads to lower cases of diseases due to improved sanitation and reduced deforestation.

Nawasco technical superintended Leonard Mutai said the briquettes have been certified by the Kenya Bureau of Standards (Kebs) as well as the National Environment Management Authority (Nema).

WASH says commercial production of the briquettes started in January, after several years of research and development.

The promoters of the project are set to acquire new dewatering and carbonisation equipment which they will use to scale up operations to produce up to 10 tonnes of the fuel per month by the end of this year.

A kilogramme of the briquettes retail at Sh30, meaning that the business could make as much as Sh300,000 per month from the innovative venture, besides ensuring a clean environment.

Once complete, the project will focus on large scale production.

"The briquettes are better than normal firewood and charcoal. They burn for longer and emit less smoke," said Mr Lawrence Kimaru, a WASH adviser.

He added that the project is a boost to Nakuru County as will generate jobs for the youth.



# LOGGING BAN FUELS DEMAND FOR WATER FIRM'S BRIQUETTES

(By Magdalene Wanja)

MONDAY, APRIL 23, 2018

The temporary ban on logging have been a boon for the Nakuru Water and Sanitation Services Company (Nawassco). Its briquettes business is now roaring more than before as households seek alternative sources of fuel.

The business that kicked off a year ago involves making the fuel from human waste tapped from the sewerage system.

Nawassco Site Manager John Irungu says they produce two tonnes of the fuel monthly which is way below the current demand of about five tonnes.

*"We sell the briquettes at Sh30 per kilogramme and the demand has gone high in the past few weeks from across the country,"* says Mr Irungu.

Initially, he says one of the by-products needed was the sawdust which is used as a biomass. However lack of sawdust forced them to use alternative biomass which include coffee husks, macadamia shells, wheat husks, water hyacinth, coconut husks and pineapple leaves and rice husks.

*"Through our experiments, we have also found bagasse suitable for the purpose,"* he says.

He notes that although the briquettes can be made 100 per cent from human waste, adding the biomass ensures that it lights faster and has more intense heat.

**“**We sell the briquettes at Sh30 per kilogramme and the demand has gone high in the past few weeks from across the country,**”**

John Irungu, Nawassco Site Manager

To meet the rising demand, the company has embarked on expansion of the production plant, a project that involves installing modern equipment.

*"With the up scaling, we shall be able to produce 10 tonnes of briquettes in a day and thus meet the increasing demands from our customers,"* says Mr Irungu.

He notes that once the expansion is complete, Nawassco will register the enterprise as a subsidiary company.

*"We shall also be targeting the wholesale market while expanding sales to retail buyers,"* he says.

The firm's sanitation and hygiene advisor Lawrence Kimaru says the sludge used in making briquettes is treated and burned under very high heat to get rid of harmful components. The biomass available is mixed with the sludge from the human waste at a ratio of 1:1.

*"We receive more than 30,000 litres of the sludge waste daily but only a little is used in the making of the fuel. This is due to the limited capacity that we have at the moment,"* says Mr Kimaru.

The waste is delivered through the sewerage system and the rest delivered by more than 60 trucks.

The firm, which has 10 employees, is also looking to sell some of the byproducts which include tar, that can be used for tarmacking and vinegar used as a wood preservative.

The company targets schools and hotels which use a lot of energy.

*"This will also see replacing of fuels that emit a lot of carbon with clean and efficient fuels,"* he adds.

<https://www.businessdailyafrica.com/corporate/enterprise/Logging-ban-fuels-demand-for-water-firm-s-briquettes/4003126-4495306-8ah4gt/index.html>

**BUSINESS DAILY**



# £3M EU GRANT SENDS KENYANS SWITCHING FROM CHARCOAL TO COOK INSTEAD ON TREATED HUMAN WASTE

(By caroline Chebet)

Saturday, 16th June 2018

The truck filled to the brim with human waste trundles to the sewerage treatment plant where a crew eagerly waits for the noxious commodity, ready to convert it into briquettes that will be used to fuel Kenya's cooking fires.

The ambitious project is providing an environment-friendly solution in addressing sanitation challenges as well as conserving trees. This indeed is a bold move from Nakuru, Kenya's fourth largest city 100 miles west of the capital, Nairobi.

The briquettes, fondly referred to by locals as makaa-dot-com, are made by adding sawdust to the human excrement. And their popularity has shot through the roof.

*"Demand is high, far outstripping the current production of three tonnes a month. We receive orders of over four tonnes daily, a need that has pushed us to upscale production to 10 tonnes a day,"* James Ng'ang'a, managing director of the Nakuru Water Sewerage and Sanitation Company Limited told Kenya's The Standard newspaper.

The project, which has received close to £3 million in European Union grants for innovative ideas that improve sanitation services, has grown in popularity following the logging moratorium and charcoal ban that is currently in place in Kenya, because it has shielded residents from the worst effects of the crippling charcoal shortage.

*"A factory is ready and equipment has already been shipped ready for installation. Once done, we can be able to meet the demand and even supply to schools, factories and supermarkets,"* Ng'ang'a said.

The Nawassco MD revealed that apart from the traditional consumers of charcoal, who were scrambling for alternatives, a large number of their customers were poultry farmers, who said they observed lower mortality rates among their birds when they used the briquettes to heat the chicken houses.

The project has also played a major role in controlling the amount of waste being channeled into Lake Nakuru - one of Kenya's most iconic lakes that is home to thousands, sometimes millions of flamingos.

*"Lake Nakuru is a Ramsar Site and it faces a lot of challenges due to pollution. This project will reduce the amount of waste channelling into the lake even after treatment since most of the waste is used as raw materials,"* Ng'ang'a said.

But before the briquettes find their way into the kitchen, they have to undergo several processes to ensure they are free from disease-causing pathogens.

*"The process has been approved by [Kenya's] National Environmental and Management Authority and the briquettes certified by the Kenya Bureau of Standards,"* the project site manager John Irungu said.

Irungu elaborated on the manufacturing process, saying after the human waste is received at the site, the raw sewage is emptied into drying beds, where excess water is left to evaporate for nearly three weeks, leaving behind a solid residue.

The residue is subsequently exposed to high temperatures to kill any living organisms. Sawdust sourced from local saw millers is also heated up in a large pan - a process known as carbonisation.

Thereafter, the two products are mixed in equal ratios and ground into a powder. Diluted molasses is then added to act as a binding agent before the mixture is moulded into small round balls.

Mary Kerubo, a resident of Kivumbini, which neighbours the treatment plant, considers herself a lucky early adopter of the new commodity.

*"As much as demand is high, we can always order ours directly at the site. It is very economical and we use very little compared to charcoal, which is even harder to source following the ban. I can use one packet of makaa dot com at least five times compared to charcoal, which I only use twice,"* she said.

Reinilde Eppinga, a sanitation advisor with SNV Netherlands Development Organisation, which is a partner in the briquette project, said only 27 per cent of Nakuru residents are connected to the town's sewerage system, highlighting the need for a better way to dispose of the large quantities of human waste generated each day.



INDEPENDENT

# HUMAN WASTE: UNPARALLELED RESOURCE FOR HOUSEHOLD ENERGYNEEDS

The Water Provider Issue No. 10 Dec 2017

For century's human waste or human excreta has been a perennial problem. While some countries have made significant leaps in addressing sanitation challenges, many more especially in developing countries in sub-Saharan Africa, have widely struggled to sustainably reduce the menace and risk associated with inadequate access to sanitation services.

People living in Low Income Areas (LIAs) are disadvantaged in receiving basic sanitation services such as toilet facilities and emptying services. The high incidence of diseases related to poor sanitation and hygiene such as cholera and typhoid is a clear indication that new interventions need to be employed to tackle the sanitation challenge.

The United Nations (UN) Sustainable Development goals (SDG) regards sanitation as a human right that should be accessible to all. This is a noble proposition with a touch of irony. It is estimated by the UN that 2.4 billion people lack access to basic sanitation services, such as toilets or latrines and that more than 80 per cent of wastewater resulting from human activities is discharged into rivers, open drains, lakes or sea without any pollution removal. It is also a known and a sad fact that each day, nearly 1,000 children die due to preventable water and sanitation-related diarrhoeal diseases.

## The Pilot Study

In light of this, Nakuru County Sanitation Programme (NCSP) in which Nakuru Water and Sanitation Services Company (NAWASSCO) a local Kenya Water Service Provider (WSP), SNV Netherlands Development Organisation (SNV), Vitens Evides International (VEI), County Government of Nakuru and Egerton University through a Memorandum of Understanding (MoU) sort to seek alternative use of faecal matter in production of biomass energy for cooking and heating. This is to demonstrate that through innovation, multi-stakeholder approach, optimising existing infrastructure and understanding local context, sanitation challenges can be turned into opportunities as sludge is turned into alternative energy sources. The relationship between the two (sanitation and energy) therefore becomes essential.

Through a pilot study, 13 households drawn from Kaloleni, a LIA in Nakuru Town, were requested to participate in a three week trial using briquettes made from 50% faecal matter and 50% saw dust. Other target group included poultry farmers and hotels in the LIA. Working closely with households, hotels and poultry farmers the study sort to get user feedback on the performance, safety, handling, pricing, as well as marketing of faecal matter briquettes in comparison with the currently used charcoal. The study methodology employed Kitchen Performance Tests during which smoke levels, burning span, time taken to cook, quantity used, cleanliness of the pot bottom, briquette size and briquettes temperature intensity were tested in the natural households setting-that involves households performing their normal routine. Controlled Cooking Tests were conducted in a controlled setting where the performance of stoves and faecal matter fuels was measured against the traditional cooking methods. Focus Group Discussions and an End-line Survey were used to firm up the data collected.

## Willing To Purchase and Use Faecal Matter Briquettes

From the study, it was evident that majority of the households would prefer to use faecal matter briquettes due to their characteristics of burning



longer, less emission of smoke as compared to charcoal. Households also expressed high satisfaction of using the briquettes with their current cook stoves since they are compatible. They also showed willingness to purchase the briquettes if available in the market. The households proposed pricing of briquettes at KES 30- KES35 for 1 kilogramme. The purchasing power is informed by household's income and therefore households indicated a preference to purchase fuel in small quantities (2 or 5 kg packets). In which all pathogens and harmful gases are eliminated. Saw dust, a byproduct of timber, is sourced from registered millers and carbonised and later milled separately to reduce particle size in preparation for mixing. In order to achieve a homogenous mix, both milled sludge and sawdust are mixed in a ratio of 50:50 using a batch mixer. Finally, the mixed material is then introduced to a rotating drum that transforms the mixture into round shaped carbonised briquettes with molasses acting as a binder.

## Market for Faecal Matter Briquette

The pilot study has shown that there is a market for the faecal matter briquettes as an alternative fuel and can be a viable competition to charcoal. This study has also shown that households are ready to use the briquettes made from the faecal matter with the main advantage being the inherent value they derive from the product and the cost savings.

## Recommendation

Further to conducting the pilot study, important lessons and recommendations were drawn. It was evident that consumers want a product that is better than their current fuel. This is aggravated by the fact that, most of the household's cook in confined places that are without defined kitchen space, thus prone to indoor air pollution. While perception towards the product is commonly overstated, consumers were found to be positive about faecal matter briquettes.

This was mainly influenced by the consumer understanding of the production process and assurance on safety of the product. It is however recommended that, consumer education should be considered when introducing the products to consumers. In order to enhance marketing, organising marketing campaigns and analysing consumer feedback to increase not only uptake of products but also demystify faecal matter is highly recommended. In addition, research should be carried out on stoves to optimise performance of briquettes and marketing efforts can potentially include fuel-stove combinations.

## Safety of Briquettes

To ensure that the briquettes are safe to use and free from disease causing germs, the briquettes are subjected to a process. The process starts with dewatering of sludge- which refers to the removal of the high percentage of water from human waste after which it is dried to 20 per cent moisture content to prepare it for carbonisation

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# NCSP PUBLICATIONS - VIDEOS



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# **SCIENTIFIC PUBLICATIONS**



# RESPONSE OF POTATO TO DIFFERENT SOILS AND FAECAL MATTER FERTILIZERS

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## Abstract

Potato (*Solanum tuberosum*, L.) is an important food and cash crop in Kenya. However, its production has declined over the years due to extensive nutrient mining without adequate replacement. A study was conducted to evaluate the response of potato grown under three soil types (Planosol, Andosol and Acrisol) to three faecal matter fertilizers (FMFs). This included vermicompost, normal compost and dried sludge. In addition, common fertilizers (urea and cow manure) were also used. Two greenhouse trials were laid out in a randomized complete block design with four replicates per treatment. Data collected on soil nutrient status, plant growth and yield variables were subjected to analysis of variance using Statistical Analysis Software v.9.1 and treatment means separated using Tukey's test. Results showed that faecal matter fertilizers (FMF), vermicompost and dried sludge, were equally effective in increasing (39.2-46.5%) the potato growth compared to untreated control. Faecal matter fertilizers also contributed to high yields where vermicompost produced (12.3 t ha<sup>-1</sup>) 3 times more than untreated control (4.2 t ha<sup>-1</sup>) but the difference was not significant at  $P \leq 0.05$  from urea, normal compost and sludge. The interaction between fertilizers and soil types was not significant at  $P \leq 0.05$ . Faecal matter fertilizers are thus ecologically viable alternative source of mineral nutrients for sustainable potato production.

**Key words:** Acrisol / Andosol / Planosol / *Solanum tuberosum* / sludge / vermicompost

## 1. Introduction

Potato is the second most important food and cash crop after maize in Kenya. It is grown both as a horticultural crop and a food security crop. In Kenya, potato plays an important role as a food staple among small scale farmers and also contributes to poverty alleviation through income generation. Approximately one million farmers grow potato in Kenya while over 2.5 million Kenyans are employed along the potato value chain either directly or indirectly (Okello et al 2017). Most farmers in Kenya dedicate more than a third of their arable land to the crop (Peter et al., 2009). Despite its importance, potato production is constrained by soil degradation, lack of quality seeds, and pest and disease management among other factors (Were et al., 2013).

Soil fertility and crop management practices are not only key components of sustainable crop production in potato based cropping systems but also decisive factors for increased productivity and crop quality (Scott et al., 2000). Soil fertility management also stimulates microbial soil life and decomposition processes, which in turn reduce the incidence of soil and seed borne diseases such as bacterial wilt. According to Amon et al., (2014), degradation of the soil causes up to 8% decline in potato yields. Apart from soil degradation, rainfall is the only source of water for potato production in Kenya and hence the main source of variations in yields. It is possible that the problem of low soil pH has led to imbalances in nutrient content leading to further decline of potato yields. (Janssens et al., 2013).

The Faecal matter fertilizers (FMFs) can be used to replenish nutrients in the soil since they contain up to 0.7% N (Nitrogen) as a percentage of wet weight (Rose et al., 2015) which is about 5 to 11 g per day (Hakan et al., 2015). Where waste water from sludge has been used for irrigation it raised N, P, and K contents in potato plants and tubers. Irrigation by wastewater could reduce the fertilizer requirement of potato by 10-15%. About 11% N, 25% P (Phosphorous) and 21% K (Potassium) can also be recycled from the feces (Vinnerås et al., 2006). Furthermore approximately 80% of N, 50% of P and nearly 60% of K are found in household waste water and can be recycled so that these nutrients can be availed for crop use. The objective

of this study was therefore to evaluate the effect of faecal matter fertilizers on potato crop grown under different soil types, Andosols, Planosols and Acrisols.

The selected soils are the major three soil types found in abundance in Nakuru County (FAO ,2006) . Acrisols are soils that originate from variety of parent materials ranging from weathering of acid rocks for highly weathered clays that are undergoing further degradation and are usually found in old land surfaces that are hilly with natural vegetation. Andosol originate from volcanic glasses or other silicate-rich material and is dominant in undulating to mountainous, humid, and arctic to tropical regions with an extensive range of different vegetation. Finally, Planosols are soils that have a coarse-textured surface horizon with a finer textured subsoil that are prone to logging in flat lands formed from clayey alluvial and colluvial deposits. Furthermore, they contain light forest or grass Vegetation (Jaetzold et al 1982) . This research aimed at using faecal matter fertilizers (FMFs) to help in making these soils productive by improving their physical, chemical and biological properties.

## 2. Materials and methods

Greenhouse experiments were set up at the Domestic Water Treatment Plant (0°19'22"N and 36°3'46"E) of Nakuru Water and Sanitation Services Company (NAWASSCO) located in Nakuru National Park, Kenya. The site lies in Lower Highland III (LH3) Agro Ecological Zone and an altitude of 1850 m.a.s.l (Jaetzold et al., 2012). Average maximum and minimum temperatures ranges from 19 to 22°C and 5 to 8°C, respectively. The annual rainfall ranges from 800 to 900 mm and the soils are predominantly well drained, deep to very deep dark brown to grayish brown friable and smeary clay loam, with thick humic topsoil (Mollic Andosols) (Mainuri et al., 2013).

### 2.1 Preparation of faecal matter based fertilizer products

Composting materials (composite market waste) were collected from the Municipal Market, Nakuru town and NAWASSCO waste water treatment plant (sludge). Proper sorting was done to ensure only degradable materials were composted and coarse / large materials like banana stalks were chopped into smaller pieces. The choppings were then placed in the in wooden boxes and mixed in the ratio of 3:1 (market waste: sludge) in the greenhouse. For normal compost, the materials were let to compost for 5 months with weekly turning and addition of water as maintenance practices. On the other hand vermicompost, worms were introduced after one month and favorable conditions (Temperature: 15-25°C, Moisture: 75% and pH: 5.7) for their survival maintained. Finally, the vermicompost was maintained in aerobic environment. Dry sludge was prepared by sun drying the sludge directly on drying beds lined with black plastic sheet in a greenhouse at 40-60°C for one month.

### 2.2 Collection and characterization of test soils

Three different soils, representing Planosol, Acrisol and Andosol, were collected from Nessuit (Latitude: -0°23'25.99"S, Longitude: 35°52'52.32"E), Egerton University (Latitude: 0°22'11.0"S, Longitude: 35°55'58.0"E) and Molo (Latitude: 0.2488° S, Longitude: 35.7324°E), respectively in Nakuru County, Kenya. The soils used are the dominant soils in Nakuru County and some parts of the central Highlands of Kenya where the potato crop is extensively grown. The sites where the soils were collected were cleared to remove vegetation cover and the soils were dug to a depth of 30 cm. Each soil sample comprised of a combination of the top soil and the subsoil. The soils were then put into sample bags (size: 240 kg soil) per soil type and was enough for the entire experiment.

Characterization of the soil was partly done in the field and the laboratory where samples were taken for analysis to determine the physical and chemical properties. The properties analyzed were pH (electrometric), N (Kjeldahl), P (Mehlich), K (Flame photometer) and bulk density (core).

### Nitrogen (Kjeldahl method)

A soil sample weighing 0.3g was digested in digestion tubes using a digestion mixture comprising of HCl, HNO<sub>3</sub>, Se and CuSO<sub>4</sub>. The temperatures in the heating block was maintained at 3600C for two hours after which the samples were let to cool and transferred to 50ml volumetric flasks and the volume made to the mark. It was then allowed to settle and 5ml of the aliquot was put in to the distillation bottle where 10ml of 40% NaOH was added. It was then steam distilled into 5ml 1% Boric acid containing 4 drops of mixed indicator for 2 minutes from the time the indicator turned green. The distillate was titrated using HCl and the end point was reached when the indicator turned green through grey to definite pink. A blank experiment was prepared using the same procedure (Kirk, 1950).

### Bulk density (Core method)

A core ring of 5cm diameter with known weight (W1) and volume (V) was inserted 5cm in the soil. It was the removed from the soil and soil around the core was wiped and trimmed at the bottom and top using a knife. They were then put in an oven at 1050C for 2 days after which they were allowed to cool and weighed (W2).

### Potassium

A soil sample weighing 0.3g was digested in digestion tubes using a digestion mixture comprising of HCl, HNO<sub>3</sub>, HF and H<sub>3</sub>BO<sub>3</sub>. The temperatures in the heating block maintained at 3600c for two hours after which the samples were let to cool and transferred to 50ml volumetric flasks and volume made to the mark. Calibration was done for each element using certified standards. Samples were analysed using Varian spectra AA10 AAS machine.

### Phosphorous

0.3g sample was digested in digestion tubes using a digestion mixture comprising of HCl, HNO<sub>3</sub>, Se and CuSO<sub>4</sub>. The temperatures in the heating block maintained at 3600c for two hours after which the samples were let to cool and transferred to 50ml volumetric flasks and volume made to the mark. 5ml of the aliquot was transferred in to the sample bottles where 1 ml of developing colour solution (Ammonium Vanadate and Ammonium Molybdate in the ratio of 1:1). The samples were left to stand for 30 minutes after which they were transferred to cuvates. Readings (absorbance) were taken using a spectrophotometer at 430 wavelength. Calibration was done using certified standards. The chemical composition of the soils used in the study are presented in Table 1 while the nutrient composition of the FMFs are presented in Table 2.

**Table 1:** Chemical and physical properties (Mean ±SE) of three soil types

| Soil Type | Chemical properties |           |           | Physical property |                          |
|-----------|---------------------|-----------|-----------|-------------------|--------------------------|
|           | pH                  | N (%)     | P (mg/kg) | K (mg/kg)         | BD (g cm <sup>-3</sup> ) |
| Andosol   | 6.23±0.07           | 0.19±0.08 | 43.0±0.61 | 68.2±1.25         | 1.26±0.04                |
| Planosol  | 6.72±0.1            | 0.23±0.03 | 35.0±0.64 | 62.4±1.02         | 1.37±0.62                |
| Acrisol   | 5.75±0.21           | 0.36±0.02 | 58.0±0.82 | 93.5±1.28         | 1.24±0.07                |

N= Nitrogen, P= Phosphorus, K= Potassium; BD= Bulk density; Means in a column whose SE values do not overlap are significantly different at α=0.05 by Tukey's HSE test

**Table 2:** Nutrient composition (Mean±SE) of test organic fertilizers

| Organic fertilizer | N (%)    | P (%)    | K (%)    |
|--------------------|----------|----------|----------|
| Vermicompost       | 2.3±0.07 | 0.4±0.02 | 0.4±0.06 |
| Normal compost     | 1.8±0.24 | 0.3±0.12 | 0.4±0.03 |
| Sludge             | 1.5±0.07 | 0.2±0.04 | 0.2±0.04 |
| Cow manure         | 0.6±0.15 | 0.3±0.08 | 0.4±0.08 |

N= Nitrogen, P= Phosphorus, K= Potassium; Means in a column whose SE values do not overlap are significantly different at P≤0.05 by Tukey's HSE test

**Table 3:** Growth response of potato to faecal matter fertilizers under different soil types.

| WAP | Fertilizers       | Andosols |           | Planosols |          | Acrisol  |          |
|-----|-------------------|----------|-----------|-----------|----------|----------|----------|
|     |                   | NB       | NL        | NB        | NL       | NB       | NL       |
| 3   | Untreated control | 2.9±0.1  | 10.7±0.9  | 4.6±0.4   | 9.9±0.4  | 3.0±0.6  | 13.4±0.3 |
|     | Urea              | 3.5±0.7  | 19.0±0.3  | 3.3±0.3   | 26.3±0.6 | 3.0±0.0  | 18.8±0.7 |
|     | Cow manure        | 4.0±0.0  | 12.0±1.0  | 3±0.1     | 20.8±0.5 | 3.5±0.4  | 17.4±0.6 |
|     | Normal compost    | 5.0±0.1  | 17.6±0.1  | 3.5±0.1   | 19.8±0.4 | 4.0±0.0  | 19.3±0.7 |
|     | Sludge            | 4.3±0.2  | 22.6±0.2  | 4.3±0.5   | 17±0.3   | 4.0±0.4  | 17.2±0.5 |
|     | Vermicompost      | 5.3±0.3  | 19.5±0.6  | 4±0.0     | 17.5±0.4 | 4.3±0.1  | 17.0±0.6 |
| 4   | Untreated control | 4.4±0.1  | 34.7±0.5  | 5.2±0.4   | 30.0±0.3 | 3.6±0.3  | 36.2±0.5 |
|     | Urea              | 5±1.8    | 34.0±0.6  | 4.7±0.6   | 53.5±0.2 | 6.0±0.3  | 57.5±0.4 |
|     | Cow manure        | 4.3±0.2  | 34.5±1.3  | 4.5±0.3   | 57.2±0.6 | 3.7±0.3  | 57.8±0.6 |
|     | Normal compost    | 6.7±0.1  | 64.3±0.8  | 6.0±0.4   | 50.0±0.5 | 5.7±0.5  | 55.0±0.6 |
|     | Sludge            | 5.3±0.4  | 62.3±0.8  | 5.4±0.8   | 53.5±1.2 | 5.0±0.1  | 53.1±0.4 |
|     | Vermicompost      | 6.3±0.3  | 51.5±0.8  | 6.0±0.4   | 61.7±0.4 | 6.3±0.1  | 50.0±0.4 |
| 5   | Untreated control | 8.7±0.1  | 46.9±0.54 | 7.5±0.1   | 43.9±0.4 | 6.7±0.4  | 67.3±0.5 |
|     | Urea              | 6.7±1.8  | 54.3±0.7  | 9.3±0.2   | 79.2±0.8 | 8.7±0.2  | 74.4±0.8 |
|     | Cow manure        | 6.3±0.5  | 54.5±1.1  | 8±0.01    | 87.8±1.0 | 7.0±0.4  | 80.2±0.3 |
|     | Normal compost    | 10.7±0.4 | 69.5±0.6  | 9.5±0.1   | 83.6±1.0 | 9.3±0.3  | 86.0±1.2 |
|     | Sludge            | 8.3±0.1  | 62.3±0.6  | 7.5±1.9   | 65.5±0.8 | 9.3±1    | 76.8±0.8 |
|     | Vermicompost      | 10.8±0.1 | 68.2±0.6  | 10.3±0.1  | 69±0.7   | 10.5±0.3 | 96.2±0.6 |
| 6   | Untreated control | 10.4±0.1 | 51.6±0.77 | 12.6±0.1  | 46.6±0.7 | 10.6±0.1 | 67.8±0.6 |
|     | Urea              | 11.8±0.5 | 60.8±0.4  | 13.7±0.4  | 83.3±0.6 | 14.3±0.3 | 84±0.6   |
|     | Cow manure        | 11.8±0.1 | 61.8±0.4  | 9.3±0.6   | 88±0.4   | 11.3±0.2 | 88.5±1.2 |
|     | Normal compost    | 12.7±0.4 | 71±0.3    | 12.0±0.3  | 94±0.8   | 14.7±0.1 | 86±0.9   |
|     | Sludge            | 11±0.4   | 66.5±0.3  | 12.6±1.6  | 72.9±0.7 | 13.0±0.6 | 79.4±0.7 |
|     | Vermicompost      | 12.9±0.3 | 68.2±0.4  | 13±0.8    | 75.5±0.7 | 13.5±0.1 | 101±0.6  |

NB = Number of branches, NL= Number of leaves, WAP= Weeks after planting; Means in a column whose SE values do not overlap are significantly different at P≤0.05 by Tukey's HSD test.

## 2.3 Experimental Design and Layout

Two pot experiments were conducted in a plastic greenhouse. The plastic containers (pots), size: 10 l, were filled with 10 kg of soil each and a total of 18 pots randomized per block in 4 blocks. The treatments were set up in a Randomized Complete Block Design (RCBD) with factorial arrangement of two factors, soil type and faecal matter fertilizers. The treatments included: three levels of soil types (Acrisol, Andosol and Planosol) and three faecal matter fertilizers (vermicompost, normal compost and sludge) and positive inorganic fertilizer control, urea and organic fertilizer cow manure, replicated four times and arranged 30 cm between the pots and 75 cm between the blocks.

## 2.4 Crop Establishment

Healthy and sprouted seed potato tubers were sliced into pieces each weighing 25 to 30 g and having 2 to 3 eyes (buds). Every pot was planted with one sliced piece of tuber at a depth of 5 cm. The various amendments were applied at different rates as follows; vermicompost, 3.9 t/ha; normal compost 4.9 t/ha; Urea 0.2 t/ha; dried sludge 6 t/ha and cow manure 15 t/ha.

## 2.5 Data Collection

Data were collected on a weekly basis for four weeks after germination on growth variables. Number of branches was determined by counting well-developed branches with leaves. Plant height measurements (cm) were taken from the base of each crop to the top of the main plant stem using a ruler. Numbers of leaves were counted on well-developed branches

and yield was obtained by weighing (grams) the tubers using electronic balance (SF-400) and later converted to t ha<sup>-1</sup>.

## 2.6 Data analysis

Data were subjected to analysis of variance (ANOVA) using Proc GLM, SAS software v.9.1 (SAS INC., 2001). Where ANOVA revealed existence of significant differences among treatments, means were separated using Tukey's HSD test at  $P \leq 0.05$ .

## 3.0 Results and Discussion

### 3.1 Effect of faecal matter fertilizers (FMFs) on Potato height

Under Andosol soil, results showed that vermicompost produced significantly ( $P \leq 0.05$ ) better potato height response compared to other fertilizers at all the growth stages. The potato crop had same level of height response to normal compost and sludge at all growth stages. The other treatments, urea, cow manure and untreated control equally produced the lowest height response and there were no differences during the period week 3, 4 and 5 (Figure 1).

Figure 1

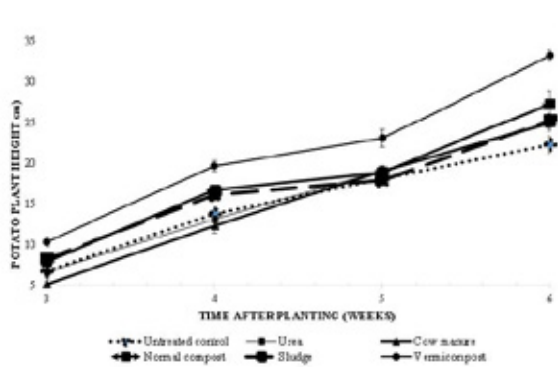


Figure 1. Potato plant height (Mean±SE) response to fecal matter fertilizer under Andosol

According to figures obtained from Planosol, however, vermicompost, normal compost, cow manure and urea treatments were different during the period week 3, 5 and 6. Untreated control had the lowest performance in all the growth stages (Figure 2)

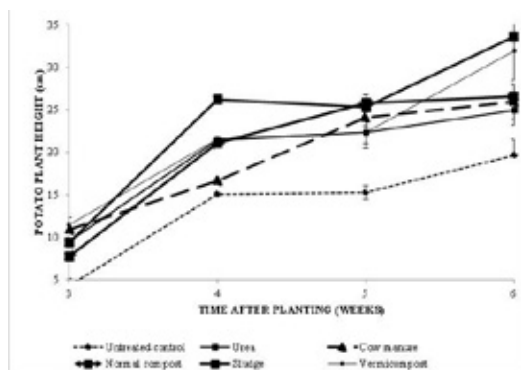


Figure 2. Potato plant height (Mean±SE) response to fecal matter fertilizer under Planosol

Figure 2

The FMFs produced comparable height responses under Acrisol soil in which sludge, urea and vermicompost recording equally taller plants at all the growth stages. The latter fertilizers produced results that were superior to cow manure, normal compost, and untreated control (Figure 3). Figure 3

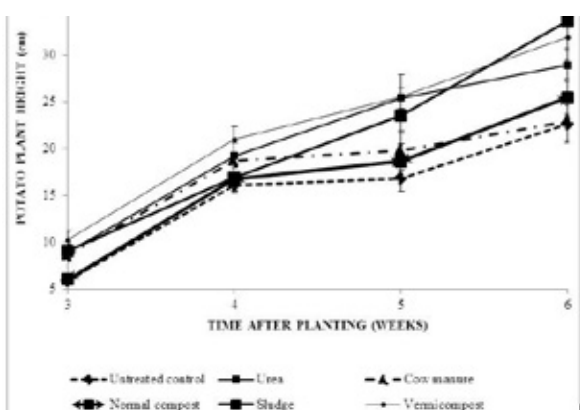


Figure 3. Potato plant height (Mean±SE) response to fecal matter fertilizer under Acrisol

FMFs vermicompost, normal compost and sludge were able to supply enough nitrogen that contributed significantly to potato plant height under Andosol and Acrisol. This is because they have the benefit of being slower-acting and gentler than urea as a chemical fertilizer. These products were in a form which did not allow them to be absorbed immediately by plants but had to be broken down first by soil bacteria and fungi into forms that plants can absorb which is in agreement with findings of Borah et al., (2005). This means that, unlike in inorganic fertilizer, they were not easily leached, and that the potato crop got the benefit of nutrients for growth more evenly over a period of time during the vegetative stage. When it came to Planosol the response was low although the performance of sludge, vermicompost, cow manure and urea had no significant difference in week 3, 5 and 6. This is attributed to the soil characteristic of Planosol that restricts root development thus low water and nutrient absorption.

### 3.2 Effect of FMF on number of branches and leaves of potato

Results showed clear plant age-dependent increase in number of branches and leaves in response to faecal matter fertilizers application. At the end-point response, 6 WAP, the normal compost, sludge and vermicompost fertilizer applications in a potato crop, under the Andosol soil, produced significantly ( $P \leq 0.05$ ) 5.8 to 24.0% more number of branches compared to the untreated control. Similarly potato grown under Acrisol produced 22.6 to 38.7% more number of branches compared to the untreated control (Table 3). The cow manure, urea and the untreated control equally recorded the lowest number of branches and leaves over the growth period. Furthermore results showed significant ( $P \leq 0.05$ ) age- and soil type-dependent response of number of plant leaves. At the end-point response, 6 WAP, the normal compost, sludge and vermicompost fertilizer applications produced 28.9-37.6, 56.4-101.8 and 30.5-49.0% more potato leaves under Andosol, Planosol and Acrisol, respectively (Table 3).

Table 3.

For number of branches the two composts had same ability to supply nitrogen throughout the growth stages and their performance was way better than the other fertilizers applied under Andosol. Andosols are soils that have been cultivated for long and nutrients have been depleted as shown in Table 1 especially the level of N. When compost is applied it improves the soil physical and chemical properties that enabled the fertilizers applied to supply the needed nitrogen to the crop as shown in Table 3. The situation was different under Planosol where low potato response was recorded due to high bulk density ( $1.37 \pm 0.072 \text{ g cm}^{-3}$ ) across the growth stages (Table 3). Such soils with high bulk density restricted root growth as it increased compaction thus the crop was not able to absorb water and nutrients from the soil and also tuber growth was limited. This is in agreement with the findings in (Usman et al., 2015). Under Acrisol, the best performance was observed where urea, vermicompost and sludge were applied. This type of soil has properties that favor good water and nutrient absorption as a result, there was extensive root development. The contribution of cow manure to potato nitrogen supply was limited when compared to FMFs. This is probably due the slow rate at which cow manure was releasing nutrients. This is in agreement with Souza et al., (2008) where slower nutrient releasing organic fertilizers hinder growth and production of potato.

For number of leaves the performance of all the fertilizers was more or less the same with no significant difference in week 3 under Andosol. This may be due to the stage of the crops where they did not have well developed roots that could absorb nutrients and also the products applied. The subsequent weeks exhibited positive response where vermicompost, sludge and normal compost interaction with all the soil types was high as shown in week 4, 5 and 6. This is because vermicompost had two characteristics that favored crop growth, first it had been broken down by worms making it finer and the increase in nutrient content. It is also in organic form thus boosted the soil physical properties. Andosols are always fertile soils but if leached the levels of nutrients decline thus use of organic fertilizers. This in line with findings filed in FAO report (2014). There was no significant difference between all the fertilizers across all the growth stages. This means that all the fertilizers applied had same ability to supply nitrogen for vegetative growth.

### 3.3 Effect of FMF on potato Yield

Results showed significant ( $P \leq 0.05$ ) FMFs and soil type-dependent potato yield responses (Figure 4). Sludge and vermicompost applications equally produced the highest potato yield of 15.4 t ha<sup>-1</sup> and 14.5 t ha<sup>-1</sup> under Acrisol soils respectively. These yield levels were comparable to the positive control, urea. Potato crop had the lowest yield response to the different FMFs under the Planosol soils. There was insignificant soil type by FMF interaction effect on potato crop yield

Figure 4

The effect of FMF was felt on yield where fertilizers applied was significant



at  $P \leq 0.05$ . The chemical properties of the products applied contributed

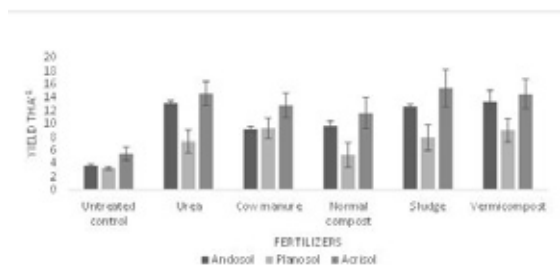


Figure 4. Potato yield ( $t\ ha^{-1}$ ; Mean $\pm$ SD) under different soil types and fecal matter fertilizer application

greatly to increased yield. Vermicompost recorded highest yields of  $15.5\ t\ ha^{-1}$  under Acrisol but the difference was not significant from sludge, urea and cow manure. Acrisols have in general low levels of nutrients so any addition of nutrients will give a positive response. In this case, acrisols had the highest content of K ( $93.5\ mg/kg$ ) and also N ( $0.36\ %$ ). Though acrisols have the ability to fix P, this may have been compensated by substantial amounts in the soil which may have been taken up by the plant. The low yields from planosols could be attributed to the low nutrient status and poor aeration due to its high clay content. This may have restricted root development. The differences noted among soils were directly proportional to the results obtained from the characterization of the soils in terms of N, P, K and bulk density level. Acrisol had the best properties which meant that it had more ability in making available the nutrients for root absorption. This is explained by the fact that application of nutrients in the soil does not guarantee availability of the same nutrients to the crop due to some processes taking place such as phosphorous fixation. For example, andosols have a tendency to fix phosphorous, any addition from the amendments may be partially fixed in the soil. Suitable soil properties like bulk density of  $1\ to\ 1.3\ g\ cm^{-3}$  ensure better tuber formation in the soil while a high bulk density restricts tuber formation through compaction leading to low yields. This results are in line with findings Amara et al. (2013).

Among the FMFs, it is evident that vermicompost promoted plant growth and production by 30% more than chemical fertilizers which agree with the findings of Sinha et al., (2010) who found that use of vermicompost in production of wheat and corn crops promoted growth by 30 -40 % higher as compared to chemical fertilizers. This result may be due the provision of organic matter by vermicompost to the soil that helped with the retention of water and nutrients for a healthy root system. Vermicompost has been found to be more superior in protecting the soil and promoting crop growth than any other organic material (Munroe 2007). The difference in performance demonstrated variation in their capability to constantly supply the required nutrient quantity which they contain as shown in Table 2 when necessary. The effect of interaction between soil types and fertilizers was not significantly different at  $P \leq 0.05$ . This shows that both soil types and fertilizers acted independently to some extent.

#### 4.0 Conclusions

Treated Faecal matter fertilizers are an important source of plant nutrients when used in crop production. They improved growth parameters and yield three times more than the untreated control. The performance was also better than cow manure. Potato crop showed positive response to these products particularly vermicompost and their performance was similar to that observed with commonly used inorganic fertilizer urea. Acrisols amended with sludge had the highest potato yield closely followed by amendment with vermicompost on the same soil. However, planosols had the least potato yield irrespective of the FMFs added.

#### 5.0 Acknowledgment

This research was part of a research partnership between Nakuru County Sanitation Program (NCSP)/Nakuru Water and Sanitation Services Company Ltd. (NAWASSCO) and Egerton University. NCSP is a European Union co-funded program implemented by NAWASSCO with the support of the Nakuru County government, Umande Trust, SNV Netherlands.

#### 6.0 References

- Amara, D.G., Mourad, S. M. (2013): Influence of organic manure on the vegetative growth and tuber production of potato (*Solanum tuberosum* L. varsputna) in a Sahara desert region. *Int. J. Agric. Crop Sci.* 22, 2724-2731.
- Amon, M. K., Chris, S., George, M. (2014): Analysis of the key challenges facing potato farmers in Oljoro-Orok Division, Kenya. *Agric. Sci.* 5, 834-838.
- Borah, M. C., Mahanta, P., Kakoty, S. K., Saha, U. K., Sahasrabudhe, A. D. (2007): Study of quality parameters in vermicomposting. Department of mechanical engineering Indian institute of science of technology Guwahati. *Indian J. Biotech.* 16, 410-413.
- FAO (2006) World reference base for soil resources 2006. A framework for international classification, correlation and communication 67: 70-88. 11.
- FAO (2014): The state of food and agriculture. <http://www.fao.org> (accessed Oct 10, 2017)
- Håkan, J., Andras, B., Ulf, J., Daniel, H., Erik, K. (2005): Composition of urine, faeces, grey water and bio waste. *Urban Water Report 2005:6*.
- Jaetzold, R., Schmidt, H., Hornetz, B., Shisanya, C. (2012): Farm management handbook of Kenya. <http://www.fao.org> (accessed Sep 20, 2017).
- Jaetzold R, Schmidt H, Hornetz B, Shisanya C (1982) Farm Management Handbook of Kenya. Central Kenya (Rift Valley and Central Provinces), Kenya
- Mainuri, Z. G., Owino, J. O. (2013). Effects of land use and management on aggregate stability and hydraulic conductivity of soils within River Njoro watershed in Kenya. *Int Soil. Water Conserv Res.* 11, 80- 87.
- Munroe, G 2007: Manual of on-farm vermicomposting and vermiculture. Organic Agriculture Centre of Canada.
- Okello, J.J., Yuan, Z., Norman, K., Sylvester, O., Ian, B., Elma, S. G., Elly, A., and Justin, T.A. 2017. Productivity and food security effects using certified seed potato: the case of Kenya's potato farmers. *Agriculture and food security*, 2017 6:25
- Peter, R., Wachira, K., Oscar, O., Agajie, T., Gebremedhin, W. (2009): Improving potato production in Kenya, Uganda and Ethiopia: A system diagnosis. *Potato Res.* 52,173-205.
- Riungu, C. (2011): No easy walk for potatoes. *E.A. Fresh Produce.* 19, 16-17.
- Rose, C., Parker, A., Jefferson, B., Cartmell, E. (2015): The characterization of faeces and urine: A review of the literature to inform advanced treatment technology. *Crit Rev. Environ Sci. Technol.* 45, 1827-1879.
- Scott, G. J., Rosegrant, M. W., Ringler, C. (2000): Global projections for root and tuber crops to the year 2020. *Food Policy.* 25, 561-597.
- Souza, P. A., Souza, G., Menezes, J. B., Bezerra, N. F. (2008): Evaluations of cabbage cultivar grown under organic compost and mixed mineral fertilizers. *Horticulture.* 26, 143-145.
- Sinha, R. K., Agarwal S., Chauhan, K., Chandran, V., Kiranbhai, B. (2010): Vermiculture Technology: Reviving the Dreams of Sir Charles Darwin for Scientific Use of Earthworms in Sustainable Development Programs, *Sci. Res.* 1, 155-172.
- Usman, M., Madu, V. U., Alkali, G. (2015). The Combined Use of Organic and Inorganic Fertilizers for Improving Maize Crop Productivity in Nigeria. *Int. J. Sci. Res Publ.* 5, 10.
- Vinnerås, B., Palmquist, H., Balmér, P., Weglin, J., Jensen, A., Andersson, Å. Jönsson, H. (2006): The characteristics of household wastewater and biodegradable waste - a proposal for new Swedish norms. *Urban Water.* 3, 3-11.



# ASSESSMENT OF HEAVY METALS IN SEWAGE SLUDGE AND THEIR ACCUMULATION IN CABBAGE (*BRASSICA OLERACEA VAR CAPITATA*)

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**Heavy metals accumulation in sewage sludge is a major concern to the environment especially when it is considered to be used for crop production. This research aimed at checking the levels of heavy metals in faecal matter based fertiliser products and if there is any subsequent absorption by cabbage when used in the field. Sewage sludge was used as major raw material to produce sludge, biochar, normal compost and vermi compost. Tests were done on the products and later on cabbage tissues. The results obtained showed that the products had no alarming levels of heavy metals as well as the levels in the tissues were not beyond the permissible levels. This indicates these products as safe for cabbage production.**

## Introduction

Globally, 2.4 billion people do not have access to improved sanitation in spite of the fact that from 1990 to 2014, 2.1 billion people gained access to improved sanitation facilities (WHO/UNICEF, 2015). There are significant sanitation gaps in regards to services offered to rural and urban populations, gender inequalities, and exclusion of the poor from water and sanitation services (Onda et al., 2012, WHO/UNICEF, 2015). According to joint monitoring program (JMP), between 1990 and 2015, the least developed countries failed to meet the sanitation targets. Only 27% of their current populations gained access to improved sanitation facilities. In Sub-Saharan Africa, less than 20% of the current population have access to improved sanitation facilities. Most use on-site pit latrines. When the on-site facilities fill up, they lead to the management burden of either emptying or building a new pit latrine. Due to space limitation in urban areas, emptying is the most appropriate management option in urban areas.

The faecal sludge emptied from pit latrines is disposed into the municipal waste water treatment plants (WWTP) without any co treatments. Municipal WWTPs are not designed for treatment of sludge because of the high organic load and solids in the faecal sludge. Disposal of faecal sludge in its state without pretreatment has a causal effect on the poor functioning of the WWTP (Lopez-Vazquez et al., 2004). Faecal matter based fertiliser products can be used to fill the gap of nutrients deficiency in the soil since they contain up to 0.7% nitrogen a percentage of wet weight (Rose et al., 2015) which is about 5 to 11 g per day.

Also about 11% nitrogen, 25% phosphorus and 21% potassium can also be recycled from the faeces (Vinnerås et al., 2006). Despite the positive attributes of faecal matter based fertiliser products, contamination of heavy metals in sludge from faecal matter is a major concern. When applying these products, there is a danger of these elements accumulating in the soil (Singh and Kalamdhad 2012). There are various sources of heavy metals that find their way in to faecal matter sludge and they include man made sources like paint chips, used motor oils, batteries, ceramics, consumer electronics and natural sources like soil erosion (Oghenerobor et al., 2014).

Soils are the major sink for heavy metals released into the environment and unlike organic contaminants which are oxidised to carbon (IV) oxide by microbial action, most metals do not undergo microbial or chemical degradation, and their total concentration in soils persists for a long time after their introduction. Changes in their chemical forms (speciation) and bioavailability are, however, possible. The presence of toxic metals in soil can severely inhibit the biodegradation of organic contaminants (Adriano, 2003). Heavy metal contamination of soil may pose risks and hazards to humans and the ecosystem through: direct ingestion or contact with contaminated soil, the food chain (soil-plant-human or soil-plant-animal human), drinking of contaminated ground water, reduction in food quality (safety and marketability) via phytotoxicity, reduction in land usability for agricultural production causing food insecurity, and land tenure problems (Wuana & Okieimen, 2011). Alternative use of faecal sludge and closing the sanitation loop was advocated for as viable venture in a project spearheaded by Nakuru Water and Sanitation Services Company Ltd (NAWASSCO) and Egerton University. This research is part of the Nakuru County Sanitation

Programme whose overall objective is to demonstrate and implement a commercially viable sanitation value chain, benefiting residents of unserved (peri-) urban low income areas in Nakuru County through production of faecal sludge related products like compost manure for crop growing and soil conditioning.

## Materials and methods

### Study area

The experiment was set up at NAWASSCO's domestic treatment plant located near Nakuru National Park within the former Nakuru Municipality now Nakuru town which is one of the fastest growing towns in Kenya. It is the fourth largest urban centre with a population of about 307,990 inhabitants. The experimental site lies 0°19'22"N 36°3'46"E and in Lower Highland III Agro Ecological Zone (LH3) with altitude of 1850 meters above sea level. Average maximum and minimum temperatures range from 19 to 22°C and 5 to 8°C respectively. The annual rainfall ranges from 800 to 900 mm and the soils are predominantly well drained, deep to very deep dark brown to greyish brown friable and smeary clay loam, with thick humic topsoil (Zachary et al., 2013).

### Compost making

Market waste was obtained from Nakuru town market, sorted out to ensure only degradable materials are composted and large particles like banana stalks were chopped in to smaller pieces. Faecal sludge was sourced from septic tanks in homesteads. The ratio of market waste: sludge was 3:1. For normal compost it was let to compost for 5 months with frequent turning and addition of water and maintenance practices. For vermi-compost, worms were introduced after one month and the conditions maintained in a level that worms can thrive i.e. temperature at 150 – 250 Fahrenheit with moisture at 75%, pH at slightly acid and finally maintaining an aerobic environment. It was composted for a period of three months then ready for use. Cabbage experiment.

This experiment compared the above faecal sludge, vermi-compost and normal compost with biochar, cow manure, struvite, Di-ammonium phosphate and untreated control to determine their suitability for growing cabbage. Cabbage 'Copenhagen' was grown in two sites: Horticulture Teaching and Research Field, Egerton University and Lanet, Nakuru in different seasons using randomized complete block design with four replications. Leaves of randomly sampled cabbage per plot were obtained at head formation stage (Figure 1) and comprehensively analysed for the concentration of heavy metals in a Soil Science Laboratory, Egerton University.

### Sampling and analysis

Sample analysis was done in accordance with the standard methods of analysing wastewater according to APHA (2005). Samples were homogenised to make representative sample, then a 0.3g sample was obtained from this and digested in digestion tubes using a digestion mixture comprising of HCl, HNO<sub>3</sub>, HF and H<sub>3</sub>BO<sub>3</sub>. The temperatures in the heating block maintained at 360°C for two hours after which the samples were let to cool and transferred to 50ml volumetric flasks and volume made to the mark. Calibration was done for each element using certified standards. Samples were analysed using Varian spectra AA10 AAS machine (210 VGT).

For data analysis, descriptive statistics was used to organise the data and ANOVA was undertaken to ascertain if there was statistical difference among the concentrations at 95% confidence level.

## Results and discussion

There was no significant difference in lead concentration between sludge, normal compost and vermicompost as shown in Table 1 which is contrary to expectations, since the worms in vermi-compost bioaccumulate heavy metals and thus expected to reduce heavy metal concentration. However, since some of the worms could have died off during the composting process, they could have been assimilated in the compost such that the lead contained within them was reflected in the compost. There was no significant difference in concentration of zinc between vermi-compost and sludge. However, the concentration was significantly lower in normal compost. Copper concentration in normal compost was higher and statistically different from sludge ( $p < 0.05$ ) but it was not statistically higher than for vermi-compost. For cadmium, there was no statistically significant difference in concentration between sludge and normal compost. However, it was statistically different for vermi-compost ( $p < 0.05$ ) having a lower concentration. The concentration of Cr in vermi-compost was lowest but was not statistically significant from that of normal compost. However, it was statistically different from that of sludge. These results are similar to those from a study undertaken by Singh and Kalamdhad (2012) in California who found lower concentrations of Cd and Cr in vermi-compost.

Concentrations for all the heavy metals were below the USEPA (1993) guidelines. There are no documented standards for Kenya. This is an indication that they are safe for use as manure.

| Elements | Sludge   | Vermicompost | Normal compost | Permissible level in sludge by USEPA (1993) |
|----------|----------|--------------|----------------|---|
| Pb       | 13.9±1.2 | 14.6±2.1     | 12.5±1.5       | 840   |
| Zn       | 51.6±4.8 | 48.2±4.2     | 35.7± 3.2      | 7500  |
| Cu       | 68.5±4.0 | 77.4± 8.1    | 83.7± 8.2      | 4300  |
| Cd       | 2.3±0.1  | 1.2±0.1      | 2.3± 0.6       | 85  |
| Cr       | 42.4±4.3 | 25.1± 3.1    | 31.6±3.7       | Not indicated                               |

Means in a column whose SD values do not overlap are significantly different at  $\alpha = 0.05$

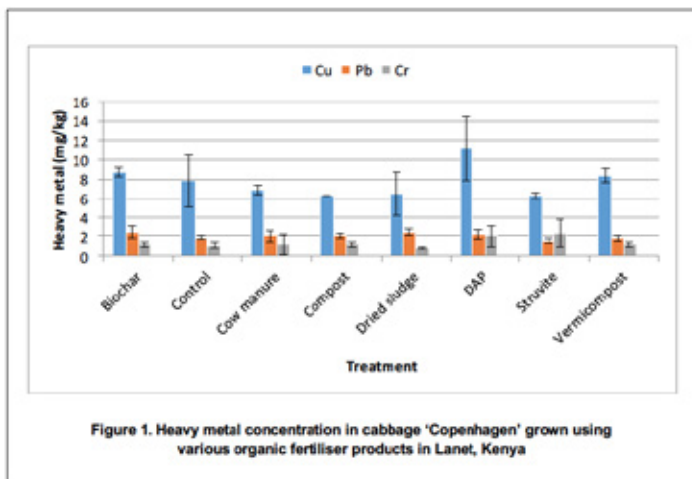


Figure 1. Heavy metal concentration in cabbage 'Copenhagen' grown using various organic fertiliser products in Lanet, Kenya

Heavy metal accumulation in edible plant parts is a health concern especially in leafy vegetables like cabbage (*Brassica oleracea* var *capitata* L.), which are consumed fresh or with minimum cooking. Cabbage is widely grown in Kenya and there is increasing demand for organic cabbages due environmental and health hazards associated with inorganic fertilizers. In this study, special attention was focused on Cadmium (Cd), Lead (Pb) and Chromium (Cr), which are extremely toxic and associated with sewage sludge.

Contrary to the usual perception, cabbages from both sites did not contain cadmium which is the most dangerous heavy metal in human food (Figure 1). Low Cd concentration in cabbage could be due to absence of free Cd ions in the soil solution which are recognized as the most unavailable metal form. This may have been caused by competition of Cd with organic matter in the sludge. In all the treatments including the untreated control, lead (Pb) content was generally higher than the maximum level (0.1 mg/kg) recommended for cabbage by Codex Standards. This suggests that the soils in the sites where the experiments were conducted had high contents

of lead (Pb). Chromium (Cr) content in the cabbages grown with the organic fertiliser products was similar to those grown without the products. Besides, all the treatments recorded similar contents of manganese (91.9 -114.6 ppm), iron (31.0 - 54.9 ppm) and zinc (20.7 - 48.2 ppm), which were below the permissible levels in sludge (Table 1). The results indicate that cabbages grown using faecal matter fertilizer materials are safe for human consumption. The results are similar to the finding of Czech et al. (2011). Dried sludge is therefore recommended for production of cabbage 'Copenhagen' without any health risk. Although, heavy metal accumulation capacity varies with vegetable species (Czech et al., 2011), these results may be applicable to other vegetables as the safety of the cabbages is largely attributed to the low contents of heavy metals in the faecal matter fertilizers used (Table 1).

## Conclusion

There was no significant difference in lead concentration between sludge, normal compost and vermicompost. Normal compost was higher than sludge and vermi-compost for concentrations of copper. It had lower concentrations for zinc. Vermicompost had higher concentrations of lead however it was lowest for Cd and Cr. Concentrations for all the heavy metals were below the USEPA (1993) guidelines, an indication that they can safely be used for growing crops especially cabbage.

## Acknowledgements

This research was part of the research partnership between Nakuru County Sanitation Programme (NCSP)/Nakuru Water and Sanitation Services Company Ltd. (NAWASSCO) and Egerton University.

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## References

- Adriano, D.C. 2003 Trace Elements in Terrestrial Environments: Biogeochemistry, Bioavailability and Risks of Metals. New York, USA, 2nd edition.
- APHA. 2005 Standard Methods for the Examination of Water and Wastewater. APHA, AWWA and WEF, 21st Edition.
- Anna Czech, A., Marek Pawlik, M. and Elzbieta Rusinek, E. 2012 Contents of Heavy Metals, Nitrates, and Nitrites in Cabbage. *Pol. J. Environ. Stud.* Vol. 21, No. 2 pp 321-329
- Lopez, Z.M. A., Funamizu, N. and Takakuwa, T. 2002 Characterization of Faeces for Describing the Aerobic Biodegradation of Faeces. *Journal of Environmental Systems and Engineering* Vol 720, pp. 99-105.
- Oghenerobor, B.A., Gladys.O. and Tomilola, D.O. 2014 Heavy Metal Pollutants in Wastewater Effluents: Sources, Effects and Remediation. *Advances in Bioscience and Bioengineering* Vol 2, No 4, pp. 37-43
- Onda, K., LoBuglio, J. and Bartram, J. 2012 Global Access to Safe Water: Accounting for Water Quality and the Resulting Impact on MDG Progress. *International Journal of Environmental Research and Public Health* Vol 9, No3, pp. 880-894.
- Singh, J., Kalamdhad, A.S. 2012 Reduction of Heavy Metals during Composting- A Review. *International Journal of Environmental Protection* Vol 2, No 9, pp. 36-43.
- Vinnerås, B., Palmquist, H., Balmér & P., Weglin, et al., 2006 The Characteristics of Household Wastewater and Biodegradable Waste - a proposal for new Swedish norms. *Urban Water* Vol 3, pp. 3- 11.
- Wuana, R.A. and Okieimen, F.E. 2011 Heavy Metals in Contaminated Soils: A Review of Sources. *ISRN Ecology*.
- WHO/UNICEF. 2015 Joint Water Supply, Sanitation Monitoring Programme, & World Health Organization. Progress on drinking water and sanitation. 2015 Update.
- Zachary, G.M. and James O. O. (2013). Effects of land use and management on aggregate stability and hydraulic conductivity of soils within River Njoro Watershed in Kenya. *International Soil and Water Conservation Research* Vol 11, pp. 80-87.
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# EFFICACY OF FAECAL FERTILIZERS ON GROWTH, NUTRIENT UPTAKE AND YIELD OF MAIZE

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## Abstract

Maize (*Zea mays* L.) is the most widely cultivated staple food crop in sub-Saharan Africa. However, its production is severely constrained by abiotic and biotic factors of which declining soil fertility is a major contributor. A study was conducted to evaluate the efficacy of faecal matter based organic fertilizers on growth, nutrient uptake, yield and yield components of maize in two distinct agro-ecological zones. Five fertilizer treatments (Control, Diammonium phosphate, Cow manure, Struvite, Compost from faecal matter) were tested in a randomized complete block design (RCBD) with four replications per site. Data were collected on crop emergence (%), plant height, number of leaves per plant, leaf area index (LAI), tasseling (%), nutrient uptake and grain yield and yield components. Data were subjected to analysis of variance and treatment means separated using Tukey's HSD test. Results showed that crop emergence in the control treatment, except for Struvite, was significantly higher than DAP and faecal matter based organic fertilizer plots in Bahati and Lanet sites. The end-point plant height (9 WAP), LAI and tasseling were significantly ( $P < 0.05$ ) influenced by location and organic fertilizer treatments. At the Lanet site DAP and Struvite treatments equally had tallest maize plants (163 cm) followed by faecal compost (128 cm), Manure (121 cm) and control (79 cm). Similar result trends were recorded in Bahati where Struvite (193 cm) had tallest plants followed by faecal compost (166 cm), DAP (155 cm), Manure (151 cm) and control (98 cm), respectively. A contrasting result was observed at the Egerton University site in which cow manure and control plots equally had the tallest plants (117-121 cm) followed by DAP and faecal compost (98-99 cm) and Struvite (91 cm). The LAI, tasseling and grain yield were significantly influenced by location with Struvite and Faecal Compost treatments producing the highest grain yield ( $\approx 8$  t/ha) and one thousand (1000)-seed weights (480-560 g) at the Egerton University and Bahati experimental sites. Nitrogen uptake by maize for organic fertilizer treatments was higher than control at all the three locations. However, there was no difference in uptake of phosphorous and potassium between control and organic fertilizer treatments. These findings have demonstrated the potential of faecal matter based organic fertilizers as alternatives to inorganic fertilizers in smallholder agriculture.

**Keywords:** Zea mays, faecal compost, struvite, nutrient uptake, manure, Nitrogen, Phosphorus, Potassium

## Introduction

Maize is the chief staple in the diet of over 85 percent of the population in Kenya. The per capita consumption of 98-103 kg which translates to at least 2700 thousand metric tonnes annually [1, 2]. However, productivity amid smallholder farmers is diminishing in the face of declining land size, soil quality, and inadequate use of complementary inputs like fertilizer, water scarcity and drought. This has led to the need of looking for alternative source of nutrients that will help bridge the gap that has contributed to food insecurity. One source that can be very vital to this approach is sewage sludge and faecal matter. Municipal sewage sludge is highly rich in the relevant components for soil fertilization and plant nutrition [3]. Since it is an organic fertilizer its addition will help to manage the current inclination of soil physical, chemical and biological degradation. These properties warrant use of sludge as fertilizer [4]. Traditionally agricultural practice of applying nutrients was through organic manures like green manures and farmyard manure. This was because they had discovered that organic manure applications enhanced soil physical properties through improved soil aggregation [5], improved aggregate stability [6].

The use of both organic and inorganic fertilizer by farmers has been reported to increase yield and withstand soil productivity [7]. The municipal sewage sludge C: N ratio is typical as 5.68-16.75:1, thus its use should not block nitrogen accessibility for plants [8]. The faecal matter fertilizers can be used to refill nutrients in the soil since they comprise up to 0.7% N (Nitrogen) as a percentage of wet weight [9] which is around 5 to 11 g per

day (Hakan et al., 2015). Pure urine is also used to produce struvite a slow-dissolving orthophosphate compound. It is a phosphate fertilizer, although it contains a substantial amount of nitrogen and magnesium ( $MgNH_4 PO_4 \cdot 6H_2O$ ) and it is an effective substitute source of rock phosphate to sustain the agricultural production system [11]. The objective of the current study was therefore to evaluate the effect of faecal matter organic fertilizers on growth, nutrient uptake and yield of maize under different agro ecological conditions.

## Materials and Methods

### Experimental Sites

Three field agronomic experiments were conducted during the long rains (April to October 2016) in representative on-farm sites (Lanet and Bahati) and on-station at Egerton University in two (2) distinct agro-ecological zones (AEZs) in Nakuru County, Kenya. The two on-farm trials were located in Lanet (near Lanet Military Barracks: -0029'S and 36015'E; altitude: 1883 meters above sea level (masl); AEZ: Lower highland (LH2)) and Bahati [Bahati Forest Station: -0°15'S and 36°12'E; 1912 masl; AEZ: Upper highland (UH2)] sub-counties. The on-station field experiment was set up at Egerton University (Horticulture Teaching and Research Field: 0°22'S and 35°56'E; altitude: 2238 masl; AEZ: LH2). The mean annual rainfalls at the experimental sites are 900, 1012 and 937 mm for Lanet, Bahati and Egerton University sites, respectively [12]. The soil types at the experimental sites were Mollic Oxisol, Latosol and Mollic Oxisol for Lanet, Bahati and Egerton University sites, respectively [12].

### Experimental Layout and Crop Management

The field experiments were set up in April 2016 and laid out in randomized complete block design (RCBD) arrangement replicated four times per site. A hybrid maize variety H628 was planted in plots measuring 3.75 m by 3.0 m at spacing of 0.75 m and 0.3 m for inter- and intra-row spacing, respectively and one (1) seed planted per hill. A total of five treatments consisting of three (3) faecal matter organic fertilizers (Struvite, Compost and Cow Manure), inorganic fertilizer, Diammonium phosphate (DAP) and an untreated control were evaluated. The rate of application for faecal matter organic fertilizers was as follows: compost at 5 t/ha ( $\approx 92$  kg N/ha and 16 kg P/ha), cow manure at 5 t/ha ( $\approx 75$  kg N/ha and 20 kg P/ha) and struvite at 222 kg/ha (equivalent to 18 kg N/ha and 58 kg P/ha). The positive control, DAP at the recommended rate of 180 kg/ha (equivalent to 30 kg N and 80 kg  $P_2O_5$ /ha) and an untreated control were included as treatments.

Three (3) hand weeding operations were performed at 3, 6 and 10 weeks after planting (WAP) and Tremor® 0.05 GR (Active ingredient: Beta-cyfluthrin 0.5g/Kg) was applied 5-6 WAP at the rate of 6 kg/ha to control stem borers in the experimental plots. Data were collected on crop growth parameters (plant height, number of leaves, leaf area index (LAI) and percent tasseling), nutrient uptake (N, P and K) and yield and yield components as described below.

### Experimental variables and data collection

#### (a) Growth parameters

Five plants were randomly sampled from each of the three middle rows and used for plant height measurements and number of leaves per plant. Maize plant height (cm) was measured from the soil surface to the highest point of the arch (the uppermost leaf whose tip is pointing down).

Plant height data were recorded after 2, 4, 6, 8 and 10 WAP. Similarly, the number of leaves was counted and recorded 2, 4, 6, 8 and 10 WAP. Data on percent tasseling and the leaf area index (LAI), on the other hand, were collected 60 days after planting from the entire experimental plot (5 rows of maize). The percent tasseling and LAI were computed as shown in equations 1 and 2 below:



$$\text{Tasseling (\%)} = \frac{\text{No. of plants tasseled in plot}}{\text{Total number of plants in plot}} \quad \text{Eq. 1}$$

$$\text{LAI} = \frac{\text{Ground area}}{L * W * K} \quad \text{Eq. 2}$$

Where L= leaf length, W= leaf maximum width and K= constant (0.74).

### (b) Nutrient uptake by maize

Fresh maize leaf samples were randomly obtained from the experimental plots at tasseling stage and transported to the laboratory within 6 hours (h). The samples were cleaned using distilled water to remove any surface impurities before being oven dried for 24 h at 105°C. Thereafter, the dry samples were ground into fine powder and sieved through 2 mm sieve before use for plant tissue analysis. The dry powder samples were used to determine the N, P and K content of maize leaves as described below:

#### i) Nitrogen (N)

Dry plant powder (0.3 g) sample was digested in a Kjeldahl digestion procedure using a digestion mixture comprising of hydrochloric acid (HCl), nitric acid (HNO<sub>3</sub>), selenium (Se) and copper sulphate (CuSO<sub>4</sub>). The temperature of the heating block was maintained at 360°C for 2 h after which the samples were left to cool and then transferred to 50 ml volumetric flasks and volume made to the mark. The solution was then allowed to settle and 5 ml aliquots measured and put into the distillation bottle where 10 ml of 40% sodium hydroxide (NaOH) was added. It was then steam distilled into 5 ml 1% boric acid containing 4 drops of mixed indicator for 2 minutes from the time the indicator turned green. The distillate was titrated using HCl and the end-point reached when indicator turned green through grey to definite pink. A blank experiment was prepared using the same procedure (Kirk, 1950). The maize tissue content of nitrogen (% N) was computed as shown in equation 3 below [14]:

$$\text{N (\%)} = \frac{(A - B) \times C \times D \times 0.014 \times 100}{W \times Q} \quad \text{Eq. 3}$$

Where A= the titer of the sample, B= the titer of the blank, C= Concentration of the HCL acid, D= Dilution volume, W= weight of the soil and Q= volume of the aliquot.

#### ii) Potassium

Dry plant powder (0.3 g) sample was digested in digestion tubes using a digestion mixture comprising of HCl, HNO<sub>3</sub>, hydrogen fluoride (HF) and boric acid (H<sub>3</sub>BO<sub>3</sub>). The temperature of the heating block was maintained at 360°C for 2 h after which the samples were left to cool and then transferred to 50 ml volumetric flasks and volume made to the mark. Calibration was done using certified standards. Samples were analyzed using Varian spectra AA10 AAS machine. The level of absorbance was recorded. The amount of potassium (%) was calculated as shown in equation 4 below [14]:

$$\text{K (\%)} = \frac{\text{GR} \times V \times 100}{W \times 1000000} \quad \text{Eq. 4}$$

Where GR= graph reading, V= Total volume after dilution and W= weight of the soil measured

#### iii) Phosphorous

Dry plant powder (0.3 g) sample was digested in digestion tubes using a digestion mixture comprising of HCl, HNO<sub>3</sub>, Se and CuSO<sub>4</sub>. The temperatures in the heating block maintained at 360 oC for 2 h after which the samples were let to cool and transferred to 50 ml volumetric flasks and volume made to the mark. Aliquots (5 ml) were transferred into sample bottles where 1 ml of developing color solution (Ammonium vanadate: H4NO3V and Ammonium molybdate: (NH4)2MoO4 in the ration of 1:1). The samples were left to stand for 30 minutes after which they were transferred to cuvettes. Readings (absorbance) were taken using a spectrophotometer (210 VGP) at 430 wavelengths. Calibration was done using certified standards. The percent P in the plant tissue was calculated as shown in equation 5 below [14]:

$$\text{P (\%)} = \frac{\text{GR} \times V \times 100}{W \times DV \times 1000000} \quad \text{Eq. 5}$$

Where GR= graph reading, V= Total volume after dilution, W= weight of the soil measured and DV=Developing color volume used.

### (c) Yield and yield components

At physiological maturity, harvesting was done by hand within the three central rows of each experimental plot, representing a harvest area of 6.75 m<sup>2</sup>. The maize cobs were dehusked, shelled, weighed and recorded as plot weight (kg). For each experimental plot, four (4) replicates of 1000 seed samples were obtained from the shelled grains and thousand seed weights (TSW) (g) recorded. Maize grain yield (kg/ha) was calculated as shown in equation 6 below [15]:

$$\text{Grain Yield (kg/ha)} = \frac{\text{Plot weight (kg)} \times 10,000 \text{ m}^2/\text{ha} \times (100 - \text{AMC})}{[\text{HA} \times (100 - \text{SMC})]} \quad \text{Eq. 6}$$

Where AMC = actual grain moisture content at harvest, HA= plot harvest area (m<sup>2</sup>) and SMC= recommended storage moisture content.

Data on counts were first subjected to appropriate angular transformation before performing analysis of variance (ANOVA), regressions and treatment means separated using Turkey's HSD test [16; 17].

## Results and Discussion

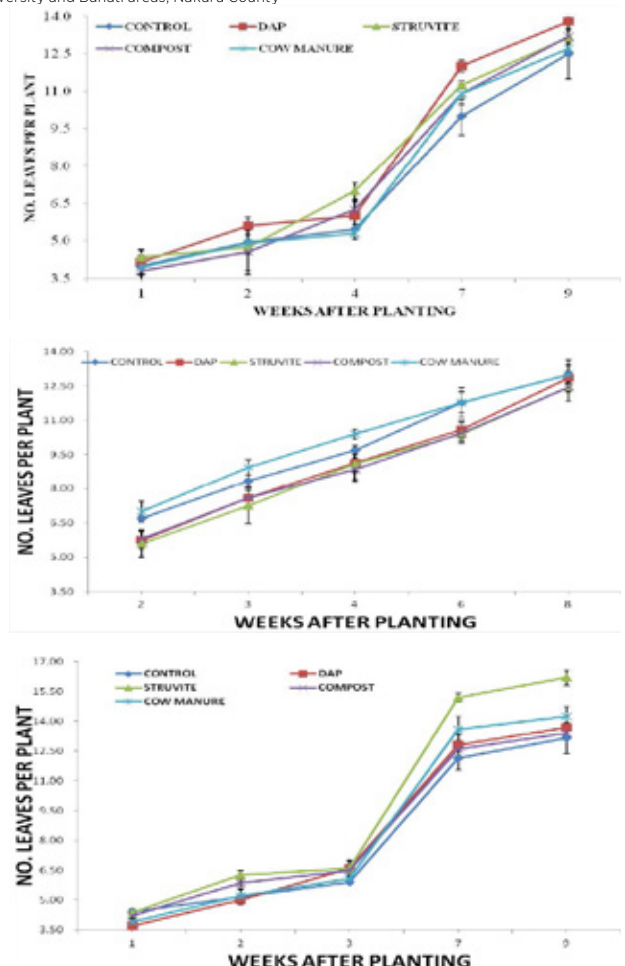
### Results

#### a. Growth parameters

Results showed that crop emergence in control treatment, except for Struvite, was significantly higher than DAP and organic fertilizer plots in Bahati and Lanet sites (Table 1). The control and struvite treated plots equally had highest emergence (90-92%) followed by Manure (83.5-88.5%), faecal compost (74-84.5%) and DAP (30.5-47.0%) in order of decreasing percent emergence. At the Egerton site, the cow manure had highest emergence (95%) followed by Struvite, faecal compost and control (77.5-81.5%) and DAP (72%).

There were no differences (P<0.05) in the number of maize leaves at Lanet and Bahati for DAP, Struvite, Compost and Manure with an exception of control (8.26±0.76; 7.80±0.71), respectively (Fig. 1). At the Egerton University experimental site, there was significant difference (P<0.05) between Control and three other treatments (DAP, Struvite and Compost). In retrospect, there was no difference between the control and manure treatments in the number of leaves per plant at the Egerton site.

Fig. 1: Effect of faecal matter fertilizers on number of leaves per maize plant in Lanet, Egerton University and Bahati areas, Nakuru County



Results showed that the end-point plant height 9 weeks after planting (WAP), LAI and tasseling were significantly ( $P < 0.05$ ) influenced by location and fertilizer treatment applied (Table 2). At the Lanet site DAP and Struvite treatment (163 cm) equally had tallest maize plants followed by faecal compost (128 cm), Manure (121 cm) and control (79 cm). Similar result trends were recorded in Bahati where Struvite (193 cm) had tallest plants followed by faecal compost (166 cm), DAP (155 cm), Manure (151 cm) and control (98 cm), respectively. A contrasting result was observed at the Egerton University site in which cow manure and control plots equally had the tallest plants (117-121 cm) followed by DAP and faecal compost (98-99 cm) and Struvite (91 cm).

The LAI and tasseling were significantly influenced by location and type of fertilizer applied. There were location-specific responses in which maize at the Egerton University site recorded the highest mean percent tasseling of 41.7 followed by Bahati (35.9) and Lanet (25.4), respectively (Table 3). Struvite treatment consistently had highest percent tasseling (38.4-48.8%) BAHATI across all the three experimental sites. Similar result trends were observed for LAI where the maize plants at the Egerton University site had highest mean LAI of 4.82 followed by Bahati (4.73) and Lanet (3.95). Diammonium phosphate (DAP) treated plots consistently had highest LAI values across the locations followed by struvite, faecal compost, manure and control, respectively.

### b. Yield and yield components

Results showed that maize grain yield and 1000-seed weights significantly ( $P < 0.05$ ) differed across experimental locations and type of fertilizer applied. Struvite and Faecal Compost treatments produced the highest grain yield ( $\approx 8$  t/ha) and 1000-seed weights (480-560 g) at the Egerton and Bahati trial sites (Fig. 2). The highest yield responses were produced by DAP, faecal compost and manure (7.7-8.2 t/ha) whereas at Bahati, Struvite, Faecal compost and manure had highest yields (7.7-8.0 t/ha). The Lanet site contrastingly had low yields of 4.0-5.5 t/ha for Struvite and faecal compost treatments. Except for the Lanet site, there were no differences in 1000-seed weight at the Egerton and Bahati sites for all the faecal based organic fertilizers tested.

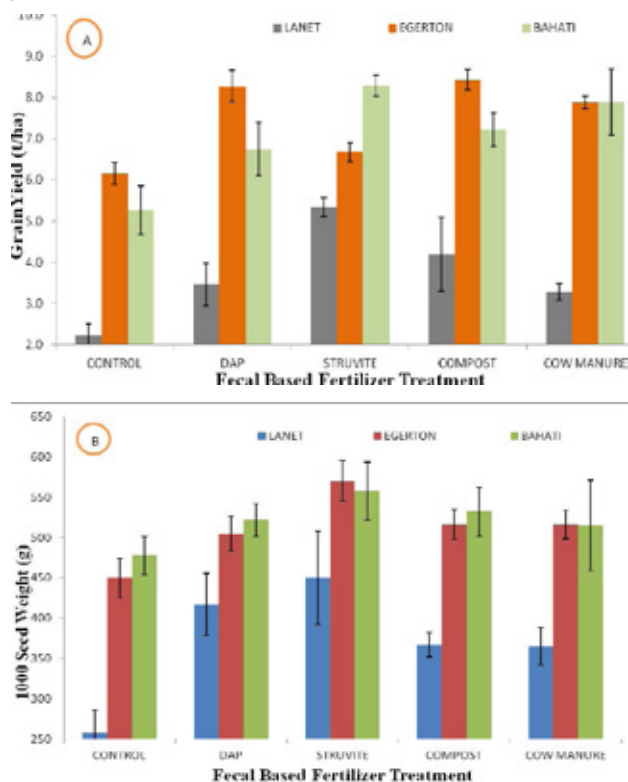


Fig. 2: Effect of faecal matter based fertilizers on (A) yield and (B) 1000-seed weight of maize in Nakuru County, Kenya

### c. Nutrient (NPK) uptake by maize

The N uptake by maize for fertilizer treatments was higher (2.95-3.73%) than control (2.15) at all the three locations (Table 4). Except for the P uptake at Egerton University, there were no differences in uptake of the other nutrients (P and K) between control and organic fertilizer treatments and among the fertilizer treatments. At Egerton University site, DAP had highest P uptake of 0.50% followed by control (0.44%), struvite (0.43%), manure (0.40%) and faecal compost had lowest uptake at 0.15%, respectively.

## Discussion

The findings of this research show that application of inorganic (DAP) and organic fertilizers (faecal compost and manure) results in reduced maize crop emergence. The results also revealed that organic fertilizers (struvite and faecal compost) produced the highest growth and grain yield. The organic fertilizers resulted in 30-45% increase in grain yield of maize over the control. The observed reduced crop stands points towards the possibility of direct contact between the seed and fertilizer. These findings are consistent with previous studies which observed that the rate and method of fertilizer application influenced growth and yield of maize [18]. The fact that organic fertilizers (struvite, faecal compost and manure) produced crop performance (growth and yield) comparable to inorganic fertilizer, DAP, holds good promise for organic fertilizers especially faecal matter based fertilizers as viable alternatives to synthetic fertilizers. This is further corroborated by other studies that detected no significant difference between inorganic and manure fertilizers in their long-term effects on crop production and yet noted that the contribution of organic manure to the development of the vegetative organs of maize [19, 20]. These results, therefore, highlight the importance that should be attached to the use of organic fertilizers in modern agriculture for sustainable higher crop yields, improved soil water retention and mineralization of soil nutrients. The location-specific variation in crop performance is attributable partially to agro-ecological and micro-climatic conditions. The three experimental sites had differences in precipitation, altitude, topography, vegetation cover and temperature which agree well with recent studies on the potential causes of varied crop performances [21].

In the present study, different faecal based organic manure and an inorganic fertilizer were used in determining the yield and yield components of maize in three different sites in Nakuru County. Organic manure and/or chemical fertilizer benefit only soil productivity and not soil quality [20]. This implies that the relative buildup of soil nutrients, particularly N and P, shown by the apparent nutrient uptake evidenced by the results and is postulated to emanate from long-term use of organic fertilizers relative to inorganic fertilizers. In spite of this, sustainable and stability in production of maize, which is the staple food in Kenya, is heavily reliant on the continued upgrading of both the soil productivity and soil quality. This highlights the advantage the organic fertilizers have over the inorganic fertilizers in improving the soil permeability by alleviating the inconsistency between scarce water resources and high water demand resulting in better grain yield. In a study to determine the effect of organic manure on yield of maize and water productivity in Arid and Semi-Arid regions of China [22] it was reported that soil organic manure increased significantly over time, and the soil improved in production and productivity when using organic manure relative to inorganic fertilizers. Long-term application of organic manure to the soil significantly increased yield of maize by 7.4% steadily, over a period of 4 years [22]. This finding is in agreement with this current study and affirms the theory of organic fertilizers resulting in better soil permeability hence, higher yields.

The nutrient uptake (NPK) showed a positive response by maize to fertilizer application (both inorganic and organic) over the untreated control. These findings revealed that lack of fertilizer application leads to low nutrient uptake especially the macro nutrients known to be limiting factors of production. The level of P observed in compost at Egerton site is capable of limiting the availability of N, P and K required by the plant [23]. The indifference in nutrient uptake between control and organic fertilizer treatments in Bahati and Egerton can be attributed to the soils in these sites having fairly adequate levels. The variations recorded across treatments in the three sites might be due to other factors such as soil properties, environmental conditions and nutrient interactions [24, 25].

## Conclusion

The results obtained from this study showed that organic fertilizer application significantly influences the performance of maize as evidenced by increased growth and yield of maize. The faecal compost increased the maize yield by up to 45% in comparison to the control and hence, a potential alternative to inorganic fertilizers in maize production in terms of anticipated soil productivity and crop returns.

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**Table 1: Effect of different fecal organic fertilizers on the emergence of maize in Lanet, Egerton and Bahati**

| Treatments       | Percent Maize Emergence |             |            |
|------------------|-------------------------|-------------|------------|
|                  | Lanet                   | Egerton     | Bahati     |
| 1. CONTROL       | 90.50±4.20              | 77.50±9.00  | 91.00±2.52 |
| 2. DAP           | 30.50±10.50             | 72.00±14.45 | 47.00±5.69 |
| 3. STRUVITE      | 90.50±3.09              | 81.50±12.12 | 92.00±2.45 |
| 4. FECAL COMPOST | 74.00±7.87              | 81.00±11.21 | 84.50±3.20 |
| 5. COW MANURE    | 83.50±2.50              | 95.00±1.00  | 88.50±3.20 |

**Table 2: Effect of different fecal based organic fertilizers on height of maize over time (weeks) in Lanet, Egerton and Bahati**

| Treatment   | HEIGHT (CM; WEEKS AFTER PLANTING) |            |            |              |              |
|-------------|-----------------------------------|------------|------------|--------------|--------------|
|             | LANET                             |            |            |              |              |
|             | 1                                 | 3          | 5          | 7            | 9            |
| 1. CONTROL  | 8.50±0.24                         | 17.05±1.91 | 61.40±6.99 | 64.65±5.86   | 78.75±5.98   |
| 2. DAP      | 7.86±1.09                         | 25.80±4.84 | 93.20±4.08 | 100.00±3.46  | 163.85±29.91 |
| 3. STRUVITE | 9.99±0.36                         | 35.95±3.14 | 99.80±5.56 | 105.65±6.12  | 163.05±18.69 |
| 4. COMPOST  | 7.35±0.38                         | 26.80±2.43 | 71.45±2.18 | 80.70±3.32   | 128.15±10.59 |
| 5. MANURE   | 7.63±0.69                         | 22.50±0.96 | 65.95±5.89 | 74.60±4.97   | 121.35±25.29 |
| Treatment   | EGERTON                           |            |            |              |              |
|             | 1                                 | 3          | 5          | 7            | 9            |
|             | 1. CONTROL                        | 23.50±1.34 | 31.66±2.04 | 44.60±0.91   | 100.15±3.70  |
| 2. DAP      | 21.93±1.36                        | 27.33±1.61 | 42.36±3.30 | 80.33±8.09   | 98.35±7.94   |
| 3. STRUVITE | 21.67±2.46                        | 23.51±3.40 | 39.60±4.66 | 76.25±10.49  | 91.06±11.71  |
| 4. COMPOST  | 23.26±0.82                        | 25.55±2.76 | 41.42±1.83 | 79.50±3.82   | 98.94±7.64   |
| 5. MANURE   | 25.33±1.79                        | 37.67±1.97 | 46.80±3.11 | 111.10±14.10 | 121.12±15.26 |
| Treatment   | BAHATI                            |            |            |              |              |
|             | 1                                 | 3          | 5          | 7            | 9            |
|             | 1. CONTROL                        | 5.59±0.77  | 18.71±1.67 | 39.59±11.88  | 60.95±8.42   |
| 2. DAP      | 6.84±0.89                         | 25.91±1.31 | 72.05±5.19 | 93.45±0.72   | 155.35±7.12  |
| 3. STRUVITE | 7.21±0.24                         | 27.98±1.54 | 80.95±5.71 | 134.48±4.11  | 193.38±13.55 |
| 4. COMPOST  | 5.89±0.52                         | 23.01±0.26 | 58.70±3.17 | 91.20±5.31   | 165.90±5.93  |
| 5. MANURE   | 4.98±0.81                         | 15.49±1.97 | 53.65±2.54 | 87.35±3.64   | 151.40±8.22  |

**Table 3: Effect of different fecal based organic fertilizers on leaf area index (LAI) and Tasseling (%) in Lanet, Egerton and Bahati**

| Treatment   | LANET     |            | EGERTON   |            | BAHATI    |            |
|-------------|-----------|------------|-----------|------------|-----------|------------|
|             | LAI       | Tasseling  | LAI       | Tasseling  | LAI       | Tasseling  |
| 1. CONTROL  | 3.51±0.33 | 16.25±3.26 | 5.00±0.12 | 41.5±1.28  | 4.74±0.24 | 36.00±2.18 |
| 2. DAP      | 4.37±0.12 | 17.00±2.32 | 5.22±0.21 | 39.25±1.05 | 4.92±0.46 | 47.50±2.89 |
| 3. STRUVITE | 4.15±0.36 | 38.35±0.88 | 4.17±0.45 | 41.5±1.20  | 4.82±0.20 | 48.75±3.14 |
| 4. COMPOST  | 3.97±0.36 | 28.00±1.51 | 4.55±0.10 | 43.5±0.77  | 4.55±0.12 | 26.5±4.79  |
| 5. MANURE   | 3.73±0.52 | 27.5±1.81  | 5.17±0.35 | 42.75±1.78 | 4.63±0.24 | 20.5±3.33  |

**Table 4: Effect of different faecal based organic fertilizers on nutrient uptake (N, P and K levels) in Lanet, Egerton and Bahati.**

| Treatment   | N (%)      |           |           | P (%)      |           |           | K (%)     |           |           |
|-------------|------------|-----------|-----------|------------|-----------|-----------|-----------|-----------|-----------|
|             | Lanet      | Egerton   | Bahati    | Lanet      | Egerton   | Bahati    | Lanet     | Egerton   | Bahati    |
| 1. CONTROL  | 2.15±0.57  | 2.93±0.98 | 3.75±0.83 | 0.54±0.05  | 0.44±0.06 | 0.49±0.03 | 1.49±0.14 | 1.27±0.18 | 1.51±0.26 |
| 2. DAP      | 3.73± 0.42 | 3.79±0.62 | 4.28±0.85 | 0.53± 0.51 | 0.50±0.06 | 0.4±0.1   | 1.83±0.73 | 1.36±0.40 | 1.63±0.21 |
| 3. STRUVITE | 3.37± 0.59 | 3.40±0.84 | 3.60±0.64 | 0.52± 0.03 | 0.43±0.14 | 0.49±0.02 | 1.50±0.13 | 1.43±0.20 | 1.38±0.43 |
| 4. COMPOST  | 2.95±0.35  | 3.95±0.73 | 3.45±0.39 | 0.50±0.01  | 0.15±0.02 | 0.48±0.06 | 1.75±0.02 | 1.43±0.32 | 1.39±0.42 |
| 5. MANURE   | 3.70±0.22  | 3.83±0.34 | 3.8±0.34  | 0.48±0.06  | 0.40±0.17 | 0.36±0.09 | 1.62±0.37 | 1.29±0.19 | 1.73±0.21 |

## References

- Abate T, Mugo S, De Groot H and M W Regassa Maize in Kenya: Chance for Getting Back to Former Glory? *DT Maize (CIMMYT)* 2015; 4(3): 1-3.
- Nyoro J, Kirimi L and T S Jayne Competitiveness of Kenyan and Ugandan maize production: Challenges for the future. Working Paper No. 10 of 2004, Egerton University, Tegemeo Institute, Nairobi.
- Singh R P and M Agrawal Potential benefits and risks of land application of sewage sludge. *Waste Management* 2008; 28(2): 347-358.
- Szymańska G, Sulewska H and K Śmiatacz Response of maize grown for silage on the application of sewage sludge. *Acta Scientiarum Polonorum Agricultura* 2013; 12(3): 55-67.
- Hati K M, Swarup A, Dwivedi A, Misra A and K Bandyopadhyay Changes in soil physical properties and organic carbon status at the topsoil horizon of a vertisol of central India after 28 years of continuous cropping, fertilization and manuring. *Agric., Ecosystems Environ.* 2007; 119: 127-134.
- Rachman A, Anderson S, Gantzer C and A Thompson Influence of long-term cropping system on soil physical properties related to soil erodibility. *Soil Sci. Soc. America J.* 2003; 67: 637-644.
- Chukwu L I, Ano A O and D O Asawalam Effects of Poultry Manure and NPK fertilizer on soil properties and Nutrient uptake of maize (*Zea mays* L.) plants grown in an ultisol. *Proc. 36th Annual Conf. the Soil Sci. Soc. Nigeria* 2012. University of Nigeria, Nsukka.
- Cuevas G, Martínez F and I Walter Field-grown maize (*Zea mays* L.) with composted sewage sludge: Effects on soil and grain quality. *Span. J. Agric. Research* 2003; 1 (3): 111-119.
- Rose C, Parker A, Jefferson B and E Cartmell The Characterization of Faeces and Urine: A Review of the Literature to Inform Advanced Treatment Technology. *Crit. Rev. Environ. Sci. Tech.* 2015; 45: 1827-1879.
- Håkan J, Andras B, Ulf J, Daniel H and K. Erik Composition of urine, faeces, grey water and biowaste. *The Mistra Programme Urban Water. Urban Water Report* 2005:6.
- Rahman M M, Salleh M A M, Rashid U, Ahsan A, Hossain M M and C S Ra Production of slow release crystal fertilizer from wastewaters through struvite crystallization. *Arabian J. Chem.* 2014; 7: 139-155.
- Jaetzold R, Schmidt H, Hornetz B and C Shisanya *Farm Management Handbook of Kenya Vol. II- Natural Conditions and Farm Management Information.* 2nd Edition of 2006 Part C: East Kenya. Published by Ministry of Agriculture, Kenya, in Cooperation with the German Agency for Technical Cooperation (GTZ). 571p.
- Kirk P L Kjeldahl Method for Total Nitrogen. *Anal. Chem.* 1950; 22(2): 354-358. DOI: 10.1021/ac60038a038
- Motsara M R and R N Roy Guide to laboratory establishment for plant nutrient analysis. *FAO Fertilizer and Plant Nutri. Bulletin* of 2008 No.19. ISSN 0259-2495. 204p.
- CIMMYT Yield and Yield Components: A Practical Guide for Comparing Crop Management Practices of 2013.
- Gomez K A and A A Gomez Statistical Procedures for Agricultural Research. 2nd Edition. An International Rice Research Institute Book. A Wiley-Interscience Publication, John Wiley & Sons, Inc. New York.
- SAS Institute SAS 9.3 Output Delivery System: User's Guide of 1995. 2nd Edition.
- Adiaha M S and A O Agba Influence of Different Methods of Fertilizer Application on the growth of Maize (*Zea mays* L.) for increase Production in South Nigeria. *World Scientific News* 2016; 54: 73-86.
- Bilalis D J and A J Karamanos Organic maize growth and mycorrhizal root colonization response to tillage and organic fertilization. *J. Sust. Agric.* 2010; 34(8): 836-849.
- Edmeades D C The long-term effects of manures and fertilisers on soil productivity and quality: a review. *Nutrient Cycling in Agroecosystems* 2003; 66(2): 165-180.
- Ashcroft M B and J R Gollan Fine-resolution (25 m) topo climatic grids of near-surface (5 cm) extreme temperatures and humidities across various habitats in a large (200 × 300 km) and diverse region. *Int. J. Climatology* 2012; 32 (14): 2134-2148.
- Wang X, Ren Y, Zhang S, Chen Y and N Wang Applications of organic manure increased maize (*Zea mays* L.) yield and water productivity in a semi-arid region. *Agric. Water Management* 2017; 187: 88-98.
- Kirkby C A, Kirkegaard J A, Richardson A E, Wade L J, Blanchard C and G Batten Stable soil organic matter: a comparison of C:N:P:S ratios in Australian and other world soils. *Geoderma* 2011; 163:197-208
- Menkir A Genetic variation for grain mineral content in tropical-adapted maize inbred lines. *Food Chemistry* 2008; 110: 454-464.
- Dalović I, Jocković Đ, Chen Y, Bekavac G, Šeremešić S, Jačimović G and M. Brdar-Jokanović Maize nutrient uptake affected by genotype and fertilization. *Genetika* 2015; 47(3): 941-950

# AVAILABILITY OF NITROGEN, MICROBIAL RESPIRATION AND BULK DENSITY AS INFLUENCED BY FAECAL MATTER FERTILISER IN ACRISOL, ANDOSOL AND PLANOSOL

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## Abstract

Crop production in Kenya has declined over the years due to nutrient mining leading to food insecurity. This research aimed at using faecal matter fertilizers as a source of Nitrogen (N) and its effect on other desirable characteristics like bulk density, soil organic carbon (SOC) in the soil. Also the ability of different types of soils to make N available for absorption by potato roots in response to application of the fertilizers was studied using Potato (*Solanum tuberosum* L.) as test crop. A greenhouse pot experiment was set up at Nakuru Water And Sanitation Services Company domestic treatment site in Nakuru County. It was in completely randomized block design, factorial arrangement with two factors: five fertilizers types (vermi compost, sludge, normal compost, cow manure and urea) and three soil types (Acrisol, Planosol and Andosol). Potato tissues were analysed for total nitrogen while soil samples were analysed for available Nitrogen, CO<sub>2</sub> emission (microbial respiration), organic carbon and bulk density. Results obtained showed considerable performance of faecal matter fertilizers where the level of N were significantly different at  $\alpha=0.05$ . The three soil types had levels of N, CO<sub>2</sub>, organic carbon significantly different. The significant levels of N in potato tissue and soil after application of faecal matter fertilizers makes these products important sources of plant nutrients and contributors to desired soil chemical, physical and biological characteristics.

## Keywords

Faecal; Microbial respiration; Mining; Potato; Compost; Andosol; Acrisol; Planosol

## Introduction

The soils in Nakuru region have been cultivated over years accompanied with inadequate replenishment leading to concerns raised on over reliance on inorganic fertilisers. This has affected not only biological aspect of soil but also physical and chemical properties [1]. Organic fertilisers are important in improving soil characteristics and achieving high crop yields [2]. Their addition to manage the current trend of soil physical, chemical and biological degradation has been recommended [3]. Therefore, there is need to use more of organic fertilisers and bio-fertilisers to strike a balance and limit nutrient mining. Uneven use of inorganic fertiliser in farms is amongst the inappropriate agricultural practices that have steered to primary soil degradation together with other practices like pesticide overuse, poor irrigation and use of dense machinery [4]. The soil physical properties affected directly or indirectly by organic fertilisers are aggregate stability, water holding capacity, porosity, infiltration rate, hydraulic conductivity and bulk density [5]. Level of soil bulk density is dependent on organic matter content, the texture of soils, constituent minerals and porosity.

Soil bulk density is an important parameter for soil management as it is important in soil compaction. Increase in soil organic matter decreases bulk density of a soil. On the other hand, increase in organic matter also leads to change in nutrient concentration in the soil. This indicates that available nutrients in soil may play an important role in variation of bulk density of a soil. To achieve suitable soil properties, combined use of organic and inorganic fertilisers is encouraged [6].

The biological aspect of the soil helps in plant nutrition symbiosis with plants (N fixing bacteria and root mycorrhizae). Nutrients distribution (N, P, K, micronutrient) directly in plant roots depend on living soil microorganisms break down of organic matter that releases available forms of nutrients for the plants (ions). Organic fertilisers are also important sources of energy for soil ecology and nutrients for microorganisms and growing plants [7]. Use of organic fertilisers encourages macro and micro fauna activities in the soil that leads to soil acidity tolerance until pH<5, processing plant residues, forming water stable soil aggregates and incorporates organic matter in soil. It also enriches topsoil with nutrients and humus, cultivating soil by creating channels, facilitating drainage, and allowing roots to explore and grow deeper [8].

The major three soil types found in abundance in Nakuru County are Acrisol, Andosol and Planosol [9]. Acrisols are soils that originate from variety of parent materials ranging from weathering of acid rocks for highly weathered clays that are undergoing further degradation and are usually found in old land surfaces that are hilly with natural vegetation. Andosol originate from volcanic glasses or other silicate-rich material and is dominant in undulating to mountainous, humid, and arctic to tropical regions with an extensive range of different vegetation. Finally, Planosols

are soils that have a coarse-textured surface horizon with a finer textured subsoil that are prone to logging in flat lands formed from clayey alluvial and colluvial deposits. Furthermore, they contain light forest or grass Vegetation [10]. This research aimed at using faecal matter fertilizers (FMFs) to help in making these soils productive by improving their physical, chemical and biological properties.

## Materials and Methods

### Site description

Greenhouse experiments were set up at the Domestic Water Treatment Plant of Nakuru Water And Sanitation Services Company (NAWASSCO) located in Nakuru National Park, Kenya. The site lies at 0°19'22"N and 36°3'46"E and in Lower Highland III Agro Ecological Zone (LH3) with an altitude of 1850 meters above sea level [11]. Average maximum and minimum temperatures ranges from 19 to 22°C and 5 to 8°C respectively. The annual rainfall ranges from 800 to 900 mm and the soils are predominantly well-drained, very deep dark brown to grayish brown friable and smeary clay loam, with thick humic topsoil (Mollic Andosols) [9].

### Preparation of faecal matter fertilisers (FMFs)

Composting materials (composite market waste) collected from the Municipal Market, Nakuru town and NAWASSCO wastewater treatment plant (sludge). Proper sorting done to ensure only degradable materials were composted and coarse / large materials like banana stalks chopped into smaller pieces. The choppings were then placed in wooden boxes and mixed in the ratio of 3:1 (market waste: sludge) in the greenhouse. For normal compost, the materials were let to compost for 5 months with weekly turning and addition of water as maintenance practices. For vermicompost, worms were introduced after one month and favorable conditions (Temperature: 15-25°C, Moisture: 75% and pH: 5.7) for their survival maintained. Finally, the vermicompost maintained in aerobic environment. Dry sludge was prepared by sun drying the sludge directly on drying beds lined with black plastic sheet in a greenhouse at 40-60°C for one month.

### Soil collection and characterization

Three different soils, Planosol, Acrisol and Andosol, were collected from Nessuit (Latitude: -0°23'25.99"S, Longitude: 35°52'52.32"E), Egerton University (Latitude: 0°22'11.0"S, Longitude: 35°55'58.0"E) and Molo (Latitude: 0.2488° S, Longitude: 35.7324° E), respectively in Nakuru County, Kenya. The sites where the soils were collected clearance was done to remove vegetation cover and the soils were dug to a depth of 30 cm. Each soil sample comprised of a combination of the top soil and the subsoil. The soils were put into bags of 90 kg with a total of 240 kg per soil type that was enough for the entire experiment. Characterization of the soil was partly done in the field, while the rest of the analysis (physical and chemical) was done in the laboratory as shown below in Tables 1 and 2.

Table 1: Level of N, P, K and bulk density in the soils.

| Soil Type | pH          | Chemical properties |                          |                          | Physical property        |  |
|-----------|-------------|---------------------|--------------------------|--------------------------|--------------------------|--|
|           |             | N (%)               | P (mg kg <sup>-1</sup> ) | K (mg kg <sup>-1</sup> ) | BD (g cm <sup>-3</sup> ) |  |
| Andosol   | 6.23 ± 0.18 | 0.19 ± 0.033        | 43.0 ± 4.03              | 68.2 ± 10.31             | 1.26 ± 0.044             |  |
| Planosol  | 6.72 ± 0.25 | 0.23 ± 0.015        | 35.0 ± 3.78              | 62.4 ± 8.06              | 1.37 ± 0.072             |  |
| Acrisol   | 5.75 ± 0.51 | 0.36 ± 0.009        | 58.0 ± 6.22              | 93.5 ± 12.33             | 1.24 ± 0.077             |  |

[Note: N= Nitrogen and P= Phosphorus, K= Potassium, Means in a column whose SD values do not overlap are significantly different at  $\alpha = 0.05$ .]

Table 2: The concentration levels of N, P and K in the selected soil amendments.

| Organic fertilizer | N (%)      | P (%)      | K (%)      |
|--------------------|------------|------------|------------|
| Vermicompost       | 2.3 ± 0.11 | 0.4 ± 0.13 | 0.4 ± 0.04 |
| Normal compost     | 1.8 ± 0.32 | 0.3 ± 0.07 | 0.4 ± 0.02 |
| Sludge             | 1.5 ± 0.09 | 0.2 ± 0.02 | 0.2 ± 0.02 |
| Cow manure         | 0.6 ± 0.1  | 0.3 ± 0.04 | 0.4 ± 0.05 |

[Note: N= Nitrogen and P= Phosphorus, K= Potassium, Means in a column whose SD values do not overlap are significantly different at  $\alpha = 0.05$ .]

## Experimental design and layout

Two pot experiments were conducted in a plastic greenhouse. The pots used were 10 liter plastic containers which were filled with 10 kg of soil each and a total of 18 pots per block, and a total of four blocks. The experimental design was randomized complete block design in factorial arrangement with two factors (soil type and fertilizer that included fecal matter products). The treatments included three levels of soil types (Acrisol, Andosol and Planosol) five levels of fertilizer products (cow manure, vermicompost, normal compost, dried sludge and urea) replicated four times and arranged in a spacing of 30cm by 75 cm.

## Crop establishment

Healthy and sprouted seed potato tubers sliced into pieces each weighing 25 to 30 g and having two to three eyes (buds). Every pot planted with one sliced piece of tuber at a depth of five cm. The fertilizers applied in the rate of 3.9, 4.9, 15, 0.2 and 6 t ha<sup>-1</sup> for vermicompost, normal compost, cow manure, urea and dried sludge, respectively. The faecal matter fertilizer product was applied to supply 90 kg N ha<sup>-1</sup> and P was standardized at 103 kg P ha<sup>-1</sup>. The crops were irrigated at the rate of one liter of water per pot per day. The crop was under intensive care and there was no disease incidence.

## Soil sample collection and preparation for soil N analysis

Soil samples were taken from each pot (100g) and were put in khaki bags. Each bag labeled accordingly then transported to the laboratory the same day. In the laboratory, the samples were air dried for 1 week after which they were crashed sieved using 2.00 mm sieve.

## Tissue sample collection and preparation for soil N analysis

The tissues were sampled at early bloom stage of potato growth, they were put in khaki bags labeled and transported to the lab where they were cleaned with distilled water. They were then oven dried for 2 days and crashed.

## Analysis of soil samples

Nitrogen (Kjeldahl method) [12].

## Bulk density (Core method)

A core ring of 5 cm diameter with known weight (W1) and volume (V) was inserted 5cm in the soil. It was then removed from the soil and soil around the core was wiped and trimmed from the bottom and top using a knife. They were then put in an oven at 105°C for 2 days after which they were allowed to cool and weighed (W2).

## Microbial respiration (CO<sub>2</sub> evolution)

100 g of soil was weighed and put in to conical flask and 25 ml of distilled water added, stirred using a stirring rod. 15 ml of NaOH was put in a universal bottle, which was inserted inside the conical flask with soil while making sure the NaOH does not spill in to the soil. The conical flask was tied at the top tightly to prevent CO<sub>2</sub> from being lost from the flask and CO<sub>2</sub> from outside to enter the flask. The flask was incubated for one week after which the universal bottle was removed and content transferred in to 250 ml conical flask. 1ml of BaCl<sub>2</sub> was added followed by 5-6 drops of phenolphthalein indicator and titrated using 1N HCl and the titer was recorded when colour changed from pink to colourless. Soil organic carbon (Walkley and Black method) [13].

## Analysis of potato tissue samples

Nitrogen (Kjeldahl method) [14].

## Data analysis

Data were subjected to analysis of variance (ANOVA) using Proc GLM, SAS software v.9.1 (SAS INC., 2001). Where significant differences was realized, mean separation was done using Tukey's HSD test.

## Results

### Soil analysis

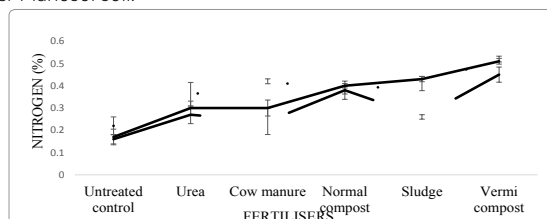
**Nitrogen:** There were significant differences at  $P \leq 0.05$  on soil response as influenced by fertilisers on N level as shown in Figure 1 although interaction between fertiliser and soil types, trial and block showed no significant difference. Vermicompost had better performance but the difference was not significant with sludge and normal compost. Sludge, normal compost cow manure and urea also had no significant differences between their means. Untreated control recorded lowest level of Nitrogen in the soil. The levels of Nitrogen concentration as shown in Figure 1 indicated that the fecal matter fertilizers had substantial amount of

nutrients compared to cow manure. This may be due to the content of fecal matter that has both urine and solid faeces where urine is a rich source of Nitrogen. This is agreement with findings of [15,16]. Having substantial levels of Nitrogen in the soil after harvesting which was  $\geq 0.24\%$  shows that the soil was not left deficient. Untreated control had deficient N levels an indication of nutrient mining, which may have resulted due to lack of enough replenishment of the Nitrogen supplying fertiliser in the respective soils.

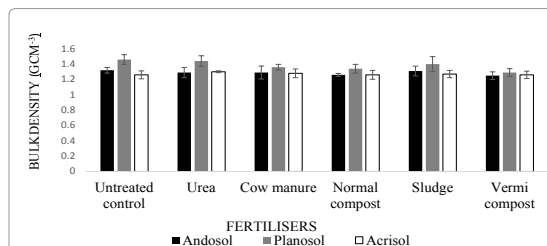
**Bulk density:** In bulk density the effect of fertiliser application, interaction between fertiliser and soil types, trial and block were not significantly different, but the soil types alone as independent variable had significant difference at  $P \leq 0.05$ . Planosol had high bulk density followed by Andosol and Acrisol respectively although there was no significant difference between Andosol and Acrisol (Figure 2). The characteristics of each soil type and the human activities on the site that soils were collected played an important role on this parameter. The values obtained were within normal range of  $1.25 \pm 0.049$  gcm<sup>-3</sup> to  $1.46 \pm 0.063$  gcm<sup>-3</sup>. Acrisol had low bulk density due high levels of organic matter compared to Planosol that had high mineral component with less organic matter. The bulk density did not change significantly during the two trials conducted. This is because the time that the experiment was done was not sufficient to influence bulk density.

It is expected that addition of organic manures result in increased soil organic matter content. This in turn has shown to increase water holding capacity, porosity, infiltration capacity and a decrease in bulk density [17].

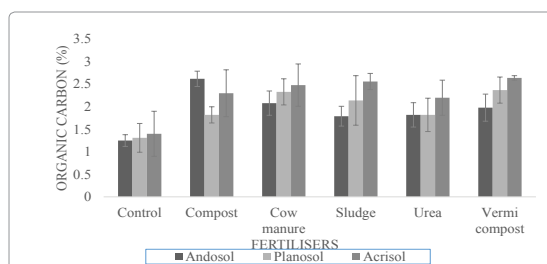
**Soil Microbial Respiration:** There were significant differences at  $P \leq 0.05$  on soil response as influenced by fertilisers and not soil types, interaction between them, trial and block in microbial respiration (CO<sub>2</sub> evolution) as shown in Table 3. Sludge under Andosol and Acrisol had the highest evolution of  $6.9 \pm 0.9$  and  $6.9 \pm 1.3$  kg ha<sup>-1</sup> d<sup>-1</sup> respectively. There was no significant difference between urea and cow manure under Andosol and Acrisol. The lowest levels were recorded in untreated control under Planosol soil.



**Figure 1:** Soil % Nitrogen (mean  $\pm$  SD) under different soil types and fecal matter fertiliser application. [Note: Means in levels whose SD values do not overlap are significantly different at  $P \leq 0.05$  by Tukey's HSD test].



**Figure 2:** Soil bulk densities (Mean  $\pm$  SD) under different soil types and fecal matter fertiliser application. [Note: Means in levels whose SD values do not overlap are significantly different at  $P \leq 0.05$  by Tukey's HSD test].



**Figure 3:** Soil organic carbon (Mean  $\pm$  SD) under different soil types and fecal matter fertiliser application. [Note: Means in levels whose SD values do not overlap are significantly different at  $P \leq 0.05$  by Tukey's HSD test].



**Table 3:** Soil microbial respiration (CO<sub>2</sub> evolution) (Mean ± SD) in terms of CO<sub>2</sub> in kg ha<sup>-1</sup> d<sup>-1</sup> under different soil types and faecal matter fertiliser application.

| Soil types        |           |           |           |
|-------------------|-----------|-----------|-----------|
| Fertilisers       | Andosol   | Planosol  | Acrisol   |
| Untreated control | 5.0 ± 0.9 | 3.2 ± 0.4 | 4.2 ± 0.5 |
| Urea              | 6.1 ± 0.9 | 5.4 ± 0.8 | 5.6 ± 1.3 |
| Cow manure        | 5.9 ± 1.8 | 5.0 ± 0.3 | 6.3 ± 1.6 |
| Normal compost    | 5.0 ± 1.1 | 5.6 ± 1.3 | 5.9 ± 1.1 |
| Sludge            | 6.9 ± 0.9 | 5.2 ± 0.1 | 6.9 ± 1.3 |
| Vermicompost      | 6.2 ± 1.1 | 5.0 ± 0.7 | 5.6 ± 1.3 |

[Note: Means in a column whose SD values do not overlap are significantly different at P ≤ 0.05 by Tukey's HSD test.]

**Table 4:** Total Nitrogen (%) (Mean ± SD) under different soil types and fecal matter fertiliser application.

| Soil types        |           |           |           |
|-------------------|-----------|-----------|-----------|
| Fertilisers       | Andosol   | Planosol  | Acrisol   |
| Untreated control | 2.8 ± 0.5 | 2.1 ± 0.6 | 3.3 ± 0.5 |
| Urea              | 3.8 ± 0.3 | 3.1 ± 0.7 | 4.1 ± 0.2 |
| Cow manure        | 4.0 ± 0.8 | 3.0 ± 0.7 | 4.0 ± 0.3 |
| Normal compost    | 3.9 ± 0.6 | 3.6 ± 0.3 | 3.9 ± 0.6 |
| Sludge            | 3.7 ± 0.3 | 3.8 ± 0.4 | 4.3 ± 0.2 |
| Vermicompost      | 4.2 ± 0.4 | 3.6 ± 0.3 | 4.5 ± 0.1 |

[Note: Means in a column whose SD values do not overlap are significantly different at P ≤ 0.05 by Tukey's HSD test]

The level of CO<sub>2</sub> was high in faecal matter fertiliser products and cow manure since these products were organic and provided a substrate for the microorganisms to break down and feed on thus increasing microbial respiration. Fabrizio et al. [18] reported that when compost is used the level of microbial respiration increases thus increase in CO<sub>2</sub>. Although the difference was not significant with inorganic fertiliser urea because it enhances vegetative growth that leads to increase in organic matter that intern act as substrate for microorganisms.

**Soil organic carbon:** The level of organic carbon in soil ranged from 1.3% in Andosol under control but the difference was not significant with Planosol and Acrisol under control. The highest level was 2.6% recorded in Andosol under normal compost but the difference was not significant with Acrisol under normal compost, Planosol and Acrisol under cow manure and Acrisol under sludge, urea and vermi compost.

The level of organic carbon in Andosol was 2.6% this was 2 times more when compared to same soil under control 1.3%. This shows that the compost from faecal matter waste being an organic waste can be an important source for maintaining a minimum level required organic carbon content in the soils. The contribution of other fertilizers like cow manure, sludge and urea was also evident but the properties of the soils involved contributed significantly to the levels of organic carbon as shown in (Figure 3). This study was able to depict the effect of land use in terms of different fertilizers application on soil organic carbon. The results were positive and in line with findings by [19-20].

**Nitrogen In Potato Tissue:** Tissues response to fertilizers and soil types were significantly different at P ≤ 0.05 but the interaction between them, trial and block were not significantly different. All the fertilizers had no significant difference between them but significantly different from the untreated control as shown in Table 4.

The relationship between SOC and bulk density in Figure 4b was different from the one with microbial respiration. The relationship was a weak slope of R=-0.1778 and this was attributed to the less time that the fertilisers had to influence the relationship. For organic fertilisers to influence this relationship the experiment must have been more than the two trials conducted. A higher bulk density indicates more compactness in soil, resulting in less pore spaces and soil porosity, which leads to low organic carbon [21].

Nitrogen tissue analysis sludge, vermicompost, normal compost, urea and cow manure had Nitrogen levels that were not significantly different from each other. These demonstrated that the ability of faecal matter fertilizers to supply Nitrogen was comparable with the commonly used fertilizers urea and cow manure. The Nitrogen levels in the tissues were within sufficiency range in line with [22].

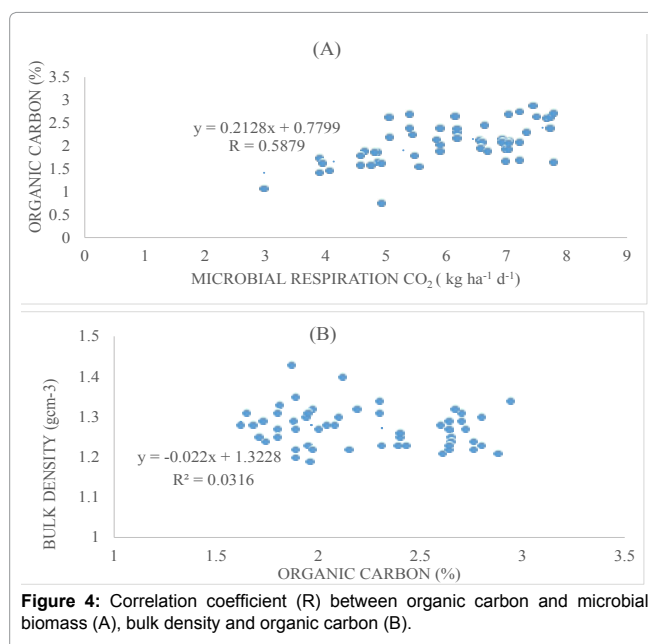
The soil type effect on Nitrogen levels in the tissues was significant at α =0.05 with Acrisol having high concentration although the difference was

not significant with Andosol this is because these soils made N available in the soil which in turn led to high levels of Nitrogen in the tissues. Planosol had low level of N although it was not below the sufficient levels range of N in potato tissues.

#### Correlation Between Soil Organic Carbon And Microbial Respiration:

The correlation coefficient R in (Figure 4a) between soil organic carbon and microbial respiration was moderately uphill with a figure of R=0.5879. In Figure 4b, the correlation between bulk density and soil organic carbon was a weak downhill with R= -0.1778. The relationship between soil organic carbon and microbial biomass is directly proportional but from the results R=0.5879 shows a moderately positive correlation.

This is because the quality of SOC is important to the energy required by microorganisms. If the quality is low, it limits the source of energy required for microbes growth, which ultimately decreases the Carbon mineralization rate and vice versa. Landgraf et al. [23] found that carbon source that simply decomposes, such as glucose and sucrose, could make the soil microorganism swiftly propagate and proliferation of their activities. Faecal matter fertilizers decomposed easily thus the microbes increased with increase in organic carbon in the soils.



**Figure 4:** Correlation coefficient (R) between organic carbon and microbial biomass (A), bulk density and organic carbon (B).

#### Conclusion

Faecal matter fertilizers products were able to supply enough nitrogen for potato growth and still were able to improve the soil nutrient status after harvesting. These products contributed not only to Nitrogen nutrient but also improved desirable properties like microbial respiration. To increase nutrient uptake, the nutrients have to be available whenever the crop needs them to enable optimum crop production. These products can contribute significantly to this course.

#### Acknowledgments

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#### References

- Sharma P, Rai SC, Sharma R, Sharma E (2004) Effects of land use change on soil microbial C, N and P in a Himalayan watershed. *Pedobiology* 48: 83-92.
- Cezer PM (2015) Organic fertilizer in rice: Myths and facts. A Public Education Series of the Asia Rice Foundation.1. *Int J Sci Res* 5: 2250-3153.
- Chukwu LI, Ano AO, Asawalam DO (2012) Effects of Poultry Manure and NPK fertilizer on soil properties and Nutrient uptake of maize (*Zea mays* L.) plants growth in an ultisol. Proceedings of the 36th Annual Conference of the Soil Science Society of Nigeria (SSSN), University of Nigeria Nsukka, Nigeria.

Ranjan B, Birendra NG, Prasanta KM, Biswapati M, Cherukumalli SR, et al. (2015) Soil Degradation in India: Challenges and Potential Solutions Sustainability 7: 3528-3570.  
Haynes R, Naidu R (1998) Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: A review. Nutr Cycl Agro ecosystem 51: 123-137.

Usman M, Madu UV, Alkali G, (2015) The combined use of organic and inorganic fertilisers for improving maize crop productivity in Nigeria. Int. J. Sci. Res 5: 2250-3153.

Ivan M, Ardian M (2014) Soil fertility and organic fertilisers in organic farming. Agricultural University, Plovdiv. Joint Bachelor Course on Organic Agriculture.

Nyle C, Ray RW (2016) The Nature and Properties of Soils, Pearson Education Upper Saddle River, USA.

Zachary GM, James OO (2013) Effects of land use and management on aggregate stability and hydraulic conductivity of soils within River Njoro Watershed in Kenya. Int. Soil Water Cons. Res II: 80-87.

FAO (2006) World reference base for soil resources 2006. A framework for international classification, correlation and communication 67: 70-88.

Jaetzold R, Schmidt H, Hornetz B, Shisanya C (1982) Farm Management Handbook of Kenya. Central Kenya (Rift Valley and Central Provinces), Kenya.

Kirk LK (1950) Kjeldahl Method for Total Nitrogen. Anal Chem 22: 354-358.

Walkley A, Black IA (1934) An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci 37: 29-37.

Okalebo JR, Gathua KW, Woomer PC (2002) Laboratory methods of soil and plant analysis: a working manual. TSBF Programme, Nairobi 36-37.

Kauthale VK, Takawale PS, Kulkarni PK, Daniel LN (2005) Influence of flyash and sewage sludge application on growth and yield of annual crops. Int J Trop Agric 23: 49-54.

Joseph SM, Ababu T, Amos OF (2014) Characterization of Sewage Sludge Generated from Wastewater Treatment Plants in Swaziland in Relation to Agricultural Uses. Res Environ 4: 190-199.

Pravin R C, Dodha V A, Vidya DA, Manab C, Saroj M (2013) Soil Bulk Density as related to Soil Texture, Organic Matter Content and available total Nutrients of Coimbatore Soil. Int J Sci Res 3: 2250-3153.

Fabrizio A, Massimo C (2001) CO<sub>2</sub> evolution in soil amended with compost. EU report Seminar proceedings Brussels, Belgium.

Yang Y, Guo J, Chen G (2009) Effects of forest conversion on soil labile organic carbon fractions and aggregate stability in subtropical China. Plant and Soil 323: 153-162.

Nsabimuna D, Haynes R J, Wallis F M (2004) Size, respiration and catabolic diversity of the soil microbial biomass as affected by land use. App Soil Ecol 26: 81-92.

Landgraf D, Klose S (2002) Mobile and readily available C and N fractions and their relationship to microbial biomass and selected enzyme activities in a sandy soil under different management systems. J Plant Nutr Soil Sci 165: 9-16.

Chen DD, Zhang SH, Dong SK (2010) Effect of land-use on soil nutrients and microbial biomass of an alpine region on the North-eastern Tibetan Plateau, China. Land Degrad Dev 21: 444-452.

Bernie Z, Gilles M, Charles K (2007) Nitrogen Management for Potatoes: Petiole Nitrate Testing. Factsheet.



# TRANSFORMATION TOWARDS SUSTAINABLE AND RESILIENT WASH SERVICES

## Faecal matter-saw dust composite briquette and pellet fuels: production and characteristics

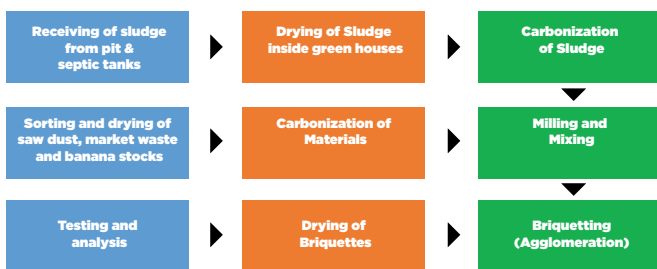
D. M. NYAANGA, P. A. KABOK, J. MBUBA, S. O. ABICH., R. EPPINGA & J. IRUNGU (KENYA)

This work relates to the sustainable development goal (SDG) 6.2 which relates to access to adequate sanitation and hygiene. Raw sludge emptied on to drying beds inside greenhouses was carbonized from milled materials (faecal matter, saw dust, banana stalks and market waste) and a binder (molasses and faecal matter). Four percentages (25, 50, 75 and 100) were variedly used. The average calorific value of faecal matter was found to be 13.1MJ/kg with average moisture content of 9.1%, volatile matter of 2.2%, ash content of 48.3% and fixed carbon of 40.4%. Caloric values of market waste, sawdust, banana stalk and human waste were respectively found to be 2.5, 2.7, 3.2 and 4.0. The briquettes and pellets showed no pathogens, concentration of heavy metals were insignificant. Mixture of sawdust and faecal matter took shorter duration to boil water compared to faecal matter mixed with other biomass materials.

### Introduction

The potential to supplement charcoal and firewood as heating and cooking energy sources has been explored by Nakuru County Sanitation Programme (NCSP) through SNV in selected estates of Nakuru town (capital of Nakuru County). It is the 4th largest town by population (307,990, by 2009 census) in Kenya with an estimated 75,216 households (CBS, 2010). In the less developed estates, pit latrines are used for human waste disposal which often need emptying as an option for abandonment/replacement due to land unavailability. Biomass such as human waste has properties (Jenkins et al.; 2008, Sivasanga et al., 2013; Paulrud, 2004; and López-González et al., 2013) that can allow their densification into fuel briquettes and pellets but after preliminary treatment.

The need for development of biomass resources as an alternative energy source (Nunes et al., 2014) in Kenya is enhanced by diminishing fossil reserves, increasing cost of fuel and rising environmental air pollution concerns. This arises as Fuel wood is also widely used in households (Kenya) for cooking, heating and lighting and respectively. In the year 2000, it supplied 89% and 7% rural and urban household energy (IIED, 2010). Matiru (2007) reported the annual energy consumption in Kenya as 70% fuel wood while respectively petroleum and electricity constituted a lower percentage (21% and 9%). About 1.6 million metric tonnes of charcoal is produced annually (Gachuri, 2015) thus creating a huge effect on deforestation and provided domestic energy for 82% of urban and 34% of rural households (GoK, 2013).



Nevertheless, densification do minimize the disadvantages of non homogeneous properties and size when using biomass as an energy source. The restrictive factors (Arranz, 2011) are also compensated by its localized nature and availability that provides substantial socio-economic and environmental benefits. The factors include low bulk densities and heterogeneity in moisture and granulometry, among others. Pelletizing and briquetting are currently the most commonly used techniques among those available (Grover and Mishra, 1996).

The availability of saw dust and sludge though can be a nuisance on the onset, they would make economic sense when used as components of briquettes. According to Wairire (1994), the economical disposal of sawdust is a concern to the wood industries as amounts of sludge are expected to increase as the Kenya's urban population rises, estimated at 22% in 2009 and to increase to 41% in 2050 (UNDESA, 2008). Burnt sawdust pollutes the environment. Therefore, such loose biomass can be upgraded by technologies such as carbonization and agglomeration to be used efficiently as a source of energy.

### Material and Methods

#### Project Sites

The project and research site was at the NAWASSCO's Domestic Treatment Plant at Kaloleni in Nakuru Town (Latitude 0° 18' 11.156" S Longitude 36° 4' 48.094" E) faecal matter was collected from Low income pilot areas of the town namely Kaloleni, Kivumbini and Manyani estates. Laboratory analysis was done at the University of Nairobi, Chemistry Department.

#### Material Collection, Drying, Carbonization and Milling

Sludge was collected from septic tanks and pit latrines in Nakuru municipality and delivered to the site using bowsers. It was mixed with sawdust, banana stocks and market wastes in order to enhance its combustion characteristics and production capacity. Figure 1 gives the flow chart for the fuel production stages.

Sludge, in its raw form, contains excess moisture that must be removed ahead of carbonization and briquetting/palletising processes. The raw sludge was foremost emptied onto drying beds inside green houses at the Nakuru NAWASSCO Sewage Treatment. Carbonisation process followed by conversion of organic substances (sludge, banana stalks and market waste) into carbon or a carbon-containing residue through pyrolysis or burning under limited oxygen supply, done using locally fabricated drum kilns. The methods involved use of drums which were either open at the top or fitted with chimneys and were effective for sludge, banana stalks and market waste. The methods were not effective in carbonizing sawdust because of the size of grain. A modification of cutting the drum into two halves along the length specifically to carbonise saw dust was effective compared to other methods, save for volume handled. The different carbonized materials were reduced (hammer and roller technology/mill) in sizes and then passed through a 2mm sieve to get powder for mixing. The small particles enable adequate distribution of binding material which permits higher compactness of the briquette or pellet.

#### Briquetting and Pelletizing

This involved compacting carbonized materials (faecal matter, saw dust, banana stalks and market waste) and a binder (molasses, faecal matter) in specific moulds by mechanical machines that enhanced coagulation of the fine particles into dense products. Mix ratios of raw material in various proportions were adopted from Chirchir et al. (2011); four percentages of 25, 50, 75 and 100) were used for faecal matter, sawdust, banana stalk. One litre of a selected a binder was diluted in 20 litres of water for making 50 kg of the mixed carbonised materials for briquette production as recommended by Mbuba et al. (2016) to enable bonding to a given shape.

The twenty-two (22) different samples of composite briquettes (based on different ratios of feedstocks with faecal matter as a constant) were made using the different binding materials. The briquettes were then allowed to dry for 3 days on the drying racks in the open air/sun or in the greenhouse. Similarly, different proportions of raw materials faecal matter, saw dust, banana stalks and market waste) were mixed with a cassava starch binder then fed into a pelletizing machine where pressure was applied mechanically to form fuel pellets. A total of thirteen (13) samples were prepared and characterized for performance as a fuel.



## Results And Discussions

### Sludge Characteristics

Raw sludge from different sanitation systems (pit latrines, septic tanks and school sanitation) were characterised in terms of pathogen and chemical loads; and physical and combustion properties. The sludge was found to contain high amounts of pathogens including bacteria and other disease causing microorganisms including Salmonella, Shigella, Escherichia coli (E. coli), Ascaris Lumbricoides and Sclostosoma mansoni eggs and heavy metals such as zinc (93.5ppm) and copper (45.8 ppm) and lead (10.4 ppm) (Wilkister et al; 2018).

The levels of heavy metals were lower than recommendations by WHO (WHO, 1993). However, for safety of working with the sludge, pathogens were eliminated by intense temperatures through heating to boiling point at 930 C for a period of 3 hours for it to be tested as a binder. Similarly, carbonization of dry sludge involved heating it in a drum kiln (200l drum cut into 2, lower half with air inlets and upper half with chimney) to temperatures as high as 4500 C and 6000 C depending on the kiln management.

The physical and combustion characteristics of faecal matter from different areas are as in Table 1 below. Note that the volatile matter and

| Sample                   | Moisture content (%) | Volatile matter content (%) | Ash content (%) | Density (kg/m <sup>3</sup> ) | Fixed carbon (%) | Calorific value (MJ/kg) |
|--------------------------|----------------------|-----------------------------|-----------------|------------------------------|------------------|-------------------------|
| Pit latrine 1            | 7.8                  | 2.2                         | 46.7            | 487.4                        | 43.4             | 17.2                    |
| Pit latrine 2            | 10.2                 | 2.3                         | 51.2            | 494.3                        | 36.4             | 9.9                     |
| Septic tank 1            | 10.9                 | 2.9                         | 50.6            | 436.8                        | 35.6             | 15.7                    |
| Septic tank 2            | 9.2                  | 2.3                         | 48.1            | 453.2                        | 40.4             | 13.4                    |
| School sanitation blocks | 7.3                  | 1.2                         | 45.1            | 578.4                        | 46.4             | 9.5                     |
| <b>Average</b>           | <b>9.1</b>           | <b>2.2</b>                  | <b>48.3</b>     | <b>490.0</b>                 | <b>40.4</b>      | <b>13.1</b>             |

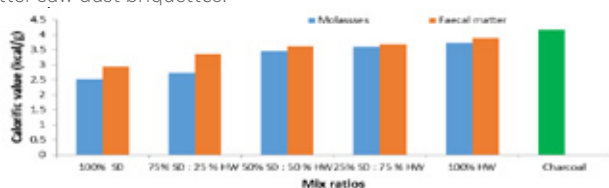
calorific matter of any organic matter have bearing on the suitability of the material as an energy recovery resource.

The calorific value of faecal matter was high at 13.1 MJ/kg. The averages of physical properties of faecal matter namely moisture content, volatile matter, ash content and fixed carbon were 9.1%, 2.2%, 48.3%, 40.4% respectively, while density was 490 kg/m<sup>3</sup>. These properties compare well with what is reported in literature (Muspratt et al., 2014).

### Briquette and Pellet Characteristics

The fuel briquettes and pellets were tested for a number of parameters to ensure safety and fuel viability. The briquettes and pellets showed no presence of pathogens. Concentration of heavy metals such as zinc (93.5ppm), copper (45.8 ppm) and lead (10.4 ppm) may be attributed to carbonisation, though (Wilkister et al., 2018) indicate that these levels are within limits. Cadmium was not detected in the raw and treated faecal matter. This implies that the pre-treatment for faecal matter was effective in elimination of pathogens but heavy metals increased by densification of the biomass fuel products. The different briquettes and pellets were evaluated for performance in three types of cook stoves commonly used in Kenyan households namely Gasifier cookstove-Terry model; Jikokoa and Kenya ceramic jiko (KCJ). This mainly tested the burning characteristics of the fuel products on the time required to ignite, boiling time (boil 1 litre of water), and the rate of burning, smell of the product when burning among others.

Round shaped briquettes were identified to have better combustion characteristics compared to triangular and cylindrical briquettes. Charcoal briquettes were found to have the highest calorific value of 4.5 kcal/g. The caloric values of market waste, sawdust, banana talk and human waste were found as 2.5, 2.7, 3.2 and 4.0 respectively. Fig 1 presents the effect of various mix ratios on calorific value of faecal matter saw dust briquettes.



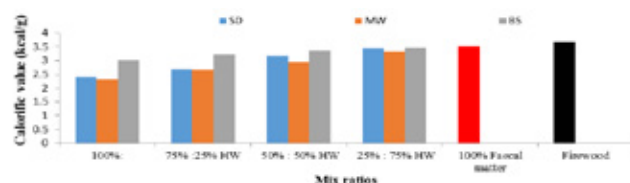
Key: SD - Saw dust, HW - Faecal matter  
Fig 1: Calorific value for faecal matter briquettes with two binders and Charcoal

Though, it was observed that there was significant difference in calorific value when different raw materials mixing ratios were used, there was no significant effect on calorific value when molasses and faecal matter were introduced as binding agent. The average calorific value of faecal matter and sawdust was 18.8 MJ/kg. This value is above 17.5 MJ/kg the minimum required for briquettes to perform satisfactory (DIN, 1996).

The carbon monoxide emitted after burning of fuel products with different mix ratios of biomass, showed that; charcoal dust briquettes produced the highest amount of CO (39%) and sawdust emitted the least amount (20%). CO emitted were respectively 35%, 32%, 25% and 22% for 100%, 75%, 50% and 25% of human waste mix ratios. There was no significant difference in amount of carbon monoxide from the different ratios used, but the difference was significant when materials were carbonised separately. Sawdust and faecal matter had low carbon monoxide emissions compared to mixture of faecal matter with other types of biomass.

### Performance of Fuel Pellets

There was a difference in calorific value of the pellets made from different the mix ratios and different raw materials (Figure 2).



Key: SD-Saw dust, MW-Market waste, BS-Banana stalk, HW-Faecal matter  
Fig. 2: calorific value of composite faecal matter pellets

In all the mix ratios, banana stalk had the highest calorific value followed by saw dust with human waste briquettes having the least calorific value. The calorific values obtained in this study of 10 MJ/kg to 16.7 MJ/kg are consistent with those obtained by Denibras (1999) based on waste paper and wheat straw mixtures. There was significant difference in percentage of ash content and mix ratios with different materials used for the briquettes. The market wastes had the highest ash content and saw dust showed the least ash content for all mix ratios. The ash content values were however higher than the tolerance level for fuel which should be below 4% (Grover, 1995). Njenga et al. (2013) and Demirbas and Sahin (2001) concluded that the ash content depends on the elemental composition of the briquette feedstock. The mean ash content of faecal matter-sawdust briquettes increased with ratios of faecal matter as a feedstock and binder. The faecal matter used in this study therefore had a lot of incombustible elements

There was a significant difference in time required to boil 1 litre of water considering mix ratios and different materials. A mixture of sawdust and faecal matter took relatively shorter duration to boil compared to faecal matter mixed with other biomass materials.

### Marketing of faecal biomass fuel

A market study was conducted to establish customer views and attitudes on faecal briquettes and pellets. (362 households and 238 businesses/institutions). The households were more receptive to briquettes than pellets due its compatibility with the fuel equipment and cost efficiency. Majority of the household's cook in confined places that are without defined kitchen space thus making them prone to indoor pollution. Controlled Cooking Tests showed that faecal matter briquettes burnt longer than charcoal and had less emissions. Consumers proposed pricing of briquettes less than half a dollar per 1kg and packaging in small quantities of 2kg or 5kg packets (Kimaru et al., 2017). The purchasing power is informed by household's income and therefore households indicated a preference to purchase the fuel. While perception towards the product is commonly overstated, households were found to be positive about faecal matter briquettes. This was mainly influenced by households understanding the production process and assurance on safety of the product. It is however recommended that, consumer education should be considered when introducing the products. In addition, research should be carried out on stoves to optimise performance of briquettes and marketing (Kimaru et al., 2017).



## Conclusion and Recommendations

The research findings do indicate that: Sludge has a relatively higher calorific value compared to sawdust, market waste and banana stocks. Sawdust was identified as the most appropriate biomass material to mix with faecal matter at a ratio of 50:50 in making fuel products for its availability, high calorific value and low ash content. The raw sludge had a high concentration of pathogens and adequate measures must be in place to ensure elimination before using sludge in making briquette and pellet fuel. Molasses was selected as the most appropriate binding agent for its properties and availability. The ratio of mixing binding agent and feedstock at 1:9 was found to be effective and appropriate. The round shaped briquettes produced by a rotating drum/ agglomeration technique was identified as the most effective for briquette making. The round shaped briquettes had better features and properties.

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## References

- Africa Turnaround Limited 2017 Biomass Fuel Market Study. Study Commissioned by EU-Nakuru County Sanitation Programme
- Arranz, J. I. 2011 Analysis of Densified of the Combination from Different Biomass Waste. Doctoral Thesis, University of Extremadura, Badajoz, Spain.
- Chirchir D., Nyaanga D and Githeko J. 2013 Effect of binder types and amount on physical and combustion characteristics Int. J. Eng. Res. & Tech,2(1):13-20.
- Demirbas, A. 1999 Physical properties of briquettes from waste paper and wheat straw mixtures. Energy Conversion and Management ( 40):437-445.
- Demirbas A, Sahin A 1998 Evaluation of biomass residue 1: briquetting waste paper and wheat straw mixtures. Fuel Processing Technology, ( 55): 175-183.
- Food and Agriculture Organization (FAO). (1987). Simple technologies for charcoal making, FAO, Rome, Italy
- Gachuri, W. G. 2015 Optimising the utilisation of sawdust of eucalyptus tree species: a fuel for tea industry. Unpublished MSc Thesis University of Nairobi.
- GoK 2013 Analysis of the charcoal value chain in Kenya. Ministry of Environment, Water and Natural Resources.
- Grover, P.D. And Mishra, S.K. 1996 Biomass Briquetting, Technology, and Practices. Regional Wood Energy Development Programme in Asia: Bangkok, Thailand; FAO. Field Document No. 46.
- IIED 2010 Biomass energy in Kenya. Nairobi, Kenya. International Institute for Environment and Development

Jenkins, P., Baxter, C. and Miles, T. 2008 Combustion Properties of Biomass Fuel Processing Technology. Journal on Fuel Processing Technology, 54: 17 - 46.

Kimaru, L. Eppinga R. and Irungu J. 2017 Consumer Pilot Study: Briquettes, Nakuru County Sanitation Programme

López-González, D., Fernandez-Lopez, M., Valverde, J. L. and Sanchez-Silva L. 2013 Thermogravimetric- mass spectrometric analysis on combustion of lignocellulosic biomass. Bioresource Technol. 143: 562-574.

Matiru, V. 2007 Forest Cover and Forest Reserve Cover in Kenya Policy and Practices. Oxford Press. Nairobi, Kenya.

Mbuba, M. Jesca, Nyaanga, D. M., Kabok, P. A., Reinilde, Eppinga 2017 Binders on Physical and Combustion Characteristics of Faecal Matter-Sawdust Briquettes

Mbuba, M. Jesca, Nyaanga, D. M., Kabok, P. A., Reinilde, Eppinga 2017 Effect of Mix Ratios and Binders on Physical and Combustion Characteristics of Faecal Matter-Sawdust Briquettes

Muspratt A. M., T. Nakato, C. Niwagaba, H. Dione, J. Kang, L. Stupin, J. Regulinski, M. Mbéguéré And L. Strande 2014 Fuel potential of faecal sludge: calorific value results from Uganda, Ghana and Senegal. Journal of Water, Sanitation and Hygiene for Development 4(2)223-230

NAWASSCO 2016 From Pit to Product: Biomass-fuels and Bio-fertilisers from Faecal Matter and Urine in Nakuru, Kenya. VIA Water Progress Report. Nakuru Water and Sanitation Services Company

Njenga, M. 2013 Evaluating Fuel Briquette Technologies and their Implications on Greenhouse Gases and Livelihoods in Kenya. PhD. Thesis, Faculty of Agriculture, University of Nairobi, Kenya.

Nunes, L.J.R.; Matias, J.C.O.; Catalao, J.P.S. 2014 Mixed biomass pellets for thermal energy production: A review of combustion models. Appl. Energy 127, 135-140.

UNDESA 2008 World Urbanization Prospects United Nations Department of Economic and Social Affairs. United Nations Department of Economic and Social Affairs Report New York

Ward , B. J. 2009 Human Faecal Biochar Briquettes from the Sol-Char Toilet for Use as a Solid Fuel in the Developing World. Thesis submitted to B.S., North Carolina State University.

WHO and UNICEF 2017 Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines [online] [viewed 15 June 2015]. Geneva: World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), 2017. Licence: CC BY-NC-SA 3.0 IGO. Available from [www.who.int/t/news/2017/launch-version-report-jmp-water-sanitation-hygiene](http://www.who.int/t/news/2017/launch-version-report-jmp-water-sanitation-hygiene).

WHO 1993 Guidelines for drinking-water quality, Vol. 1. Geneva, World Health Organization.

Wilkister, N., Nakitare, K., Kimaru, L. and Eppinga, R 2018 Microbial Safety of Faecal Sludge for Biomass Fuels and Bio-Fertilizer Production: Case Study of Nakuru County Sanitation Programme

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# EFFECT OF MIX RATIOS & BINDERS ON PHYSICAL & PHYSICAL COMBUSTION CHARACTERISTICS OF FAECAL MATTER - SAWDUST BRIQUETTES

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## Abstract

Faecal matter is globally viewed as an expensive liability with its potential value as a resource neglected. This arises majorly due to the associated large infrastructure capital costs, operation, maintenance, rehabilitation and expansion of the sewage treatment plants. However, there is need to find sustainable ways to utilize this resource as sludge is expected to rise as the population increases. In Kenya, firewood and charcoal have been and will still be the major source of energy in households in rural and peri-urban households. This consumption has led to the decline of the forest cover in Kenya. Hence, there is an urgent need to find alternative fuels to replace the traditional ones. It suffices to say that biomass such as agricultural residues, sludge, wood and animal waste can be agglomerated to form briquettes which can be used as an alternative sources of energy. Also there are growing concerns in the economical disposal of the sawdust at the country wide dotted timber workshops and saw mills. The research was therefore conducted on this background to establish whether faecal matter and sawdust can be densified and used as a source of energy. The research focused on selected physical and combustion characteristics of faecal matter and sawdust briquettes using different ratios and binders. The briquettes were sun dried for two weeks and subjected to various tests to determine their moisture content, density, volatile matter, fixed carbon, ash content and calorific value. The activities carried out included pre-treatment of drying, carbonization, size reduction, binding and agglomeration of faecal matter and sawdust. Molasses and boiled faecal matter formed the binders and a rotating drum with the technique of non - pressure agglomeration was used to form fireball briquettes. Carbonized faecal matter and sawdust were mixed at the ratios (3:1, 1:1 and 1:3) and bonded with a binder at 10%. It was found that moisture content and density ranged between 6.9% - 8.6% and 499 kg/m<sup>3</sup> - 745 kg/m<sup>3</sup>. The volatile matter, ash content/caloric value of the bonded briquettes depended on the type of binder and raw material used. Molasses had the highest volatile matter at 56.3%. Faecal matter had the highest ash content of 52.4% and calorific value of 23.246 MJ/kg. The results suggest that the faecal matter and sawdust could be developed as a source of energy for domestic purpose.

## Keywords

Binders, faecal-sawdust-briquettes, physical-combustion characteristics and ratios.

## 1. Introduction

Fuel wood is a biomass which is widely used in households for cooking, heating and lighting. In Kenya, the annual energy consumption is 70% fuel wood, 21% petroleum and 9% electricity (Matiru, 2007). Fuel wood supplied 89% and 7% rural and urban household energy respectively in the year 2000 (IIED, 2010). Today it is known that charcoal provides domestic energy for 82% of urban and 34% of rural households (GoK, 2013). Due to deforestation, Kenya's closed forest canopy was 6.99% in 2010 (Republic of Kenya, 2016) and in 1963 the forested area in Kenya was estimated at 10% (Gachuri, 2015). The situation is expected to decline further as the charcoal demand is projected to double from the year 2000 to 2030 because of the expected high rates of urbanization in Sub-Saharan Africa (SSA) (Arnold et al., 2006).

Apart from fuel wood, there are other biomass which can be utilized to provide energy such as agricultural residues, sludge, wood chips, poultry waste and sawdust (Dhughana, 2011). There is also a growing need for renewable and sustainable energy sources to serve as alternative to traditional household sources of energy. According to Wairire (1994), the economical disposal of sawdust and wood shavings is a growing concern to the wood industries. This is because sawdust is burnt releasing a lot of smoke which pollutes the environment or it is disposed in no-man's land such as railway reserves. In Kenya, the amounts of sludge is expected to increase as the urban population is projected to rise from 22% in the year 2009 to 41% in the year 2050 (UNDESA, 2008). Oladeji (2010) also affirms that biomass can be upgraded and used as fuel by determining parameters such as calorific value, ash content, density and moisture content.

Grover and Mishra (2006) found out that loose biomass can be upgraded by agglomeration in order to improve their physical and combustion properties. According Li and Liu (2000), a moisture content of 15% and above results into less dense briquettes. In addition, briquettes below 4% moisture content crumble and absorb moisture from atmosphere.

The findings of Chirchir et al. (2013) showed that the density of the original materials have a direct impact on the briquettes densities. The carbonized material is less dense but after agglomeration its volumetric energy density increases (Dhughana, 2011).

The calorific value of carbonized material is influenced by the type, chemical composition and moisture content of the biomass (Jenkins et al, 2008). According to Ndiema et al. (2002), Dermirbas and Sahin (2001), the ash content depends on the elemental composition of the biomass.

Little information exists on the physical and combustion properties of spherical faecal matter-sawdust briquettes. The aim of this study was to find suitable ratio and binder of faecal matter-sawdust briquettes which can be utilized as energy by determining selected physical and combustion characteristics.

## ii. Material and Methods

### Raw Materials Preparation

Domestic sludge was obtained from the exhausters trucks using buckets and poured into the drying beds in a greenhouse to dry for a period of two weeks. Once the sludge dried to 10 % moisture content, it was carbonized in a drum kiln. The sawdust was collected from the saw mills in Nakuru town, dried in the greenhouse drying beds for two days to a moisture content of 10% and carbonized.

Later on, the carbonized faecal matter and sawdust were reduced into small particle sizes of about 1 mm using a hammer mill. Milled faecal matter and sawdust were mixed in the mix ratios of 1:3, 1:1 and 3:1. To form a binder solution, 1kg of dried and milled uncarbonized faecal matter was boiled in 20 litres of water for 3 hours. The boiling of the uncarbonized faecal matter was necessary to eliminate harmful bacteria such as E.coli, Strep. faecalis and Salm. typhimurium which do not survive at temperatures above 62° C (Jorgensen.A.J et al. 1998).The binder amount was 10% of each mix ratio by weight.

### Briquetting

The rotating drum was used in making the fireball briquettes. In each session of briquetting, 18 kg of the mix ratio was poured on the bed of the rotating drum. As the briquetting machine rotated 2kg of the binder (boiled faecal matter or molasses) was sprinkled.

The briquettes formed by nucleation, coalescence and consolidation to a diameter of 40mm. After briquetting process the briquettes were spread on the beds to dry for four days and selected to determine the following physical and combustion characteristics.

### A. Moisture Content

Three briquettes were taken from each set of the ratios. The briquettes were weighed using an electronic balance. The oven was pre-heated to an internal temperature of (105±5)°C, samples were then put in it and logging of the weight was done after every one hour. The sample was considered oven dry when the weight remained unchanged to within (1g) for two consecutive measurements. The moisture content was determined as per ASTM D-3173-87(39) (2004a) Specification and equation 1.

$$M_{wb} = \frac{M_w}{M_w + M_{dm}} \quad (1)$$

Where (Mwb) is moisture content in wet basis, (Mw) amount of the moisture content (kg), (Mdm) amount of dry matter (kg)

### B. Density

Three samples were be collected from each ratio for determination of the density. The diameter of each briquette was measured using the vernier caliber and mass using an electronic balance. The density was determined as per equation (2).

$$\rho = \frac{m}{v} \quad (2)$$

Where (P) density (kg/m<sup>3</sup>), (m) briquette mass (kg) and (v) volume (m<sup>3</sup>).

### C. Volatile Matter (%Vm)

The percentage volatile matter was determined by using the standard method, ASTM 872-82 whereby a given mass of the briquette sample was pulverized in a crucible and placed in an oven until a constant weight was obtained. The briquettes were then kept in a furnace at a temperature of 550°C for 10 min and weighed after cooling in a desiccator. The percentage volatile matter was calculated as equation 3.

Where ODW - Oven Dry Weigh, Ws - Weight of sample after 10 min in the furnace .

### D. Ash Content

Ash content was determined by weighing one gram of the sample and putting it in a crucible and covering it with a lid. The crucible was placed in a muffle furnace and heated gradually to temperature of 7500 C within two hours. It was then allowed to cool and weighed. The ash content was determined according to ASTM Standards D 3174 - 97 (1998) Specifications and equation 4.

$$\% V_m = \frac{ODW - W_s}{ODW} \times 100 \quad (3)$$

Where (PAC) is percentage ash content, (A) and (B) weight of ash and briquette respectively.

### E. Fixed Carbon

Fixed carbon was calculated by subtracting the sum of (%) volatile matter and (%) ash content from 100 % as shown in equation 5.

$$PAC = \frac{A}{B} * 100\% \quad (4)$$

Where fc is fixed carbon, Vm volatile matter

### F. Calorific Value

Calorific value is an indication of the amount of heat generated when one kilogram of fuel is burnt. The experiment was carried out using an adiabatic bomb calorimeter in accordance to standard procedures outlined in ASTM E 711-87 (2004b). A reaction vessel containing one gram of the sample and excess pure oxygen was immersed in the water bath at ambient conditions. The current was passed through an ignition wire leading to combustion of the reactants and release of energy which was absorbed by water bath causing the water jacket temperatures to rise. The calorific value was then read on the digital screen of the bomb calorimeter.

## iii. Results

### A. Moisture Content

The average moisture content of the faecal matter - sawdust briquettes at selected mix ratios ranged between 6% and 9% as shown in figure (1). The percentages depended on the type of binder as faecal matter bonded briquettes at the mix ratio of 1:3 had the lowest moisture content at 6.9% wb as compared with molasses bonded briquettes that had the highest moisture content of 8.6% wb.

$$\% f_c = 100\% - (\% V_m + \% Ash) \quad (5)$$

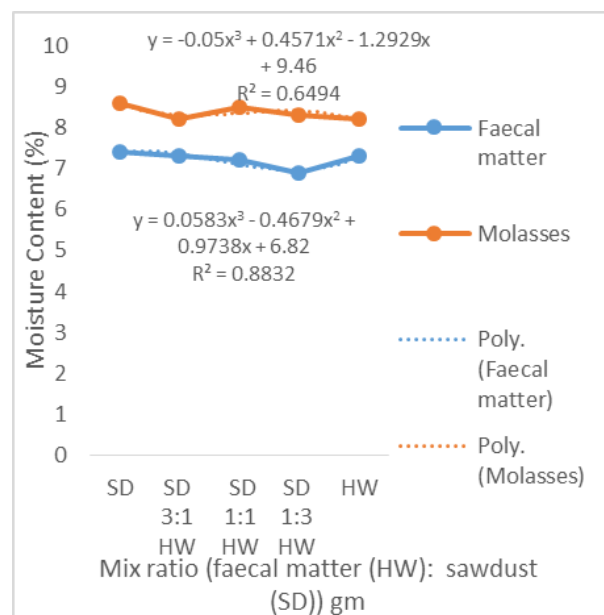


Figure (1)

### B. Density

The determined density of briquettes ranged between 499 kg/m<sup>3</sup> – 745 kg/m<sup>3</sup> and 487 kg/m<sup>3</sup> – 734 kg/m<sup>3</sup> for faecal matter and molasses bonded briquettes respectively. Faecal matter bonded briquettes were higher in density than molasses bonded briquettes. Thus the density of the composite briquettes had a relationship on the type of the biomass and binder as shown in figure (2).

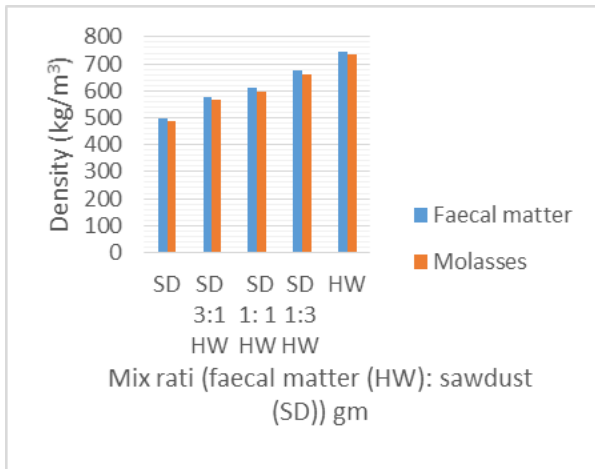


Figure (2)

### C. Volatile matter

The volatile matter for the composite briquettes increased with increase in the mix ratio of sawdust and molasses as a binder and decreased with increase in the faecal matter. Pure sawdust briquettes had volatile matter of 56.3% and 54.7% when bonded with molasses and faecal matter respectively. The volatile matter was contributed to by the elemental composition of the materials used figure (3).

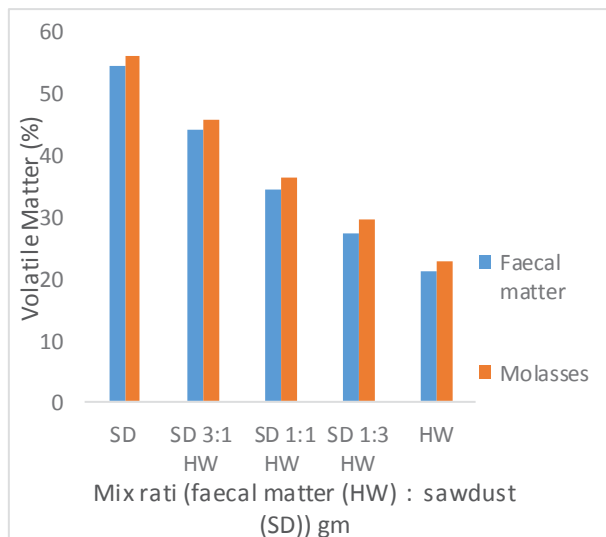


Figure (3)

### D. Ash content

Pure faecal matter briquettes had ash content of 52.4% which declined with increase in sawdust in the mix ratios. The mean ash content of the sampled briquettes ranged between 12.4% - 52.4% and it depended on the type of binder and biomass used. Faecal matter bonded briquettes had higher ash content than those briquettes bonded with molasses. There was significant effect of the ash content as the mix ratio of faecal matter changed as shown in figure

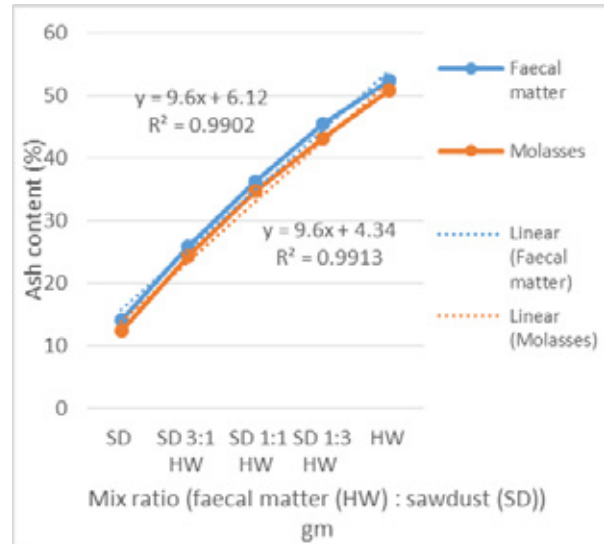
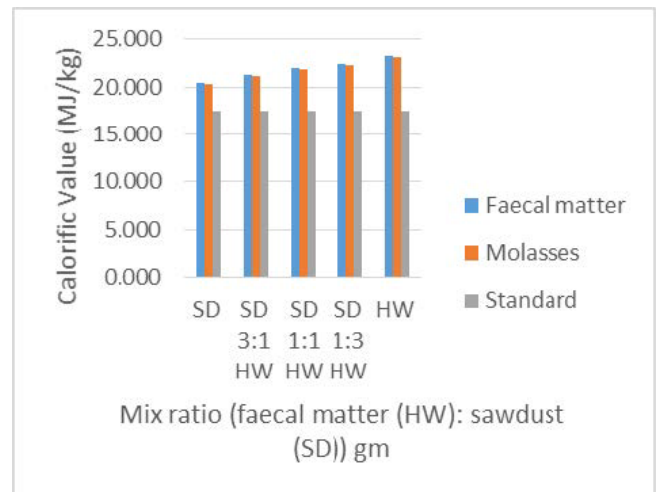


Figure (4)

### F. Calorific value

The calorific value of faecal matter-sawdust briquettes inclined to the type of biomass and the binder as in figure (6). The average calorific values ranged from 20.385 MJ/kg – 23.083 MJ/kg and 20.527 MJ/kg - 23.246 MJ/kg for molasses and faecal matter bonded briquettes respectively. Faecal matter bonded briquettes had the highest calorific value of 23.246 MJ/kg. The calorific value was above 17.5 MJ/kg which is the DIN 51731 minimum value for briquettes to be considered as having satisfactory calorific value (Deutsches Institut für Normung (DIN), 1996).





## IV. Discussions

Singh (2004) and Li and Liu (2000) found that briquettes with moisture content between (5-10)% are strong, durable and burn with little smoke as compared to briquettes with moisture content of 15% and above. Briquettes with moisture content below 5% tend to absorb the moisture from the atmosphere leading to decrease in the quality of the fuel (Fasina, 2008). In this study, the moisture content was between 6%-9% which was within the acceptable limit of less than 12% according to the German standards (Deutsches Institut für Normung (DIN), 1996).

Density is directly proportional to the energy density and it depends with the original density of the biomass and the method of agglomeration. The densities of the raw materials were 0.4663 g/cm<sup>3</sup> and 0.1969 g/cm<sup>3</sup> for faecal matter and sawdust respectively. This explains why briquettes with a high percentage of faecal matter had higher densities as compared to those with high sawdust content.

The briquette densities obtained from this study were between (487 - 745) kg/m<sup>3</sup> which does not meet the requirements of the DIN 51731 German standard of (1000 - 1400) kg m<sup>-3</sup>. The low briquette densities were due to the non-pressure agglomeration method used. In addition, there was a significant difference ( $p \leq 0.05$ ) between the densities of all briquettes due to the binders used.

The ignitability of the fuel and the release of smoke is directly proportional to the amount of the volatile matter which depends on the raw material (Chirchir, 2011). The amount of volatile matter decreases during the carbonization process due to the reduction of oxygen leading to increase in the carbon content (Dhughana, 2011). Volatile matter of composite briquettes increased with increase in the mix ratios of sawdust and use of molasses as a binder. The results were supported by Sotannde et al. (2010) findings in which the volatile matter depended on the type of the binder and composition of original biomass.

According to DIN (1996), the minimum ash content recommended by DIN 51731 is 0.7% which is lesser than the range of (12.4 - 52.4) % obtained in this study. Ndiema et al. (2002), Demirbas and Sahin (2001) found out that the ash content depends on the elemental composition of the briquette feedstock. The mean ash content of faecal matter-sawdust briquettes increased with ratios of faecal matter as a feedstock and binder.

The calorific value of the briquettes in this study was higher than the minimum required calorific value of 17.5 MJ/kg for commercial briquettes DIN, (1996) and Sotannde et al. (2010). It is evident that at high proportion of faecal matter there was high calorific value obtained. However, the calorific values obtained in this study of (20.385 - 23.246) MJ/kg were lower than that of charcoal dust (28.7 MJ/kg) (Chirchir, 2011). This could be ascribed to the high ash content of the briquettes.

## V. Conclusion and Recommendation

This study examined the physical and combustion characteristics of carbonized faecal matter-sawdust briquettes using selected binding agents. It was observed that the physical and combustion characteristics were significantly affected by the type of biomass and binder. It showed further that the faecal matter-sawdust briquettes at 50%/50% bonded with faecal matter exhibited the positive attributes for moisture content (7.3%), volatile matter (34.5%), ash content (36.4%) and calorific value (22.001 MJ/kg). Molasses bonded briquettes had lower calorific value as compared to faecal matter bonded briquettes.

The study revealed that faecal matter and sawdust are suitable for production of domestic solid fuel that can be used as a source of energy since the calorific value was above 17.5 MJ/kg (DIN, 1996) for all mix ratios. However, the results suggests that more study should be conducted on the emissions from the faecal matter bonded briquettes because of health purposes.

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## References

- [1] Arnold, J., Köhlin, G., and Persson, R. (2006). Woodfuels, livelihoods, and policy interventions: changing perspectives. *World Development*, 34(3); 596-611.
- [2] ASTM (American Society for Testing and Materials, (2004a). *Annual Books of ASTM Standards Parts Gaseous Fuel; Coal and Coke, Atmosphere Analysis*, Easton Maryland, USA.
- [3] ASTM (American Society for Testing and Materials, (2004b). *Standard Test Methods for Gross Calorific Value of Refuse - Derived Fuel by Bomb Calorimeter Annual Books of ASTM Standards*.
- [4] ASTM Standards D 3174-97, (1998). Standard test method for ash in the analysis sample of coal and coke. *Annual Book of ASTM Standards*, 5:05.05, West Conshohocken, PA: American Society for Testing and Materials, 303-302
- [5] ASTM Standards E 872-82, (2013). Standard test method for volatile matter in the analysis of particulate wood fuels, ASTM Standards, International, West Conshohocken.
- [6] Chirchir, D.K. (2011). Evaluation of Physical and Combustion Characteristics of Biomass Composite Briquettes. Master of Science Degree in Engineering Systems and Management. Egerton University, Nakuru.
- [7] Chirchir, D., Nyaanga, D., and Kitheko, J. (2013). Effects of binder types and amount on Physical and Combustion Characteristics of Biomass Composite Briquettes. *International Journal of Engineering Research, Science and Technology*, 2(1).
- [8] Demirbas, A., and Sahin, A. (2001). Evaluation of Biomass Residue; Briquetting Waste Papers and Wheat Straw Mixtures. *Journal on Fuel Processing Technology*, 55: 175 - 183.
- [9] Deutsches Institut für Normung (DIN). (1996). *Testing of solid fuels - Compressed untreated wood - Requirements and testing*. German National Standard, 4p.
- [10] Dhughana, A. (2011). *Torrefaction of Biomass*. Master of degree in Applied Science. Dalhousie University, Halifax, Nova Scotia.
- [11] Fasina, O. O. (2008). Physical properties of peanut hull pellets. *Bioresource Technology*, 99(5):1259-1266.
- [12] Gachuri, W. G. (2015). Optimising the utilisation of sawdust of eucalyptus tree species. A fuel tea industry. Master of Science Degree in Environmental and Biosystems Engineering. University of Nairobi, Nairobi.
- [13] GoK, (2013). *Analysis of the charcoal value chain in Kenya*. Ministry of Environment, Water and Natural Resources.
- [14] Grover, P., and Mishra, K. (2006). *Biomass Briquetting Technology and Practices*.
- [15] International Institute for Environment and Development (IIED). (2010). *Biomass energy in Kenya*. Nairobi, Kenya.
- [16] Jenkins, P., Baxter, C., and Miles, T. (2008). Combustion Properties of Biomass Fuel Processing Technology. *Journal on Fuel Processing Technology*, 54: 17 - 46
- [17] Jorgensen et al. (1998). Decontamination of water by direct heating in solar panels. *Journal of Applied Microbiology*, 85: 441 - 447.
- [18] Li Y., and Liu H. (2000). High pressure densification of wood residues to form an upgraded fuel. *Biomass and Bioenergy* 19(3):177 - 186.
- [19] Matiru, V. (2007). *Forest Cover and Forest Reserve Cover in Kenya Policy and Practices*. Oxford Press. Nairobi, Kenya.
- [20] Ndiema, C., Manga, P., and Ruttoh, C. (2002). Cashew Nut Shell Liquid: An agricultural by product with potential for commercial exploitation in Kenya, 2013 vol.15 no.1. *Journal of Agriculture, Science and Technology*.
- [21] Oladeji, M. (2010). Fuel characterization of briquettes produced from corncob and rice husk residues. *The Pacific Journal of Science and Technology*, 11: 101-106.
- [22] Republic of Kenya, (2016). *National Forest Programme 2016-2030*. Ministry of Environment and Natural Resources, Nairobi, Kenya.
- [23] Singh, R. (2004). Equilibrium Moisture Content of Biomass. *Journal of Bio Energy and Biomass*, 26:251 - 253.
- [24] Sotannde, O., Oluyege, G., and Abah, B. (2010). Physical and combustion properties of Briquettes from sawdust of *Azadirachta indica*. *Journal of Forestry Research*, 21: 63 - 67.
- [25] UNDESA. (2008). *World Urbanization Prospects*. New York: United Nations Department of Economic and Social Affairs.
- [26] Wairire, S.M. (1994). *Sustainable Urban Development and Resources Base Sustenance*. Master of Arts in planning, development of urban and region planning. University of Nairobi, Nairobi.







# International Scientific Research Organization Journal (ISROJ)

## COMBUSTION PERFORMANCE OF SPHERICAL-SHAPED FAECAL MATTER – SAWDUST BRIQUETTES

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### Abstract

Faecal matter and sawdust can be considered as an expensive liability in the environment but have a huge potential for fuel briquettes that can replace firewood and charcoal as major sources of energy in rural and peri-urban households in Kenya. The research evaluated the effect of the faecal matter - sawdust mix ratio and binder on the performance of the composite briquette as a source of energy in selected cook stoves. The raw materials were dried, carbonised, reduced in size, mixed and agglomerated using mix ratios (of carbonised faecal matter to sawdust) of 1:0, 3:1, 1:1, 1:3, 0:1 and bonded with a binder at 10% of total mass. Molasses and boiled faecal matter were selected as binders. The briquettes were evaluated in a 500g cook stove ("Jikokoa") using standard water boiling tests of ignition time, burning rate, specific fuel consumption and power output. The performance characteristics varied with the type of binder, proportion of raw materials used and combustion phase. Molasses compared to faecal matter bonded briquettes burned faster and took less time to boil water. Ignition time and burning rate increased with increase of faecal matter in the briquettes while specific fuel consumption, power output and burning rate decreased with decrease of faecal matter. Average specific fuel consumption and power output of molasses bonded briquettes ranged from 95-119 g/l and 2048- 2404 watts while for faecal matter bonded briquettes ranged from 98-120 g/l and 2071-2417 watts during the high-power phase, respectively.

**Keywords:** Spherical-Shaped briquettes, Faecal Matter, Sawdust, Ratios, Binders, Performance.

### 1. Introduction

Fuel wood is widely used in households for cooking, heating and lighting in many developing economies. The annual energy consumption in Kenya averages 70% fuel wood, 21% petroleum and 9% electricity in the mid 2000 (Matiru, 2007). Wood fuel can contribute respectively to as high as 89% and as low as 7% of the rural and urban household cooking energy (IIED, 2010). Charcoal provides 82% of domestic energy in the urban and 34% in rural households (GoK, 2013). The forested area in Kenya was estimated at 10% in 1963 (Gachuri, 2015) but today the closed forest canopy is less than 6.99% (GOK, 2016) due to deforestation. This situation is expected to deteriorate as charcoal demand is projected to double from the year 2000 to 2030 because of urbanisation in Sub-Saharan Africa (Arnold et al., 2006).

Due to worldwide concern on environmental impacts from fossil fuels and the need for alternative energy supplies for sustenance of economic development, there is increased interest in renewable energy. The agricultural residues can be utilised by agglomeration to reduce the consumption of wood fuel blamed partly in some areas as a factor of deforestation (Shekhar, 2011). Also, the wood industries have challenges in disposal of large volumes of sawdust (Wairire, 1994). In developing countries like Kenya, the amount of faecal matter today is increasing as population rises and causes constraints on maintenance and operation of treatment plants and sludge systems in urban areas. However, for biomass to qualify as feedstock for agglomeration factors like availability, composition, low moisture and ash content (Grover and Mishra, 1996) should be considered.

The agglomeration process need binders. These are characterized as either organic agents such as heavy crude oil, cassava, and molasses or inorganic like clay, sodium silicate and cement. The commonly used binders are starch from corn, cassava, sugarcane molasses, and cow dung (Gachuri, 2015). According to Olorunnisola (2007), briquettes made using starch produce less ash, burn faster and more efficiently than clay. Altun et al., (2003) state that binder type and amounts have substantial effects on the combustion of briquettes. Little information though is known on use of boiled faecal matter as a binder and the performance characteristics of non-pressure spherical faecal matter-sawdust briquettes. The study therefore determined selected performance characteristics of carbonised ratios of faecal matter and sawdust briquettes and a suitable binder between molasses and boiled faecal matter.

### 2. Methodology

#### 2.1 Raw Materials Preparation

Domestic sludge was obtained from exhauster trucks and sawdust was collected from saw mills around Nakuru town at 00018.204'S and 036005.255'E.

The sludge and saw dust were dried in beds in a greenhouse respectively for two weeks and two days to a moisture content of 10%. The materials were sin a drum kiln (faecal matter), half drum open pan (sawdust) and separately milled to about 1mm particle sizes by a hammer mill. These were mixed in the mix ratios of 3:1, 1:1 and 1:3. A binder solution of faecal matter was made by boiling 1kg of dried and milled non-carbonised faecal matter in 20 litres of water for 3 hours. The boiling was for elimination of harmful bacteria such as E. coli, Strep. faecalis and Salm. typhimurium which do not survive at temperatures above 62o C (Jørgensen et al., 1998). The binder amount was added up to 10% of weight of each mix ratio.

#### 2.2 Agglomeration of Materials to Briquettes

Non-pressure agglomeration is a process of size enlargement of fine particles by use of a rotating drum. In each session of briquetting, 18 kg (plus the 2 kg equivalent lighting gel) of mixed carbonised powder of faecal matter and sawdust was poured on the rotating drum bed. As the agglomerator rotated, a binder solution (2 kg of boiled faecal matter or molasses) was sprinkled onto the mixed material until briquettes of 40mm diameter were achieved. The binder solution assisted in forming granule nuclei which enlarged by collisions with other granules and the surface of the rotating drum. The process incorporates nucleation, coalescence and consolidation before surface wear due to friction, the attrition of the spherical briquettes. The briquettes were then dried in a greenhouse drying bed for four days to 8% moisture content before use, in a 500 g biomass cook stove (Jikokoa) and ignited by use of 1g of lighting gel ("motopoa") poured on the ash tray and lit. The gel energy is assumed to be about 2g of briquettes (Ward, 2009).

#### 2.3 Briquette Performance

The altitude(h) for the experimental site, Kaloleni in Nakuru, Kenya, was determined by a hand held geographical positioning system (GPS) as 1784 m and used in equation (1) to calculate the local boiling point ( $T_b = 94 \text{ }^\circ\text{C}$ )

$$T_b = \left(100 - \frac{h}{300}\right)^0 C$$



## 2.4 Time of Ignition and Burning

Briquettes were kindled and ignition time noted using a stop watch. Burning Rate (rate at which a certain mass of fuel is combusted in air) is expressed as;

$$\text{Burning Rate} = \frac{\text{Mass of fuel burnt (kg)}}{\text{Time taken to burn the fuel (sec)}}$$

The water boiling test was conducted according to version 4.2.3 WBT (2014), equation 1. Two litres of water at room temperature were poured into a pot. The initial water temperature was taken by a digital thermometer at a depth of about 1 cm above the bottom of the pot. A weighing balance of 1g accuracy was used to determine the initial weight of pot with water and cook stove with briquettes. The pot with water was placed on the cook stove and time taken to reach the boiling point of 94°C was recorded. At boiling point, water temperature, weight of pot with remaining water, weight of cook stove with remaining briquettes (after shaking onto ash tray and removing), weight of ash and time to boil were determined and recorded.

The hot start high power phase was started immediately after the cold start phase while the stove was hot. The pot containing two litres of water at room temperature was placed on the cook stove to utilise the remainder hot briquettes from cold start phase. The starting and stopping time when water was placed on the cook stove and when the boiling point at 94°C was reached were recorded.

The final water temperature, time to boil, weight of pot with remaining water, weight of cook stove with remaining briquettes after shaking for the ash to fall on the ash tray were determined and recorded. Low power phase (LPPh) was conducted immediately after the hot start phase (HSPh) ended from the cold start high power phase (CSHPh). A known weight of briquettes was added to fill the cook stove. The pot with the remaining hot water from the hot start phase was simmered for 45 minutes and the water temperature was maintained at 91°C (3°C below the boiling point) by controlling the stove vent (oxygen supply). After 45 minutes, the final water temperature, weight of pot with remaining water, weight of cook stove with remaining briquettes after removing ash, weight of ash and time to boil were determined and recorded. The shift from one phase to another was conducted within two minutes. Three replications of the water boiling test were done and equation 2 and 3 were used to determine; Specific Fuel Consumption; amount of solid fuel equivalent used in achieving a defined task divided by the weight of the task, that is;

$$\text{Specific Fuel Consumption} = \frac{\text{Mass of fuel burnt (kg)}}{\text{Mass of boiled water in the pot (kg)}}$$

Power Output; the available amount of energy released from the fuel in a given time as;

$$\text{Power Output} = \frac{\text{Mass of fuel burnt (kg)} \times \text{Calorific Value of the fuel (kJ/kg)}}{\text{Time taken to burn fuel (sec)}}$$

## 2.5 Burning Time

Burning time is the average time taken for the briquettes to burn into ash after ignition until the water boiled (Rotich, 1998). Three replications of the burning time were determined and recorded during the high power cold start and hot start phases using a stop watch.

## 3. Results and Discussions

### 3.1 Specific Fuel Consumption

The average specific fuel consumption of three replications of water boiling test of the sampled faecal matter-sawdust briquettes at selected mix ratios ranged respectively between 97-120 g/l, 95-118g/l and (54.4 -73.8) x 101 g/l for high power cold start, high power hot start and low power phases as shown in figure (1). Based on the averages and graph, faecal matter bonded briquettes had higher specific fuel consumption than molasses bonded briquettes at all the mix ratios. This can be ascribed to the high ignitability and low dry matter of molasses compared to faecal matter.

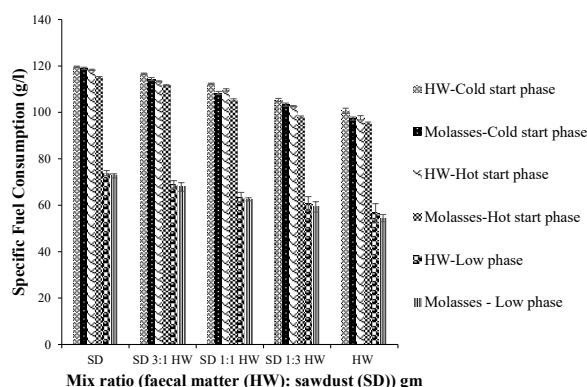


Figure 1: Effect of mix ratio on specific fuel consumption

The specific fuel consumption decreased with increase in the faecal matter which had higher calorific value compared to sawdust and less was required to bring the water to boiling. Furthermore, briquettes with low density were consumed faster which explains why mix ratios with higher proportion of sawdust had higher specific fuel consumption. There was more consumption of fuel in the cold start than in the hot start because some heat was used to warm the cook stove and the environment around as shown in figure (1). During the low power phase there was higher specific fuel consumption (54.4 -73.8) x 101 g/l against (95-120g/l) during the high power phase because the water was kept at a temperature as close as possible to 91°C (3°C below the boiling point) for a long time (45 minutes).

There was a significant difference ( $p < 0.05$ ) in the specific fuel consumption considering the mix ratios and type of binder used. Less mass of faecal matter briquettes was used to bring the water to the boiling because of its high calorific value and density (Mbuba et al., 2017). The findings agree with Chinyere et al., (2014) whereby the low specific fuel consumption of the biomass was due to the high heat content of biomass briquettes. Furthermore, the low specific fuel consumption due to high density of briquettes compares well with the findings of Abdulsheed et al., (2015). The results obtained also match that of Oyelaran et al., (2015) who reported that the specific fuel consumption of low power phase was higher than the hot power phase for the groundnut shell briquettes.

### 3.2 Power Output

The average amount of energy released by burning the faecal matter-sawdust briquettes in sequence (HPCSPH, HPHSPH, CSHPH) of the phases of three replications of WBT at selected mix ratios ranged between 2048-2388 watts, 2064-2418 watts and 775-1011 watts. Figure (2) shows the power output of the composite briquettes of the three phases considering the selected binders. It depended on the type of binder and material used in briquetting as faecal matter bonded briquettes had higher power output than molasses bonded at all the mix ratios.

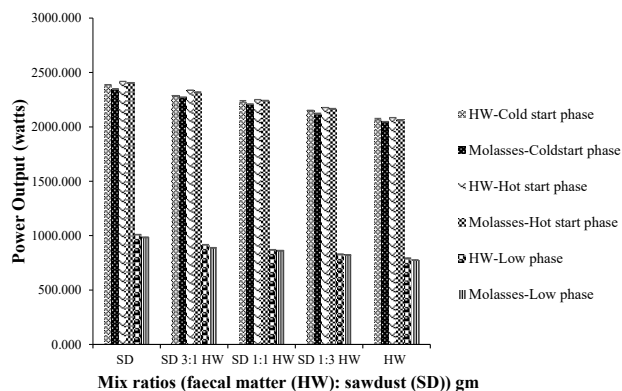


Figure 2: Influence of mix ratio on power output

Analysis of Variance showed significant difference in the power output on account of the materials (carbonised faecal matter and sawdust) and type of binder (molasses and non-carbonised faecal matter) used in briquetting. Briquettes with high percentage of faecal matter took more time and less amount was consumed to bring the water to the boiling. This explains why the power output was low as it is indirectly proportional to time and directly proportional to the product of mass and calorific value of the fuel. More briquettes with high percentage of sawdust were consumed because of the low density as pure sawdust briquettes had the highest power output of 2418 watts. Molasses bonded briquettes had lower power output as compared to faecal matter bonded briquettes which is ascribed to the higher calorific value of the faecal matter. The low power phase had the lowest power output which ranged from 775 watts to 1011 watts compared to the high power phase (2048-2418 watts) since simmering was at 30C below the boiling point, whereas in high power phase the water was brought to boiling from room temperature. Kuti (2009) observed that the power output of the low power phase was lower than that of the high power phase which supports these findings.

### 3.3 Burning Rate

Burning rate measures the quantity of briquettes burnt in a given time. Figure (3) indicates that the highest burning rate was obtained during high power hot start phase (8.3 g/min) compared to high power cold start phase (8.0 g/min) and low power phase (5 g/min). Molasses bonded briquettes had the highest burning rate as compared to faecal matter bonded briquettes. Sawdust briquettes bonded with molasses had the highest burning rate of 8.3 g/min and faecal matter briquettes had the lowest burning rate of 3 g/min. The high burning rate could be attributed to the high ignitability of the molasses as compared to faecal matter since it has more volatile matter. The increase in burning rate of mix ratios with high percentage of sawdust agrees with the findings of Kuti (2009) that the burning rate increased with the increase in the proportion of sawdust for sawdust-charred palm kernel shell briquettes.

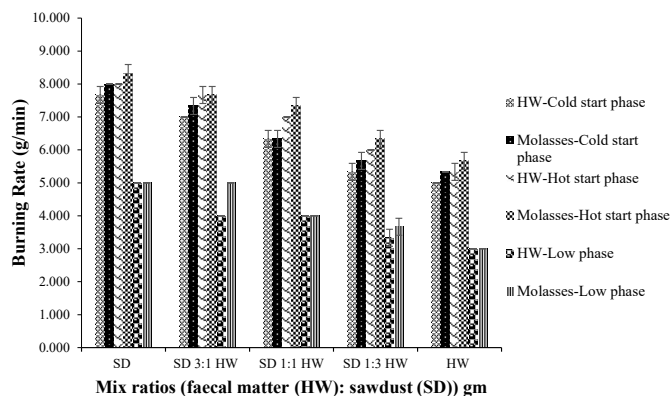


Figure 3: Burning rate and mix ratio

The burning rate decreased as the proportion of faecal matter increased in the mix ratios of the briquettes compared to sawdust. This was deduced in its high ash content and low volatile matter of the faecal matter (Mbuba et al., 2017), as also observed by Sotannde et al., (2010). The highest burning rate was in high power phase and lowest in simmering which compares well with the findings of Oyelaran et al., (2015) and contrary to Kuti (2009) who reported that the burning rate decreased from the high power hot start phase to the simmering. The difference would be in the raw materials used by Kuti (2009) which were of low density compared to faecal matter-sawdust briquettes. There was also difference in time taken during the low power phase of thirty minutes against that of the study of forty-five minutes. Chaney et al. (2008) stated that briquettes of low density such as sawdust tend to burn faster due to high porosity which allows oxygen to diffuse into the briquettes.

### 3.3 Burning Time

Burning time is the duration taken to bring one litre of water to boiling using briquettes as a source of fuel. The boiling point that depends on altitude was 940C at Kaloleni NAWASSCO domestic treatment plant which is 1784m above mean sea level in Nakuru (00018.204'S and 036005.255'E) and the month was October. The burning time of briquettes was affected

by the type of the binder and material used in briquetting as shown in figure (4).

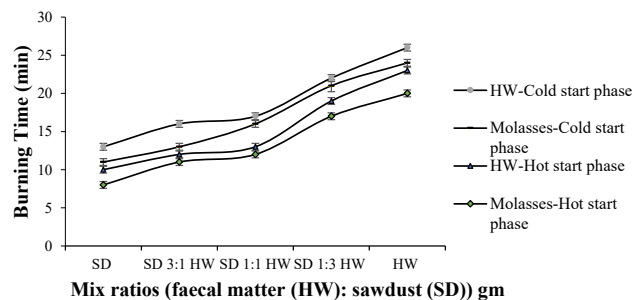


Figure 4: Effect of mix ratio on burning time

Faecal matter bonded briquettes had the longest burning time compared to molasses bonded briquettes since the faecal matter was denser than molasses. It could be having some incombustible materials which reduce the flame propagation as a result of low thermal conductivity (Dhughana, 2011). In addition, molasses has more volatile matter than faecal matter which leads to less burning time. In this case, the least time was taken by molasses bonded sawdust briquettes, that is 8 minutes at high power hot start phase compared to faecal matter bonded briquettes highest burning time of 26 minutes at high power cold start phase. The burning time increased with the increase in the amount of faecal matter in all mix ratios. This was evidenced by the high ash content formed during the burning which has low thermal conductivity as it is incombustible. Faecal matter also has higher density compared to sawdust that reduces oxygen infiltration into the briquettes due to low porosity hence decreasing burning rate and increasing burning time. The long burning time of briquettes due to low volatile matter and high density compares well with the findings of Chaney et al. (2008), Chirchir (2011) and Sotannde et al., (2010). However, the results do not support Ikelle et al. (2014) which showed that thermal conductivity decreased with decrease in density hence more air spaces and oxygen which support burning. The burning time in low phase was maintained for forty-five minutes.

## 4. Conclusion and Recommendation

The study examined the performance characteristics of carbonised faecal matter-sawdust briquettes using faecal matter and molasses as binding agent. The performance characteristics of the composite briquettes were significantly affected by the type of biomass and binder. Pure faecal matter briquettes had the highest ash content which indicates more burning time which decreases the burning rate. The non-carbonised faecal matter produced more smoke comparatively during the ignition stage which renders it unfit to be used as a binder. Using the Taguchi analysis, a faecal matter and sawdust composite briquette at a mix ratio of 1:3 was found suitable for production of domestic solid fuel. This is due to less specific fuel consumption, long burning time, ash content and high calorific value which was above the minimum recommended for commercial briquettes comparing the other mix ratios enumerating the aspects of a good briquette. Hence it can be adopted as an alternative source of energy to charcoal and firewood. Additional studies should focus on the commercial viability of faecal matter and saw-dust composite briquettes as well as explore the combination of other biomass sources with faecal matter for briquette production.

## 5. Acknowledgements

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## References

- Abdulrasheed, A., Aroke, U., and Ibrahim, M. (2015). Compression pressure effect on mechanical and combustion properties of sawdust briquette using styrofoam adhesive as binder. *American Journal of Engineering Research* . 4(8), 205-211.
- Altun, N. E., Hicilymaz, C., and Bagci, A. S. (2003). Combustion characteristics of coal briquettes. 1. Thermal features. *Energy & fuels*, 17(5), 1266-1276.
- Arnold, J. M., Köhlin, G., and Persson, R. (2006). Woodfuels, livelihoods, and policy interventions: Changing perspectives. *World development*, 34(3), 596-611.
- Chaney, J., Clifford, M., and Wilson, R. (2010). An experimental study of the combustion characteristics of low-density biomass briquettes. *Biomass magazine*, 1.
- Chinyere, D., Asoegwu, S., and Nwandikom, G. (2014). An evaluation of briquettes from sawdust and corn starch binder. *The International Journal of Science and Technoledge*, 2(7), 149-157.
- Chirchir, D. K. (2011). Evaluation of physical and combustion characteristics of biomass composite briquettes. (M.Sc), Egerton University, Nakuru.
- Dhungana, A. (2011). Torrefaction of biomass. (M.Sc.), Dalhousie University, Halifax, Nova Scotia.
- Gachuri, W. G. (2015). Optimizing the utilization of sawdust of eucalyptus tree species. A fuel tea industry. Unpublished M.Sc. Thesis, University of Nairobi, Nairobi.
- GoK (Government of Kenya). (2013). Analysis of the charcoal value chain in kenya. Ministry of environment, water and natural resources.
- Grover, P., and Mishra, S. (1996). Biomass briquetting: Technology and practices: Food and Agriculture Organization of the United Nations.
- International Institute for Environment and Development (IIED). (2010). Biomass energy in Kenya. Nairobi, Kenya.
- Ikelle, I. I., and Joseph, M. N. (2014). The study of briquettes produced with bitumen, caso4 and starch as binders. *American Journal of Engineering Research (AJER)* e-ISSN, 2320-0847.
- Jørgensen, A., Nøhr, K., Sørensen, H., and Boisen, F. (1998). Decontamination of drinking water by direct heating in solar panels. *Journal of applied microbiology*, 85(3), 441-447.
- Kuti, O. A. (2009). Performance of composite sawdust briquette fuel in a biomass stove under simulated condition. *AU JT*, 12(4), 284-288.
- Mbuba, M.J., Nyaanga, D.M., Kabok, P.A. and Eppinga, R. (2017). Effect of Mix Ratios and Binders on Physical and Combustion Characteristics of Faecal Matter – Sawdust Briquettes. *International Journal of Emerging Technology and Advanced Engineering*.
- Matiru, V. (2007). *Forest cover and forest reserve cover in kenya policy and practises*: Oxford Press, Nairobi, Kenya.
- Murali G., Channankaiah P., Goutham I., Hasan, E., Anbarasan, P. (2015). Performance Study of Briquettes from Agricultural Waste for Wood Stove with Catalytic Combustor. *International Journal of ChemTech Research*. CODEN (USA): IJCRGG ISSN: 0974-4290. Vol.8, No.1, pp 30-36.
- Olorunnisola, A.O. (2007). Production of Fuel Briquettes from Waste Paper and Coconut Admixtures. *Agricultural Engineering Journal*, 9: 1-15.
- Oyelaran, O. A., Bolaji, B. O., Waheed, M. A., and Adekunle, M. F. (2015). Performance evaluation of the effect of waste paper on groundnut shell briquette. *KMUTNB Int J Appl Sci Technol*, 8(1): 11 -19, <http://dx.doi.org/10.14416/ijast.2014.11.004>
- GoK (Government of Kenya). (2016). National Forest Programme 2016–2030. Ministry of Environment and Natural Resources, Nairobi, Kenya.
- Rajaseenivasan, T. Srinivasan, V. Mohamed G. S. Qadir and K. Srihar (2016). An investigation on the performance of sawdust briquette blending with neem powder. *Alexandria Engineering Journal* 55, 2833–2838. <http://dx.doi.org/10.1016/j.aej.2016.07.009>
- Rotich, P. K. (1998). Carbonization and briquetting of sawdust for use in domestic cookers. (M.Sc), University of Nairobi, Kenya.
- Shekhar, D. (2011). Popularization of biomass briquettes: A means for sustainable rural development. *Asian Journal of Management Research*, 1, 2229 – 3795
- Sotannde, O., Oluyeye, A., and Abah, G. (2010). Physical and combustion properties of briquettes from sawdust of *azadirachta indica*. *Journal of Forestry research*, 21(1), 63-67.
- Wairire, S. M. (1994). Sustainable urban development and resources base sustenance. (M.A in planning, development of urban and region planning), University of Nairobi, Nairobi.
- WBT (Water Boiling Test). (2014). The water boiling test: Version 4.2.3. Cook stove Emissions and Efficiency in a Controlled Laboratory Setting. Available: <https://cleancookstoves.org/binary-data/DOCUMENT/file/000/000/399-1>. Pdf. Accessed: 6 July 2015.





# EFFECT OF SHAPES, BINDERS AND DENSITIES OF FAECAL MATTER - SAWDUST BRIQUETTES ON IGNITION AND BURNING TIMES

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## Abstract

Wood fuels are a major source of energy in the developing world whose sustainability is diminishing in forest cover and production increases in demand due to rising population. Alternative environmentally friendly accessible sources of energy for households are therefore a necessity. These include faecal matter, forest and agricultural residues that are convertible into briquettes. These sources will depend on availability, impact on environment, renewability and energy content. The benefit of briquettes arises from near equal mass balance of carbon dioxide demand by photosynthesis in the atmosphere to the amount released during combustion. Briquetting thus needs designed agglomeration machines and understanding of the engineering properties. The parameters density and shape have effect on combustion and performance characteristics hence should be determined. The research thus focused on spherical, triangular and cylindrical shapes and densities of 600 kg/m<sup>3</sup>, 700 kg/m<sup>3</sup> and 800 kg/m<sup>3</sup> on ignition and burning time. Carbonization of faecal matter and sawdust with binders was the activities. There was significant difference on ignition time on shapes and densities and none on burning times with shapes and binders. The average ignition time ranged from 2.7 to 3.7 minutes irrespective of shapes and binders. The average burning time ranged from 18 to 26 minutes for molasses and starch bonded cylindrical briquettes. The spherical briquettes had the least ignition time of 2.7 minutes. Packing ratio, evenly distributed air spaces, higher volatile matter in binder, porosity due to density advantaged the spherical briquettes.

**Keywords:** Carbonization; Faecal-sawdust-briquettes; Densities; Shapes; Ignition and burning time

## Introduction

Interest is growing in renewable energy due to increasing worldwide concern regarding environmental impacts and need for alternative energy supplies. Though, the forested area in Kenya has declined from independence and fuel wood is still being widely used in households for cooking, heating and lighting. It supplied 89% and 7% rural and urban household energy respectively in the year 2000 [1]. There are also other materials such as agricultural residues that can still be utilized to reduce the consumption of wood fuel blamed partly in some areas as a factor of deforestation [2]. Hence, conversion of raw materials that have challenges in disposal such as sawdust and faecal matter to sources of energy for households needs proper understanding of the engineering properties and techniques for conversion. Biomass in consideration thus qualifies as a feedstock for agglomeration due to its factors of availability, composition, low moisture and ash content [3].

Agglomeration is the process of production of a compact product from loose raw material into high density fuel briquettes [2], categorized into pressure and non-pressure. Pressure agglomeration technology uses mechanical compression to form a homogeneous dense product and options include; compaction or granulation, briquetting or densification using screw extruders or mechanical and hydraulic piston presses [4]. Choice of the agglomerator depends on the equipment capabilities, desired product for instance type, shape, binder properties and raw material characteristics. The non-pressure agglomeration technology is a tumbling process where the material grows spherically into a compact product depended on the desired size using a pan or disc pelletiser, rotary drum agglomerator or drum granulator [5]. The benefit is briquettes of uniform size and shape which are easily handled, stored and transported using existing equipment [6]. Agglomerates are then tested to ascertain their suitability as a source of energy.

Attempts have been on densifying various agricultural residues into briquettes but few studies have been towards understanding effect of briquette shapes and densities on performance characteristics. On the other hand, and according to Olorunnisola [7], briquettes made using starch produce less ash, burn faster and more efficiently than those made using clay. Gachuri [8], also indicates that the commonly used binders are starch from corn, cassava, sugarcane molasses, and cow dung. Altun et al., [9] too notes that the binder types and amount do have substantial effects on the combustion of briquettes.

The easiness of the briquettes to ignite leads to proportionate increase in the flame length [10]. The ignition time of the composite faecal matter-sawdust briquettes was lower compared to coal briquettes which took 4.8 minutes, charcoal 7-10 minutes [11] and higher than water hyacinth

briquettes in which ignition time was 1-2 minutes [12]. Therefore, the faecal matter-sawdust briquettes performed better as compared to charcoal and coal.

## Materials and Methods

### Raw material preparation

Domestic sludge was discharged from exhauster trucks into drying beds in a greenhouse to dry for two weeks. Once dried to 10% moisture content, it was carbonized in a drum kiln. Using a weighing balance, 40kg of dry faecal matter was measured and poured in the drum kiln. The fireplace of the kiln was charcoal filled, sprinkled with 200 ml of paraffin and lit by a matchstick. The air intake ports and exhaust vent were opened to draw in enough oxygen for firing for 20 minutes. The ports were then closed and the vent sealed for carbonization to take place for 2 hours. A thermometer was mounted on the side of the kiln 10 cm from the top to monitor the temperatures.

Sawdust was collected from the saw mills in Nakuru Town, and then dried in greenhouse beds for two days to a moisture content of about 10%. The sawdust was passed through a 2.8 mm screen to remove large wood shavings. Using a spring balance, 40 kg of sawdust was weighed and carbonized in a half open drum for 1 hour. Carbonized sawdust was reduced into small particle sizes by a hammer mill. The carbonized sawdust and faecal matter was hammer milled to small particle sizes of about 1 mm and mixed in a 1:1 ratio by volume. The binder amount added was 10% by weight of each replication.

### Briquetting

**Shape preparation:** A 40 mm internal diameter cylindrical mold was made by drilling through a cylindrical mild steel bar of 75 mm diameter and 100 mm length using a lathe machine. The mold was perforated at about one third of the height to allow water to drain during briquetting as recommended by Dahlam et al. (2001). Polishing was done by fine emery paper to attain a smooth internal surface. Equivalently, an equilateral triangular mold of 40 mm height and 46 mm on the sides was prepared by welding to produce briquettes of the same size as the cylindrical briquettes. The dies were slightly smaller than the molds to reduce friction force during briquetting.

**Drum granulation:** Twenty kilograms of mixed ratio faecal matter and sawdust were weighed using a spring balance and poured into the drum granulator. The binding agent was then sprinkled as the drum rotated until the granules grew in size to 40mm diameter. Once formed, the granulator was turned off and the spherical briquettes were spread in greenhouse beds to dry to a moisture content of 8% on wet basis. The briquettes were then sampled for analysis.

**Hydraulic pressing:** Fifty grams of carbonized faecal matter and sawdust were weighed, mixed with a binder and hand-fed into the molds. The mixture was compacted to form briquettes of different shapes (cylindrical and triangular) using a hydraulic press and held for 5 minutes as recommended

[13]. Using the cylindrical mold, briquettes of densities 600, 700 and 800 kg/m<sup>3</sup> were produced by the hydraulic press and dried in a greenhouse to a moisture content of 8%. The briquettes were sampled and tested for ignition and burning time.

**Water boiling test:** Water boiling tests (WBT) were carried out in a controlled environment without wind but well ventilated to determine the performance of the fuel and stove. The test consists of high power (cold start and hot start) and low power (simmering) phases. The parameters determined and maintained during the WBT include; local boiling point confirmed for an altitude using a Global Positioning System (GPS) hand gadget, volume of water, weight of cook stove, ash tray and pot. Other equipment includes a small shovel for removing hot briquettes from the stove, tongs for handling briquettes, heat resistance gloves and a wood fixture for holding the thermometer probe in water. The local boiling point was determined from equation 1.

$$T_b = \left( 100 - \frac{h}{300} \right) C$$

Where (T<sub>b</sub>) is local boiling temperature and (h) altitude in meters. Only the high power cold start phase was conducted in determination of ignition and burning time of the briquettes.

**Firing briquettes for water boiling test**

In the high power cold start phase, the cook stove temperature is equal to room temperature. Two liters of water at room temperature were poured into a pot and the briquettes stacked in the cook stove combustion chamber. Initial water temperature was determined using a digital thermometer at a depth of about 1 cm above bottom of the pot. The initial weight of the pot with water and cook stove with briquettes were determined using a weighing balance of 1g accuracy. One gram of “moto sawa” assumed to be about 2g of briquettes [14], was poured on the ash tray and lit. Briquettes were allowed to kindle and ignition time noted using a stop watch. Once the briquettes ignited, the pot with water was placed on the cook stove, starting and stopping time was recorded when the water reached the boiling point of 94oC. Final water temperature, weight of pot with remaining water, weight of cook stove with remaining briquettes after shaking to allow the ash to fall on the ash tray, weight of ash and time to boil were recorded. Later, the characteristics were determined.

**Ignition and burning time**

Ignition time is the average time taken to light the briquettes [11]. It was determined and recorded using a stop watch. Three replications of each shape were done and average time determined. Burning time is the average time taken for the briquettes to burn into ash after ignition until the water boiled [11]. It was determined and recorded using a stop watch for each of the three replications.

**Results and Discussion**

Effect of shape and binder on ignition and burning time Ignition time is the average time required to ignite the composite briquettes. It is affected by the amount of volatile matter and the surface area of the briquettes exposed to the airflow. The base area of briquettes on the combustion mesh exposed to air flow was 117.32 cm<sup>2</sup>, 115.92 cm<sup>2</sup> and 100.56 cm<sup>2</sup> for spherical, triangular and cylindrical briquettes. The more the surface area exposed to air the less the ignition time was required. Spherical briquettes had the lowest ignition time of 2.7 minutes as shown in Figure 1.

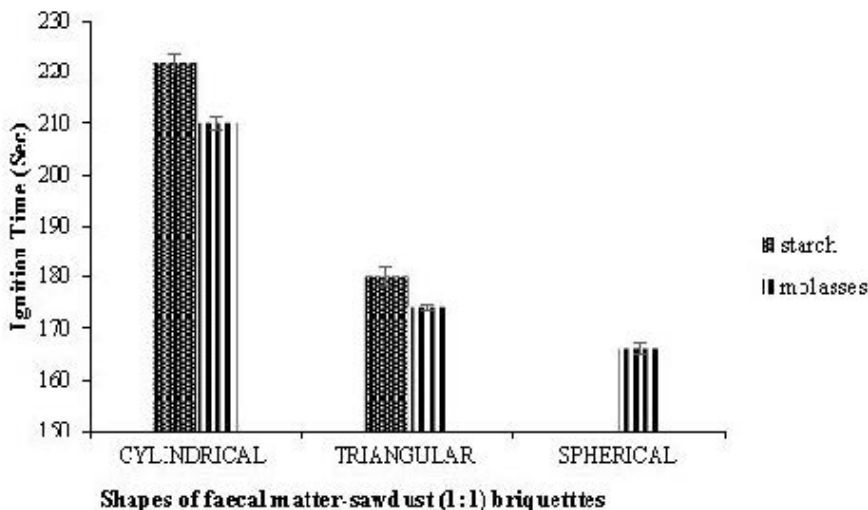
There was a significant difference (P > 0.05) in the ignition time for different shapes and binders. Cylindrical shaped briquettes had the longest (3.5 minutes) time while triangular and spherical shapes had ignitions of 2.9 minutes and 2.7 minutes respectively. The reason for the undesirable longer ignition time for cylindrical shapes could be partly attributed to low air spaces in between the briquettes due the higher packing factor thus restricting air flow and oxygen supply. Molasses bonded briquettes had least time compared to starch bonded briquettes because these have more volatile matter. However, in terms of smoke assessed by visual observation, molasses had the least which compares well with the results by Rotich [11]. The burning time which is the duration taken to bring a certain amount of water to boiling is influenced by volatile matter, porosity and biomass of the fuel. Different shapes of briquettes created different air spaces between which allowed the air to circulate. Packing ratio is the volume of briquettes to the volume of the combustion chamber of the briquettes. Briquettes that fitted the combustion chamber were 24, 21 and 22 with a packing ratio of 0.819, 0.695 and 0.760 for spherical, triangular and cylindrical briquettes, respectively. By maintaining the number of briquettes at 21 for all shapes, the packing ratio was 0.695, 0.717 and 0.726 for triangular, spherical and cylindrical briquettes.

Triangular briquettes had lower packing ratio than spherical but the air spaces were not as evenly distributed as those of spherical. This led to faster ignition and burning rate of spherical briquettes than triangular briquettes leading to less burning time as shown in Figure 2. The shape and binder of the briquettes did not result in any significant difference on the burning time (averaging 17 minutes) for the cylindrical, triangular and spherical composite briquettes of the same density. This could be because the calorific value of the fuel was the same as the briquettes were of the same materials. Air spaces between cylindrical briquettes were less compared to triangular and spherical briquettes which led to more ignition and burning time.

The results agree with previous studies by Onuegbu et al. [15] which showed that packing of briquettes in the combustion chamber of the cook stove influenced air flow in between the fuel surfaces that affected the ignition and burning time. Triangular and spherical briquettes had more air spaces in between the briquettes which allowed more air flow leading to more surface area being in contact with the oxygen. The base area (packing ratio), evenly distributed air spaces, higher volatile matter in binder, porosity guided by density were an advantage in spherical briquettes compared to cylindrical and triangular briquettes. This led to faster ignition and burning rate of molasses bound spherical briquettes. Due to uniform size and shape the spherical briquettes are easily handled, stored, transported and produced by existing equipment.

**Effect of binder and density on ignition and burning time**

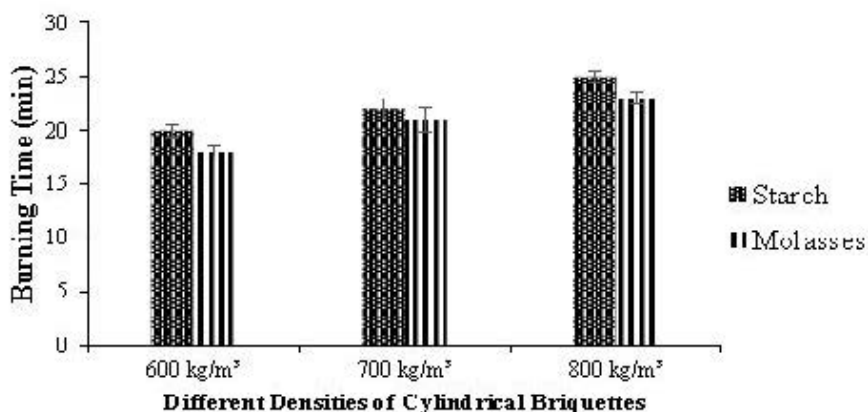
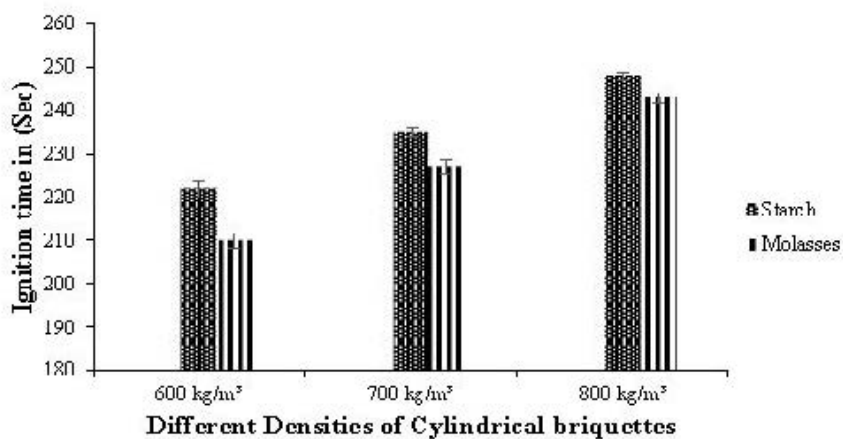
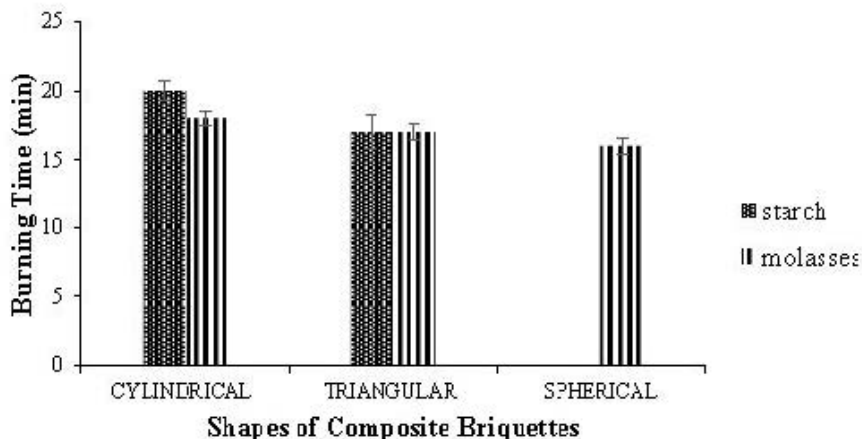
Density is an indicator of the energy concentration of a fuel. High energy density is desirable in terms of handling, transportation, storage and combustion of the fuel. Only cylindrical briquettes of different densities were considered in determination of the time taken to ignite the briquettes. The results as in Figure 3 show that molasses bonded briquettes had a significantly lower ignition time than starch; this could be attributed to higher volatile matter content in the former. The results show that the lower the briquette density, the lower the time required to ignite. The ignition time was 3.5, 3.8 and 4.0 minutes for briquettes with densities of 600, 700 and 800 kg/m<sup>3</sup>, respectively.



The size of the briquettes was constant but the density and mass of the carbonized materials varied. The higher density, the more the mass. Composite briquettes with lower density were less compacted than those with high density which means that cylindrical briquettes at 600 kg/m<sup>3</sup> had more air pores as compared to 800 kg/m<sup>3</sup>. The air pores allowed the oxygen to percolate into the briquettes leading to combustion process as less time was required to ignite the briquettes. The results agree with the findings of Abdulrasheed et al. [16] that briquettes with low compaction have low density and burn faster than those of higher compaction. It was also observed that the flame propagation decreased with increase in density due to decrease in porosity and low oxygen penetration into the fuel agreeing with Ajayi and Lawal [17] and Davies and Abolude [12] who observed that increase in compaction pressure reduces the void spaces of the briquettes as particles are forced closer to one another causing elongation of the ignition time. The optimum density for composite briquettes with respect to the time required to ignite, was therefore the lowest density of 600 kg/m<sup>3</sup>.

The results as in Figure 4 show that the burning duration increased with increase in density. The average burning time was not significantly different but varied between 18-23 minutes and 20-26 minutes for molasses and starch bonded briquettes, respectively. However, the effect of density on burning time was significant. Increase in density led to increase in mass which resulted into more ash formation during the combustion inhibiting percolation of oxygen into the fuel. The ash formed decreases the burning rate and increases the burning time comparing well with arguments by Abdulrasheed et al. [16] and Zaror and Pyle [18] who note that an increase in density reduces the porosity thus decreasing the burning rate which affects the burning time.

Molasses is more volatile than starch which resulted to less burning time of briquettes compared to starch, though the difference was not significant.





## Conclusion and Recommendations

The study examined the ignition and burning time of carbonized faecal matter-sawdust briquettes using molasses and starch as binding agents. The ignition time was affected by shapes and densities of the briquettes. The burning time of briquettes increased with increase in density but was not significantly influenced by the binders (molasses and starch) and briquette shapes. Molasses is suggested a better option compared to starch as it is an easily available, has less smoke and a byproduct of sugar processing while starch (cassava) can be used but is a source of food. Briquettes with lower density (600kg/m<sup>3</sup>) were easier to ignite but had a shorter burning time while higher density briquettes (800 kg/m<sup>3</sup>) posted reverse results. Preliminarily, the longer the burning time, the better the briquette, it is herein inferred that higher density briquettes and shapes that reduce packing factor and increase air flow rate (spherical rather than cylindrical or triangular) are better as energy fuels. Additional studies should be on increased process efficiency, acceptability of faecal matter briquettes, marketing strategies and commercial viability.

## References

1. International Institute for Environment and Development (2010) Biomass energy in Kenya. Nairobi, Kenya.
2. Shekhar N (2011) Popularisation of biomass briquettes - A means for sustainable rural Development. *As J Manag Res* : 458-473.
3. Grover P, Mishra K (2006) Biomass briquetting technology and practices. RWEDP Home publications: Field Document 46, Chapter 1.
4. Grover P, Mishra SK (1996) Biomass briquetting: Technology and practices. FAO Regional Wood and Energy Development Programme in Asia, Bangkok, Thailand.
5. Bowden GB (2016) Granulation of biochar for soil amendment. Master of Engineering Science in Chemical and Biochemical Engineering. University of Western Ontario, London, Ontario, Canada.
6. Karunanithy C, Wang YK, Pugalendhi S (2012) Physiochemical characterization of briquettes made from different feedstock. *Biotechnol Res Int* 2: 1-12.
7. Olorunnisola AO (2007) Production of fuel briquettes from waste paper and coconut husk admixtures. *Ag Eng Int* 9: 1-15.
8. Gachuri WG (2015) Optimising the utilisation of sawdust of eucalyptus tree species. A fuel tea industry. Master of Science Degree in Environmental and Biosystems Engineering. University of Nairobi, Nairobi.
9. Altun NE, Hicyilmaz C, Bagci A (2003) Combustion characteristics of coal briquettes: Thermal features. *Energy Fuels* 17: 1266-1276.
10. Loo SV, Koppejan J (2008) *The Handbook of Biomass Combustion and Cofiring*. Earthscan, London.
11. Rotich K (1998) Carbonization and briquetting of sawdust for use in domestic cookers. Thesis, Department of Agricultural Engineering, University of Nairobi, Kenya.
12. Davies RM (2013) Ignition and burning rate of water hyacinth briquettes. *J Sci Res Rep* 2: 111-120.
13. Onaji P, Siemons R (2003) Production of charcoal briquettes from cotton stalks in Malawi: methodology for feasibility studies using experiences in Sudan. *Biomass Bioenergy* 4: 199-211.
14. Ward BJ (2009) Human fecal biochar briquettes from the sol-char toilet for use as a solid fuel in the developing world. University of Colorado at Boulder, Pro Quest Dissertations.
15. Onuegbu TU, Ekpunobi UE, Ogbu IM, Ekeoma MO, Obumelu FO (2011) Comparative studies of ignition time and water boiling test of coal and biomass briquettes blend. *Int J Rec Res App Stud* 7: 153-159.
16. Abdulrasheed A, Aroke UO, Ibrahim M (2015) Compression pressure effect on mechanical & combustion properties of sawdust briquette using styrofoam adhesive as binder. *Am J Eng Res* 4: 205-211.
17. Ajayi OA, Lawal GT (1995) Some quality indicators of sawdust/palm oil sludge briquettes. *J Ag Eng Tech* 3: 55-65.
18. Zoror A, Pyle D (2002) The pyrolysis of biomass. A general review. Indian Academy of Sciences Section C: Engineering Sciences.

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# PERFORMANCE OF COMPOSITE FAECAL SLUDGE-BIOFUEL IN IMPROVED COOK STOVES

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## Abstract:

This study tested the performance of faecal sludge - saw dust biofuel briquettes (FssDbb) in three commonly used cook stoves in Kenyan households by the standardized Water Boiling Test (WBT). The governing briquettes physical characteristics obtained were; calorific value (25.93 MJ/Kg), ash content (26.7%), fixed carbon (51.3%), moisture content (5.49%) and volatile matter (15.9%). The fuel had good burning characteristics (fuel consumption, CO<sub>2</sub>, CO, specific fuel consumption, thermal efficiency, burning rate and time to boil) indicated by the cook stoves. Based on the findings, the product performance was identified as a suitable alternative to conventional fuel for households. A preliminary market study confirmed the viability of introducing the briquette fuel product in the Nakuru market.

## Introduction

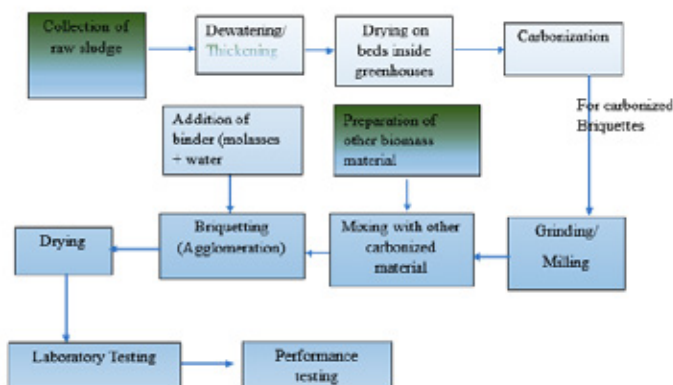
There has been a quest to develop efficient, environmental friendly, safe and sustainable energy technology methods (cook stoves) together with alternative biomass fuels using locally available materials. The Nakuru Water and Sanitation Services Company (NAWASSCO) and partners implement the Nakuru County Sanitation Programme (NCSP) and developed the innovative FssDbb using sludge obtained from septic tanks, pit latrines and combined with sawdust from within the township. Technologies testing has been one of the crucial activities for the performance indicators of the alternative biomass fuels and cook stoves. The study is a follow-up on the briquette product (FssDbb) development (design) process and aims at testing the performance with different types of cook stoves for house hold use. The fuel briquettes are designed and intended for both household and institutional use.

After briquette development (Mbuba et al, 2017 a & b), the water boiling test was carried out using Kenya Ceramic Jiko (KCJ), Jiko Koa and Envirofit super at the University of Nairobi laboratories using the WBT as outlined in the International Workshop Agreement (IWA) framework for cook stove testing. The test is in response to a number of developed cook stoves and improved biomass fuels that call for testing their efficiency and efficacy.

A high percentage of households in developing countries use biomass fuel such as charcoal and firewood as their main source of household energy. Past studies (Lewis, 2012 and Gathitu, 2012) have linked traditional methods of consumption of biomass fuel, for example cooking with firewood and charcoal; with low efficiency, negative environmental consequences, including high rate of desertification due to cutting of trees, and increase in carbon emissions. NCSP conducted a market study in the Nakuru town area both by qualitative (focus groups discussions) and quantitative (Akvo Flow survey tool) methods. This was to determine the market size and the suitability of the faecal sludge related biofuel products for the Kenyan market.

## Methodology

### Briquette Production



The briquettes were made using faecal matter, sawdust, and charcoal dust (FssDbb) at a ratio of 1:1:2 and 5 % molasses as a binding agent. The blend was chosen after a previous NCSP research where several tests were performed on raw materials and with different binding agents. The bio-

fuel products were made using carbonized raw materials (sludge, sawdust and charcoal dust), produced by using improved drum kilns, agglomeration with a rotating drum and the output spherical fireballs were open air dried (Mbuba et al., 2017 a & b). The briquette making process is as shown in figure 1. above.

### Selection of Cook Stoves

The FssDbb performance was tested by applying the standardized WBT using three commonly used varieties of cook stoves in Kenya to provide a basis for comparison of the new fuel relative to the existing fuels. The tests were guided by the international organization for standardization (ISO) framework for testing cookstoves based on four specific parameters; efficiency, indoor emissions, total emissions and safety. The frame work provides for categorization of cook stoves into five tiers (0 - 4), where tier 0 is the lowest and tier 4 with the highest performance (Global Alliance for Clean Cookstoves, 2016). The commonly used cook stoves for the target test market (households within Nakuru County), were selected with the following details;

- (KCJ), is a commonly used Jiko within Nakuru County. In a previous study (NCSP, 2017b; NCSP, 2017b) it was identified to have a good rating in thermal efficiency with low fuel consumption especially in the low power phase (long duration cooking) when different types of cook stoves were compared. It is thus the most preferred cookstove in a majority of low income households in urban and peri-urban areas in Kenya.
- (Jiko Koa), the cook stove is an industry produced standard model with no variation and is an improved cookstove which is second in penetration in the Kenyan market.
- (Envirofit super):- is a cook stove on the list of emerging improved technologies.

### Water Boiling Test

The WBT tests were undertaken at the University of Nairobi laboratory and repeated three times as in the standardized protocol. The tests were done for efficiency and emission of cook stoves in a controlled laboratory setting that consisted of three phases; Phase 1 (High power-Cold start), Phase 2 (high power-Hot start) and Phase 3 (Low power-Simmering). The FssDbb were used as fuel for the three categories of cook stoves. The parameters determined included emission of carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), time to boil, burning rate, thermal efficiency, specific fuel consumption, fuel consumption and amount of particulate matter as in the following subsections.

### Performance and Efficiency Testing

The performance testing encompassed time to boil, specific fuel consumption (sfc), thermal efficiency and burning rate as is described in the (WBT) with brief definitions as below;

1. *Time to boil*; is the time (t) in minutes taken to bring water to boil.
2. *Specific Fuel Consumption*; is the amount of solid fuel equivalent used in achieving a defined task divided by the weight of the task, that is, the amount of fuel needed to boil 1kg or 1 liter of water when starting from a cold cookstove and also is applicable in the other phases, expressed as,

$$\text{Specific Fuel Consumption} = \frac{\text{Mass of fuel burnt (kg)}}{\text{Mass of boiled water in the pot (kg)}}$$

3. *Fuel Consumption*; is the amount of fuel in grams that is consumed in bringing the water to boil and is calculated by subtracting weight of dry fuel after water boils from the dry weight of fuel before ignition.

4. *Thermal efficiency*; is the extent to which a cookstove transfers heat to the pot when cooking or the portion of heat utilized in directly heating the cooking pot until water reaches boiling point. The remaining portion of heat is lost to the surrounding environment and is represented by the following formula;

$$hc = \frac{(\Delta E_{H2O} + \Delta E_{H2O, \text{evap}})}{E_{\text{released},c}} \quad (2)$$

5. Where: energy required to boil water (EH20,Heat ) equals to mass of water (Mh20) multiplied by specific heat capacity (Cp) and by change in temperature (▲t) given in equation 3.

$$\Delta E_{H20, \text{Heat}} = m_{h20} \times C_p \times \Delta T ; C_p \text{ is estimated at } 4.186 \text{ KJ/KgK} \quad (3)$$

6. Where; Wvc is mass of water evaporated and ▲hh20,fg = 2,260KJ/kg Energy released is equal to mass of fuel (M) used multiplied by heating value (HV)

$$E_{\text{released},c} = F_{cd} \cdot LHV \quad (4)$$

7. *Burning rate*; is the weight of fuel consumed (Fcd) divided by the time (▲tc) taken to boil the water or the consumption of fuel when water is brought to the boiling point.

$$Rc = \frac{F_{cd}}{\Delta tc} \quad (5)$$

8. *Specific Fuel Consumption (SCcold)*; is the amount of fuel that is needed to produce 1 unit of output. In this case output is boiled water. In the high power cold starting the specific fuel consumption is the amount of fuel that is needed to boil 1kg or 1 liter of water when starting from a cold cookstove. The same formula is used in the high power hot star calculated as;

$$SC_{\text{cold}} = \frac{F_{cd}}{W_{cT}} \quad (6)$$

9. *Fuel Consumption*; is the amount of fuel in grams that is consumed in bringing the water to boil. It is calculated by subtracting weight of dry fuel after water boils from the dry weight of fuel before ignition.

$$F_{\text{consumed}} = F_{\text{cold start}} - F_{\text{boil}} \quad (7)$$

10. *Emission Testing*; involved measurement of concentration and composition of Carbon Monoxide (CO), Carbon Dioxide (CO<sub>2</sub>) as well as Particulate Matter or generally the emissions form the exhaust fumes. Emission testing is part of WBT protocol version 4.2.3.

• *i) Exhaust Carbon Concentration (CO<sub>2</sub> and CO)*; includes the carbon atoms in Carbon Dioxide (CO<sub>2</sub>), Carbon Monoxide (CO) and carbon content in particulate matter (PM). The measure determines the carbon atoms in the cookstove exhaust fumes as;

$$CC_c = CO_{2\text{carbonic},c} = CO_{\text{carbonic}} + PM_{\text{carbonic}} \quad (8)$$

• A molecule of Carbon Dioxide or Carbon Monoxide contains 1 atom and are determined respectively by the following formulae;

$$a) CO_{2\text{carbonic},c} = CO_{2c} - CO_{2b} \quad (9)$$

$$b) CO_{\text{carbonic},c} = CO_c - CO_b \quad (10)$$

11. *Particulate Matter*; in exhaust fumes is calculated by equation 10 and is assumed to contain 80 percent carbon, based on WBT.

$$PM_{\text{carbonic},c} \left[ \frac{\mu g}{m^3} \right] = 0.8 \cdot (PM_c - PM_b) \quad (11)$$

## Findings and Discussions

The results of an average of WBT laboratory tests for the three phases are outlined in sections 3.1 to 3.3 consisting of tables and figures for results illustrations.

### Phase 1 - Cold Start

The findings for phase 1 tests are as shown in Table 1. Based on table 1 and figure 1 (a); Cook stove A, was only best in burning rate and equivalent to C. Cook stove B; was best in time to boil, CO, CO<sub>2</sub>, and particulate matter. Cook stove C, was best on thermal efficiency, specific fuel consumption and fuel consumption. Overall as in figure 2(b); the performance of Cook stove B was the best based on its low emission except for time to boil, burning rate, specific fuel consumption, thermal efficiency and fuel consumption. Cook stove A was second best in performance for two of the emission parameters while C was best on CO as a parameter though almost comparable to A and highest volume of carbon dioxide and particulate matter. Cook stove B would then be selected based on emissions as A and C were better in thermal efficiency in the range of 20% - 50%.

**Table 1: Briquettes Performance in Phase 1 – Cold Start**

| Parameters                | Units             | Cook Stoves |     |     |
|---------------------------|-------------------|-------------|-----|-----|
|                           |                   | A           | B   | C   |
| Time to boil              | Min               | 31          | 15  | 20  |
| Burning rate              | g/min             | 8           | 14  | 8   |
| Thermal efficiency        | %                 | 19          | 16  | 24  |
| Specific fuel consumption | g/liter           | 110         | 86  | 71  |
| Fuel Consumption          | G                 | 270         | 217 | 180 |
| CO                        | Ppm               | 67          | 41  | 55  |
| Particulate               | µg/m <sup>3</sup> | 108         | 98  | 180 |
| CO <sub>2</sub>           | Ppm               | 344         | 331 | 402 |



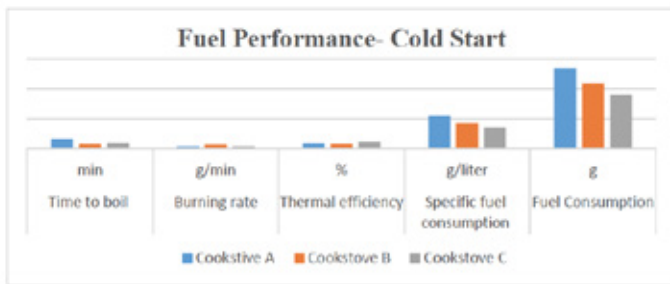


Figure 1(a): Fuel Performance during Cold Start

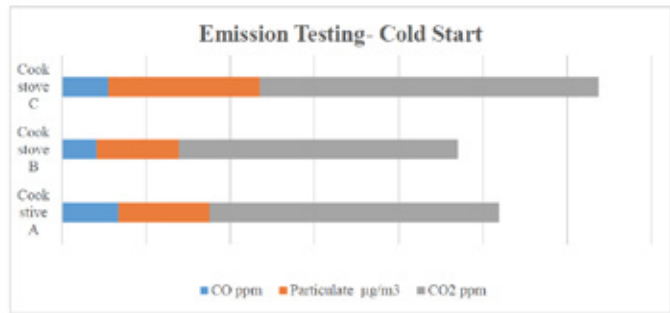


Figure 2(b): Emission Testing Results

Table 2: Briquettes Performances in Phase 2 – Hot Start

| Parameters                | Units   | Cookstove A | Cookstove B | Cookstove C |
|---------------------------|---------|-------------|-------------|-------------|
| Time to boil              | Min     | 20          | 13          | 17          |
| Burning rate              | g/min   | 6           | 5           | 3           |
| Thermal efficiency        | %       | 46          | 53          | 81          |
| Specific fuel consumption | g/liter | 45          | 26          | 23          |
| Fuel Consumption          | G       | 112         | 65          | 58          |
| CO                        | Ppm     | 54          | 42          | 25          |
| Particulate               | µg/m³   | 34          | 46          | 47          |
| CO2                       | Ppm     | 336         | 333         | 326         |

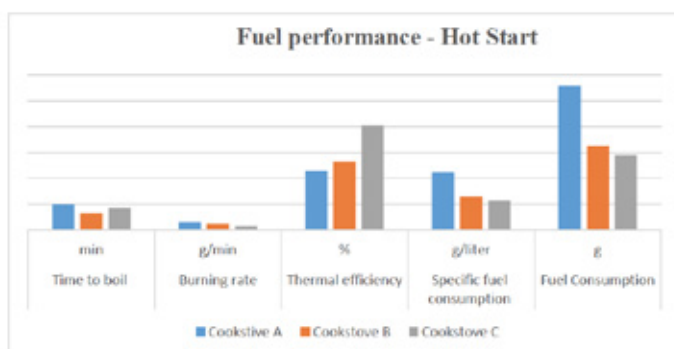


Figure 3(a): Fuel performance - Hot Start

### Phase 2 – Hot Start

The findings for phase 2 tests are as shown in figure 3(a) and table 2 that shows the performance of the cook stoves in the high power, hot-start phase. Cook stove A was outperformed by the other cook stoves in regard to time taken to boil, thermal efficiency and high fuel consumption. Cook stove B was rated second in all the parameters but comparable to C on emission parameters. Overall, Cook stove C outperformed the other cook stoves in all aspects during the high power hot start phase. The good performance was notable in low burning rate, high thermal efficiency, and low fuel consumption. Statistically B and C would be in the same range.

Figure 3(b) shows the results of emission tests for the three cook stoves. Cook stove A produced the highest amount of carbon monoxide and carbon dioxide followed by Cook stove B. This is unlike Cook stove C whose performance was best in CO and CO<sub>2</sub> emissions and highest in Particulate Matter. It was comparatively better in the hot-start phase for both fuel performance and emissions.

### Phase 3 – Simmering

The findings for phase 3 tests are as shown in the table 3 and figure 4 below that shows the results for fuel performance in the low-power simmer phase. The time to boil and burning rate were similar for the three cook stoves. However, the performance of B was second to C in most cases except in thermal efficiency and CO<sub>2</sub>. Notably, Cook stove C outperformed all except on Particulate Matter.

Figure 4(b) are the results of emission testing in the simmer phase. Cook stove A produced the highest amount of carbon monoxide and the reverse was true for Particulate Matter emission. Overall, Cook stove C outperformed the other two in this phase and Cook stove B and A shared equal second position in different parameters. Cook stove B had the highest emission in CO<sub>2</sub>. Though Cook stove C was better in all parameter performance, Cook stove A and B showed mixed results.

Table 4 and figure 5 are given to illustrate and compare the physical performance of lump charcoal (original charcoal that is made by burning logs of wood) and the Fss Dbb that was tested in the above results and discussions. The charcoal results are from a prior University of Nairobi laboratory test. The variation in the results may be attributed to preparation before testing, the machine for briquetting and the equipment for the testing.

It can be noted that specific fuel consumption, CO<sub>2</sub> and CO are within the recommended standards as in table 4 of the identified reference standards. Time to boil and Particulate Matter are above the range specified. The density and ash content were not within limits but the rest of the physical quantities (moisture content, Volatile matter, Fixed carbon, and Caloric Value) met the standards in table 4 for the faecal sludge.

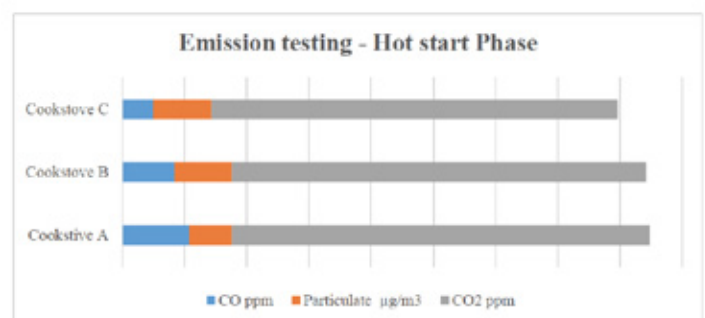
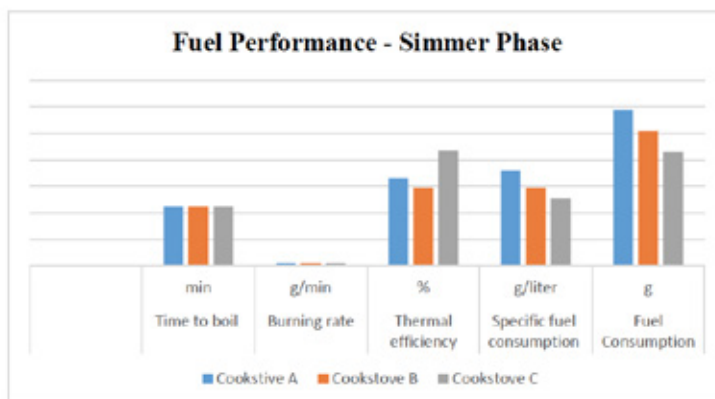


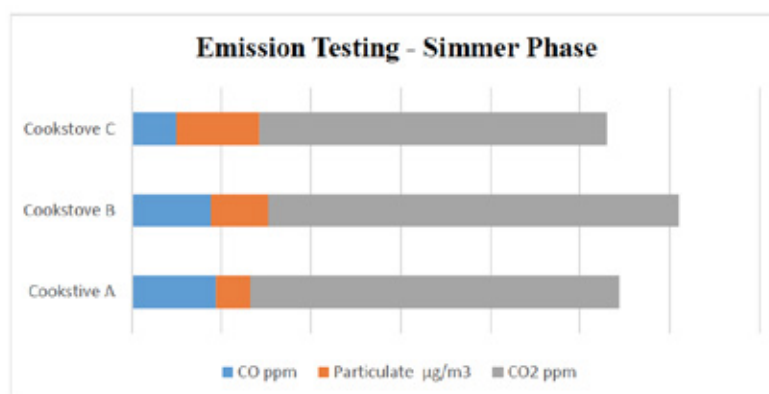
Figure 3(b): Emission testing results - Hot start

**Table 3: Briquettes Performances in Phase 3 – Simmering**

| Parameters                | Units             | Cookstove A | Cookstove B | Cookstove C |
|---------------------------|-------------------|-------------|-------------|-------------|
| Time to boil              | Min               | 45          | 45          | 45          |
| Burning rate              | g/min             | 2           | 2           | 2           |
| Thermal efficiency        | %                 | 65          | 59          | 87          |
| Specific fuel consumption | g/liter           | 72          | 59          | 51          |
| Fuel Consumption          | G                 | 118         | 102         | 86          |
| CO                        | Ppm               | 47          | 44          | 25          |
| Particulate               | µg/m <sup>3</sup> | 19          | 32          | 46          |
| CO <sub>2</sub>           | Ppm               | 206         | 229         | 194         |



**Figure 4(a): Fuel Performance - Simmering phase**



**Figure 4(b): Emission test results- Simmer phase**

**Table 4: Reference Standards**

| Briquette Characteristics | Charcoal Source : University of Nairobi Lab | Fecal sludge Briquettes | Standard Values              | Reference Source                 |
|---------------------------|---|-------------------------|------------------------------|----------------------------------|
| Moisture Content          | 6.2   | 5.49                    | < 12%                        | (DIN, 1996)                      |
| Density                   | -   | -                       | 1000 -1400 kg/m <sup>3</sup> | (DIN, 1996)                      |
| Ash Content               | 1   | 26.7                    | 0.70%                        | (DIN, 1996)                      |
| Volatile Matter           | 10.6  | 15.9                    | 35%                          | (Ragland <i>et al.</i> , 1991)   |
| Fixed Carbon              | 82.1  | 51.3                    | 58.13%                       | (Adenikele <i>et al.</i> , 2015) |
| Calorific Value           | 29.8  | 25.03                   | 17.5 MJ/kg                   | (DIN, 1996)                      |
| Specific Fuel Consumption | -   | as above                | 228 g/l                      | (Davies <i>et al.</i> , 2013)    |
| Burning Time              | -   | as above                | 14.94 min                    | (Davies <i>et al.</i> , 2013)    |
| Carbon dioxide            | -   | as above                | 5000 ppm                     | OSHA Limit                       |
| Carbon monoxide           | -   | as above                | 50-200 ppm                   | OSHA Limit                       |
| Particulate Matter        | -   | as above                | 25 mg/m <sup>3</sup>         | WHO,2006                         |

## Marketing of Faecal Biomass Fuel

Charcoal is confirmed the main type of fuel used by a majority of households in Kenya and is followed by kerosene and natural gas (Nunes et al., 2014, Gachuri, 2015; GoK, 2013; IIED, 2010 and Matiru, 2007). A market study (NCSP, (2017 a&b) was conducted to establish customer views and attitudes on faecal briquettes and fuel pellets (362 households and 238 businesses/institutions). Perception towards the product was expected to be adverse but households were found to respond positively towards faecal matter briquettes. This was influenced by household assurance on safety of the product through understanding of the production process. Consumer education is thus recommended before introducing the products.

In addition, research should be carried out on stoves to optimise performance of briquettes and marketing (NCSP, (2017a &b). It was further noted that there is a tendency for switching of fuels in households with charcoal as the immediate alternative fuel in peri urban areas. Natural gas is ranked top followed by firewood, kerosene and charcoal. The study showed that eighty percent of the population were positive about using briquettes made from different biomass wastes including human waste and were more appealing among low-income households. The level of satisfaction with a particular type of fuel is based mostly on factors such as performance, cost and cleanliness (user friendliness). Smoke emission becomes a major cause of dissatisfaction.

Likewise, majority of household's choice of equipment is driven by cost, efficiency and level of smoke emission. The preferred technology for most households was Kenya Ceramic Jiko (KCJ) with Jiko Koa being perceived as efficient although more expensive. To fuel vendors, cost would be a crucial factor as market awareness of alternative fuel (mainly biomass briquettes) was also noted as good. On average, households spend approximately Ksh. 1,323 on purchase of equipment and use approximately Ksh. 1,110 on fuel per month. Consumers proposed packaging in small quantities of 2kg or 5kg packets (NCSP, (2017a &b) and pricing of briquettes to be less than half a dollar per 1kg.

WBT showed that faecal matter briquettes burnt longer than charcoal and had less emissions and majority of the household's cook in confined places that are without defined kitchen space thus prone to indoor pollution (Nyaanga et al., 2018). Briquettes were positively received more than pellets due its compatibility with their fuel equipment and cost efficiency. The households indicated preference to purchase the fuel but this was dependent on household's income.

## Conclusion

Briquettes made from a combination of carbonized faecal matter (25%) and sawdust (25%) and charcoal dust (50%) were found to be feasible with both Jiko Koa and KCJ cookstoves and are the most common types in the market. The performance of cook stove type A when using faecal sludge biofuel product lagged behind B and C in all the Phases of the WBT tests. The performance of the fuel in the three cookstoves improved from high power phase to Low power phase. Cook stove C was best in all the phases considering the thermal efficiency, specific fuel consumption and fuel consumption. This makes the fuel suitable for cooking food that takes less time to cook as well as for those that takes relatively long time to prepare. Overall Cook stove B was performed better in phase 2.

Low briquettes consumption indicated that the faecal matter briquettes are an efficient form of fuel. Burning rate and fuel consumption indicates that the faecal sludge - sawdust briquettes burn for a long period of time which makes the fuel suitable for cooking any type of food.

Based on the parameters in the tables and the figures, Cook stove C (Envirofit) performed better followed by Cook stove B (Jiko koa - though preferred) and least was Cook stove A (KCJ) with Fss Dbb product. High thermal efficiency for the phases indicated that the heat generated was utilized well for the task that was intended. Emissions recorded were relatively low but requires that the stoves should be used in well-ventilated places.

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## References

- Gachuri, W. G. (2015); Optimising the utilisation of sawdust of eucalyptus tree species; a fuel for tea industry. Unpublished MSc Thesis University of Nairobi.
- GoK (2013); Analysis of the charcoal value chain in Kenya. Ministry of Environment, Water and Natural Resources.
- Guidelines for reporting and analyzing laboratory tests results; for biomass cooking stoves (Politecnico- milano 1863) jan2017.
- IIED (2010); Biomass energy in Kenya, International Institute for Environment and Development
- NCSP (2017b); Consumer Pilot Study: Establishing Performance and Acceptance of Faecal Matter Briquettes in Nakuru's Low Income Areas.
- Matiru, V. (2007); Forest Cover and Forest Reserve Cover in Kenya Policy and Practices. Oxford Press. Nairobi, Kenya.
- Mbuba, M. Jesca, Nyaanga, D. M., Kabok, P. A., Eppinga, R; (2017); Binders on Physical and Combustion Characteristics of Faecal Matter-Sawdust Briquettes
- Mbuba, M. Jesca, Nyaanga, D. M., Kabok, P. A., Reinilde, Eppinga (2017); Effect of Mix Ratios and Binders on Physical and Combustion Characteristics of Faecal Matter-Sawdust Briquettes
- Njenga, M. (2013); Evaluating Fuel Briquette Technologies and their Implications on Greenhouse Gases and Livelihoods in Kenya. PhD. Thesis, Faculty of Agriculture, University of Nairobi, Kenya.
- Nunes, L.J.R.; Matias, J.C.O.; Catalao, J.P.S. (2014); Mixed biomass pellets for thermal energy production: A review of combustion models. Appl. Energy 127, 135-140.
- NCSP, (2017a) Biomass Fuel Market Study. Study Commissioned by EU-Nakuru County Sanitation Programme





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