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Assessment of the effectiveness of biogas slurry as biofertilizer for vegetable gardening in Kumbo, Cameroon: case of *Solanum scabrum*.

Dissertation presented and defended in partial fulfilment of the requirement for the award of a Professional Masters Degree in Environmental Sciences.

Option: Environmental Rehabilitation and Restoration

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DEDICATION

This work is dedicated to the following:

- my wife Sevidzem Ernestine L, my son Wirsiy Clinton-Moise and my two daughters Wirsiy Gayle-Liza and Wirsiy Felicitas, for encouraging me and bearing my absence for six months;
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ABSTRACT

This research was carried out between August 2010 and January 2011. The research had as objective to assess the effectiveness of biogas slurry as biofertilizer for huckleberry cultivation in Kumbo, Cameroon. To carry out this experiment, soil and biogas slurry samples were collected for Laboratory analysis to determine their physico-chemical characteristics. The biogas slurry was produced using pig dung. Biogas slurry was collected from the biogas outlet tank dried, crushed and used as biofertilizer. Different quantities of biofertilizer (digestate) were applied in each bed. This ranged from 0.5 to 3.5 kg/m^2 with a variation of 0.5 kg/m^2 each. Chemical fertilizers were also applied in some beds. Urea was applied at 0.06 kg/m^2 and NPK (20-10-10) applied at 0.12 kg/m^2. One of the beds in each block served as a control without any manure or chemical fertilizer application. The choice of application of variables on beds in each block was obtained by complete block randomized design method. Huckleberry was nursed and transplanted after 7 weeks immediately when biofertilizer was applied. To determine growth rate of crops these parameters were measured per plant on weekly interval for 8 weeks: the number of leaves produce, the surface area of a chosen leaf, the height of plant and the weight of harvested crops.

The results obtained show that biogas slurry (digestate) after biogas production is richer in nutrient than the soil and is therefore suitable to be used as fertilizer for soil. The quantity of biofertilizer observed to produce good plant growth were 2.5 Kg/m^2, 3.0 Kg/m^2 and 3.5 Kg/m^2 applications. The quantities of Urea and NPK (20-10-10) applied in soil never produced good growth rate. Considering that 2.5 Kg/m^2 biofertilizer application was among the best three biofertilizer application that recorded good results and the fact that increasing biofertilizer application entails increased cost, 2.5 Kg/m^2 biofertilizer application is recommended as the best quantity of biogas slurry application for a better cost/ production ratio.

Key words: biofertilizer, biogas slurry, huckleberry, mineralization, productivity

RESUME

Ce travail de recherche mené entre Août 2010 et janvier 2011 ; avait pour objectif d’évaluer l’efficacité des boues issues de la production du biogaz comme biofertilisant pour la culture de la morelle noire (*Solanum scabrum*) a Kumbo au Cameroun. Pour cela, les échantillons de sol et de boues de biogaz ont été analysés au laboratoire pour déterminer leurs caractéristiques physicochimiques. Les boues de biogaz produites a base des fumiers de porc ont été collectées à la sortie des réservoirs de vidanges, puis séchées, écrasées et utilisées comme biofertilisant. De différentes doses de biofertilisant allant de 0,5 kg à 3,5 kg /m^2 avec une variation (pas) de 0,5 kg/m^2 par traitement ont été appliquées sur chaque lit. Les engrais chimiques ont également été testés sur d’autres lits. L’urée a été utilisée en raison de 0,06 kg/m^2 et le NPK (20/10/10) à 0,12 kg/m^2. L’un des lits dans chaque rangé a servi de témoin sans application d’engrais. Le dispositif expérimental était un bloc complet randomisé. La morelle noire a été semée en pépinière et transplantée 07 semaines après, suivant l’application des biofertilisants. Les paramètres de croissance tels que le nombre de feuilles, la surface foliaire et la taille des plantes ont été mesurés par semaines durant une période de 08 semaines. Le poids des plantes après récolte étaient aussi mesurés.

Les résultats obtenues montrent que les boues issues de la production de biogaz sont plus riches en nutriment que le sol, et ainsi favorable pour utilisation come biofertilisant pour les sols. Les biofertilisants appliqués à la dose de 2,5 Kg/m^2, 3,0 Kg/m^2 et 3,5 Kg/m^2 ont produit un meilleur rendement en termes de croissance de la plante. Les doses d’urée et de NPK (20/10/10) appliquée n’ont pas permis d’obtenir un bon taux de croissance. En considérant que 2,5 kg/m^2 de biofertilisant a produit l’un des meilleurs rendements et que c’est plus économique en terme de coût, il est recommandé d’utiliser les biofertilisants à la dose de 2.5 kg /m^2 pour meilleur ratio cout/production.

Mots clés : biofertilisants, boues de biogaz, morelle noire, minéralisation, productivité

CHAPTER I: GENERALITIES

I.1. Introduction

Solanum scabrum Miller, commonly called huckleberry or jamajama in Cameroon is an important indigenous leafy vegetable in Africa (Schippers, 2000). It is the most commonly grown indigenous vegetable in Cameroon, and commercial fields are found mostly in the western and north western provinces of the country (Stevel, 1990; Westphal, 1981). In Cameroon, huckleberry is exported to neighbouring countries, such as Gabon and Nigeria (Schippers and Fereday, 1998). Huckleberry leaves and fresh shoots are used widely as a cooked vegetable and are often referred to as spinach. The spinach can be served with cornfufu, plantains, sweet potatoes, potatoes, yams, maize and pounded cocoyams (Ngundam, 1997). There is empirical evidence that African leafy vegetables have several advantages and values that include high micronutrient content, medicinal properties, several agronomic advantages and contributed to food and nutrition security and income generation (Schippers, 2002). A major constraint to increase huckleberry cultivation in Cameroon is the susceptibility of the crop to disease (Fontem, 1991a) among which is late blight.

Organic sources of manure, besides providing nutrients to the crop plants, also improve the structure of the soil and give residual effects on subsequent crops (Anonymous, 1992). Soil organic matter content and turnover are regarded as important indicators of soil fertility. For crop production, it is of prime interest to know which immediately beneficial effects these indicators have on land use criteria such as crop yield stability and environmental impact (Raupp, 2001). Soil organic matter is vital to the sustainable use of soil because of its role in maintaining soil structure, water-holding capacity, the microbial biomass and soil fauna, and in nutrient cycling (Goulding et *al*., 2001).

Chemicals are widely used on many farms. Nevertheless, there is an increasing debate about their use. Chemicals offer a quick way to increase the harvest but there are hidden costs. Safety is perhaps the most obvious one. These chemicals are expensive. These chemicals cost money and time and many people believe that the soil is not made healthy by the application of chemicals (Mathew, 1986). Emma, (2002) says biogas systems produces biogas slurry (organic matter) which is a by-product of biogas production and this slurry is a high quality fertilizer which does not smell. This fertilizer can be spread directly on the crops at any time of the year. This slurry can be used in the farm for it adds to production and reduces dependency on chemical fertilizer thus increasing savings. In addition, the biogas system is an alternative source of energy that reduces pressure on forest. In the national level, the production of biogas could help alleviate the energy crisis faced by Cameroonians.There are few expertspopularizing biogas technology in Cameroon and Africa in general (Tize, 2009). Tize also recommended in his studies that research should be carried out to determine the right quantity of the processed biogas slurry or digestate to be used as biofertilizer in farms.

I.1.1.General objective

The general objective is to assess the effectiveness of biogas slurry as biofertilizer for huckleberry (*Solanum scabrum*) cultivation in Kumbo, Cameroon

I.1.2.Specific objectives

The specific objectives are to:

- Assess the physico-chemical characteristics of biogas slurry;
- Assess the physico-chemical characteristics of composite soil sample from experiment site;
- Assess the effects of biogas slurry on huckleberry growth.

I.2. Literature review

I.2.1.Biogas systems for energy and biofertilizer production

Biogas systems are made up of four components: the inlet, the digester, the gas holder and the outlet or expansion chamber. The inlet collects and mix dung and water in equal quantities. This dung and water is called slurry which is then send through the bottom of the inlet by removing the plug for the slurry to flow through the pipe into the digester. The digester is a flat-bottom, round chamber, covered with a dome-shape concrete gas holder. The fixed dome plant needs to be properly sealed in order to prevent any gas leakage. The bacteria thrive on the dung in an anaerobic environment (air tight digester) and create biogas. The gas then rises and is stored in the gas holder before being released in to a pipe. The slurry leaves through the outlet chamber and flows into the compost pit. There exist two types of biogas systems, the dome shape that has just been described and the floating drum which is different from the former in that the gas holder is a floating drum. Digestion time ranges from a couple of weeks to a couple of months depending on the feedstock and the digestion temperature. The residual slurry is removed at the outlet and can be used as a fertilizer, which increases agricultural production especially in vegetable growing. During the digestion process bacteria in the manure are killed, which is a great benefit to the environment (Emma, 2002).

I.2.2. Biogas system in SHUMAS' BIOFARM and production of biogas

Biogas is produced in the Strategic Humanitarian Services (SHUMAS) Integrated Organic Farm (BIOFARM) Centre at Kingomen, Kumbo. The BIOFARM Centre biogas system is a floating drum system measuring 25 m^3. The system provides 18m^3 of biogas per day to prepare food for 35 students. The temperature test showed a stable and favourable temperature for methanisation in a psychrophile zone. Averagely in Kingomen BIOFARM centre temperature daily variation is less than 2 °C (Tize, 2009). There are 3 ranges of temperature with exploitable biogas production observed: psychrophile (15 – 25 °C), mesophile (25 – 55 °C) and thermophile (55 – 75 °C) (Agu et *al*., 2000).

Table I. Average monthly and annual temperatures in °C Kumbo (Anonymous, 2007 and 2008).

Month \ Annual Temperature	2007	2008	Average
January	23,9	21,4	22,65
February	22,1	22,9	22,5
March	23,1	24,0	23,55
April	24,8	23,5	24,15
May	22,1	22,8	22,45
June	22,5	23,1	22,8
July	22,2	21,8	22
August	22	21,8	21,9
September	21,5	23,6	22,55
October	22,7	23,4	23,05
November	20	23,6	21,8
December	21,8	25,1	23,45
Total average	22,6	23,1	22,85

Optimal pH zone for methanisation to be situated around neutral. The methanogenic bacteria are highly inhibited when the pH is inferior to 6 (Kuria and Maringa, 2008). The discharge from digester destroys pathogens and that digestate (biogas slurry) can totally or partially replace inorganic fertilizer (Caussade, 2006). The biogas system was set in the BIOFARM Centre to do the following:

- produce biogas to prepare food for students;
- treat effectively animal waste for use as biofertilizer;
- produce earthworms for table birds and increase algae growth in fish pond;
- use clean energy in the place of firewood for food preparation and
- in the long run produce biopesticide from digestate to fight plant diseases.

Tize (2009) recommended in his studies that research should be carried out on the right quantity of biogas digestate to be used as biofertilizer in various crops present in the farm.

Fig.1. BIOFARM Centre floating drum biogas system built in 2008.

Fig. 2. Preparation of biogas slurry from pig dung and water. a : Biogas mixing tank; b : Fresh cow dung mixed with water to form slurry.

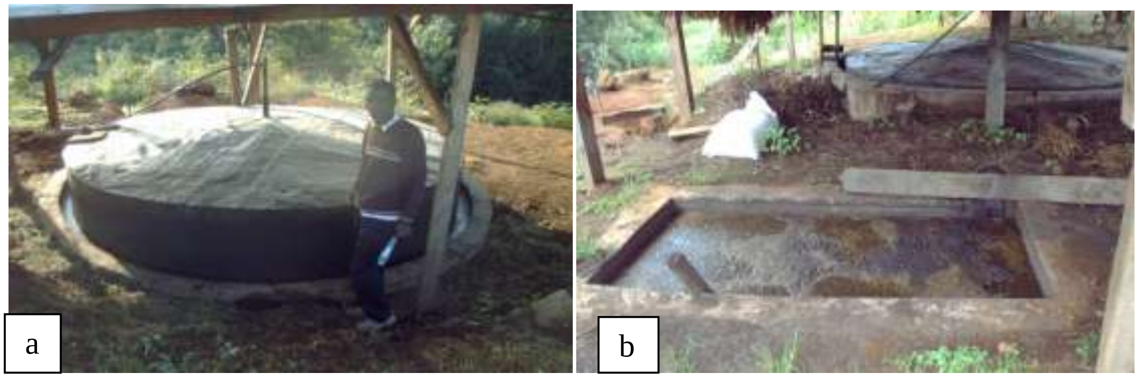

Fig.3. Biogas and digestate production. a : Inverted drum on digester raised by biogas; b : Biogas by-product (slurry) tank.

I.2.3.Comparison of digested biogas slurry as biofertilizer and undigested manure

In biomethanation (process of biogas-methane production), the Nitrogen compounds of the substrate (undigested biogas slurry) undergo some mineralization. A part of NH_4 becomes ammonia that is reputed to be more accessible for plants. On the other hand, ammonia is more volatile and is easily leached. It therefore requires some particular application conditions for example rapid soil incorporation, cover of the tank (Schenkeh et *al*., 2009). Some studies have been carried out in Denmark (Arhuus University- Peter Sørensen) on fate of slurry Nitrogen coming from anaerobic digestion and in particular the following aspects have been analyzed: the concerned on the one hand with manure Nitrogen transformations and losses and on the other hand the manure Nitrogen in terms of uptake in crop, residual Nitrogen in soil and losses. Digested slurry has been compared with the untreated slurry and it was clear that, both in case of pig and cattle slurries, the net mineral release (as a percentage of total Nitrogen) was higher in the case of digested slurry. The final conclusions, after the mentioned tests performed in Denmark in order to demonstrate the better manure Nitrogen uptake, in case of digestate (rather than slurry) used, are the following:

- Less organic Nitrogen and consequent lower risk of long-term Nitrogen leaching ;
- Higher first year utilization but lower residual Nitrogen effect ;
- More Nitrogen available for the plants and less organic matter to soil ;
- Improved infiltration and reduced greenhouse gas emission (CH_4, N_2O, and CO_2).

When the digestate is spread on growing plants, nutrients are absorbed faster by the plants as it infiltrates more quickly into the soil than raw slurry. This in agricultural practice means a minor risk of plant etches and ammonia losses after application on arable land. In manure and organic residues, most of the Nitrogen is bound to proteins and is not directly available for plant nutrition. During the digestion process, a part of the organic bound Nitrogen is reduced to dissolved ammonium by deamination. As a result of this process, the ammonium rate of the total Nitrogen content is enhanced in the digestate. The ammonium rates of total Nitrogen content of the analysed digestates compared to the untreated manure, increase from 0.2 % to 27 %. The increase of ammonium content depends on the hydraulic retention time in the digester like the decrease of the organic dry matter. Applied correctly, this enhanced mineral Nitrogen content results in a faster and better plant uptake to 23 % of the Nitrogen of raw manure is drained away. In digested manure, the drainage averages 14 %. A study by Svensson et *al.*, (2004) shows that more than half of the total Nitrogen content occurred as ammonium in the biogas residue (digestate), whereas only small amounts of mineral Nitrogen, mainly nitrate, are found in the compost. But neither compost nor digestate can be used as the sole fertilizer in intensive grain cropping. Digestate should be regarded as a mineral Nitrogen fertilizer. Preferably, crops with a short and intensive period of Nitrogen uptake, like barley, are the best target for biogas residues. Due to the low content of Phosphate, digestate must be complemented with Super Phosphate in order to avoid Phosphate deficits in soil.

I.2.4.Quantities of fertilizer application

Studies carried out at the World Vegetable Center in Arusha, Tanzania to evaluate the yield response of nightshade to Nitrogen fertilization presents four rates of urea fertilizer, that is control (= no urea added), 60, 90 and 120 kg/ha that were used as treatments in the research plot. The urea fertilizer was applied as side-dressing in two equal splits two and six weeks after transplanting. Data on leaf, fruit and seed yield were collected at a two-week interval beginning six weeks after transplanting and subjected to ANOVA using CoStat software. Results revealed that fruit and seed yields increased significantly with an increase in application of urea, but differences in leaf yield between the Nitrogen rates used were not significant. Significant differences were observed in leaf, fruit and seed yield components between the accessions evaluated. It is recommended that Nitrogen fertilizer should be applied at lower rates (60 kg/ha) for leaf production of nightshade while higher rates of up to 120 kg/ha should be applied for fruit and seed production (Onyango et *al.,* 2009). *Solanum scabrum* were also planted in rows spaced 0.40 m apart with 0.25 m between plants within the row. In both seasons, field plots were fertilized with 120 kg ha-1 of 20-10-10 (N-P-K) 7 and 49 days after transplanting (Fontem et *al*., 2003).

I.2.5.Origin and botany of *Solanum scabrum*

According to Muthomi *et al.*, (2009)**,** *Solanum scabrum* occurs as a cultivated vegetable from Liberia to Ethiopia, and south to Mozambique and South Africa. It is very common in lowland as well as highland regions in West and East Africa. The wide range of diversity of *Solanum scabrum* found especially in Nigeria and Cameroon suggests that its origin is likely to be in the warm humid forest belt of West and Central Africa. Outside Africa, *Solanum scabrum* can be found in Europe, Asia, Australia, New Zealand, North America and the Caribbean. *Solanum scabrum* can be scientifically classified.

Fig.4. *Solanum scabrum* Plant.

Table II. Scientific classification of *Solanum scabrum*.

Kingdom	Plantae
Subkingdom	Tracheobionta
Superdivision	Spermatophyta
Division	Magnoliophyta
Class	Magnoliopsida
Subclass	Asteridae
Order	Solanales
Family	Solanaceae
Genus	*Solanum* L.
Species	*Solanum scabrum* Mill.

I.2.6.Morphology of *Solanum scabrum*

Solanum scabrum is the most common specie in West Africa and many different cultivars can be seen, often of local importance only. Huckleberries (a common name for *Solanum scabrum*) can be recognized with relative ease by its strong green or purple stem with more-or-less tooth wings. Plants are usually about 60 cm high but could grow to 1.20 m or more. There are both small and large leaved cultivars with different leaf shapes and the leaf colour can be either green or dark-purple. Leaves have entire margins (rarely situated) and apices that are more obtuse than acute. The flowers are either white or light purple and this is the only species in *Solanum* with brown or dark-yellow anthers. It is also the only species whose berries remain on the plant at maturity. Fruits are spherical and 11-17 mm broad. The dark purple fruit have a distinct bloom when young and become glossy when they are older (Schippers, 2002).

I.2.7.Seed processing and germination problems with *Solanum scabrum*

Solanum scabrum berries are easy to collect since they always remain on the plant. A popular way to extract seeds in Cameroon is for farmers to put the berries in a bag with small holes on the bottom and hang the bag in a ventilated environment. The fruits rot and juice leak out and the seeds dry out. The seeds are collected dry in berries and this reduces chances of damage by mice and other rodents. Fruits could also be squashed in a container with or without water and seeds collected and dried. From 1 Kg of *Solanum scabrum* berries, farmers obtain about 40 g of seed. The number of seeds/berry varies from about 20-60 depending on variety and conditions. Many farmers experience problems with the germination of seeds. This may be due to: low vigour caused by inadequate removal of sugar and removal of germination inhibitors present in the fruit. These inhibitors include Abscic acid and ethylene, which normally prevent seeds from germinating within the fruit. The second reason is that seeds may not be dried well enough or that seeds are kept under ambient conditions in an environment with varying humidity. Seeds need to be very dry and kept in airtight container. Seeds can remain viable for several years when kept dry. Seeds usually take 5-7 days to germinate but could take longer when the soil moisture content is inadequate (Schippers, 2002).

I.2.8.Transplanting, harvesting and importance of nutrients to crop

In Kenya, *Solanum scabrum* was planted twice a year in all the six Kenyan districts during the long rains (March-July) and the short rains (September-December). Harvesting started 4-5 weeks after sowing, at thinning time and thereafter harvesting was done weekly by removal of young shoots resulting in subsequent ratoon crop. This type of harvesting could go on for a period of three months, then another 2 months for seed maturity. Most of the farmers depended on rainfall and only 20 % of farmers from the Luo community practiced irrigation using watering cans (Abukutsa-Onyango, 2007).

Normally, yields increase with increasing nutrient concentration to a maximum, beyond which there is no further benefit from additional nutrient. Tony, (2006) presents the importance of nutrients to crops.

Table III. Importance of nutrients to crops (Adapted from Tony, 2006).

Function and Remarks / Types of nutrient	Function of nutrient in crop	Remarks
Nitrogen (N)	Increase plant growth, the size of leaves and yields	Addition of Nitrogen may give dramatic and quick response to plants, but much Nitrogen causes much vegetative growth with weak stems, sometimes causing lodging and also increase the susceptibility of plants to disease, frost and drought
Phosphorus (P)	Develop root growth to establish young plants and help early ripening	Phosphorus is best applied a little or often, but there are no problems if excessive amounts are applied. It is most available to plants when the soil PH is 5.5 – 6.5. Often deficient in tropical soil.
Potassium (K)	Improve plant quality, vigour and health. It makes crops drought resistant and gives them the ability to store sugar and starch. It forms chlorophyll and also improve stomata functioning	Too much potassium makes plants slow to mature. Wood ash, compost and manure are good sources of Potassium. Not deficient in tropical soils as often as Phosphorus
Sodium (Na)	Allow plants of the *Chenopodiaceae* family (beet, spinach, etc) to develop properly	Sodium is rarely a problem and is not easily diagnosed
Calcium (Ca)	Component of cell walls and membrane and balance organic anions.	
Magnesium (Mg)	Allow chlorophyll formation and growth, Assist in nodulation of legumes, and in the utilizations of Phosphorus	More common in light soils with high rainfall and in soils with low organic matter content or excessive Potassium or Calcium

I.2.9.Pests and diseases

Huckleberries and black nightshades are frequently eaten by insects but apparently people do not mind buying leaves with holes in them (it is a sign that chemicals have not been used). In Cameroon, ants are said to be responsible for holes. Black aphids may cause leaves to curl and affect further growth of the plant. In some areas aphids appear to have taken over altogether and even when they are controlled by chemicals, the characteristic curly leaves remain. Caterpillars and occasionally grasshoppers including *Zonocerus variegates* can also be most problematic. Small black beetles found at the underside of huckleberry leaves cause those leaves to twist and fold, making them unattractive for sale. Black aphids, millipedes and snails have been reported in Kenya. A traditional cure for pests is wood ash, spread onto the leaves. Chemicals are not always effective against insects that are hiding underneath the leaves. Many farmers believe that the effects of chemicals last only 24 hours and will thus harvest one day after spraying, thus causing problems to consumers. A major disease in huckleberry was found to be *Phytophtora infestans*, the late blight which is also common in tomatoes and Irish potatoes. This causes a grayish rot of leaves and stems and drop of leaves. It is said to be particularly problematic during the rainy season when temperatures are low. A second important disease is *Cladosporium oxysporum* which can be recognized by a greyish green mould on the lower side of the leaves and the light green-yellow colour above. Other diseases recorded include a specie of downy mildew, the eye spot, *Cercospora nigrescens* and the powdery mildew, *Leveillula taurica* with yellow spot and the upper surface and a white mould below (Schippers, 1998).

CHAPTER II: MATERIAL AND METHODS

II.1. Material

II.1.1. Location of study site

This research was carried out in a small village called Kingomen located in Kumbo of Bui Division in the North West Region of Cameroon. Kingomen hosts the Strategic Humanitarian Services' (SHUMAS) Integrated Organic Farm, Training and Demonstration (BIOFARM) Centre where this research was carried out. The BIOFARM Centre has a biogas system that provides cooking energy for preparing students food and biofertilizer to increase food production. Kumbo is located at approximately 113 km from Bamenda, the regional capital of North West Region and the distance between Kumbo centre and the BIOFARM is approximately 30 km.

II.1.2. Materials

The following materials and equipments were used

- Spade was used for soil sample and biogas slurry collection;
- Cutlass was used for clearing research plot and fencing;
- Hammer and nails were used for plot fencing;
- Hoe was used for tilling soil;
- Digital camera of mark Sony Cyber-shot DSC-W310 was used for picture snapping;
- Measuring tape was used to measure plot size;
- Ruler was used for measuring crop height and leaf diameter and length;
- Biogas slurry was used as biofertilizer;
- Watering cans were used for crop watering;
- Scale was used to measure crop yield after harvesting;
- Calculator marked CASHO CS-8012 for data analysis and
- Laptop marked Acer was used for data analysis using excel.

II.2.Methods

II.2.1. Experimental plot design

Research plot was cleared and divided into three blocks and each block tilt to have ten beds (fig.5). Each bed was flattened to have 3 m length and 1m width. Different quantities of biofertilizer (digestate) were applied in each bed. This ranged from 0.5 to 3.5 kg/m^2 with a variation of 0.5 kg/m^2 each. Chemical fertilizers were also applied in some beds. These chemical fertilizers were urea and NPK (20-10-10). Urea was applied at 0.06 kg/m^2 and NPK (20-10-10) applied at 0.12 kg/m^2. One of the beds in each block served as a control without any manure or chemical fertilizer application. The choice of application of variables on beds in each block was done by complete block randomized design method (Fig. 5). This plot was fenced and other traditional methods of pest and risk management used to prevent pests attack and animal encroachment. Scarecrows were used to chase pests like birds and animals (Fig. 6). Two blocks were prepared at the sides of research blocks and planted with huckleberry. These two blocks were aimed at giving animals and birds that succeeded to enter the research plot the opportunity to consume vegetable at the outskirts of the research plot thereby sparing research plot crops from damage. No weed was allowed to grow in the plot at anytime.

BLOCK A	BLOCK B	BLOCK C
Type and quality of fertilizer application	Type and quality of fertilizer application	Type and quality of fertilizer application
2.0 kg/m^2 biofertilizer	0.06Kg/m2 Urea	1.5 kg/m^2 biofertilizer
0.5 kg/m^2 biofertilizer	2.5 kg/m^2 biofertilizer	0.5 kg/m^2 biofertilizer
Control No application	1.0 kg/m^2 biofertilizer	2.0 kg/m^2 biofertilizer
3.5 kg/m^2 biofertilizer	2.0 kg/m^2 biofertilizer	3.0 kg/m^2 biofertilizer
3.0 kg/m^2 biofertilizer	3.5 kg/m^2 biofertilizer	2.5 kg/m^2 biofertilizer
2.5 kg/m^2 biofertilizer	0.12 Kg/m^2 NPK(20-10-10)	Control No application
1.0 kg/m^2 biofertilizer	0.5 kg/m^2 biofertilizer	0.12 Kg/m^2 NPK(20-10-10)
1.5 kg/m^2 biofertilizer	1.5 kg/m^2 biofertilizer	1.0 kg/m^2 biofertilizer
0.12 Kg/m^2 NPK(20-10-10)	3.0 kg/m^2 biofertilizer	3.5 kg/m^2 biofertilizer
0.06 Kg/m^2 Urea	Control No application	0.06 Kg/m^2 Urea

Fig.5. Experimental plot design with Complete block Randomized Method

Fig.6. Fenced research plots with scarecrows and chosen plants to measure growth.

II.2.2.Soil and biogas slurry collection

With the use of a clean spade and knife, about 30 cm of soil sample was dug from the research plot and stored in a clean dry plastic bag. The dug soil was thoroughly mixed and 1kg of composite soil collected. 10 soil samples were collected from the experiment site using a zig-zag method and a composite sample from the 10 soil samples prepared for laboratory analysis (Fig. 7). The soil samples were collected in September during the rainy season and the predominant vegetation in this area was bracken fern plants. The research plot was relatively flat. The biogas slurry (biofertilizer or digestate) was collected from the biogas system digester outlet and thoroughly mixed and a sample of it also collected for laboratory analysis. The biogas slurry is derived from biogas system processed pig dung. These samples were transported for analysis at the Waste Water Research Laboratory in the University of Yaounde I to know their content in Carbon, Nitrogen, Phosphorous, Potassium, Calcium, Magnesium, Sodium, conductivity, P^H and C/N.

Fig. 7: Soil sample from research plot for analysis. a :Soil sample collection; b : Soil sample mixing.

II.2.3.Physico-chemical analysis of soil and biogas digestate samples

II.2.3.1.Preparation of soil and biogas slurry sample for analysis

The method used for soil extraction is Mehlich 3-Extractable Elements. 3 g of dry soil was weighed and passed through a 2 mm sieve into 125 ml Erlenmeyer flask and 30 ml of the M3 extracting solution was added (Soil: Solution 1:10). Immediately, it was shaken on reciprocating shaker for 5 minutes (120 oscillations per minute). The elements were analyzed in the filtrate immediately using either an automated or manual method as described below.

II.2.3.2.Determination of electrical conductivity

Conductivity measures the capacity of ions especially dissolved inorganic solids to transport electrical current in water. A measure of this value can give a general idea of mineralization of water. A conductimeter HACH model was used to measure these values in the laboratory. For each measurement, the instrument was brought to a standard electrode which was plunged vertically into each sample. The value for conductivity was read directly on a digital screen attached to the conductimeter by selecting the corresponding button for each parameter.

II.2.3.3.Determination of Phosphorus by Manual Calorimetric Method

2 ml of the clear filtrate or standard (0 to 10 µgml-1) phosphorus solution was pipetted into a 25 ml volumetric flask. The sample aliquot contained less than 10 µg of phosphorus and dilution of the filtrate with M3 was done. 15 ml of distilled water and 4 ml of solution B were added and made to volume with distilled water and mixed. Colour developed in 10 minutes and the absorbance was measured at 845 nm.

II.2.3.4.Determination of Total Organic Carbon

This was done using the Dry Combustion method. A standard was prepared by adding a range of aliquots of glucose solution to borosilicate tubes (25 mm OD) marked at 100 ml. A convenient range of standard was 1-12 ml that equated to 2-24 mg of Organic Carbon. Tubes containing glucose solution and a blank were dried in an oven at a temperature not exceeding 60 °C. 0.1 – 2.0 g of air-dried soil (> 0.15 mm) containing > 20 mg of Organic Carbon were added Organic Carbon into digestion tubes. 10.0 ml of $Na_2Cr_2O_7$ solution was added, and while agitating 20.0 ml of 98 % H_2SO_4 was added cautiously so that the reaction is confined to the bottom of the tube. It was agitated for a further 30 seconds before inserting into a pre-treated (135 °C) digestion block. Tubes were agitated occasionally to ensure all of the soil material was exposed to the chromic acid mixture. After 45 minutes, tubes were removed from block and allowed to cool. 50 ml of distilled or de-ionized water was added to digest and agitated with thick-walled glass capillary tube that had a stream of air passing through it so that the samples are thoroughly mixed. After removal from the block, the samples still contained H_2SO_4 at strong enough concentration to cause heating when water is added. When the tubes were inverted after the addition of water, enough heat was generated to potentially cause hot chromic acid to be lost. Agitation with the assistance of a stream of air prevented any losses. When cold, the tubes were made up to 100 ml with distilled or de-ionized water and inverted to mix using a rubber bung. Diluted Chromic acid mixture was decanted into 15 ml centrifuge tubes and centrifuge at 2000 rpm for 15 minutes. The absorbance of the centrifuged samples was measured at 600 nm in a 10 mm cell.

- **Calculations of Total Organic Carbon**

A standard curve was constructed by plotting absorbance at 600 nm against mg Carbon present in standards. Using this curve, estimate of mg Carbon in unknown samples were determined.

g Carbon Kg-1 soil = mg Carbon in digest/weight soil in grams

If the mg C content of samples is < 2 or > 20, analysis should be repeated with more or less weight to bring them within the optimum range of the determination.

- **Modification for saline soil**

For saline soils, a separate determination of Chloride content in soil is required and expressed as g.Cl.Kg-. The Organic Carbon content of the soil is then corrected for the Chloride content.

g.C.kg-1 soil = apparent g.C.Kg-1 soil – (g.Cl.kg-1 soil/12)

II.2.3.5.Determination of Potassium, Calcium, Magnesium and Sodium

This was done using the Flame Emission method. 1 to 5 ml of filtrate was pipetted into a 5 ml volumetric flask and approximately 40 ml of de-ionized water added and mixed. 1 ml of the $CsCl-LaCl_3$ solution was added to bring to volume with de-ionized water and mixed. Calcium, magnesium, Potassium and Sodium elements were determined by flame test since all elements produce different colours.

II.2.3.6. Determination of Hydrogen Potential

This represents the degree of acidity or alkalinity of water and was measured in the laboratory using a P^H meter SCHOT GERATE 818 model. In the presence of H+ ions, the electrode of the P^H meter develops an electric potential proportional to the concentration of H+ ions at the glass interface of the P^H meter. The electrode of the P^H meter was plunged into a 100 ml prepared sample. A preliminary calibration of the P^H meter was done using buffer solutions of value 7.00 and 4.01. The value was read directly on the P^H meter.

II.2.3.7. Determining Total Kjeldahl Nitrogen (TKN) Analysis

For the analysis of total Kjeldahl Nitrogen, 40ml of sample solution was digested using Sulphuric acid (H_2SO_4) in a Bucchi digester at 350 ^oC for two hours. The digested sample obtained was then mixed with 40 % sodium hydroxide (NaOH) in a Bucchi distillatory and distilled for 2 minutes. The distillate was collected in a beaker containing 20ml of Boric acid (H_2BO_3) 4 % colored with an indicator. The solution obtained was titrated with H_2SO_4 0.1 N until there was a colour change from green-yellow (indicating the presence of Nitrogen) to orange (the initial colouration). The volume of H_2SO_4 used for that color change was used to that of a known blank TKN standard to calculate the amount of TKN of the sample.

II.2.4. Method of processing and applying biogas slurry andchemical fertilizers

The biogas digestate in semi liquid form was collected from the biogas system outlet chamber with spades in the dry season and allowed to dry by placing it on a specially prepared disgetate space (Fig.9). This digestate took 10 days to dry after which it was crushed and kept for use in the experiment (Fig.10). This digestate was collected for about 40 days to get the right quantity needed for the experiment. Before application in the research plot all of the digestate was thoroughly mixed and applied to the research plot (Fig. 11). The digestate was spread on the various beds uniformly respecting the variations. Quantities of digestate application on each bed were determined by complete block randomized design method. The application ranged from 0.5 to 3.5 kg/m^2 in each bed with a variation of 0.5 kg/m^2. When the expected quantity was spread on each bed uniformly it was then thoroughly mixed with the topsoil in each bed. The biogas digestate was applied and well watered a day before transplanting the huckleberry seedling. Chemical fertilizers [Urea and NPK (20-10-10)] were also applied in two beds of each block 3 days after seedlings were transplanted. Urea was applied at 0.06 kg/m^2 and NPK (20-10-10) applied at 0.12 Kg/m^2 through bed dressing and covered lightly with soil to prevent Nitrogen escaping. The control beds were also watered. Chemical fertilizer was included in the research to give opportunity for comparative study. One of the beds in each block served as a control without any manure or chemical fertilizer application.

Fig.8. Obtaining pig dung for biogas production.a: BIOFARM piggery attached to the biogas system; b: biogas plant mixing tank.

Fig.9. Digestate collection and dried. a: Collection of discharged biogas slurry; b: Drying slurry.

Fig.10. Dried slurry to be used as biofertilizer.a: Dried biogas slurry; b: Crushed dried biogas slurry to be used as biofertilizer.

Fig.11. Utilisation of biofertilizer in soil. a: Weighing ; b: application in experiment plot; c: Mixing in soil

II.2.5.Method used to nurse, transplant and measurehuckleberry growth

A nursery was prepared and fowl droppings applied as manure. Huckleberry seeds were nursed. Seven weeks later, after nursing seeds, healthy seedlings were selected and transplanted in the research plot. The selected seedlings were planted 20 cm apart from each other in the beds to give four seedlings on the bed width and twelve seedlings on the bed length. Ten plants within the middle rows were selected and the following parameters measured: plant height; number of leaves produced per plant; crop yield; and length and width of chosen leaf measured weekly for a period of eight weeks (Fig. 13 and 14). The number of leaves produced by the ten plants in each bed was counted. Harvesting was done 6 weeks after transplanting and after the 8^{th} week. Weighing was done each time harvesting was done. Watering was done on daily basis during the first two weeks and once every two days from the third week onward every evening (Fig. 12).

Fig. 12. Watering of plants in experiment plot.

Fig.13. Measuring the height of plant.

Fig.14. Weighing of harvested crop from an experiment bed.

II.2.6. Research plot used as a training site

Considering that the SHUMAS' BIOFARM Centre is a research, production, training and demonstration centre, students learning organic agriculture and renewable energy in the centre followed-up the experiment procedure in the experiment site closely. This was part of their practical lessons. They received explanations and saw for themselves changes in the various blocks with different applications. The changes were visible. The students appreciated this research.

CHAPTER III: RESULTS AND DISCUSSION

III.1. Results

III.1.1. Biogas slurry and soil sample analysis

The physico-chemical analyses of soil sample and biogas slurry show in general that the biogas slurry is richer than the soil in nutrients (Table IV). The pH of biogas slurry and soil samples demonstrates that the soil is acidic while biogas slurry is basic. The conductivity of the soil sample and biogas slurry indicates that biogas slurry is more mineralize than soil sample. The main elements of growth which are Nitrogen, Phosporus and Potassium have a higher concentration in biogas slurry than the soil.

Table IV. Indicate physico-chemical analysis results of soil and biogas slurry samples.

Properties / Samples	N (g/kg)	P (g/kg)	C/N	TOC (g/kg)	Na (ppm)	Mg (ppm)	Ca (ppm)	K (ppm)	pH water	Cnd (µS/cm)
Biogaz	2.1	1.4	13.6	28.6	0,41	0,04	0,14	0,51	7,85	287
Soil	0.7	0.6	41.2	29.3	0,043	0,01	0,06	0,38	6,27	8,86

III.1.2. Growth rate results

III.1.2.1. Measurement of height of plant

Generally, all plants with biofertilizer and chemical fertilizer applications increased in height from week 1 to week 8 as compared to control (Fig. 15). The heights of *Solanum scabrum* vary according to the various types and quantity of fertilizer application. The maximum crop height in cm obtained for 0.5 kg/m^2, 1.0 kg/m^2, 1.5 kg/m^2, 2.0 kg/m^2, 2.5 kg/m^2, 3.0 kg/m^2, 3.5 kg/m^2, Control, NPK and Urea applications are 13.46, 17.17, 15.25, 23.39, 27.5, 26.58, 26.53, 12.33, 13.07 and 17.7 respectively. Similar growth rates in height of plants were observed from week 1 to week 3 and from week 4 to week 8 they were different with different applications. The biofertilizer applications had a better growth result in height than chemical fertilizer applications. The plant with 2.5 kg/m^2 biofertilizer application recorded the highest growth. Crops with biofertilizer application of 2.5 kg/m^2, 3.0 kg/m^2 and 3.5 kg/m^2 had a great increase in height above 25 cm from week 1 to week 8. For chemical fertilizer application in *Solanum scabrum* Urea had a higher growth rate in height than NPK.

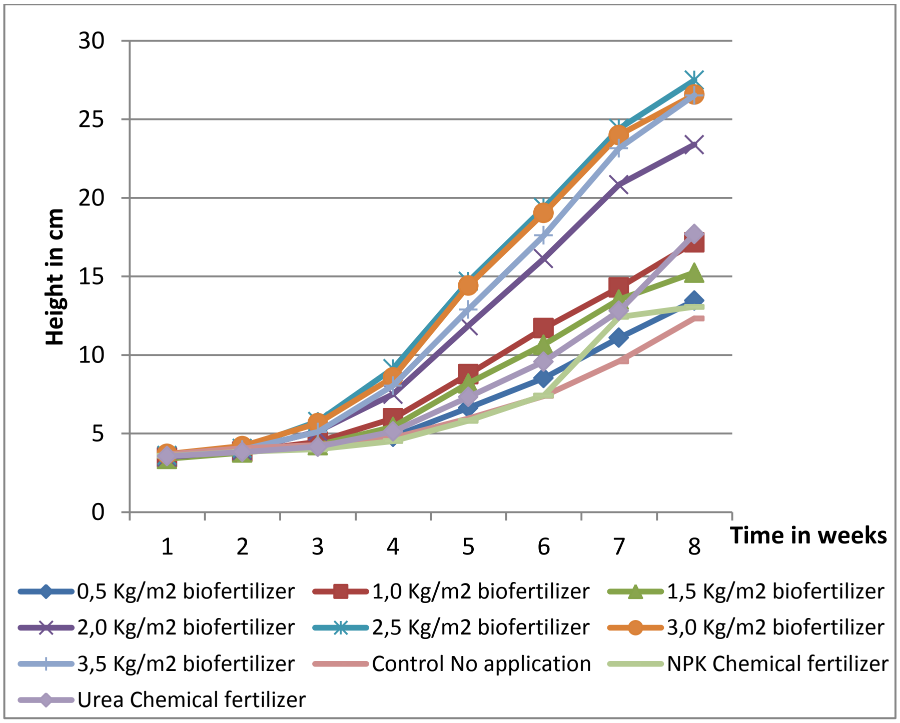

Fig.15. Presents plant growth rate in height in response to different quantities and types of biofertilizer and chemical fertilizer application in weekly intervals.

III.1.2.2. Counting of number of leaves

Generally, the number of leaves in *Solanum scabrum* increase gradually with time with all the different types and quantities of fertilizer application (Fig.16). Between the first week and third week of transplanting Solanum scabrum with different fertilizer application the number of leaves increase almost the same. After the fourth week there was a great difference. From the fourth week to the eighth week biofertilizer application in *Solanum scabrum* witness a higher increase in number of leaves than in chemical fertizer application and control.

The maximum number of leaves obtained for 0.5 kg/m^2, 1.0 kg/m^2, 1.5 kg/m^2, 2.0 kg/m^2, 2.5 kg/m^2, 3.0 kg/m^2, 3.5 kg/m^2, Control, NPK and Urea applications are 83, 96, 110, 150, 156, 166, 176, 58, 67 and 78 respectively. Generally the best growth rate in number of leaves was recorded by crops with 2.0 kg/m^2, 2.5 kg/m^2, 3.0 kg/m^2 and 3.5 kg/m^2 biofertilizer application respectively. The best results were obtained with 3.5 kg/m^2 biofertilizer application. The application of Urea in *Solanum scabrum* produce more leaves than NPK application.

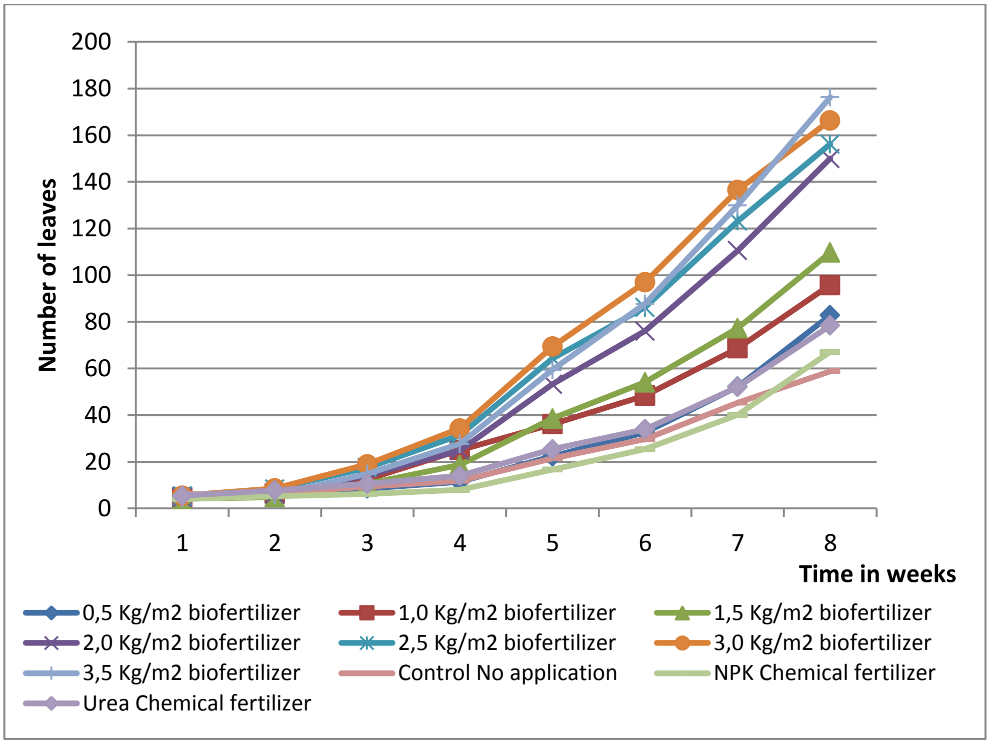

Fig. 16. Presents increase in crops' number of leaves in response to different quantities and types of biofertilizer and chemical fertilizer application on weekly intervals.

III.1.2.3. Measurement of plant chosen leaf surface area

Generally, the leaf surface area of different *Solanum scabrum* plants increase gradually between the fifth week and eighth week of transplanting with different fertilizer applications(Fig. 17). Biofertilizer applications in *Solanum scabrum* witness a higher increase in leaf surface area than in chemical fertizer application and control. The maximum leaf surface area for various *Solanum scabrum* with different applications of biofertilizer and chemical fertilizer obtained for 0.5 kg/m^2, 1.0 kg/m^2, 1.5 kg/m^2, 2.0 kg/m^2, 2.5 kg/m^2, 3.0 kg/m^2, 3.5 kg/m^2, Control, NPK and Urea were 3.95, 4.89, 5.25, 7.93, 10.04, 9.7, 3.47, 3.64 and 4.2 respectively. Generally the best growth rate in leaf surface area was recorded by crops with 2.5 kg/m^2, 3.0 kg/m^2 and 3.5 kg/m^2 biofertilizer application respectively. The best results were obtained with 3.0 kg/m^2 biofertilizer application. The application of Urea in *Solanum scabrum* had a higher leaf surface area increase than NPK application

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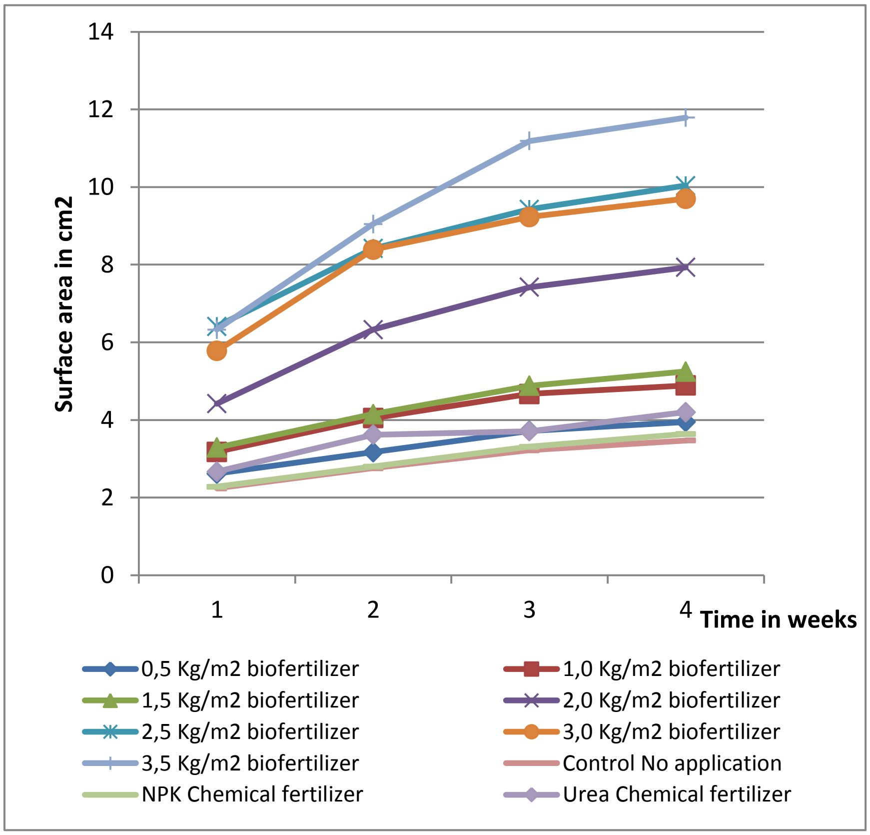

Fig. 17. Presents increase in crops' chosen leaf surface area in response to different quantities and types of fertilizer application in weekly intervals.

III.1.2.4. Crop yields during harvest

Each bed in the experiment block had 48 plants. 10 plants in each bed were chosen from the middle lines to measure growth parameters of number of leaves, height of plant and leaf surface area. Harvesting was done using a razorblade for the remaining 38 plants in each bed on the 6^{th} and 8^{th} week after transplanting (Table V). The first harvesting was done on each crop four steps above the ground on the plant to permit new shoots to develop and form new branches. The second harvesting was done at the end of experiment and harvesting was done by cutting the crop close to the ground.

The maximum crop total yield in kg for the 38 crops harvested per bed in Table V with different applications of 0.5 Kg/m^2 biofertilizer, 1.0 Kg/m^2 , 1.5 Kg/m^2, 2.0 Kg/m^2, 2.5 Kg/m^2, 3.0 Kg/m^2, 3.5 Kg/m^2, Control, NPK and Urea were 0.15, 0.28, 0.34, 0.53, 0.62, 0.65, 0.80, 0.18 and 0.15 respectively. Generally the best crop yields were recorded by crops with 2.0 kg/m^2, 2.5 kg/m^2, 3.0 kg/m^2 and 3.5 kg/m^2 biofertilizer application. The best results were obtained with 3.5 kg/m^2 biofertilizer application with yields of 0.8 kg/m^2. The applications of Urea and NPK in *Solanum scabrum* produce almost similar results (0.15 and 0.18) respectively.

Table V: Crops yield for 38 crops in each bed after 6 and 8 weeks of transplanting.

Crop yield / Application fertilizers	Yields for 38 plants after 6 weeks of transplanting (kg)	Yields for 38 plants after 8 weeks of transplanting (kg)	Total yield for 38 crops after 6 and 8 weeks of transplanting (kg)
3.5 kg/m^2 biofertilizer	0.27	0.53	0.80
3.0 kg/m^2 biofertilizer	0.25	0.40	0.65
2.5 kg/m^2 biofertilizer	0.22	0.40	0.62
2.0 kg/m^2 biofertilizer	0.20	0.33	0.53
1.5 kg/m^2 biofertilizer	0.12	0.22	0.34
1.0 kg/m^2 biofertilizer	0.10	0.18	0.28
0.5 kg/m^2 biofertilizer	0.00	0.15	0.15
Urea	0.02	0.13	0.15
NPK (20-10-10)	0.00	0.18	0.18
Control	0.00	0.12	0.12

Harvesting of the 10 chosen plants after experiment was done by cutting the plant with the razorblade at the base close to the soil. All the crop mass above the soil was removed. This was done after 8 weeks when the experiment ended. The crop yield in kg for 10 crops in Table VI harvested after experiment whose height, number of leaves and surface area were measured gave similar results to 38 crops. Table VI shows yields with different applications of 0.5 kg/m^2 biofertilizer, 1.0 kg/m^2 , 1.5kg/m^2, 2.0 kg/m^2, 2.5 kg/m^2, 3.0 kg/m^2, 3.5 Kg/m^2, Control, NPK and Urea. The results obtained were 0.05, 0.10, 0.08, 0.15, 0.20, 0.22, 0.23, 0.03, 0.05 and 0.05 respectively. Generally the best crop yields were recorded by crops with 2.5 kg/m^2, 3.0 kg/m^2 and 3.5 kg/m^2 biofertilizer application. The best results were obtained with 3.5 kg/m^2 biofertilizer application with yields of 0.23 kg/m^2. The applications of Urea and NPK in *Solanum scabrum* produce similar results (0.05 and 0.05 respectively).

Table VI: Crop yield for 10 chosen plants after the end of experiment.

Application fertilizers \ Crop yield	Yields for 10 plants after 8 weeks of transplanting when experiment ended (kg)
3.5 kg/m^2 biofertilizer	0.23
3.0 kg/m^2 biofertilizer	0.22
2.5 kg/m^2 biofertilizer	0.20
2.0 kg/m^2 biofertilizer	0.15
1.5 kg/m^2 biofertilizer	0.08
1.0 kg/m^2 biofertilizer	0.10
0.5 kg/m^2 biofertilizer	0.05
Urea	0.05
NPK (20-10-10)	0.05
Control	0.03

III.1.3. General observation in experiment plants during growth

As plants grow old, the main stems became stronger and larger and more branches and leaves developed on it especially at the base. Crops with much biofertilizer application were observed to be fresher and greener than those with little or no application. Although, growth rate was slow in crops applied with urea, the crops look fresher than those with NPK and less biofertilizer application. The main stem leaves and branch production reduced from the base towards the top (Fig. 18). Number of branches, leaves and leaf size increased from crops with less biofertilizer application to crops with more biofertilizer application. No plant branch leaf was seen to be bigger than leaves produced by the main stem. Flowering occurred in crops with 3.5 kg/m^2, 3.0 kg/m^2 and 2.5 kg/m^2 biofertilizer applications from week 6 through week 8 after transplanting.

Table VII. Physical observation in *Solanum scabrum* with different fertilizer application

Physical characteristic / Fertilizers application	Colour of plant	Degree of freshness	Flowering	Number of branches
3.5 kg/m^2 to 2.0 kg/m^2	Very green	Very fresh	faster	Very much
1.5 kg/m^2 to 1.0 kg/m^2	Green	Fresh	slow	Much
Urea	Green	Fresh	slow	Much
NPK	Dark green	Not fresh	slow	Few
Control	Dark green	Not fresh	slow	Few

Fig. 18. Number of leaves and branches in stem reduces from plant base to top.

Fig.19. Plants develop more branches and leaves after main shoots are cut during first harvest.

III.2. Discussion

III.2.1. Physicochemical characteristic of Biogas slurry and soil sample

The result show that the soil is weak in nutrients which in essence will allow response to organic matter like biogas slurry that is rich in nutrients like Nitrogen, Phosphorus and Potassium. Among the mineral nutrients, Nitrogen is perhaps the most important because of its biological roles and also because it is required in large quantities by the plants. In Nigeria and other West Africa countries where other species of Solanum like *Solanum macrocarpon* is grown as vegetable, most farmers do not apply chemical fertilizer, as a result of high prices that is associated with its usage (Ehiagiator, 1998). Under continuous cropping, the maintenance of organic matter content of soil through the use of manure is of primary importance to any soil management programme.

Response of the various growth parameters measured depended on various types and quantities of fertilizer application. Plant growth parameters such as plant height, number of leaves and leaf area easily respond to nitrogen application (Gungula et *al*., 2005). These results are similar to those reported in other studies that involved the use of both organic and inorganic sources of nitrogen nutrients. For example, Overcash et *al*. (2005), reported an enhanced growth of many crops through replenishment of the used up nitrogen by addition of organic and inorganic sources of nitrogen into the soil. The organic sources retained the soil moisture for a longer period of time resulting into improved growth and yield of the tested crops.

Recently, there has been a global shift from chemical fertilizers to organic fertilizers that are renewable, quite easily accessible and cheap and less harmful (Ehiagiator, 1998). The use of organic manures such as poultry droppings, cow dung, compost, crop residue, had been an age old practice among the agricultural communities in Nigeria (Omueti et *al*., 2000). In cultivation of vegetables, farmers however, prefer the use of organic manure despite its bulkiness and low nutrient content especially nitrogen.

III.2.2.Growth rate of plant

The results of this study indicate that *Solanum scabrum* is sensitive to the availability of the types and quantities of fertilizer application in the soil, but the magnitudes of their responses differ. This growth rate is as a result of the absorption of nutrients available in the soil. These nutrients are made available in the soil by micro-organism activities on organic matter. Response of the various growth parameters measured depended on the variety of the African nightshade and the level of compost manure applied. Plant growth parameters such as plant height, number of leaves and leaf area easily respond to nitrogen application (Gungula et *al*., 2005). Our results are similar to those reported in other studies that involved the use of both organic and inorganic sources of nitrogen nutrients. For example, Overcash et *al*., (2005), reported that the organic sources retained the soil moisture for a longer period of time resulting into improved growth and yield of the tested crops.

Nitrogen is reportedly more responsible for plant growth than any other element. It stimulates vegetative growth resulting in large stems and leaves. Our observations support those reported by Edmonds and Chweya, (1997), Chweya, 1997, Schippers, 2000; and Mwai and Schippers, (2004) where this stage of growth was reached in four to five weeks after transplanting. The results also support the findings of Onyango et *al*., (1999) who reported enhanced growth of plants grown under different organic and inorganic nitrogen sources. On the other hand, the presence of other nutrients like Magnesium and Calcium in biogas slurry added to soil also modified physico-chemical properties of the soil. The properties that could be modified are pH, porosity, available of nutrients like Magnesium for chlorophyll. These elements were in very low quantities in soil (control) and in different soil mixture (like soil plus urea and soil plus NPK). The presence of these elements and other primary elements in biofertilizer applied on experimental plot lead to increase in growth rate. These results confirm that increase in biofertilizer application leads to increase growth rate.

Schilppers, (2002) reports that plant heights for *solanum scabrum* are usually about 60 cm but could grow to 1.20 m or more and that there are both small and large leave cultivars with different leaf shapes and leaf colour which can be either green or dark purple. These results present the highest plant height after 8 weeks of transplanting to be 27.5 cm with 2.5 kg/m^2 biofertilizer application. After 8 weeks of transplanting the crops still showed signs to grow higher before flowering.

African nightshade plants subjected to low levels or no fortified manure application exhibited poor growth rate associated with nitrogen deficiency. Plants suffering from nitrogen deficiency mature earlier and their vegetative growth stage is shortened (Wolf, 1999). This report supports the results this research obtained with the control plant. On the other hand excess nitrogen results in lush plants with soft tissue and subsequent lateness in maturity (Wolf, 1999). The results also confirm those reported by Indira (2005) who attributed the response of plants to nitrogen application to enhanced nitrogen mining capacity of plants due to increased translocation of photoassimilates brought about by faster root growth.

Schilppers in 2002 reported that in Cameroon, the optimum yield on *Solanum scabrum* are obtained during the third harvest, which is about 2 months after planting. The findings of this research confirm yields increasing from the first harvest on the six week and second harvest on the eighth week after transplanting. Schilppers also report that a commercial farmer can obtain up to 150-200 tones per hectare and with good management, even more from his dry-season crop of the large-leaved type. For the dark, small-leaved type, which is very popular in West Cameroon that this research was done on, the average yield per 1000 m^2 is about 50 large bundles (of about 20 kg each) per harvest. The total yields are about 30-50 t/ha for smaller-leaved *scabrum* varieties. The results of this research confirm this report by Schilppers, (2002). These results show that the best crop yields increased with application of organic manure and the highest yield was obtained with 3.5 kg/m^2 biofertilizer application at 0.08 kg/m^2.

CHAPTER IV: CONCLUSION AND RECOMMENDATIONS

IV.1. CONCLUSION

This research had as objective to assess the effectiveness of biogas slurry as biofertilizer for huckleberry cultivation in Kumbo, Cameroon.

The results of this research after laboratory analysis show that digestate obtained after biogas production is richer in nutrient than the soil in the experiment plot and is therefore is suitable to be used as fertilizer to improve soil fertility. The right quantity of digestate to be used to fertilize has been determine by this experiment. This has been determined using huckleberry (*Solanum scabrum*) vegetable grown in Kumbo and other parts of Cameroon with a high local and international market. The quantity of biofertilizer observed to produce good huckleberry growth were biofertilizer application of 2.5 kg/m^2, 3.0 kg/m^2 and 3.5 kg/m^2. Biofertilizer application of 2.5 kg/m^2 had the best growth rate in crop height. Number of leaves in crops increased most with biofertilizer application of 3.0 kg/m^2, less with biofertilizer application of 3.0 $kg/m^2$and least with biofertilizer application 2.5 kg/m^2. The trend was same for crop yields of 38 crops per bed that were not selected to measure crop growth and 10 chosen crops for growth measurement.

Considering that 2.5 kg/m^2 biofertilizer application was among the best three biofertilizer application that recorded good results and the fact that increasing biofertilizer application from 2.5 kg/m^2 through 3.0kg/m^2 and 3.5 kg/m^2 entails increase cost, 2.5 kg/m^2 biofertilizer application is recommended as the best quantity of biogas slurry application. Quantity of biogas slurry application could also be increase if the biogas slurry is in large quantities. The quantities of Urea and NPK (20,10,10) applied in soil was not enough and this needed a new studies to determined the right quantity to be applied.

Biogas technology is not yet popular in Cameroon and in Africa as a whole but it has a big role to play in poverty alleviation and food production. Biogas technology should be promoted as a source of clean energy and a source of biofertilizer needed by rural communities in developing world like Cameroon. Families in rural areas like Kingomen where this study was carried out own some animals but lack cooking energy and money to buy chemical fertilizer that is expensive. Biogas technology can provide energy and biofertilizer.

IV.2. RECOMMENDATIONS

The following recommendations are suggested for the following actors:

SHUMAS

- Popularize the results of this research to local farmers and to the public. This will encourage local people to develop biogas systems and get biofertilizer for vegetable gardening and energy for cooking thereby reducing dependency on scarce forest resource and fighting climate change;
- Advocate for research to be carried out to know the right quantities of Urea and NPK (20-10-10) that should be applied in vegetables farms locally;
- Allow farmers have access to biogas slurry from their BIOFAARM Centre to use in their farms because sometimes biogas slurry overflows without use;
- Encourage students to carry out research on the amount of biogas slurry to be used as biofertilizer for the cultivation of other vegetables and crops and
- Allocate land purposely for research in the BIOFARM Centre that has accessibility to water and is suitable for research.

Local population

- The population living around Kingomen and other areas should study and engage in practical work at the SHUMAS' BIOFARM Centre to learn from her rich knowledge, experience and skills on improved methods of integrated organic agriculture especially on vegetable cultivation so as to increase food production and improve their livelihoods.

Other Non Governmental Organisations and Institutions

- Need to partner with SHUMAS and other like minded structures to share knowledge, skills and experience on this technology in order for them to replicate it in other areas.

Government

- Considering the energy problems in rural areas, the increase in prices of chemical fertilizer and the need to implicate local people in the fight against climate change there is need for the government to set demonstrative biogas systems in local communities that will help them see the potential of biogas system in energy and biofertilizer production.
- Government support SHUMAS and other like-minded institutions with funds to make available this workable technology to local people. This will help local people get biofertilizer for their farms and energy for cooking and go a long way to protect the remaining forest from degradation while reducing human suffering in search of firewood.

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