IMPROVING RURAL LIVELIHOODS THROUGH BIOGAS GENERATION USING LIVESTOCK MANURE AND RAINWATER HARVESTING

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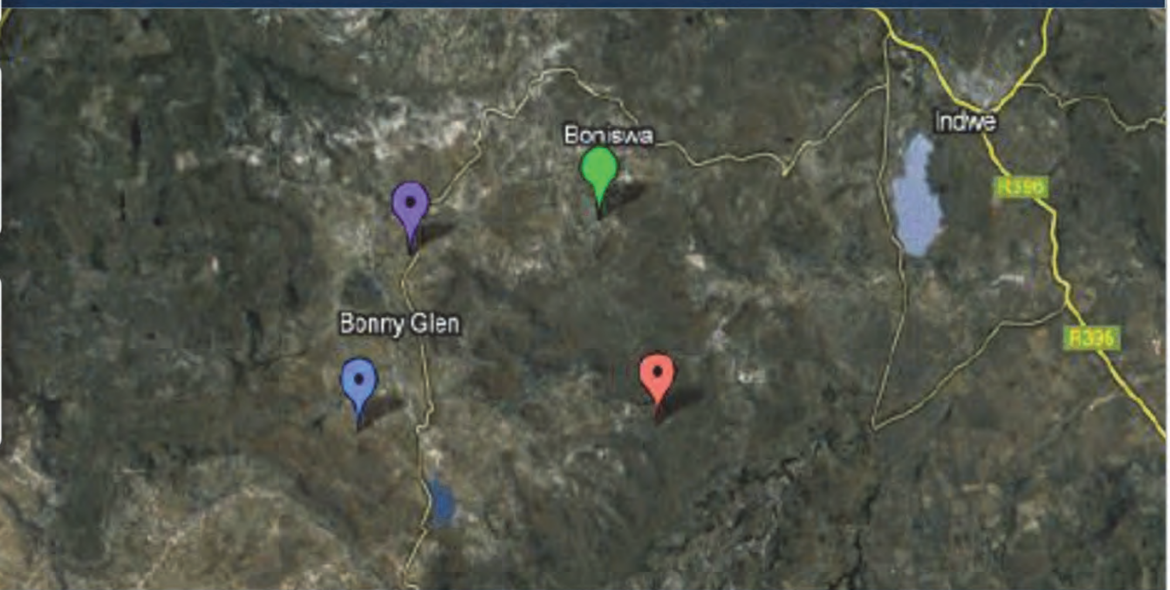

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executive summary

Environmental challenges for sustainable development in agriculture are mainly linked to natural resources (water, land and biodiversity). Land degradation is the most important environmental problem affecting many areas of South Africa (DoA, 2002). Soils are characterised by low fertility and rainfall is generally low, erratic, unevenly distributed and unreliable. Nearly 91% of the country is arid, semi-arid and dry sub-humid. Research on technologies and production methods that can provide sustainable increases in agricultural production and improved management of natural resources among poor populations is therefore urgently needed in South Africa. In particular, Smith et al. (1997) highlighted the need to develop technological alternatives which promote better resource use through synergies from crop and livestock integration. The maintenance of soil fertility, provision of livestock feeds and use of alternative sources of energy are areas where these reciprocal benefits can be achieved (Hagmann and Chuma, 2002). This project aims to promote sustainable development through research on the three key elements (people, environment and economic factors) that comprise this development. The importance of these factors in sustainable development is highlighted in the National Department of Agriculture's policy on rural development.

In their discussion document on 'The policy on agriculture in sustainable development" the National Department of Agriculture (NDA, 2002) stated that national agricultural research and extension systems have lost some of their effectiveness and capacity to respond better to the technology needs of small farmers. They highlight the need to find alternatives to increased use of purchased inputs such as fertilizers. The National Department of Agriculture's strategies to achieve this include proposals to:

- Decrease the depletion of non-renewable energy resources, i.e. oil, gas, coal and promote methods extending their 'life' through recycling, using less or switching to renewable substitutes;
- Develop and implement programmes that would combine, more efficiently, and as appropriate, the use of traditional, renewable energy resources, and cleaner fossil fuel technologies which could meet the growing need for energy services in the longer term to achieve sustainable development;
- Provide support for the development of safe low-cost technologies that provide or conserve fuel for cooking and water heating;
- Intensify research and the development, diversification and conservation of energy, taking into account the need for efficient use and environmentally sound technology;
- Promote integrated production systems, incorporating both plants and animals;
- Develop and adopt, where appropriate, alternative crops and cropping systems suitable to the circumstances of farmers and climatic and soil conditions of a particular area;
- Encourage the reduction of dependence on inorganic fertilisers and agrochemicals through the increased use of organic alternatives;
- Address nutrient depletion, especially in communal areas, through appropriate interventions, like liming, promotion of the use of organic manures, etc.

Since the links between the different components of multifunctional rangelands have received little research attention, the current project aims to develop technological alternatives for resource-poor farmers, which promote better resource use through synergies between livestock, crops and water. As livestock production is already an important component of many smallholder farming systems, farmers need to develop innovative ways to capitalize on the use of low-cost natural resources to increase production. One such innovation is the use of livestock manure to produce biogas, which is an environmentally friendly energy source. Since energy is central to improved social and economic well-being, and is a key factor for relieving poverty, improving human welfare and raising living standards (IAEA, 2005), biogas can play a central role in sustainable development of rural communities in South Africa.

The aim of this project is to introduce biogas (for energy and liquid fertilizer) and rainwater harvesting (for domestic use, fodder production and use in the biogas digester) at selected sites in South Africa. The objectives of the project are:

1: To review available knowledge of (a) the current state of natural resources, land use and management practices of grasslands in communal areas; (b) the opportunities for improving grazing capacity and livestock production; (c) the potential for overnight kraaled livestock manure production; (d) current state of technology and application of biogas as an energy source

2: To determine the level of awareness and acceptability of biogas as a source of energy for domestic purposes at the selected study sites

3: To develop and/or implement appropriate rainwater harvesting (RWH) and conservation techniques and practices for (a) improved grazing capacity and (b) operating biogas digesters at household and/or village scale; (c) using effluent as a liquid fertiliser from biogas digesters for homestead and/or community food gardens

4: To design and/or implement the biogas digesters for renewable energy generation from manure produced by livestock subject to best manure management practices

5: To regularly assess, monitor and evaluate changes in awareness, social acceptability and uptake of biogas as a source of energy for domestic purposes at the selected study sites

6: To evaluate the financial and economic feasibility of biogas generation to meet energy demands at household and/or village scale within appropriate institutional arrangements and organisational structures

7: To develop guidelines for sustainable grasslands management with rainwater harvesting in communal areas

8: To assess the potential for replication and development of guidelines for various scales of biogas generation of renewable energy with conversion of livestock manure to biogas.

The terms of reference for this solicited project specified that these objectives should be applied in three provinces, namely KwaZulu-Natal, Limpopo and the Eastern Cape. These were considered to be the most suitable provinces for implementation of the biogas project as (i) they were representative of the grassland and savanna biomes (ii) they had high levels of poverty (iii) their long-term grazing capacity was generally <9 hectares/LSU (anything greater than nine was considered too large an area to support animals for biogas production) and (iv) they had large areas of degraded communal rangeland which could be improved through the project. Six potential study sites (Giyani and Vleifontein in Limpopo, Msinga and Okhombe in KwaZulu-Natal and Mgwalana and Machubeni in the Eastern Cape) were identified in these provinces using environmental, social, economic and institutional indicators, based on a framework developed by the International Energy Agency. The final sites selected were Vleifontein, Okhombe, and Machubeni, based on the regional and community level criteria developed by the project team.

Livestock production is generally poor in communal areas due to both low quantity and quality of feed for livestock. This project aimed to improve rangeland condition and livestock production by developing strategies that promote sustainable management of rangelands and livestock. These strategies included the use of rainwater harvesting, fodder production and biogas technologies to assist in water, food and energy security. Interventions were based on survey data on local management practices with respect to current livestock and fodder technologies, energy requirements and rainwater harvesting technologies that are currently used by each household.

A total of 12 biodigesters were installed comprising three designs (two types of pre-fabricated: Agama BiogasPro and Sintex, and one combination of a brick base and pre-fabricated top Agama BiogasPro SmartTop). Households were required to feed the biodigesters with 20 litres of cow manure and 20 litres of water on a daily basis (except one digester which was fed with chicken manure). Rainwater tanks were installed following a design rainfall analysis to determine the roof top area to calculate the size of the tank necessary to feed the biodigester.

In KwaZulu-Natal the crops tested were Napier grass (*Pennisetum purpureum*), an annual legume *Vigna sinensis* (cow pea) and an annual grass *Sorghum bicolor* (Sorghum). In Limpopo the tested crops were guinea grass (*Panicum maximum*) and Napier grass. In the Eastern Cape four crops were tested including an annual legume *Trifolium vesiculosum* (arrow leaf clover), an annual grass *Avena sativa* (oats), a perennial legume *Trifolium repens* (white clover) and a perennial grass *Festuca arundinaceae* (tall fescue). In all provinces Napier fodder was the most promising fodder species because of its high production and quality.

One strategy that has been reported to reduce evaporation and conserve moisture for crop growth is mulching. Digested animal manure (bioslurry) can be used as an organic mulch since it contains bulk and fibre which holds soil moisture. It also forms a hard cap of organic material which has the potential to reduce soil evaporation. The experimental trial in KwaZulu-Natal compared the effect of bioslurry, grass clippings and live mulch (maize-pumpkin intercrop) on water conservation in a maize field. The results showed that the amount of water conserved in the profile to a soil depth of 12 cm was significantly greater under the bioslurry mulch treatment (21.7%) than the control (18.3%), but there were no significant differences between mulches. By contrast, in the Napier fodder trial to determine the effects of different applications of nutrients on soil water content, there were no significant differences between treatments: chemical fertilizer, bioslurry worked into the soil, bioslurry-overlay where bioslurry was left to form a cap on the soil, and the control with no nutrients. This may be attributed to the fact that the soils had a higher water content at this study site (24-28%) and soil moisture may not be a limiting factor. Grain yield was highly affected by the mulching treatments. The highest grain yield was obtained from the bioslurry mulch treatment (3498 kg ha^{-1}) which was significantly higher ($P>0.05$) than the grass clippings mulch (3420 kg ha^{-1}), pumpkin mulch (1332 kg ha^{-1}) and the control (1017 kg ha^{-1}). These results support reports in the literature that bioslurry has positive effects on crop yields (see review by de Groot and Bogdanski, 2013). However, the results of this study showed that across all three provinces there were no significant effects of bioslurry on fodder crop yield. One reason for this may that fodder is grown on marginal land which may be affected by the slow release patterns of nutrients from bioslurry when compared to inorganic fertilizers. The soil incubation study indicated that bioslurry released mineral-N in the form of ammonia in the soil; however, this ammonium-N was not converted to nitrate-N during the incubation. Since bioslurry may have a slower nutrient release pattern than the 70 day incubation study, long-term field experiments are recommended to determine the mineralisation potential of bioslurry over several seasons of application. Another factor that may affect the value of bioslurry as a fertilizer is the quality of the digestate (material going into the digester). This was supported by the fact that in the Limpopo study the bioslurry from the poultry manure digestate resulted in significantly higher crude protein in Napier fodder than the bioslurry from the livestock manure digestate.

Although fodder yields did not increase with bioslurry application, all the fodder trials in all provinces showed that supplementary feeding with quality has the potential of filling the fodder shortage gap faced by communal livestock owners. In the case study presented for Potshini in KwaZulu-Natal, the natural rangeland production was 1.195 tons ha-1. In the experimental cowpea and sorghum fodder trial cowpea yield ranged from 3.7 to 5.3 ton ha^{-1} for three different fertilizer treatments. These results indicate that when planting cowpea about 91-121 ha of land, depending on fertilizer treatment, would be required to produce sufficient fodder to meet the fodder requirements of the 378 animal units in the study area. For sorghum the yields ranged from 1.8-3.09 ton ha^{-1} and 145-250 ha is required to produce sufficient sorghum fodder. Napier fodder was the most productive crop producing 11.9-25.9 tons ha^{-1} which would require 17-38 ha to support the current carrying capacity.

One of the main challenges facing smallholder farmers is a shortage of land available for fodder production. Since Napier fodder requires the least land, it is a hardy crop that was productive on the marginal sites of this study and it produces vegetatively resulting in low input costs, it is strongly recommended for supplementation in semi-zero grazing systems in South Africa. In addition, the Limpopo fodder silage trial indicated that excess green Napier grass has the potential for the conservation of fodder in the form of silage. The study showed the fermentative and nutritional quality of Napier grass silage using additives was excellent. This is considered a key factor in the storage of this fodder grass. Although one of the requirements for operating a biodigester is ownership of four livestock, this study showed that there is potential for Napier grass to be grown on fallow land for input into the digester for households who do not own livestock.

The sustainability of development and conservation initiatives is largely dependent on the degree to which they are deemed financially feasible. This project investigated the potential for a system – including rainwater harvesting and small-scale anaerobic digesters for rural households – to have positive impacts on the livelihoods of rural people and the sustainability of the natural resources surrounding them. A comprehensive financial and economic assessment was conducted in the Okhombe community, Ward number 7 of the Okhahlamba Local Municipality – one of the areas included in the broad KwaZulu-Natal study site. The application of the research to a single community was intentional to gain a comprehensive and accurate representation of the costs and benefits for a community in which a statistically significant sample group can be investigated.

Surveys were conducted in the three provinces to identify the level of awareness and acceptability of biodigesters and biogas use for personal households. From the surveys it was apparent that biogas technology was perceived to be a potential solution to energy provision. Households claimed that the ever increasing price of electricity was prohibitive to its use. Although firewood energy was still widely used, there was a need for biogas as it was a clean energy which saved time and money.

The results of the cost-benefit assessment revealed that a biodigester is not a financially feasible investment in Okhombe, but was considered to be resoundingly economically feasible with positive economic net present value and economic internal rates of return as well as an economic benefit-cost ratio above unity. The high level of economic benefit was dictated largely by the values attributed to (i) health benefits, (ii) time saving benefits, and (iii) value of life benefits associated to using a biodigester to replace traditional cooking energies (i.e. solid biomass fuels causing indoor air pollution). The high level of economic benefit identified in the Okhombe study revealed the significant social (welfare) benefits relating to biodigesters, and it was suggested that government subsidisation should be considered in an effort to create financial incentive for households to invest in the technology, thereby securing the economic benefits for their households and society as a whole.

Following this sentiment, it was suggested that government subsidisation, at least to a point where financial desirability became evident, would be worthy of consideration. Financial desirability would be at a point where the financial internal rates of return of household benefits is in excess of the rate of interest of a loan (i.e. a minimum subsidy of R16 593.79, and a recommended subsidy of R20 000 per installation to provide strong incentive for uptake). This value did not include the cost of structures for rainwater harvesting since not all households would need these.

Modelling a scaled-up scenario, where biodigesters are rolled-out to a village and/or entire rural community in a local municipality is, however, a challenging task from a financial and economic perspective. As has been seen in the discussion of the Okhombe study results, the financial returns on investment are negative and marginal in the case of a government subsidy. In addition to this, it is clear that the energy use practices and therefore financial/economic impacts are highly site specific. It is therefore not feasible, at the current level of research, to present an accurate feasibility study for the rollout of biodigesters at larger scales of implementation. It is, however, possible to develop hypothetical models, displaying the potential for rollout scenarios based on stated assumptions. Hypothetical rollout scenarios were considered for village, municipal and national scale. The research has shown that such initiatives would have significant sociological and ecological benefits to the areas involved and the country as a whole. A large-scale rollout would, however, need to be planned and orchestrated with adherence to the recommendations made in the Guidelines Report (Volume 2). Biodigesters have been proven not to be self-sustaining, 'plug-and-play' technology, and therefore require education and training as well as support and maintenance programmes to accompany their implementation – which potentially open opportunities for job creation and support industries in rural areas.

Recently, through its strategic plan, the Water Research Commission formally initiated the Green Village concept, one of the five lighthouse programs aimed at integrating and implementing knowledge in relatively complex pilot studies. The Green Village program provides the opportunity to address the research integration gap through the simultaneous implementation of innovative research (green innovations) at Green Village demonstration sites.

With respect to a Green Village concept, the research has suggested that a biodigester would be a valuable addition to an off-grid rural home – providing energy for cooking, waste management and slurry fertiliser for crop and fodder production. A biodigester is, however, not a complete solution and needs to be accompanied by rainwater harvesting and other sustainable energy technologies to ensure that all household energy requirements are met. Pilot households reported that the available biogas was not always sufficient for all their cooking needs, and especially during winter months when biogas production decreased. This supports the notion that sustainable solutions should be developed with a combination of various, supporting technologies.

In conclusion, the results of this study have shown that integrating the three components of sustainable development (energy, water and food/fodder) is a feasible option to improve the livelihoods of rural households. However, communal rangelands are complex systems that require specific interventions that need the full participation of communities at every level of decision making. The up-scaling of this pilot project from 11 households to a Green Village will need multi-disciplinary action at a multitude of levels (researcher, government and land user). The economic analysis of this study has shown that there is compelling evidence for a biodigester to be a valuable asset to the progress of sustainable development in rural areas.

This was supported by community member's responses in questionnaire surveys that were conducted in the three provinces to identify the level of awareness and acceptability of biodigesters and biogas use for personal households. From the surveys it was apparent that biogas technology was perceived to be a potential solution to energy provision. Households claimed that the ever increasing price of electricity was prohibitive to its use. For example, the Nyikiti family in the Eastern Cape reported that the digester saved them R50 per month on electricity and R50 per month on paraffin. They no longer have to collect firewood, which saves them 40 hours a month. They were very happy with the performance of their digester and said that it supplies them with enough gas. They get over one hour a day of biogas which makes them tea every morning and cooks their food every day. They said that it was easy to maintain and only took 30 minutes a day to load. They have not had to do any maintenance on the digester and have had no leaks and bad smells. The Nyikiti family reported that they were very happy with the whole process and said that the site was kept clean and the process did not interfere with their day-to-day living. Mrs Khumalo reported that biogas had changed her life because of the savings from purchasing firewood (R950 for a bakkie load). She said that there was a problem with collecting firewood as forests have been cut down so they have to go far to collect firewood. She also stated that biogas is more reliable than electricity which goes off if there is wind or lightning. Several households mentioned that biogas was good for health and that it prepared food fast. It also saved time and energy which could be utilized in other household chores. Although firewood energy was still widely used by most households, people stated that there was a need for biogas as it was a clean energy which saved time and money. The slurry produced from the digester saved on fertilizer costs and could be utilized in the homestead vegetable garden.

This study therefore showed that biodigesters have the ability to contribute up to two hours per day of burn time towards the energy needs of rural people as well as the potential to aid in food security development and natural resource management. Modelling a scaled-up scenario, where biodigesters are rolled-out to a village and/or entire rural community in a local municipality is, however, a challenging task from a financial and economic perspective. It is clear that the energy use practices and therefore financial/economic impacts are highly site specific.

Recommendations, based on the practical experiences and research undertaken through this project are:

- Basics of anaerobic digestion

  - Biogas is most easily used as a cooking fuel in a rural setting.
  - Bioslurry can be used as a liquid fertilizer for food and fodder crop production as it is nutrient rich.
  - There are many different types of biodigesters and the needs of the receiving household/user should be considered carefully before choosing one. A pre-fabricated tank digester appears to be one of the most suitable designs for the South African rural setting – due mainly to its ease of installation and reliability as a factory tested unit.
- Community engagement
  - Local authorities, tribal authorities and a community itself must be approached respectfully for the support of a biodigester project.
  - The support of these parties, and especially the people within a community, is crucial to the success of a project and community engagement must therefore be carefully planned and undertaken.
- Household selection
  - It is often necessary that households must be selected for a biodigester project.
  - Depending on the type, scale and plan of the project, household selection must be enacted carefully and with inclusion of the local community leadership.
  - Suitability of a household for biodigester operation and use is a pre-requisite.
  - Including the community in the selection process, and keeping them informed, will assist greatly in gaining their acceptance of the process and their support of the project.
- Biodigester installation
  - Biodigesters need to be installed carefully and within the recommendations of the suppliers and/or professional artisans. A failing biodigester is often difficult to remedy and detrimental to the conceptual success and acceptance of biogas technology.
- Biodigester operation
  - Consistency of a feeding regime is essential for the optimisation of a biodigester system.
  - A biodigester should be treated like a living animal. The operator should pay attention to its changing characteristics on a daily basis.
  - Loading rates and limitations should be adhered to and changed to accommodate environmental conditions (e.g. slower digest rates in cold winter months).
- Education and training
  - Education and training is crucial to the success of a biodigesters operation and a biogas programme. An inappropriately managed or used biodigester is not only a useless entity, but detrimental to the delivery of services via renewable energy and potentially damaging to the way in which alternative technologies may be perceived.
  - Training should include a practical display of efficient cooking mechanisms.
- Technical support and maintenance
  - This is necessary for long-term sustainability.

The studies carried out in this pilot project have highlighted the following research opportunities:

- The input from "greywater" from normal household activities such as washing and showering needs to be quantified and accounted for as it provides an additional source of water.
- There is an urgent need to determine ways of storing bioslurry so that households can store it for the cropping season. Dried bioslurry can be more easily stored and transported than liquid bioslurry. Furthermore, there are income-generating opportunities that need to be explored as excess bioslurry can be sold as a fertilizer.
- There is a continued need to identify alternative biodigester options, as they become available on the market. A crucial consideration here is the need to reduce capital cost of implementation, while not compromising the need for effective and reliable technologies.
- Further research needs to be conducted to understand the impacts of temperature on digestion rates and production of biogas.
- Further experiments need to be conducted to better understand the rate of gas usage at each household and to determine whether biodigester systems can meet the energy demands of households.
- An investigation is needed into developing a suite of alternative energy options to provide a composite solution to meet a household's needs.
- Further research is needed to determine the optimum bioslurry application rates and the impact of breaking the bioslurry crust on infiltration rate.
- Further research into the potential for large scale biodigester projects is required to clarify the potential for biodigesters to have a quantifiable impact on the environment. It is recommended that a rollout of 50-100 households be implemented with an integrated research programme that investigates ecological, economic and social factors associated with a full suite of green technologies for up-scaling to a green village.

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symbols & abbreviations

AOAC	Association of Official Analytical Chemists
ARC	Agricultural Research Council
ARDI	Actors, Resources, Dynamics, and Interactions
AU	Animal units
BCR	Benefit Cost Ratio
BRG	Bioresource Group
CBNRM	Community Based Natural Resources Management
CHDM	Chris Hani District Municipality
CSFAS	Cedara Soil Fertility and Analytical Services
DAFF	Department of Agriculture, Forestry and Fisheries
DAP	Diammonium phosphate
DEAT	Department of Environment Affairs and Tourism
DoA	Department of Agriculture
EBCR	Economic Benefit-Cost Ratio
EIRR	Economic Internal Rates Of Return
ENPV	Economic Net Present Value
FBCR	Financial Benefit-Cost Ratio
FIRR	Financial Internal Rates Of Return
FNPV	Financial Net Present Value
GEEM	Generalized Estimating Equations Model
GV	Green Village
HSRC	Human Sciences Research Council
IDP	Independent Development Plan
IRWH	In-field Rainwater Harvesting
LAN	Limestone ammonium nitrate
MAP	mono-ammonium phosphate
NPV	Net Present Value
NRM	Natural Resources Management
RDP	Reconstruction and Development Programme
RWH	Rainwater Harvesting
SOP	Standard Operation Procedure
STM	State and transition models
VRMP	Village Resource Management Plan
WAP	Weeks After Planting
WRC	Water Research Commission

CHAPTER 1: INTRODUCTION

by Everson T, Smith M

1.1 BACKGROUND AND MOTIVATION

Sustainable agricultural land-use is vital for economic and social development in the communal areas of South Africa. These areas constitute 13% (15.86 million hectares) of South Africa's land surface and an estimated 13 million (28%) of the population is crowded in these areas (DEAT, 2006). High population densities in many of these areas have resulted in over-utilisation of resources because almost every population in rural areas depends on natural resources for their livelihoods. The need for crop and livestock production to keep pace with the increasing demand for food, fodder and energy is critical for the improvement of livelihoods for resource-poor farmers. Morris (2011) noted that the global importance of the ecosystem services provided by rangelands (e.g. water and nutrient cycling, fodder and energy production, erosion control, carbon sequestration, biological diversity) has not yet been fully recognized. In addition, the links between the different components of multifunctional rangelands have received little research attention.

Since livestock production is already an important component of many smallholder farming systems, farmers need to develop innovative ways to capitalize on the use of low-cost natural resources to increase production. One such innovation is the use of livestock manure to produce biogas, which is an environmentally friendly energy source. Since energy is central to improved social and economic well-being, and is a key factor for relieving poverty, improving human welfare and raising living standards (IAEA, 2005), biogas can play a central role in sustainable development of rural communities in South Africa.

The need to address sustained economic growth while simultaneously preserving the natural environment presents important policy challenges for countries such as South Africa. Growing concerns about climate change, a loss of biodiversity, and the poor management of natural resources such as water and forests, all indicate that economic growth must be considered in light of environmental costs and social well-being (Sherbut, 2012). In agricultural landscapes, balancing the provisioning of food and energy with maintenance of biodiversity and ecosystem functions is a global challenge. Agriculture needs to keep up with the demand to provide food and fuel for the growing population. Sound management of rangelands is needed to ensure the provision of ecosystem services which are the benefits that humans derive from ecosystems (Egoh, 2011). Bengtsson et al. (in press) show that grasslands can supply services highly demanded from society (e.g. water supply and flow regulation, carbon storage, erosion control, climate mitigation, cultural values, pollination and biological control of agricultural pests), and that proper management makes it possible to create synergies and avoid trade-offs among many of these services. Therefore sound management of these grasslands should be a major goal to ensure ecosystem stability to enhance the sustainability of agricultural production and ecosystem services.

The South African government is working towards this goal through their Working for Water programme and their particular thrust towards a Payment for Ecosystems services programme. These programmes aim to assist the poorest, mostly rural populations by first targeting communities where land is communally rather than privately owned, such as the Upper Thukela. The current project on integrated ecosystem management aims to link in with these programmes to ensure that ecosystem conservation will be adopted by rural communities.

1.2 INTEGRATION OF WATER, FOOD, FODDER AND ENERGY PRODUCTION IN COMMUNAL RANGELANDS

In South Africa, one of the factors responsible for low agricultural production is unreliable rainfall and poor water resources. In recent years the WRC has funded a number of studies on rainwater harvesting to improve water resources (Botha et al., 2008; Kahinda et al., 2008; Stimie et al., 2010). Different rainwater harvesting techniques have potential application in communal rangelands. One such application is the use of rainwater for energy provision in the form of biogas. The SA Domestic Biogas feasibility study (Austin and Blignaut, 2008) has shown that in addition to rainwater, organic matter (e.g. manure) is required to implement biogas technology in rural households. While manure of any kind can be digested to produce biogas, with varying amounts of biogas per kilogram of feedstock, the focus here is on cattle manure because of the strong ownership of cattle in rural communities, as well as the cultural relationship between cattle ownership and status/wealth in a given community. The amount of manure required and factors affecting its availability and accessibility for biogas production form part of this study.

The current state of technology and application of biogas as an energy source needs to be determined for South Africa. If this technology is to be successfully implemented in communal rangelands of South Africa, the socio-ecological impact of such an integrated approach to economic development needs to be ascertained to maximize the benefits from multifunctional, communal rangelands.

In terms of natural resources, rangeland remains the main and the cheapest source of fodder for South Africa's animal production sector (DOA, 2009). However, in many communal areas of South Africa, rangelands are in poor condition which has a negative effect on animal production (Everson and Hatch, 1999). The links between communal range management, poor rangeland condition and historical issues will be outlined in this study. Improvements to the rangeland will directly benefit livestock and numerous other users since rangelands are multifunctional, providing many non-forage goods and services in addition to forage (Morris, 2011). Since there are links between these different components the excessive utilization of one rangeland resource can have numerous multiplier (positive or negative) effects on the productivity and availability of other extractable and non-consumptive goods that rangelands provide (Morris, 2011). An understanding of the use of these natural resources and opportunities for improving grazing capacity and livestock production will provide some guidelines for interventions that are likely to be successful in the management of multifunctional communal rangelands.

This project will research whether rural households can produce biogas from kraal manure effectively and efficiently, and whether biogas can replace other sources of energy such as fuel wood and paraffin that are more costly and hazardous to human health and the environment. The integrated management system will comprise a biodigester (closed storage or tank in which biogas is generated), harvesting of rainwater, kraaled cattle, and the production of food and fodder. The biodigester will produce biogas by anaerobically digesting the combined harvested water and cattle manure. The liquid bioslurry effluent will be used to water and fertilize the food and fodder crops. An example of an integrated water, food, fodder and biogas energy production system is shown in Figure 1-1.

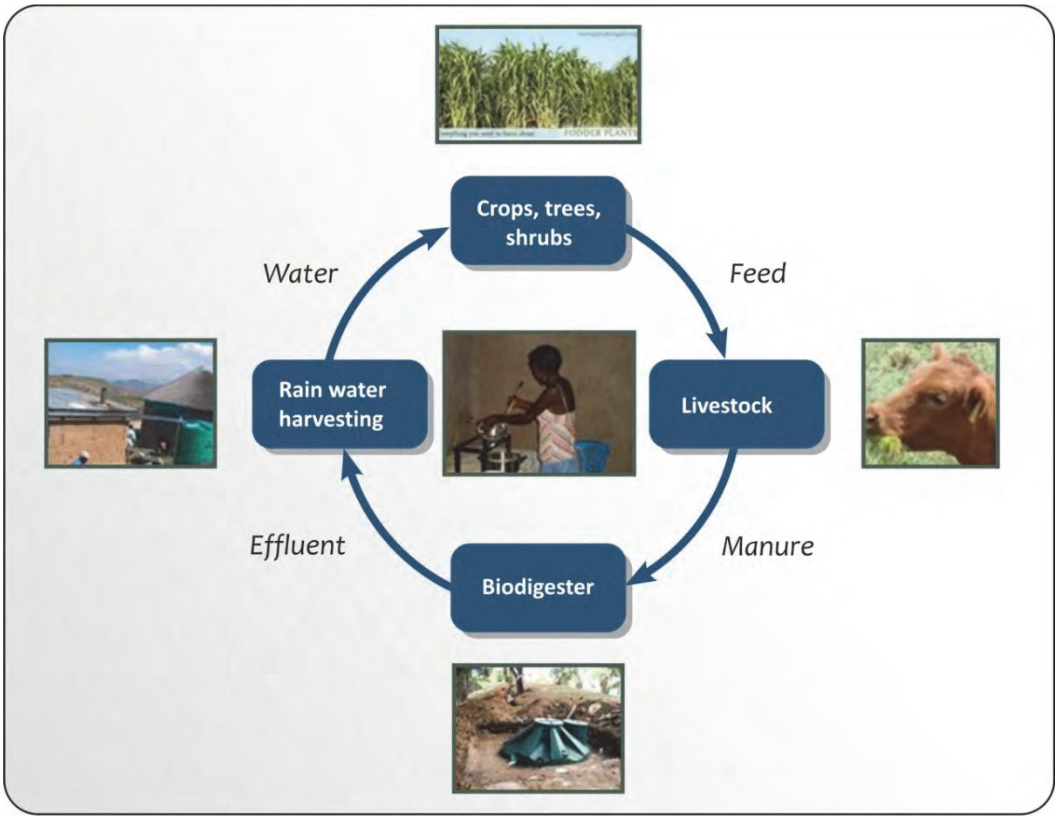


Figure 1-1: Example of water, food, fodder and biogas energy production system.

1.3 APPLICATIONS OF BIOGAS TECHNOLOGY

Biogas technology is responsible for the production of biogas (a renewable energy source) from the anaerobic digestion of organic matter (e.g. cow dung). Although biogas technology can be used at different scales (household to industrial), this research project will focus on the use of biogas at the household level, and examine its potential to upscale to a village level.

There are three distinct designs for biogas technology. These are:

- the flexible vessel biogas digester
- the floating drum, and
- the fixed dome.

Although the chemical processes taking place in these digesters are essentially the same, each technology has specific strengths and weaknesses which are summarized below.

The cheapest design to implement is the flexible biogas digester. It consists of a plastic tube with an inlet and outlet, set in a trench in the ground. This design is also technically very simple, but tends to have shorter technical life-expectancy than the other types of biogas digesters (Fogle, 2008). The shorter life-expectancy may make it less suitable for a programmatic approach to digester installations (e.g. up-scaling to a green village), in particular where a financing mechanism (including subsidies linked to quality assurance measures, as well as long-term production of carbon credits and therefore long-term functionality is required. However, given the low costs of such digesters, a long-term financing mechanism may not be needed.

The floating drum design offers the most consistent pressure out of the biogas digester, but it is relatively technically complex and requires regular maintenance attention. It also has a higher cost, approximately 25 to 50% more than the fixed dome design (Dlamini and Austin, 2006). The gas produced is kept under pressure by the weight of the floating drum.

The fixed dome is more expensive than the flexible biogas digester, but costs about two-thirds of the cost of the floating drum design, and offers relatively very low maintenance and complexity issues. In this biogas digester design, the gas produced is kept under pressure by the water level differential between the digester vessel/gas holder and the compensation/removal tank. The fixed dome and floating drum take roughly the same length of time to construct – up to four weeks for inexperienced masons, while the flexible tube only takes a few days. What is clear from the trend in the past 15 years is that the fixed dome design is the most viable design approach from a technical and reliability perspective, and is the design philosophy of choice internationally. This design was therefore adopted in the current study.

Energy from biogas has potential application in a number of end-uses (i.e. cooking, lighting, refrigeration and entertainment):

Lighting: Biogas can also be used for lighting using adjusted Liquefied Petroleum Gas (LPG) lamps or lamps that are designed for biogas. In general it is not recommendable to use biogas for lighting as a biogas lamp is inefficient (approximately 5% efficiency, Thom, 1994) and hence should only really be used where there is an excess of biogas. In addition, practical experience has shown that the biogas lights are not particularly robust and are generally problematic for the users (Pers. comm., Kellner 2012). Using biogas for lighting is also more complicated from a technical and safety perspective.

Cooking: Historically biogas has mostly been used to replace fuel wood or fossil fuels as an energy source for cooking purposes, including heating of water for both food preparation and bathing. An LPG-stove can be easily modified for use of biogas and there are commercially available biogas stoves. The use of biogas for thermal end uses is the most efficient use of the biogas, with typical efficiencies being in the order of 55% (Thom, 1994).

Refrigeration: LPG-refrigerators can be adjusted so that they are suitable to run on biogas (Pers. comm., Alcock 2012). However, the fluctuating gas pressure in the case of fixed dome biogas digesters might make it difficult to maintain a stable temperature of the flame and the materials used in LPG-refrigerators may be corrosive in nature and therefore not suitable for biogas. This is not a generally recommended application.

Entertainment: Most entertainment appliances like television and sound installations are not suitable for gas. However, biogas is used to generate electricity. This is not as energy-efficient a conversion process as for thermal end-uses (about 28% efficient, Thom, 1994) and as a result very expensive, in particular at small-scale.

Space heating: Biogas can also be very effective for space heating as it creates a lot of heat. However, there is little experience with this application in South Africa and suitable appliances have not yet been well developed. Another issue is that biogas digesters produce less gas when it is cold, which is when demand for space heating is high. Therefore it is difficult to match supply and demand when biogas is used for space heating purposes. However, if the objective of a biogas project is to substantially reduce the use of fuel wood and to benefit from the carbon credits generated from this, suitable appliances for space heating need to be developed.

In general it can be said that, from a financial perspective, the energy aspect alone does not justify the cost for biogas technology unless the systems are subsidised to some degree (at least 30% of the capital cost). However, technically well-functioning and optimally managed biogas digesters can yield a whole range of benefits for their users, the society and the environment in general:

- production of energy (heat, light, electricity)
- transformation of organic waste into high quality fertilizer
- improvement of hygienic conditions through reduction of pathogens, worm eggs and flies
- reduction of unpleasant odours
- reduction of workload, mainly for women, in firewood collection and cooking
- environmental advantages through protection of soil, water, air and woody vegetation
- household-level benefits through energy and fertilizer substitution, additional income sources and increasing yields of animal husbandry and agriculture
- macro-economical or societal benefits through decentralized energy generation, import substitution and environmental protection
- biogas technology can substantially contribute to conservation and development, if the conditions are favourable.

It is apparent that the overall objective, to which biogas technology contributes, is environmental protection that includes energy-related objectives (e.g. decrease of greenhouse gas emissions as well as deforestation) and the improvement of livelihoods of biogas users. It is clear that the energy aspect alone cannot be used to justify the cost of biogas implementation and potential subsidization by the South

African government. The current pilot project which involved the implementation of biodigesters on a small scale (12) across three provinces, therefore examined a wide range of potential benefits from an ecological and economical aspect. The results of this study will ultimately be used to advise the South African government on the potential application of these “green” options for meeting the fundamental services of poor rural communities on a sustainable basis for up-scaling to a Green Village.

1.4 AIM AND OBJECTIVES

The aim of this project was to introduce biogas (for energy and liquid fertilizer) and rainwater harvesting (for domestic use, fodder production and use in the biogas digester) at selected sites in South Africa. The objectives of the project were:

1: To review available knowledge of (a) the current state of natural resources, land use and management practices of grasslands in communal areas; (b) the opportunities for improving grazing capacity and livestock production; (c) the potential for overnight kraaled livestock manure production; (d) current state of technology and application of biogas as an energy source

2: To determine the level of awareness and acceptability of biogas as a source of energy for domestic purposes at the selected study sites

3: To develop and/or implement appropriate rainwater harvesting and conservation techniques and practices for (a) improved grazing capacity and (b) operating biogas digesters at household and/or village scale; (c) using effluent as a liquid fertiliser from biogas digesters for homestead and/or community food gardens

4: To design and/or implement the biogas digesters for renewable energy generation from manure produced by livestock subject to best manure management practices

5: To regularly assess, monitor and evaluate changes in awareness, social acceptability and uptake of biogas as a source of energy for domestic purposes at the selected study sites

6: To evaluate the financial and economic feasibility of biogas generation to meet energy demands at household and/or village scale within appropriate institutional arrangements and organisational structures

7: To develop guidelines for sustainable grasslands management with rainwater harvesting in communal areas

8: To assess the potential for replication and development of guidelines for various scales of biogas generation of renewable energy with conversion of livestock manure to biogas.

CHAPTER 2: A REVIEW OF THE CURRENT STATE OF NATURAL RESOURCES IN COMMUNAL RANGELANDS OF SOUTH AFRICA AND SUSTAINABLE MANAGEMENT OPTIONS

by Everson T, Smith M, Gambiza J, Everson C.

2.1 CURRENT STATE OF NATURAL RESOURCES IN COMMUNAL RANGELANDS

2.1.1 Current use of natural resources in communal rangelands

Although the livelihoods of people in rural areas in South Africa are largely based on remittances and grants as main sources of income, many rural households still depend on natural resources to some extent (Twine, 2005; Gogwana et al., 2008; Moyo et al., 2008). Gogwana et al. (2008) identified a range of different sources of income in Eastern Cape villages, including crop production, livestock keeping and temporary employment.

Hoffman and Ashwell (2001) reported that about 17 million people in 3.2 million households in South Africa rely on firewood for energy. Many households are still not connected to the grid, or cannot afford the connection and monthly costs of electricity, and use candles and paraffin lamps for lighting and fuel wood for cooking, and heating during winter months. For example, some of the most commonly used firewood trees in rural Limpopo include *Acacia nigrescens, Afzelia quanzensis, Combretum apiculatum* (Grundy, 2003).

Natural woody vegetation provides rural communities with a wide range of resources, including firewood, poles for construction, and poles for fencing and animal pens, wood for carving utensils, edible fruits, bark, roots for medicine and leaves for livestock (Grundy, 2003; Twine, 2005). Twine (2005) reported that over the last 20 years, there has been a change in the pattern of harvesting of natural resources. There has been a rise in extraction of these resources and communities are now harvesting using vehicles and trade elsewhere. Twine (2005) also indicated that a rise in unemployment has influenced the harvesting patterns particularly in the rural areas in Limpopo. For instance, regions in the Bushbuckridge area have fewer formal employment opportunities and natural resources provide opportunities for generating income through the trade of raw materials such as medicinal plants and fuel wood. This indicates rural people are increasingly able to include these resources into a market economy, to enhance their income generation (Grundy, 2003, Twine, 2005). These current patterns contribute to the current state of natural resources in communal areas.

In the 1990s, the South African Government initiated several programmes to promote resource conservation and sustainable land management particularly to address resource degradation in areas under communal land tenure. Such programmes included LandCare implemented by the National Department of Agriculture, Community-Based Natural Resources Management by the Department of

Environmental Affairs and Tourism, and Working for Wetlands and Working for Water by the Department of Water Affairs and Forestry. These initiatives aimed at promoting conservation and sustainable management of natural resources. Acknowledging failures of the past, a bottom-up approach was adopted to engage communities in planning, implementation and monitoring of projects, to develop strong local organisations that could develop and apply institutions and to promote a sense of ownership among the communities.

For example, in Okhombe the LandCare project aimed to improve cattle management as part of a broader land rehabilitation process. Cattle grazing camps were established, crush pens built, eroded areas were rehabilitated, and local institutions were strengthened (Tau, 2005). An extensive series of participatory exercises were held with community members to develop plans to improve communal grazing management (Peden, 2005, Tau, 2005). However, the majority of cattle keepers did not apply rotational resting due to the incidence of stock theft and the lack of household labour for daily herding (Salomon et al., 2012).

Thus, communal rangeland management cannot be looked at in isolation from local and regional socio-economic trends. Twine (2005) recommended that rangeland ecologists recognise the value of social sciences such as anthropology, sociology and economics. A multidisciplinary partnership is vital for the management of communal resources. Everson and Hatch (1999) noted the most important factors to consider when planning with communities are basically to understand historical background, land tenure, social issues (conduct participatory rural appraisals) and understand the current state of the vegetation (ecological issues).

The erosion and soil degradation in many communal areas has been attributed to continuous grazing (Hoffman and Ashwell, 2001). There are currently few published studies on the current state of natural resources in communal rangelands. However, results will be drawn from Hoffman and Ashwell (2001) and from DEAT (2006).

2.1.1.1 Soil

More than 80% of the land in South Africa is grazing land and the raising of livestock is thus the dominant form of landuse in the country (Hoffman and Ashwell, 2001). In communal rangelands, the major driver of soil degradation is poor rangeland management. Intensive grazing is the major problem across communal lands (Harrison and Shackelton, 1999). Saravi et al. (2003) reported a significant relationship between increased livestock trampling and decreased soil infiltration as well as increased soil compaction. Intensive grazing reduces soil organic matter and consequently compacts soil surface layer and ultimately increases run-off (Saravi et al., 2003).

Hoffman and Ashwell (2001) found that soil degradation in grazing lands of the communal areas is more severe and took place more rapidly than in commercial areas. A number of the most degraded areas are in the former homelands and self governing territories of Ciskei, Transkei, Lebowa, KwaZulu and Venda. Thus it is more severe in KwaZulu-Natal, Limpopo and the Eastern Cape and the rate of degradation is decreasing in the Free State, Northern Cape and the Western Cape. The soil degradation index (an index that incorporates the severity and rate of soil degradation for all land use types) for communal areas is nearly three times that for commercial areas (Table 2-1) (Hoffman and Ashwell, 2001, DEAT, 2006).

Soil degradation costs South Africa nearly R2 billion annually. Costs include both on-site effects such as water and wind erosion, and off-site effects like sedimentation of dams and the need for water purification (Hoffman and Ashwell, 2001; DEAT, 2006). Each year, soil erosion in South Africa causes losses of 30 000 tons of nitrogen, 26 400 tons of phosphorus and 363 000 tons of potassium. The total cost of replacing soil nutrients exceeds R1.5 billion per annum. The rate of soil formation under favourable conditions is estimated to be between 12-40 years or even longer for each millimetre of topsoil (Hoffman and Ashwell, 2001). Given the prevalence of soil degradation in communal lands, this is very disturbing and opportunities for increasing a protective vegetation cover must be investigated.

Table 2-1: Comparative severity, rates of soil degradation and soil degradation indices in grazing land. A negative rate implies that degradation in decreasing.

Province	Severity	Rate	SDI
Eastern Cape	1.6	0.6	116
Free State	1.4	-0.6	36
Gauteng	0.9	0.1	24
KwaZulu-Natal	2.0	0.0	181
Mpumalanga	1.2	0.1	56
Northern Cape	1.3	-0.5	80
Limpopo	1.7	1.0	144
NorthWest	1.3	0.0	72
Western Cape	1.2	-0.1	56
Commercial districts	1.3	-0.2	68
Communal districts	1.9	1.3	159

Adapted from Hoffman and Ashwell (2001)

2.1.1.2 Water

South Africa has a highly variable rainfall and hydrology. As the rapidly expanding population puts pressure on the water resources, water deficits are becoming severe. Because of the variation in rainfall over the country it is necessary to move water from high rainfall catchments to areas where water resources are poor. Optimising the yield of water from catchments is therefore becoming an important issue in catchment management. In South Africa, the mountain catchments represent only 8% of the land but generate 49% of the runoff.

The major catchment areas for South Africa's water resources are covered by natural grasslands that occupy approximately 29% (350 000 km^2) of the country (Everson, 2011). These areas are relatively cool, and have an annual rainfall between 600 and 1 200 mm. These areas coincide with the afforestation zones for commercial exotic tree species, whose site requirements for growth are mostly limited by the availability of soil water. Given that 1 257 341 ha of land were under commercial plantation forestry in 2008 (DAFF, 2010), and the increased demand for timber products resulting from the impact of the

Reconstruction and Development Programme, there can be no doubt that afforestation will have a further impact on the country's already scarce water supplies. Large areas of communal rangelands in the high yielding water production areas of South Africa are currently being converted into commercial forestry plantations which will place even more pressure on the rangelands for grazing.

Rural communities in the upper catchments and their stock are also dependent on sustained stream flow throughout the year and during drought years. Sustainable low flow is often dependent on thresholds in terms of vegetation cover and soil condition. Many communal areas in South Africa are characterised by severe overgrazing, accelerated soil erosion and reduced availability of water in streams and rivers (Hoffman and Ashwell, 2001). This degradation has resulted from the artificially high population pressures forced on these lands by the apartheid-era homeland policies and other forms of social engineering. A major hydrological consequence of over-stocking is the promotion of overland flow and consequent reduction in the amount of rainwater infiltrating the soil profile, leading to enhanced stormflows and diminished baseflows. The consequences to rural communities reliant on degraded catchments may be severe, and include accelerated soil erosion and reduced water supply, especially during rainless weather. This is a common situation in the communal rangelands north of Bergville in KwaZulu-Natal, South Africa, where a combination of high rainfall, steep slopes, unstable sub-soils and over-stocking has led to severe degradation over extensive areas of land. Rural communities in the region have expressed deep concern over the loss of formerly reliable streams, and the spread of gullies. The latter problem is so severe that increasing numbers of livestock are lost as a result of animals falling into deep gullies. Addressing the problem of soil degradation and the provision of alternative fodder for livestock will therefore have major hydrological benefits for rural communities.

2.1.1.3 Vegetation

Natural vegetation provides rural communities with a range of resources, the most important being thatching grass, medicinal and wild food plants and fuel wood which are harvested from communal rangelands for domestic or commercial use (Morris, 2011). Woody plants are key multifunctional natural resource assets in savanna and woodland areas, providing a large variety of harvestable products such as timber, fruit, bark and leaves (Morris, 2011). One of the most important woodland resources used by rural communities is fuel wood. Hoffman and Ashwell (2001) reported on high fuel wood consumption in rural areas. Taking into account factors of accessibility, usability and wastage of wood, woodlands in communal areas can supply only about 4.6 million tons of fuel wood per year. However between 6 and 11 million tons of wood are used annually leaving a deficit of at least 1.4 million tons. The use of biogas as an alternative energy resource therefore has the potential in addressing this deficit.

A common type of degradation in communal rangelands is a change in species composition which in turn influences the grazing capacity of the rangeland (Scholes, 2009). An increasing trend is for communities to keep their cattle closer to their homesteads to avoid cattle theft. This has resulted in over-utilization of rangeland close to the homesteads and lenient grazing further away. Tau (2005) reported that in Okhombe, KwaZulu-Natal, this prevailing management system has resulted in the dominance of Increaser II species such as *Eragrostis curvula* and *Eragrostis plana* on the bottom lands resulting in poor condition of the rangeland. A study by Vetter et al. (2006) revealed that the communal lands of the Herschel district in the Eastern Cape were dominated by undesirable plants when compared to their neighbouring commercial farms. Granger and Morris (2003) found similar results in the Highland grasslands of KwaZulu-Natal. Coarse unpalatable perennial grasses (e.g. *Eragrostis* species, *Sporobolus africanus*) tended to be abundant while palatable productive grasses (e.g. *Themeda triandra*) were less abundant under subsistence grazing than commercial grazing and conservation areas.

A dominance of unpalatable grasses will reduce the quality and quantity of fodder available for livestock. Strategies to improve grazing capacity and livestock production should view livestock management from a systems perspective (Gunderson and Holling, 2002). Hopcraft et al. (2010) have proposed a framework that can be used to understand the ecological functioning of livestock systems (Figure 2-1).

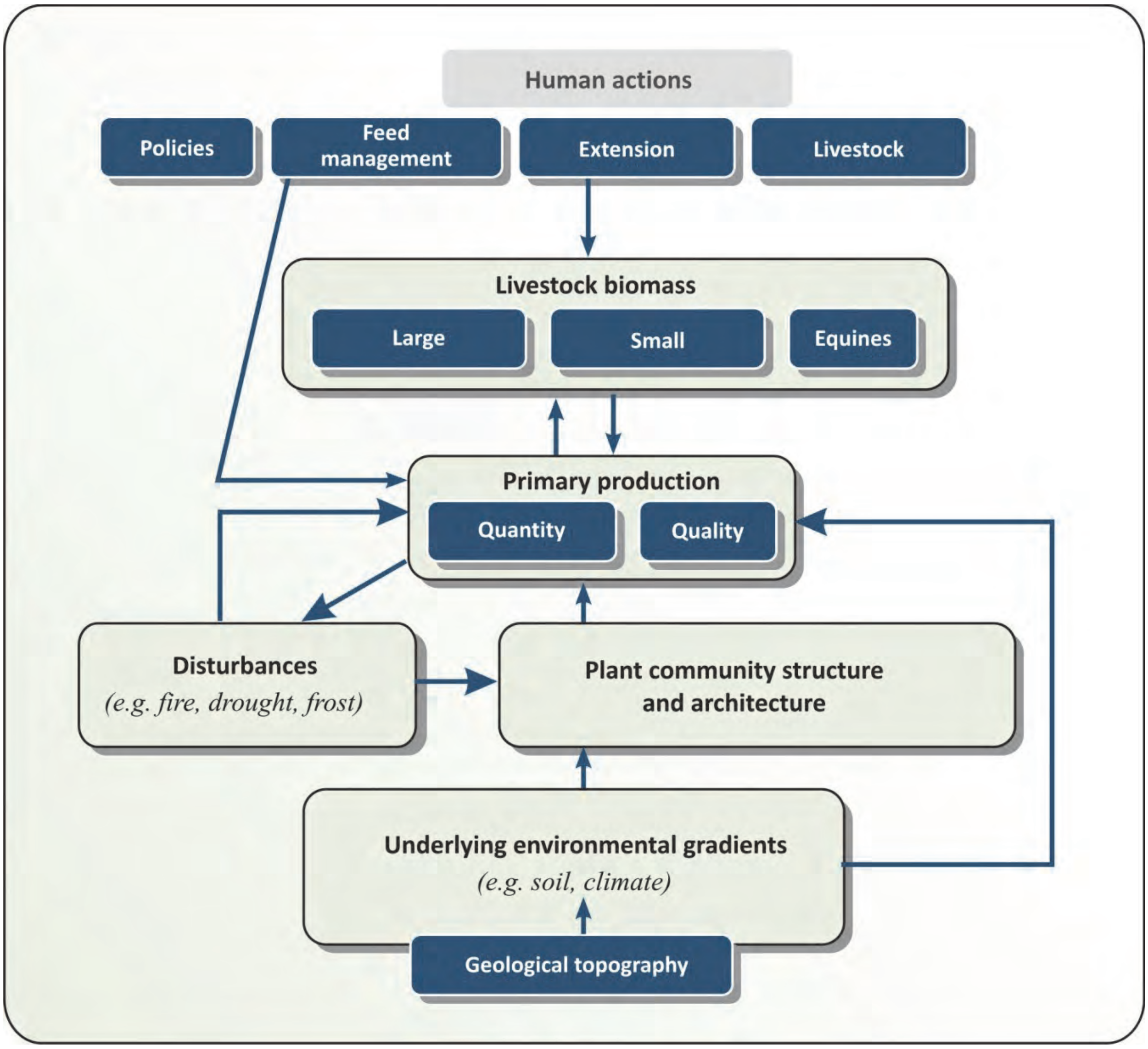


Figure 2-1: Systems model of livestock population regulation showing the interaction of both bottom-up and top-down population regulation mechanisms (Adopted from Hopcraft et al., 2010).

The key human actions that influence livestock numbers are the policies; feed management; extension advice, and basic livestock management strategies. Marketing, drought relief and re-stocking policies are prime examples of how human actions influence the recovery of livestock populations after droughts (Gambiza et al., 2010). Feed management practices include rangeland management, rangeland reinforcement, supplementary feeding, establishment of fodder banks, and treatment of crop residues. These practices are crucial in alleviating pressure on rangeland especially during below average rainfall seasons.

One of the major opportunities for improving grazing capacity and livestock production in this project lies in putting strategies in place to improve the nutrition of the animals. The establishment of forage legumes can be used to improve forage quality especially in the dry season. Both herbaceous and woody forage legume species can be used for this purpose. The successful establishment of legume species is a major challenge in communal areas where livestock densities tend to be generally twice higher than those in commercial farming systems (Gambiza and Nyama, 2000; Hoffman and Ashwell, 2001).

Another option is supplementary feeding through the cultivation of forage species for cut and carry systems (zero grazing). Numerous species can be used for this purpose. Harvested water can be used for growing forage plants. The main limitation of cut and carry systems is the high demand for labour and financial resources. Furthermore, there is a need for small holder farmers to change their world view regarding the cultivation of forage crops. Education of farmers will be required to promote this strategy.

The establishment of fodder banks is another strategy to provide high quality fodder and to improve livestock production. The fodder banks can be established as agroforestry systems whereby palatable grasses (e.g. cocksfoot, tall fescue) can be intercropped with trees such as *Acacia karroo*, *Morus alba* or *Leucaena leucocephala*. Alternatively, maize can be inter-cropped with leguminous crops such as lablab or cowpeas. Trytsman and Mappledoram (2003) reported a yield of maize, cowpeas and lablab, which were 4.89 t/ha, 3.34 t/ha and 6.89 t/ha dry matter for each crop respectively. An on-farm trial by Everson et al. (2004) reported that over a three-year period, *Acacia karroo* was the most productive fodder tree with yields of about 1600-3000 kg ha^{-1} and *Leucaena leucocephala* yields increased significantly from 1999 (500 kg ha^{-1}) to 2001 (3800 kg ha^{-1}). Van Zyl and Dannhauser (2005) also reported promising results of establishing alternative fodder banks. The adoption of agroforestry and alternative fodder systems has the potential to play a key role in addressing feed deficits and restoring ecosystem services.

2.1.2 Opportunities for improving grazing capacity and livestock production

The key human actions that influence livestock numbers are feed management, extension advice and basic livestock management strategies. Feed management practices include rangeland management, rangeland reinforcement, supplementary feeding, establishment of fodder banks, and treatment of crop residues. These practices are crucial in alleviating pressure on rangeland especially during below average rainfall seasons.

The quality and quantity of forage is an important factor regulating livestock numbers. Human actions, however, can to a large extent improve both the quality and quantity of available forage. The general perceptions of development agencies regarding communal grazing lands is that these areas are carrying more animals than their capacity, resulting in low productivity and increasing land degradation (Vetter, 2005, Goqwana et al., 2008). The interventions tend to be less successful because they overlook a number of issues regarding the livestock production systems. According to Goqwana et al. (2008) the underlying fact is that livestock keepers are a small proportion of the population in communal areas, the majority own very few animals, are mostly aged and may exhibit reluctance to move and start new lives as commercial farmers. Salomon (pers. comm., 2010) observed similar trends in Okhombe, KwaZulu-Natal.

2.1.3 Livestock management practices in communal areas

Three livestock management systems are generally recognised across land tenure types (Upton, 2004; Gambiza et al., 2010). These are rangeland-based systems, mixed crop-livestock systems and landless systems. The systems vary in terms of the land required for production and the degree of intensification. Rangeland-based systems depend on feed from extensive areas of rangelands mainly in arid and semi-arid regions. Feed mainly consists of herbaceous species and browse. The degree of intensification ranges from relatively low in traditional subsistence systems to high in commercial systems.

According to Upton (2004) mixed crop-livestock production systems are the most important source of ruminant livestock production globally. These systems are likely to play an even greater role given the future global change in climate and human population growth. In Africa, these systems are common in regions where rainfall is adequate to support the cultivation of crops in some years. Crop and livestock production complement each other in the smallholder sector (Rukuni, 1994, Herrero et al., 2010). Livestock provide draught power and manure that are used for crop production. Crop residues and other plant materials are in turn fed to livestock. In contrast, Upton (2004) has argued that livestock and crops compete for land as livestock numbers and intensity of production increase. The current project explored technologies to promote complementary crop and livestock production.

The global increase in meat production is largely attributed to landless production systems (Upton, 2004). Landless systems are the most intensive in terms of requirements for labour, feeding, housing and other production inputs. Pigs and poultry are the main livestock species that are raised in these systems because they have higher food conversion efficiency and reproductive rates than ruminant species. However, the adoption of landless systems is increasing in African countries where land shortage is a major constraint for extensive livestock systems. The potential for this system will be examined in the current project.

2.1.4 Constraints to cattle production

Many factors constrain cattle production (Table 2-2). There is inadequate and poor supply of feeds due to erratic rainfall and frequent droughts. This is exacerbated by overstocking and overgrazing in communal areas. There is also a marked seasonal shortage of feed in arid and semi-arid areas. In the early part of the wet season forage quantity is low while quality in terms of nutrient content and digestibility is high. Forage quality deteriorates as grasses mature because of lignification. Forage is often unavailable in the dry season with the result that young and mature animals do not get adequate nutrients for growth and maintenance, respectively. Scarcity of drinking water for animals is also a common problem during the dry season. Animals have to travel long distances to get water resulting in loss of body weight.

Table 2-2: Factors constraining cattle production in African countries.

Factor	Major causes
1. Inadequate feed	• Erratic rainfall • Drought • Overstocking and overgrazing • Inefficient utilization of crop residues and agro-industrial by-products • Unreliable supply and high costs of commercial feeds
2. High mortality rates	• Diseases – lack of efficient and effective control measures • Poor nutrition
3. Poor policies and institutions	• No incentives to stimulate marketing • Poor incentives for livestock research and extension • Low prioritization of livestock programmes in resource allocation by governments • Lack of organized credit facilities • Poor research, extension and farmer linkages • Poor planning for the control of episodic and catastrophic events such as foraging locusts and army worm (*Spodoptera exempta*) • Absence of drought-mitigation strategies and means to cope with emergencies resulting in large losses through density-dependent mortality of livestock

Source: From various sources

Other factors constraining cattle production include poor polices and institutions (Pica-Ciamarra, 2005) and inadequate disease control. The current project will focus on strategies to reduce the major constraint of inadequate feed for livestock production.

2.2 CURRENT STATE OF TECHNOLOGY AND APPLICATION OF BIOGAS AS AN ENERGY SOURCE

The following section is a summary of the state and application of biogas technology in South Africa.

2.2.1 Technology overview

The technology used in this project was an anaerobic digester. Anaerobic digestion is the process in which biogas is made. Quite simply, it is the biodegrading of organic material under the absence of oxygen. To achieve an oxygen free environment in which the organic material can be digested, various types of biodigester (also called biogas digesters, anaerobic digesters, or digesters) are used. The products of anaerobic digestion are biogas and bioslurry.

Biodigesters vary greatly in size, from small scale home/domestic units, to farm scale digesters for processing of animal and agricultural waste, to industrial/utility scale digesters for processing large quantities of organic waste (often the organic fraction of municipal solid waste).

Three different types of domestic biodigesters were used in this study: two types of pre-fabricated (Agama BiogasPro and Sintex, Plate 2.1) and one combination of a brick base and pre-fabricated top (BiogasPro SmartTop, Plate 2.2).

Plate 2.1: Agama BiogasPro (left) and Sintex (right) pre-fabricated tank digesters.

Plate 2.2: A BiogasPro SmartTop digester being installed, the base of tank is built on site (left), the SmartTop is installed and sealed onto the unit (right).

The reason for using the Agama biodigesters (both the BiogasPro 6 pre-fabricated tank, and the BiogasPro SmartTop built and pre-fabricated tank)[1] was because these were South African designed and built. The Sintex digester was used as an alternative for comparison.

2.2.2 Application of biogas technology

The biodigesters used in this project were installed at separate households, crèches and cooperatives in various villages in Limpopo, the Eastern Cape, and KwaZulu-Natal. All digesters were installed with biogas burners, for utilisation of the gas as a cooking fuel (Plate 2.3).

Households were required to feed the biodigesters with cow manure and water on a daily basis (except one digester which was fed with chicken manure). Rainwater tanks and rainwater harvesting systems were designed and installed at the households to assist by providing accessible, auxiliary water for feeding of the biodigester (Section 5.1.2).

Plate 2.3: Biogas flames at a pilot household.

2.2.3 Benefits (and costs) of biogas

Table 2-3 summarises the costs and benefits associated with the use and operation of a biodigester.

Table 2-3: Summary of costs and benefits of a biodigester system.

Level of analysis	Costs	Benefits
Household-level analysis *(financial)*	▪ Cost of biodigester plant including all materials, labour and installation ▪ Cost of rainwater harvesting system ▪ Cost of biogas utilising equipment (gas burner, etc.) ▪ Repair and maintenance cost of system	▪ Cooking and lighting fuel saving ▪ Chemical fertiliser saving ▪ Income effects of improved health
(economic)	▪ Cost of extra time used in the adoption of biodigester use	▪ Time saving due to biogas and rainwater harvesting (not having to collect 'traditional fuels' and using more efficient cooking practices) ▪ Increased personal 'wellbeing' as a result of using clean burning energy (reduced respiratory and eye ailments related to poor indoor air quality)
Societal-level *(financial)*	▪ Training and technical assistance ▪ Programme related costs	▪ Saving in health related expenditures*
(economic)	▪ External costs of biodigester (related to carbon footprint of construction)	▪ Greenhouse gas (GHG) and CO_2 reduction ▪ Local environmental benefits (reduced erosion due to reduced overgrazing, reduced deforestation)

2.2.4 Challenges for biogas projects

High upfront capital expenses, unrealistic expectations by the consumer and problems with collecting manure have been obstacles for many biogas projects. For successful implementation of biogas project it is important that the system is convenient to the consumer and that is suits the local circumstances, that there is sufficient feedstock available, and that there is a financial commitment. Larger systems are financially more viable than smaller ones.

In South Africa approximately 50% of households use fuel wood as an energy source for cooking while over 20% use electricity. The collection times and distance to fuel wood increase as fuel wood becomes scarce. The monthly affordability level for energy per household for rural households in Limpopo, Eastern Cape and KwaZulu-Natal is R90, R113 and R104 respectively.

A biogas digester consumes the same amount of water as the amount of manure it consumes. Therefore the minimum amount of water required is 20 litres per day. The digested manure is called bioslurry, which is an excellent fertiliser. It can improve farming yields by 6 to 10% and more. Bioslurry could become more valuable as it can be marketed as organic fertiliser to meet an increasing demand for organic products.

Over centuries biogas technology has been used in Asia where there are now millions of digesters. Biogas experiences in Africa have been on a far smaller scale and have been often disappointing at the household level. Many of the barriers to biogas technology in South Africa are national level constraints such as lack of supportive policy environment, financial incentives and information sharing (Boyd, 2012). Recently a number of countries have started a national biogas programme. In South Africa biogas technology was introduced in the 1950s as pilot projects. In recent years a larger number of biogas digesters have been built making use of more reliable technologies.

Recent developments on biogas technology in South Africa are the introduction of prefabricated systems and experiments with cost-saving technologies, improved flexible vessel digesters and the institutional set-up of biogas projects (e.g. letting households buy gas rather than digesters). The main challenges associated with the development and operation of biogas projects are:

- Capital cost of a biodigester system and installation.
- Absence of education and understanding of how to appropriately operate and use a biodigester.
- Lack of knowledge and social awareness (e.g. biogas demonstration projects).
- Challenges associated with the acceptance of communities where subsidised technology can only be given to a limited number of people.
- Need for support and maintenance of systems subsequent to installation.

2.2.5 Bioslurry

Biogas digester systems require a certain amount of liquid per day (which is in the order of one component solids to one component liquids) for the biological processes to occur optimally. Therefore, access to 20 litres of water per day is essential, and this can include waste-water from within the household.

After digestion, the water and organic material, which is fed into the biogas digester, will come out in the form of 'bioslurry'. The extent to which bioslurry can theoretically be monetized as a benefit depends largely on the previous use of the substrate to be digested (Austin and Blignaut, 2008). The more wasteful the present method of utilizing farmyard manure, the higher the potential for monetizing the benefits, assuming that the bioslurry is put to productive use. In many traditional systems the manure and fodder residues are heaped in the open, leading to heavy losses of minerals through solar radiation and leaching by rain.

Increased agricultural production of crops and vegetables has been reported from the use of bioslurry (Shahbaz, 2011). Application of both the liquid and composted form of bioslurry resulted in higher incremental yield (18.4% and 28.4% respectively) of cabbage as compared to that of the application of farmyard manure and also compared to the full recommended dose of chemical fertilizer, which resulted in 14% and 19.6% incremental yield respectively Karki, 2006). Comparatively, for maize, biogas slurry in liquid form yielded 6.6% higher yields than the manure treatment; slurry compost produced 11.06% higher yields than the liquid slurry, whereas mineral fertiliser produced 6.0% lower yields than the slurry compost (Karki, 2006).

There is a growing market for natural organic products (fruits, vegetables, etc.). If the market is able to carve a niche to this effect, the bioslurry would be very important and can be marketed as organic by biogas owners. What is needed here is branding and marketing for promotion. In light of the concerns associated with genetically modified foods, products that utilise bioslurry would be rated as being more valuable than the others.

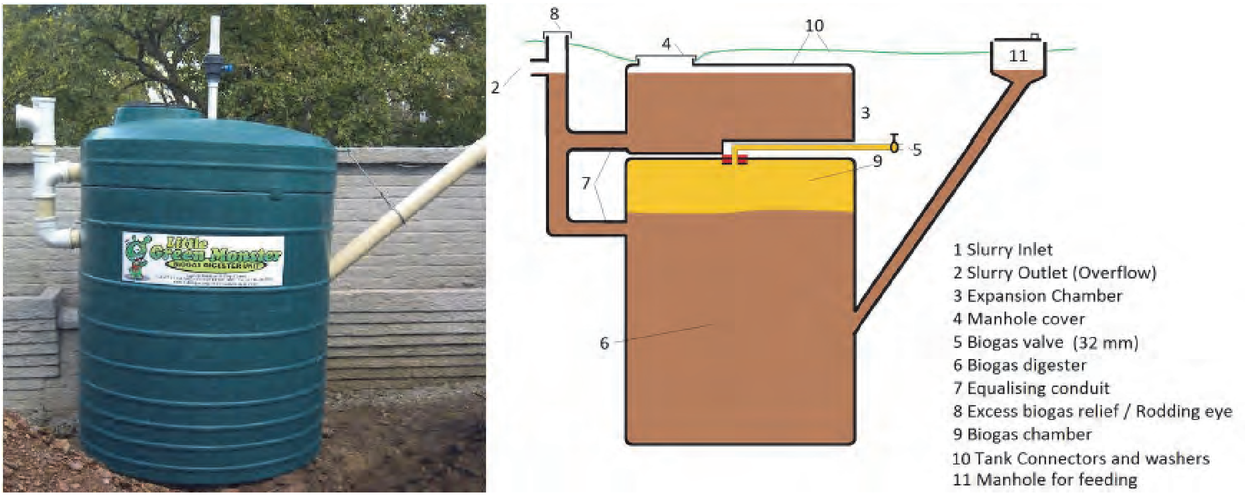
2.2.6 Recent developments in South Africa

2.2.6.1 Biodigesters

The Agama BiogasPro is one of the most recent technological developments that have taken place in South Africa. Since the inception of the project in 2010, the Agama team has further developed the BiogasPro and has made a number of small improvements to the system. These have included modifications to strengthen the design and to improve the flow of the biological process in the system.

More recently another prefabricated biodigester has become available in South Africa. The "Little Green Monster" is a converted LDPE tank which is advertised online as costing R16 340 including VAT, excluding installation. The tank has a gas storage capacity of 500 L (i.e. half that of a BiogasPro6), with a quoted daily production ability of 1 000 L (requiring correct operation and daily usage) (EnergyWeb, 2015).

Although the project team has not had the opportunity to see one of these tanks in operation, or test one, there appear to be mixed reviews about its abilities from the biogas industry community. Some sources have noted its ease of application and price as being positive aspects. Others have raised concern about its ability to perform to advertised performance levels, its light material construction and the impact this may have on ground application. Further investigation and testing would be necessary to provide any objective review of the system.



(source: Sustainable Engineering Solutions n.d.).

Plate 2.4: Little Green Monster biodigester

2.2.6.2 Remote biodigester monitoring

Renen Energy Solutions, a renewable and alternate energy company in South Africa, have developed a monitoring system to remotely monitor temperature, tank pressure and gas production of biodigesters (Plate 2.5). Two of these systems were installed at project pilot sites in KZN, and while the equipment is still under development, it has provided some interesting and meaningful data for the team to assess usage behaviour by household members and changes in gas production (Section 4.6).

Plate 2.5: BiogasPro Meter installed at Okhombe pilot household, KZN.

CHAPTER 3: STUDY AREA

by Everson T, Everson C, Tinarwo D, Baloyi J, Gambiza J.

3.1 CRITERIA FOR SELECTION OF STUDY SITES

Site selection was an iterative consultative process involving a planning workshop, a teleconference, and input by representatives of the Agricultural Research Council, the South African Environmental Observation Network and the South African Botanical Research Institute. The process involved the selection of criteria at the provincial, regional, community and household level. This was followed by the selection of indicators for site selection based on a framework developed by the International Energy Agency (IAEA, 2005).

3.1.1 Provincial level criteria for site selection

3.1.1.1 Inclusion of Grassland and Savanna Biomes

The two most significant biomes in relation to communal areas and livestock husbandry are the Grassland and Savanna Biomes of South Africa (Figure 3-1). These two biomes are situated in the eastern half of South Africa with the Limpopo Province dominated by Savanna and KwaZulu-Natal and the Eastern Cape dominated by both. The Savanna areas are located mainly along the eastern seaboard and the grasslands occur in the more mountainous inland areas (Figure 3-1).

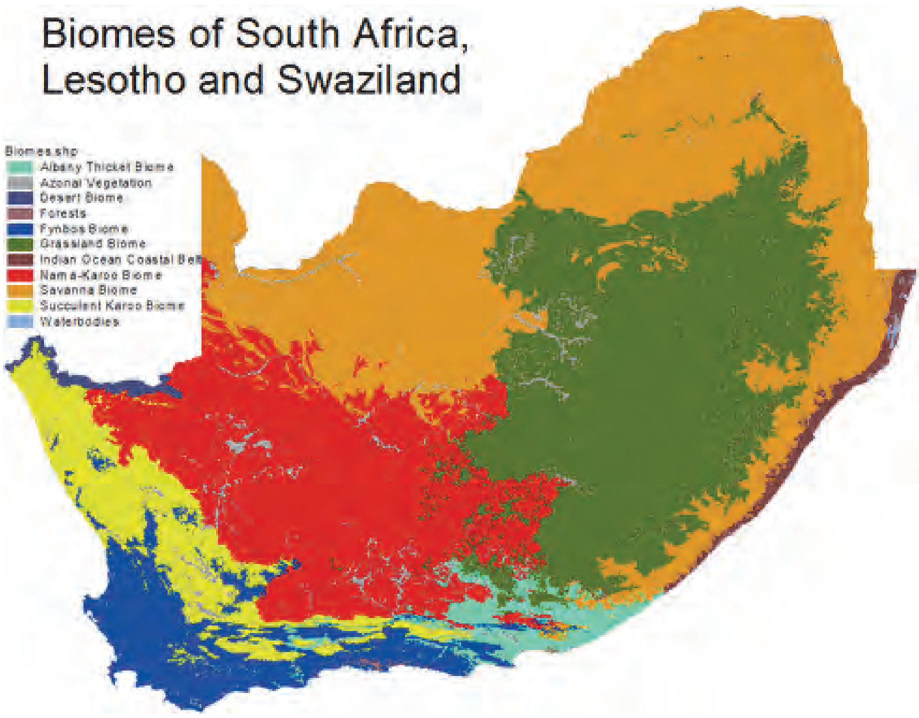


Figure 3-1: Distribution of the vegetation biomes of South Africa, Lesotho and Swaziland (Mucina and Rutherford, 2006).

3.1.1.2 Poverty

An important selection criterion for the three study regions was the level of poverty, since the main objective of this project was to determine the impact of fodder, food, energy and water security on the economic development of resource-poor farmers in rural areas. According to figures published in 2001 by the HSRC, approximately 57% of individuals in South Africa were living below the poverty income line in 2001. However, these figures do not give any indication of how far below the poverty line poor households are. For this the HSRC has used a measure called the poverty gap that measures the required annual income transfer to all poor households to bring them out of poverty (HSRC, 2001).

The poverty statistics from the 2001 HSRC study were given a ranking score by members of the project team according to the magnitude of the four criteria in Table 3-1 (population size, % of population in poverty, poverty gap and share of poverty gap). The top three criteria were ranked 3 (red), 2 (yellow) and 1 (purple) respectively. For example, KwaZulu-Natal scored highest (rank 3) for three of the criteria but 0 for the % population in poverty, to give a total score of 9 out of 12. Using this simple index, KwaZulu-Natal had the highest overall poverty index (9), followed by the Eastern Cape (8) and Limpopo (4) (Table 3-1).

Table 3-1: Incidence of poverty in the provinces of South Africa.

Province	No. of poor persons (million)	% of population in poverty	Poverty gap (R billion)	Share of poverty gap	Ranking Score
KwaZulu-Natal	5.7	61%	18.3	22.5%	9
Eastern Cape	4.6	72%	14.8	18.2%	8
Limpopo	4.1	77%	11.5	14.1%	4
Gauteng	3.7	42%	12.1	14.9%	2
Free State	1.8	68%	5.9	7.2%	1
Mpumalanga	1.8	57%	7.1	8.7%	0
North West	1.9	52%	6.1	7.5%	0
Western Cape	1.4	32%	4.1	5.0%	0
Northern Cape	0.5	61%	1.5	1.8%	0
South Africa	**25.7**	**57%**	**81.3**	**100.0%**	

3.1.1.3 Long-term Grazing Capacity

The long-term grazing capacity of an area is an important criterion for site selection since areas with high grazing capacity are necessary for livestock production. The grazing capacity is the number of hectares that are required to support grazing animals which are termed livestock units (LSU). A map of the long-term grazing capacity for South Africa (Figure 3-2) shows that the most suitable areas for livestock grazing are in the Limpopo, Mpumalanga, KwaZulu-Natal and the Eastern Cape provinces where the number of hectares/LSU was generally <9. We considered anything greater than 9 to be too large an area to support animals for biogas production.

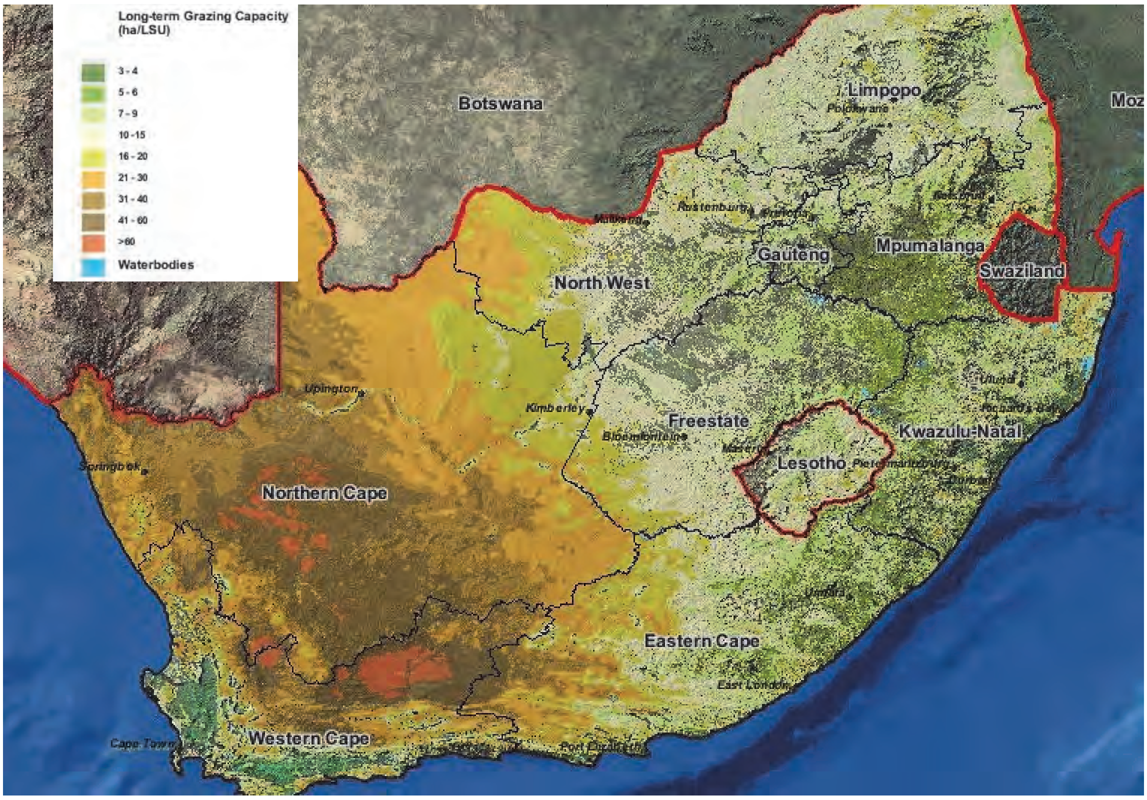


Figure 3-2: Long-term grazing capacity in South Africa.

3.1.1.4 Land Degradation

Degradation is an important form of land transformation and one of South Africa's most critical environmental issues. Land degradation is intricately linked to food security and poverty (DEAT, 2011). Areas of severe land degradation in South Africa are perceived to correspond closely with the distribution of communal rangelands, specifically in the steeply sloping environments adjacent to the escarpment in Limpopo, KwaZulu-Natal, and the Eastern Cape (Figure 3-3). These areas were therefore targeted as important in the selection of the study sites as the project aims to ultimately reduce land degradation through reducing grazing pressure through the introduction of alternative fodder resources through water provision from rainwater harvesting.

3.1.1.5 Biogas potential

In their report "South African: Domestic Biogas Feasibility Study", Austin and Blignaut (2008) state that the provinces with the best technical potential for biogas are KwaZulu-Natal, Limpopo and the Eastern Cape. The study will therefore target rural communities living in these provinces**.**

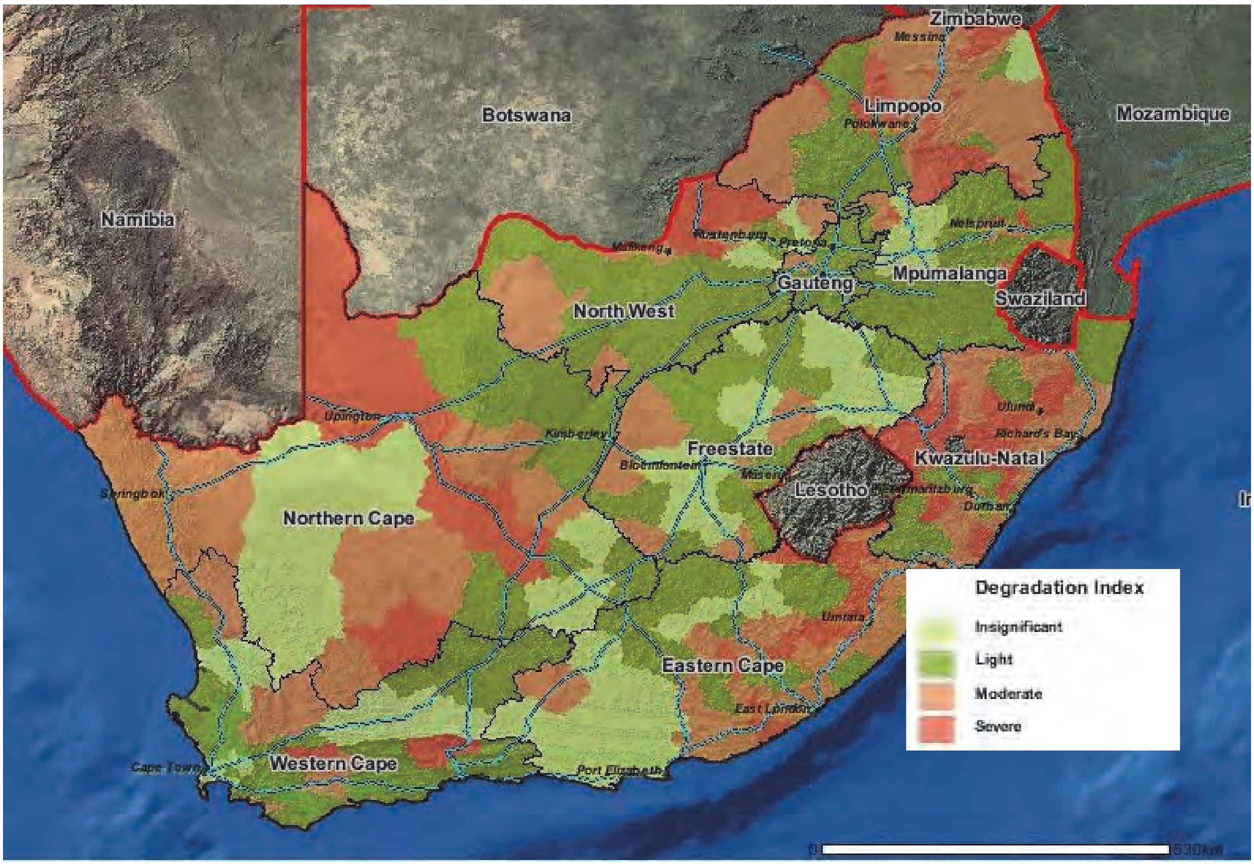


Figure 3-3: Map of South Africa showing extent of land degradation.

3.1.2 Regional level criteria for site selection

- High and low rainfall areas
- Geographical variation (topography, etc.)

3.1.3 Community level criteria for site selection

- Willingness to cooperate
- Disadvantaged, rural communities
- Good relationship of team members with community

3.1.4 Household level criteria for site selection

- Access to 20 kg of manure, requiring an estimated 4 head of cattle, for a 6 m^3 biodigester producing 1m^3 biogas per day sufficient for a large family of 7-10 people. The project may want to consider smaller biodigesters.
- Sufficient water ±20-50 litres (including waste water and, if possible, water from existing rainwater harvesting techniques), accessible within a range of 1 km to water source (walking/fetching distance)
- Preference to those with no access to electricity, but not exclusively as benefits to households with electricity may be very different
- Different income ranges, but with sufficient income and commitment to pay required fee (monthly service fee or equipment instalment fee) varying per business model
- Female-headed and male-headed households
- Different herd sizes, and different ways of looking after cattle
- Interest and commitment to improve livestock management practice
- Existing secure livestock management system (kraal)

3.2 INDICATORS FOR SELECTION OF STUDY SITES

The indicators used for the selection of the study sites were based on a framework developed by the International Energy Agency (IAEA, 2005). The framework is divided into the four dimensions which underlie sustainable development: social, economic, environmental and institutional. The indicators were used as aids in the decision-making process of selecting the study sites. However, not all of the indicators were applicable in every situation. Indicators were examined for six potential study sites (Giyani, Vleifontein, Msinga, Okhombe, Mgwalana and Machubeni). Only the successful sites are outlined below.

3.2.1 Environmental dimension

Since the production of biogas requires water and manure, access to these will be critical for the success of the project. It is noted that in some cases the use of already-used water may be adequate, i.e. there is no requirement to add the burden to households of obtaining a marginal increased amount of fresh water to their current consumption. The production of manure will be related to availability of fodder which will be determined by the vegetation type. To test the feasibility of biogas implementation under variable environmental conditions, sites will be selected that cover high and low rainfall areas and which have variable topography.

3.2.2 Social Dimension

An important social factor will be the willingness of the community to co-operate in the project. This will be related to the relationship that the team members have with the communities, existing projects and the potential benefits to disadvantaged, rural communities.

3.2.3 Economic Dimension

One of the main economic factors that will influence the success of biogas technology is the level of poverty. Although poorer households will benefit most from the availability of biogas, limited income and access to adequate quantities of manure may prevent poorer households from participating in the project. A range in income groups within a region would enable comparisons to be made on the degree of income distribution on uptake of biogas technology.

3.2.4 Institutional Dimension

Institutional indicators may be a measure of the potential effectiveness of the project at specific study sites. The strength of community organizations at the different study sites and their adequacy and effectiveness in institutional aspects will be a positive factor in site selection.

3.3 EASTERN CAPE STUDY SITE: MACHUBENI

3.3.1 Environmental Dimension

Machubeni is situated in the Eastern Cape Province (31°34'S; 27°11'E) in the former Transkei (Figure 3-4). The Machubeni area lies in the upper reaches of the Cacadu catchment area. It is 40 km south west of Indwe and 20 km north of Lady Frere towns. It falls under the Emalahleni Local Municipality, which is part of the Chris Hani District nodal area and comprises 16150 ha of land (Shackleton and Gambiza, 2008). It is worth noting that during 2010 six biogas digesters were installed within the Chris Hani District Municipality (CHDM), at five different schools.

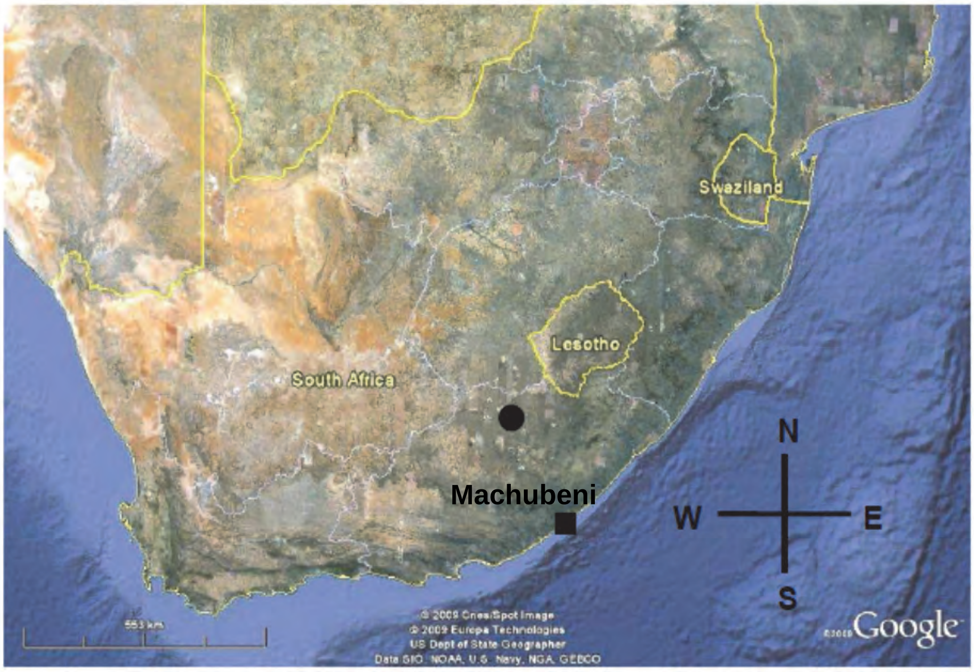


Figure 3-4: The location of Machubeni in the Eastern Cape Province, South Africa.

In 2004 there were 14 villages consisting of about 700 households and a population of 7800 with an annual growth rate of 0.6% (Ikhwezi Development, 2004a). The area was readjusted recently to include an extra three villages to make a total of 17 villages defined by the community (Bolus, 2009).

Machubeni is characterized by a catchment basin which is surrounded by mountains with cultivated lands found on the arable lands next to the Cacadu River (Bolus, 2009). The Cacadu River drains into the Machubeni dam and supplies water to the Emalahleni local municipality. Rainfall is erratic and droughts are frequent. The mean annual rainfall is about 711 mm. It falls in the summer between October and March. The temperature ranges from a mean maximum of 13°C in July to 20°C in December (Weather SA, 2006). The altitude ranges between 1300 m and 2100 m with valley floors and villages found at about 1500 m (Bolus, 2009).

Mountains surrounding the catchment are steep and the underlying geology is a mosaic of mudstones and sandstones with dolerite intrusions (Shackleton and Gambiza, 2008). Shallow lithosols are found in grazing areas with deeper duplex soils found next to the river where arable lands are. The duplex soils are highly erodible and most soils in the area show signs of sheet and gully erosion (Ikhwezi Development, 2004a). Rangeland degradation resulting in severe erosion is a major environmental threat. The prevalence of soil erosion has resulted in some agricultural lands being taken out of cultivation to save the soils (Ikhwezi Development, 2004a).

Low and Rebelo (1996) described the vegetation as part of the South-eastern Mountain Grassland which is specifically called the Tsomo grassland (Mucina and Rutherford, 2006). The grassland is described as having a high basal cover but with low grazing potential. The dominant grass species are *Elionurus muticus, Festuca* species, *Heteropogon contortus, Themeda triandra* and a number of forb species. Overgrazing and cultivation of highly erodible soils have been highlighted as major causes of erosion and land degradation. The use of rainwater harvesting to provide water for fodder production therefore has the potential to relieve the grazing pressure on this land.

3.3.2 Social dimension

Machubeni qualifies as a potential site in terms of poverty as it has a low level of formal employment (Ikhwezi Development, 2003). Welfare grants contribute about 50% to household income while livestock sales and cash remittances contribute 14%. Only five of the 17 villages have access to electricity at the household level while only two villages have bulk water supply through communal stand pipes. The project will therefore be able to determine the economic feasibility of biogas production in households with no access electricity. Other villages have to collect water from rivers and streams (Ikhwezi Development, 2003) which will enable the impact of the rainwater harvesting component of this project to be determined under these conditions.

3.3.3 Economic dimension

The dominant livelihood strategies are livestock (25%) and crops (8%). Maize is the main crop grown. Livestock has a large economic potential because of its commercial value, the production of by-products, use and cultural values (Bolus, 2009). Livestock are estimated to be stocked at more than three times the recommended rate (Ikhwezi Development, 2004b). One third of households own ruminant livestock. Up to 65% of households have no local livelihood strategies at all (Ikhwezi Development, 2004a).

3.3.4 Institutional dimension

The break down in grazing regulation institutions has been attributed as one of the main reasons for high levels of erosion in grazing areas and agricultural lands. From an institutional perspective the CHDM are already supportive of biogas use within the area, and will be approached for providing additional support to this project. One of the project team members has had a good working relationship with the community since 2004 through a government relief project on rehabilitation. This positive relationship will be a key factor in the selection of this study site. In addition, the development of an organization for the management of the environment and the administration of the institutional aspects will provide the foundation for the integrated biogas project.

3.4 KWAZULU-NATAL STUDY SITE: OKHOMBE

3.4.1 Environmental Dimension

Okhombe is situated in the foothills of the KwaZulu-Natal Drakensberg Mountains between the Royal Natal and the Cathedral Peak National Parks (Figure 3-5). The Drakensberg mountains in KwaZulu-Natal form a continuous crescent-shaped escarpment situated between 160 and 240 km inland of the east coast of South Africa varying in altitude between 1380 m and 3350 m. The KwaZulu-Natal Drakensberg lies in the summer rainfall area of South Africa. The Okhombe ward is located in the KwaZulu-Natal province of South Africa in the Bergville district (28°30’27” S and 29°00’23” E). This ward is located between 1200 m to 1800 m altitude and this higher altitude and the proximity to the Drakensberg results in cool dry winters and warm wet summers. Mean annual rainfall ranges from a minimum of 800 mm to 1265 mm per year with the higher altitude receiving more rainfall. Okhombe has a sub-humid climate. The high amount of precipitation that occurs in the summer period has led to significant leaching of the major soils in the area and heavy erosion along the slopes. This has resulted in the region experiencing shortage of fodder as a result of these conditions (Tau, 2005).

Okhombe rangelands are characterized by sour grasslands. Due to the leaching of vital nutrients by heavy rainfall, the veld type generally occurs in acid soil that is poor in nutrients. The sour grassveld is palatable for only six to nine months of the year from early spring (October/November) to winter (May/June) after which the grass palatability and quality declines rapidly. As a result its forage value is poor in winter. Fodder shortage, especially during the dry winter season, is one of the main problems facing rural livestock owners in Okhombe. This project intends to address fodder shortage and energy issues, and as a result, Okhombe village does qualify as a site for this Water Research Commission (WRC) project.

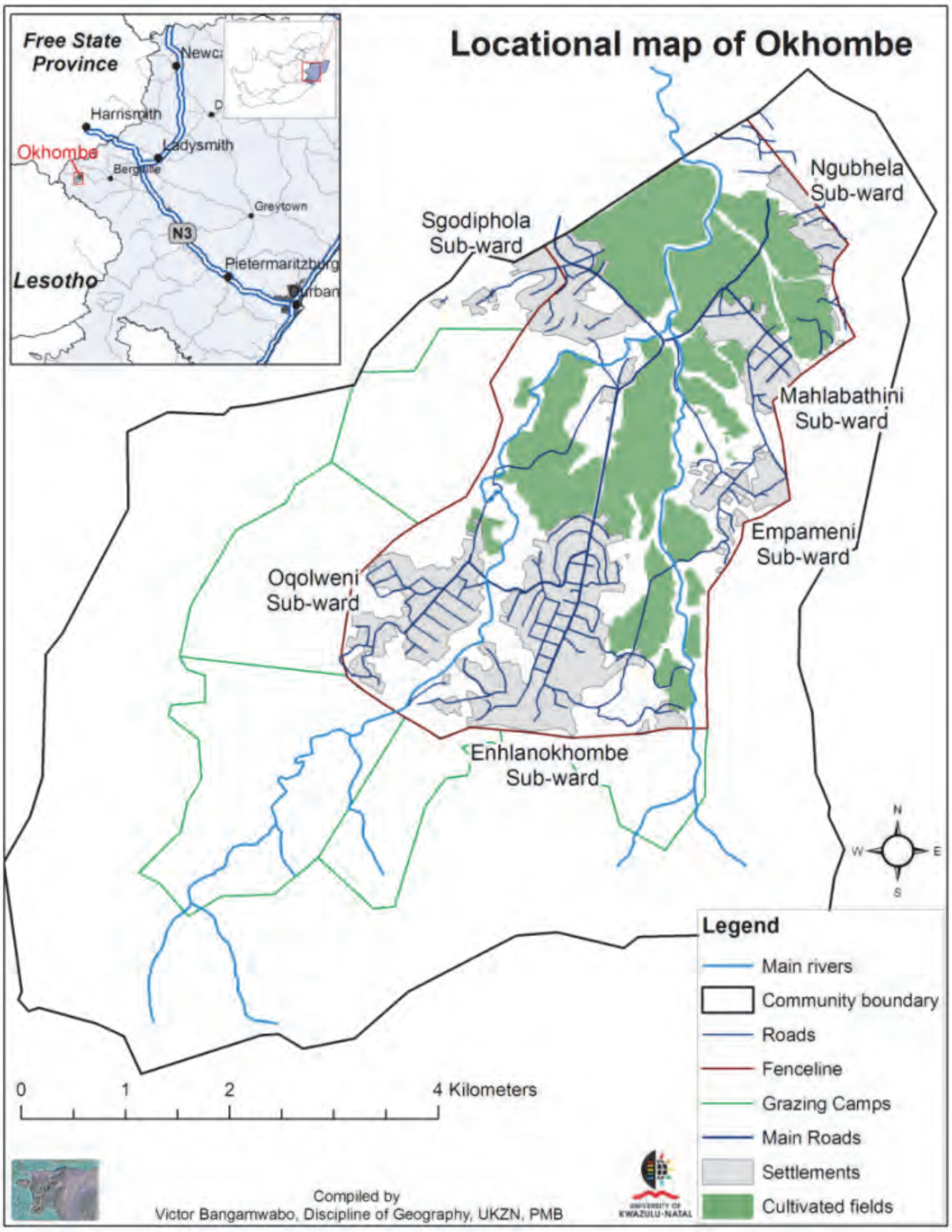


Figure 3-5: Location of research site Okhombe, and insert western KwaZulu-Natal (Salomon, 2010).

3.4.2 Social dimension

Okhombe land is communal whereby every member of the Okhombe community is the legal owner of the rangeland with individual ownership of stock. While some households have breadwinners working in Gauteng and other metro areas, the majority of the community still rely heavily on their natural resources for their daily living (e.g. soil, fuelwood, stream water, subsistence farming). The people of Okhombe are generally extremely poor and depend on limited employment income, pensions, welfare payments and income from migrant labour who work on the mines in Gauteng. There are a wide variety of informal economic activities to enhance food security and generate income. This is an extremely disadvantaged community that fulfils the poverty criterion.

Various project team members have a good relationship with the community through previous projects such as the LandCare project, a Water Research Commission (WRC) project and the recent Maloti Drakensberg Transfrontier Project. The team worked on institutional arrangements, building capacity and piloting various livelihoods projects. For instance, the relationship between the project leader and the community dates back to 1992 when nursery projects were introduced to the community. The community has been very cooperative working with the project team and is willing to pilot any natural research management research brought in their area.

3.4.3 Economic dimension

In Okhombe women's role in cattle management is becoming more and more important. Discussions noted during the participatory rural appraisal exercises in the area, particularly from the ranking matrix exercises revealed that cattle management is influenced to a large extent by lack of men in the area. The absence of men through the migrant labour system, and the unavailability of school-going boys have resulted in women increasingly becoming herders, owners and managers of cattle. It is therefore necessary that women kraal their cattle every night, because they do not have time to trace stolen cattle. Calves of the milking cows are kept in kraals everyday to keep their mothers near the homesteads. Almost all stock owners own kraals in their homesteads. This system of kraaling cattle every night offers a great opportunity for the project to achieve its goals.

The existing community gardens were either established near the river or wetlands or where there is an existing community borehole. Okhombe village also experiences high rainfall which offers an opportunity for water harvesting during summer and the use of streams during winter to maintain the biodigester and the fodder banks. The availability of a minimum of 20 litres a day in the area is possible. The keeping of cattle in the kraals is an existing popular system in Okhombe and this will enable the project team to select potential stock owners to participate in the trial.

3.4.4 Institutional dimension

Various natural resource management projects that have been introduced in the area since the 1990's have led to the successful development of local organizations such as the Okhombe Monitoring Group and the Livestock Committee. These groups have over the years shown commitment and willingness to participate in research projects, and pilot natural resource management projects and determine institutional aspects to ensure their success. For instance, in the early 1990's various organizations set up a community garden, initiated a tree project (nursery) and introduced a tree educational project. The existing community gardens provide a perfect opportunity for establishing fodder banks for the biogas project. In a LandCare project, the Livestock Committee piloted the development and implementation of a communal grazing management plan and promoted the willingness from the community to show ownership of the project. The WRC biogas project can use the existing skills and institutions built in the past to introduce the new biodigester project.

3.5 LIMPOPO PROVINCE STUDY SITE: VLEIFONTEIN

3.5.1 Environmental Dimension

Vleifontein is a village in the in Makhado municipality area of the Limpopo province (23°12'52.00" S, 29°59'35.00" E) which is situated 100 km from the Zimbabwean border. The rural area is the most underdeveloped with large open sections which are used for farming purposes (IDP, 2010). Makhado Municipality has inadequate and fragmented water service provision which implies that less water will be available for agriculture, which is one of the pillars of the economy. Most rural villages do not have access to water per household stand. Provision of water is limited and some villages do not meet the RDP's minimum standard of water (e.g. Water provision should be within 200 m from the household; 20-25 litres per capita per day).

Most of the rural areas are utilised for extensive farming purposes resulting in these areas being under constant threat of environmental degradation. Most cattle owners view their cattle as a status symbol rather than economic entities, which contribute towards the problem of overgrazing (IDP, 2010).

3.5.2 Social dimension

The majority of the people in Vleifontein live in rural communities. Small-scale livestock, agriculture and harvest of natural resources contribute to the welfare of most people in the villages. The presence of livestock ensures that there is a lot of cow dung available for biogas production in all villages. Although many people are involved in these activities, unemployment is 54% on average, but much higher in most villages.

3.5.3 Economic dimension

At present the local economy is not able to provide sufficient employment opportunities to provide the needs of the economically active population in Vleifontein. Most people heavily depend on the government, either because they are employed by the government or projects financed by the government, or because they depend on transfers from the government such as child grants and public pensions.

The majority of the population in the Makhado municipality live in the rural areas and nearly 50% of the population is younger than 15 years (IDP, 2010). The rural area is also the most underdeveloped area. The largest percentage of the rural black population between the ages of 15-65 years comprises women. This can be attributed to the men being involved in migrant labour. The high level of male absenteeism implies that women make day-to-day household decisions.

The activities that mostly take place in Vleifontein are small-scale agriculture (maize, vegetables, tomatoes, beef), transport and retail development. According to the IDP (2010), agriculture drives the formal economy of Vleifontein, and is the third highest employer within the Makhado municipality. However, it is undergoing a serious decline due to the climatic conditions. In addition to climatic conditions, the municipality identified the following obstacles for economic development: geographical location (distance to markets), shortage of skills, poor infrastructure, and diseases.

3.5.4 Institutional dimension

The Makhado municipality is made up of wards which are governed by elected councillors and ward committees which have been recently been re-launched. There are also traditional leaders who are ex-officio members of the municipal council. According to the IDP (2010), the SMME sector lacks institutional arrangements and structure.

3.6 CONSULTATION AND OBTAINING ENDORSEMENT FOR PARTICIPATION BY HOUSEHOLDS IN SELECTED RURAL VILLAGES

The project team felt that a critical issue was the need to standardize the process of obtaining community endorsement and selecting households across the three provinces. To complete this critical, complex and time-consuming process various activities (outlined in Table 3-2) were carried out in all three provinces.

Table 3-2/….

Table 3-2: Process to obtain community endorsement of household selection.

Action	Purpose/need to be addressed	Description
1.Teleconference: Discussion of household criteria	Criteria needed for a rural household to be selected as part of the WRC Biogas Project	Criteria including the access to 20 l of water and 20 kg of cow dung (as found in *SA National Biogas Feasibility Study, Austin and Blignaut, 2008*) are basic requirements for the successful running of a biodigester system. These and other criteria need to be present for a household to manage a digester successfully. The reference team agreed upon seven criteria which must be met and/or description must be provided for the reference team to base nominations on.
2. Creation: of an introductory presentation	Introduce the concept of a biodigester, biogas and bio-slurry effluent (fertiliser) in a simple way	A *Power Point* presentation was developed to introduce the biodigester system to the community members involved in the household nomination process. This presentation was designed in such a way that it would present a relatively complex system in a simple way. Graphical representations and basic language was used in the presentation so as to appeal to a potentially illiterate and uneducated group of people.
3.Creation: of introductory pamphlet, including nomination forms	Introduce the WRC biogas Project, the concept of a biodigester and related outputs and the household nomination process to community members	An introduction to the WRC Biogas Project and biodigester systems was compiled in brief pamphlet form to support the introductory presentations given to community members. The pamphlet was a useful tool for attendees to revisit some of the issues discussed. It also provided the opportunity for those community members who were unable to attend the introductory presentations to read about the project. Included in the pamphlet is a nomination form, which community members were asked to fill in for the households they nominated for the biodigester installment.
4.Translation: of pamphlet	For non-English speaking communities	The introductory pamphlet was translated into the relevant community's home language by a translator. Although some community members can both read and write English, most are only able to speak their home language.
5.Community meeting: Introductory presentation and	Introduce the WRC biogas Project, the concept of a biodigester and related outputs and the household nomination process to	Community meetings were held in the relevant villages to introduce the concept of a biodigester and its related outputs and to introduce the WRC Biogas Project that may be instigated in their villages. The household nominations procedure was also introduced. It is highly important to have communities actively involved in a household selection process. Experience has shown that communities tend to support a project and the

Action	Purpose/need to be addressed	Description
nomination meeting (2 day process in each province)	community members	selection made if they are involved in the process. Community members were asked to have community discussions and put forward nominations of 5-6 households they thought plausible for biodigester installment. *Community meetings are slow and convoluted processes as it is necessary to conduct procedures in a manner which is culturally acceptable. Procedures include the need for translation (which slows the process), prayers before and after meetings and the provision of drinks and eats after or during a long meeting.*
6.Teleconference: Discussion of nomination procedure and criteria	Keep the project team informed on community activities and confirm procedures and criteria for selection	A teleconference provided the opportunity for team members who were involved in the community liaison process to report back to the reference group and confirm the process being used. This allowed for members of the different provinces to hear about the progress in each province and learn from each other's experiences. This teleconference also provided the opportunity to discuss required selection criteria before team members conducted the next stage of the process.
7.Community meeting: Review of nominated households (2 day process in each province)	Review the households that had been nominated	Community meetings were held with some of the members who had been involved in the first round of the nominations procedure. The nomination forms were returned to the project team members. In many cases the forms were partially or entirely incomplete and the meetings took some time as team members filled in the forms with the help of the community members. *As an anecdotal example of this process: in one meeting, one of the community members kept leaving the meeting to ask a child in a nearby school about his father's household for the purposes of filling in the form.* Each of the nominated households was then visited by the team members. The process was complex and slow as it became necessary to sit down with some household owners and explain in detail the purpose of the project and visit. The size of each plot was measured roughly and pictures were taken of all important household features (kraals, agriculture, water-harvesting, household size).
8.Teleconference: Selection of	Select households in each area	A teleconference will be held with the relevant reference group members to discuss the selection of households in each area. It has been identified by the reference group that a variety of households with

Action	Purpose/need to be addressed	Description
households		differences in size, cattle numbers, water-access and whether they are male or female headed would be beneficial to the investigation. For this purpose the teleconference is needed so that team members can select a variety of homes across the provinces. In each area a first and second choice household will be selected. Rural communities tend to be quite frugal and it is quite plausible that the household chosen may opt out of the project for some reason. The process has been carefully conducted, and the communities involved, to avoid these situations - they must, however, still be catered for.
9.Community meeting: Selected household discussed (2 day process in each province)	To introduce the selected household to the community and discuss the project with the respective household	Once the selection of each household has been made a community meeting needs to be conducted to inform the community members about which household has been selected for the project. It will be necessary to ask if there are any complaints about the selection and to ask for the community member's acceptance of the selected household. Once acceptance from the community has been achieved the team members will visit the relevant household and inform them of their selection for the projects. Again, their acceptance of the project will need to be gained and it will be necessary to inform them of the details of the project. Details will include the timeline of actions to be taken and the finer details of what will be involved in their participation. It is important that the household is made aware of all potential requirements and not made any promises that cannot be kept.

3.7 COMMUNITY LIAISON AND SELECTION PROCESS

The next phase of the selection process was the selection of the final households that would participate in the research project. The process that took place in KwaZulu-Natal is presented as a case-study here.

Project team members had worked in the Okhahlamba Local Municipality since the late 1990s and had developed relationships of trust with communities in the amaZizi and amaNgwane traditional areas. Using the agreed upon selection criteria (Box 1), the team reassessed their initial choice of Okhombe as the main site for research. Okhombe has been exposed to research and project work since 1992. Community members are active in research trials, recording data, and analysing findings. Thus, community capacity is well developed to engage in the biogas project.

In the past, the honourable Inkosi Miya expressed his desire that besides Okhombe, other neighbouring communities under his jurisdiction, should benefit from research and development endeavours by the University of KwaZulu-Natal. In the past few years, community members in Obonjaneni and New Stand, neighbouring villages of Okhombe, have become involved in projects in sustainable agriculture, natural resources management, and savings and credit. The savings and credit group is particularly well organized and can serve as a vehicle through which the biogas project can engage.

Box 1: Selection Criteria for Households.

- at least 4 head of cattle
- water supply of 20 litres per day
- land for biodigester, kraaling cattle, water harvesting, and fodder production (the "biogas system")
- labour to manage the biogas system
- produce food crops (to use the effluent)
- commitment to research
- labour and skill to manage the system and document the process
- inclusion of poorer, female-headed and/or child-headed households

Owing to research and development projects on sustainable water management since 2000, community members in Potshini, a village approximately 30 km from Okhombe, harvest rainwater in surface and underground tanks. The production of biogas requires a daily supply of 20 litres water, which the households who use rainwater harvesting can meet. The inclusion of one or two of these households in the biogas project will also allow for a comparison with biogas systems that rely on other means of water supply.

All four communities – Okhombe, Obonjaneni, New Stand and Potshini - are in regular contact with each other. They are all members of the Sivasimpilo Okhahlamba Farmer Forum which meets bi-monthly and is facilitated by the Farmer Support Group, where one of the project team members is based.

3.7.1 Meetings in community sites

In Okhombe, two meetings were held to introduce the project to community members – called co-researchers - involved in action research on communal cattle keeping (17 Feb 2011) and representatives from different committees in farming and natural resources management (25 Feb 2011). In Obonjaneni, a meeting was held with representatives from the livestock association, and savings and credit groups (25 Feb 2011). In Potshini and New Stand, a presentation was made to the Sivusimpilo Farmers Forum, and a meeting was held with representatives from different committees in farming and natural resources management (2 Mar 2011). During the meetings, the team explained the basic components of the biogas system by handing out brochures in isiZulu (Annexure 1), showing a Power Point presentation, and two short DVD's of different operational biodigester designs.

People posed many questions during the introductory meetings. They were interested in the technical process of producing biogas, whether chemicals were needed to generate biogas, and how long it takes. In some sites, people also wondered whether biogas could power a television. There was particular concern about safety and the risk of explosions when producing and using biogas.

3.7.2 Nomination of households

In Okhombe, the co-researchers nominated seven households. The project team visited each household, checked the data on the nomination forms, and took photos of the lay-out of each homestead (24 Mar 2011). Using the selection criteria, three households were chosen and ranked by two co-researchers and the village headman Induna Xaba (15 Mar 2011).

In Obonjaneni, eight members of the savings and credit groups submitted a nomination form. All members of the savings and credit group were then asked to select four household. They then visited each homestead with the project team, who checked the data on the nomination form and took photos of the lay-out of the homestead. One of the four nominated households did not qualify because they had no livestock, which resulted in three nominations (31 Mar 2011).

In Potshini, the community facilitator submitted three forms of household which were interested in the biogas project. In New Stand the Farmer Support Group submitted a nomination. The project team and community facilitator visited each household, they checked the data on the nomination form, and took photos of the lay-out of the homestead (1 Apr 2011).

3.7.3 Selection of households

The full project team reviewed the nominations of all sites, and made a selection of households to ensure that the range of households in terms of herd size, land size, resources, and gender, were included (Table 3-3). One household was selected in the villages of Okhombe, Obonjaneni, New Stand and Potshini.

Site visits were then scheduled to assess the location and land size of each selected household and ensure that all households met the technical requirements. The final decision was discussed with traditional leaders and/or community representatives, and fed back to the selected households.

Table 3-3: Example of household nomination form for Mr Khumalo in KwaZulu-Natal.

FORM FOR HOUSEHOLDS NOMINATED FOR WRC BIOGAS PROJECT	
Full name	Velum W. Khumalo
Community site	Okhombe, Mahlabathini S28° 42’ 13.5’’ E29° 05’ 50.1’’ (#1) Plate 3.1
CRITERIA	**DESCRIPTION OF EVIDENCE AT HOUSEHOLD**
1. Number of cattle	4 head
2. Water supply of 20 l per day	Spring 5-10m from household
3. Land for biodigester, kraaling cattle, water harvesting, and fodder production (the “biogas system”)	Large 238 X 112 (male steps) Cattle kraaled overnight
4. Labour to manage the biogas system	2 Pensioners 1 younger female (22years) 1 baby TOTAL: 4
5. Produce food crops (to use the effluent)	Extensive Maize
6. Commitment to research	Involved in SaveAct Involved in ISA Happy to be involved in research
7. Labour and skill to manage the system and document the process	Yes
8. Include poorer, female-headed and/or child-headed households	No external income Survive on Mother + Father pensions
9. Nominated by	Dubazane: Excited about the project and always understands procedures. Motivated and serious about work.
10. Comments	Large area of lands with extensive cropping (possibly too much). Clear example of where fertiliser use has helped crops and non-fertiliser use resulted in crop failure.

Plate 3.1: Mr Khumalo's homestead.

3.8 CONCLUSION

An analysis of the criteria developed for the selection of the provinces (i.e. representative of the grassland and savanna biome, poverty, long-term grazing capacity, communal areas, land degradation and biogas potential) indicate that KwaZulu-Natal, Limpopo and the Eastern Cape are the most suitable provinces for implementation of the biogas project. Six potential study sites (Giyani, Vleifontein, Msinga, Okhombe, Mgwalana and Machubeni) were identified in these provinces using environmental, social, economic and institutional indicators, based on a framework developed by the International Energy Agency. The final sites selected were Vleifontein, Okhombe, and Machubeni, based on the regional and community level criteria developed by the project team:

- They are all rural areas in the selected provinces identified in the terms of reference.
- They cover high and low rainfall areas and have variable topography which will enable the feasibility of biogas implementation under variable environmental conditions to be determined.

The project team members have a good and long relationship with the disadvantaged communities living in each of these areas. Since developing trust and commitment with communities is a long process, the foundation that has been built by the project team in the three areas was critical to the success of the project.

CHAPTER 4: BIOGAS IMPLEMENTATION

by Smith M, Everson T Austin G, Langley K, Gambiza J and Tinarwo D

A total of 12 biodigesters were installed at separate sites in the EC, KZN and Limpopo. Table 4-1 summarises the details of the study sites.

Table 4-1: Details of biodigesters installed at various study sites.

Project team	Research site	Type
EC	Boomplaas	Agama BiogasPro6
EC	Tschamazimba	Agama BiogasPro6
EC	Tschamazimba	Agama SmartTop
EC	Nkunkulu	Agama SmartTop
EC	Plaatkop	Sintex
KZN	Obonjaneni	Agama BiogasPro6
KZN	New Stand	Agama BiogasPro6
KZN	Okhombe	Agama BiogasPro6
KZN	Potshini	Agama BiogasPro6
Limpopo	Nthabalala cooperative	Agama BiogasPro6
Limpopo	Maila crèche	Agama BiogasPro6
Limpopo	Maila crèche	Agama BiogasPro6

Figure 4-1: Biodigester en route to the Eastern Cape and KwaZulu-Natal.

4.1 IMPLEMENTATION BY PROVINCE

4.1.1 Biogas implementation – KwaZulu-Natal

The KZN team implemented biogas and rainwater harvesting systems in the uThukela catchment area in the Okhahlamba Local Municipality (See Section 3.4 for detail) (Plate 4.1). Four biodigesters were installed in this area. The details of these 'pilot households' are listed in Table 4-2 and their relative location to each other is shown in Plate 4.1.

Table 4-2: Details of the four KZN pilot households.

Household name	Place	Altitude (m)	Geo-graphic co-ordinates	Agriculture area (ha)	Water harvesting area (m^2)
Mrs Miya	New Stand	1346	28°41'0.53"S 29° 1'48.69"E	0.18	142
Mr Mdakane	Potshini	1346	28°49'13.46"S 29°21'56.76"E	1.12	25
Mr V Khumalo	Okhombe	1342	28°42'13.85"S 29° 5'50.39"E	0.84	50
Mrs E Khumalo	Obonjaneni	1363	28°41'18.97"S 28°59'34.80"E	0.22	105

Plate 4.1: Geographic location of the four KZN pilot households.

Plate 4.2: Installation of biodigesters in KZN.

Plate 4.3: Completed installation - clockwise from top left; Obonjaneni pilot site, New Stand pilot site, Potshini pilot site, Okhombe pilot site, in KZN.

4.1.2 *Biogas implementation – Eastern Cape*

Four of the five biodigesters installed in Machubeni were locally designed and manufactured by Agama Energy (Agama Energy). These prefabricated units are a variation of the fixed dome design, with inspection hatches added to allow access to both the reactor chamber as well as the gas chamber (Plate 4.4). The fifth biodigester installed was an imported “Deenbandhu style” biodigester produced by Sintex in India. Notable differences between these two types are the ease of access and increased reactor and gas chamber volume afforded by the Agama biodigesters. All five biodigesters were installed at separate households.

Plate 4.4: Left to Right: (a) 'Biogas Pro', (b) 'Biogas Smart-Top' (c) 'Deenbandhu Sintex'
Source: (Agama Energy).

The installation of the prefabricated units went smoothly. Community members dug the holes (Plate 4.5). The units were covered with soil to insulate them and to prevent accidental damage.

Plate 4.5: Clockwise from top left: (a) Biogas Pro digester before installation (b) Biogas Pro digester installed and insulated (c) Indian Syntex before installation and (d) Moisture trap (brick structure in foreground) in relation to biodigester.

The installation of the smart top biodigesters was complicated as these units are only partly prefabricated, requiring the reaction chamber to be cast in concrete (Plate 4.6). This was hampered by inclement weather and the long 'curing' time of the reinforced concrete. This biodigester design requires additional labour, with the benefit of a larger reaction chamber, allowing hypothetically for more biogas to be produced.

Plate 4.6: Clockwise from top left: (a) expanding the initial hole due to collapse, (b) flooding of the site, (c) concrete frame completed (d) final view before coverage.

4.1.3 Biogas implementation – Limpopo

Three Agama BiogasPro6 digesters were installed at two study sites in Limpopo. Two biodigesters were installed at Maila Crèche for feeding with chicken manure and cow manure, and the third digester was installed at Nthabalala cooperative.

The Nthabalala cooperative is owned and run by the local Nthabalala community. The site consists of a piece of land with donated infrastructure including a broiler hen shed, rearing shed and other out-buildings which are intended for community use.

Plate 4.7: Pictures showing the biodigester and slurry outlet pipe installed at Nthabalala.

The Maila crèche consists of a pre-school crèche with 95 students in 2013 and a linked farming cooperative run by a group of woman from the surrounding community. Farming activity included three layer hen sheds, currently with 3 500 laying hens, and a farming initiative including maize, beetroot, spinach, butternut and cabbage, amongst other vegetables – for consumption at the crèche and for sale at local markets.

Plate 4.8: Biodigesters installed at Maila crèche.

The digesters at Maila crèche are fed with differing wastes. One of the digesters is fed with chicken manure only and the other is fed predominantly with cow manure and with some vegetable wastes (Plate 4.9).

Plate 4.9: Biodigester feedstock, chicken manure (left) and cow manure (right) at Maila crèche.

4.2 BASELINE SURVEYS

The following set of results were generated from the baseline survey conducted in Okhombe and are extracted from Smith (2011: 127-145).

4.2.1 Demographics

Of the 120 valid households that made up the sample group the minimum household size was one person, the maximum was 14 people and the mode was four people. The average household size was 5.39 people which correlated closely with information from IES (2001) and Statistics South Africa statistics (1996) which revealed an average household size of 5.47 people.

The range of combined household stated monthly incomes was R25 to R7 000.00 with a mean monthly income of R1 089.63. This mean stated monthly income indicates that the average per capita income was R202.10 which is substantially below the R235 poverty line used by The Presidency of South Africa as an indicator of relative poverty in 2009 (The Presidency, 2009).

The distribution of stated monthly household income revealed that the majority of households (33.3%) received an income between R1 001.00 and R 1500.00 per month. 96% of the sample population received a stated monthly household income of less than R2 501.00, with the remainder (only 4.2%) earning above R2 501.00. Figure 4-2 graphically displays the distribution of income across the sample population (R is used interchangeably to represent Rand (R) – South African Rands).

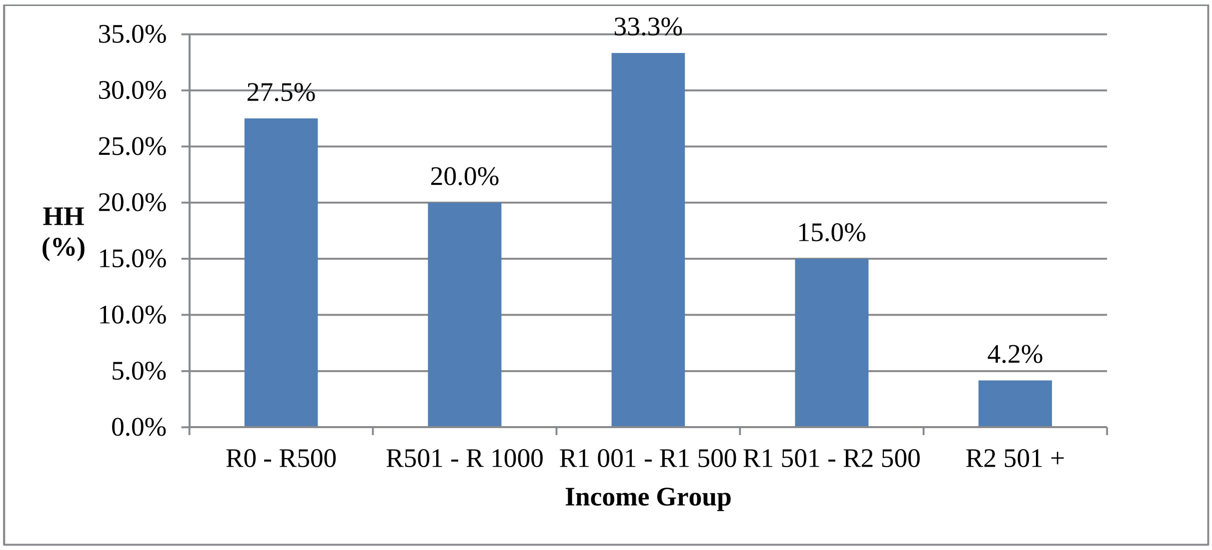


Figure 4-2: The distribution of stated monthly household income in Okhombe. (Note: HH represents 'households') Energy Use Profile.

The energy use profile for the sample group is important in the valuation of costs and benefits. Where households used multiple fuels for specific activities, they were asked to state the order of fuel use, from fuel used most often to least often. The top three ranking fuels were classified as primary (most used) followed by secondary and tertiary (least used). The potential saving from fuel switching (using biogas in place of other energy forms) is dependent on the cooking fuels that are originally used by a household.

4.2.1.1 Electrification of Households

One third of the sample group had electricity in their households and there was no distinction between the stated cost of use in summer and winter. The majority of households were connected to the national electricity grid in the 1990s, with the exception of four respondents (3.3%) who were connected after the year 2000.

4.2.1.2 Energy Forms Used for Household Lighting

The graphical representation of energy forms used for lighting households in the sample group (Figure 4-3) clearly shows that candles were the most widely used primary energy for lighting (65.8%). Electricity was the next most used primary source of lighting at 31.7%.

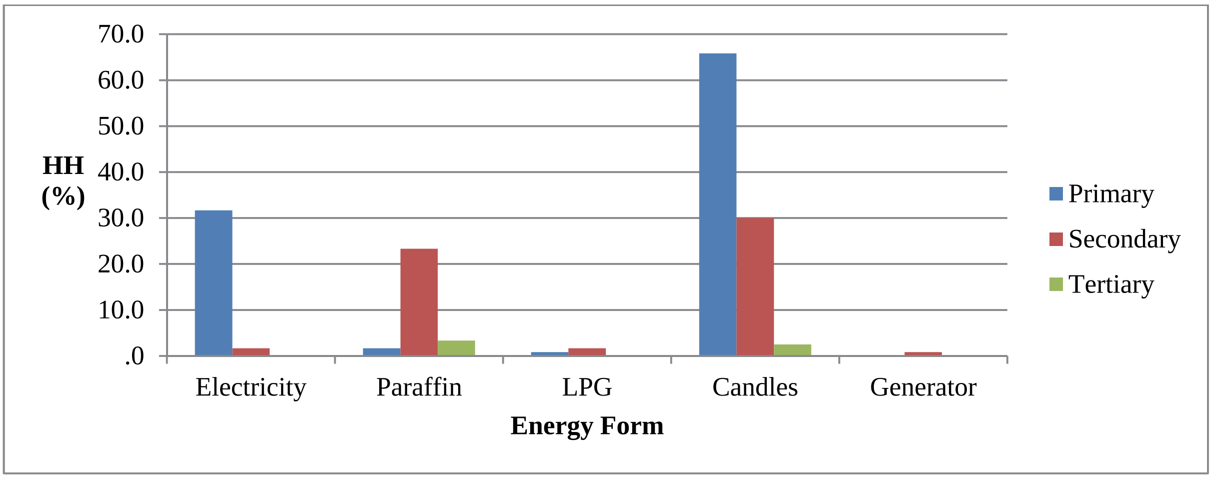


Figure 4-3: Percentage of households using different energy forms for lighting.

4.2.1.3 Energy Forms Used for Cooking

Firewood is the most widely used form of energy with 90.0% of households making use of it for cooking. For the purpose of cooking, firewood is the most commonly used primary energy (47.5%), paraffin is second (25.8%) and electricity (21.7%) is third. The most commonly used secondary energy form is paraffin (40.8%) and dung is used by 52.5% of households as a tertiary source of energy. The full results of the energy use profile for cooking is graphically portrayed in Figure 4-4.

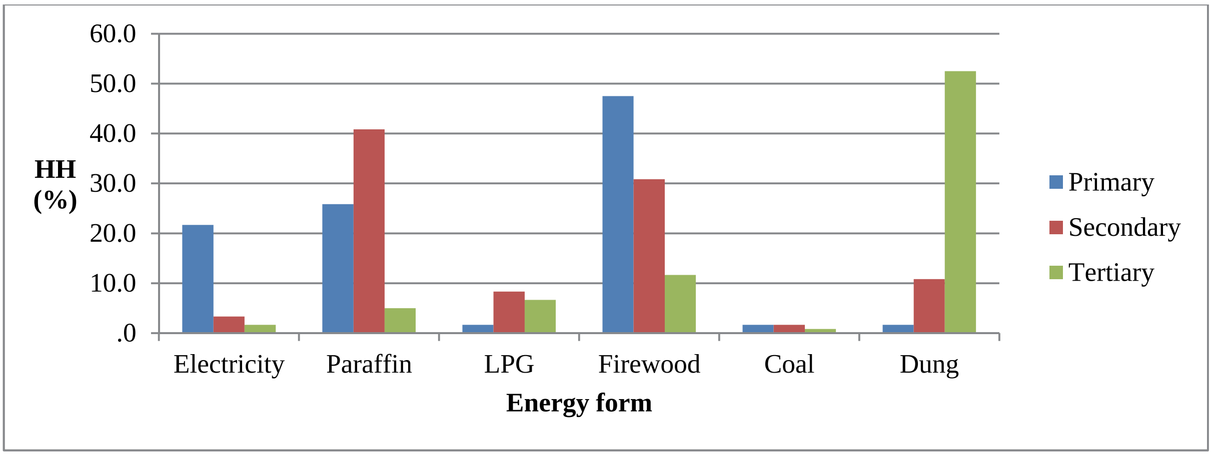


Figure 4-4: Percentage of households using different energy forms for cooking.

4.2.1.4 Energy Forms Used for Thermal Heating in Households.

Figure 4-5 clearly shows that firewood (67.5%) is the primary source of energy for heating households, followed by paraffin (9.2%) and electricity (8.3%). Cow dung was the predominant secondary source of heating (56.7%) and was the only registered tertiary source for heating.

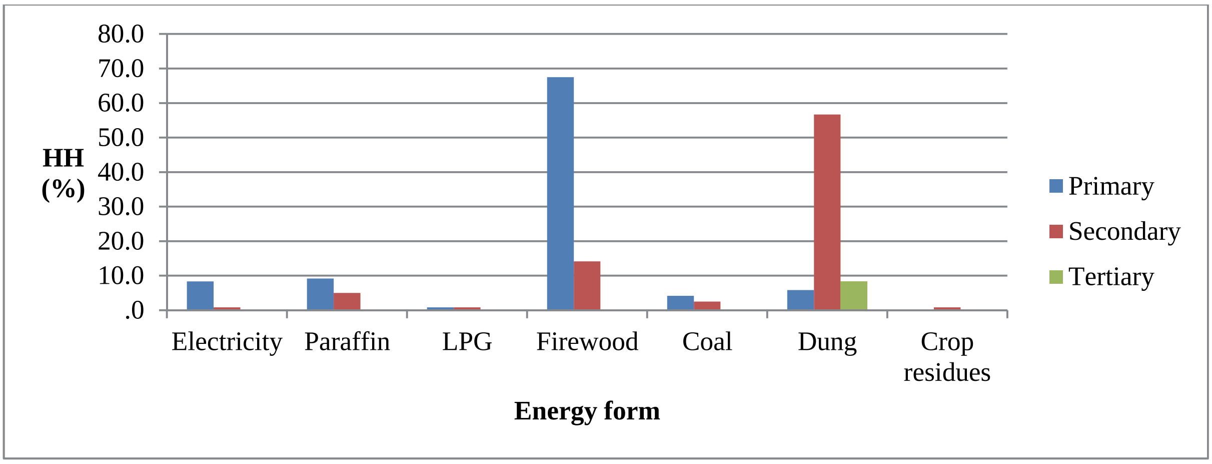


Figure 4-5: Percentage of households using different energy forms for thermal heating.

4.2.2 Water Source and Collection

4.2.2.1 Source of Collection

Municipal community stand taps and boreholes were the most common sources of water with 34.2% and 30.0% of households collecting at each source respectively (Figure 4-6). River or streams were the next most used source of primary collection as well as being the most used secondary source of water collection. No households had municipal water inside their houses and 13.3% of households had a municipal tap directly outside their households.

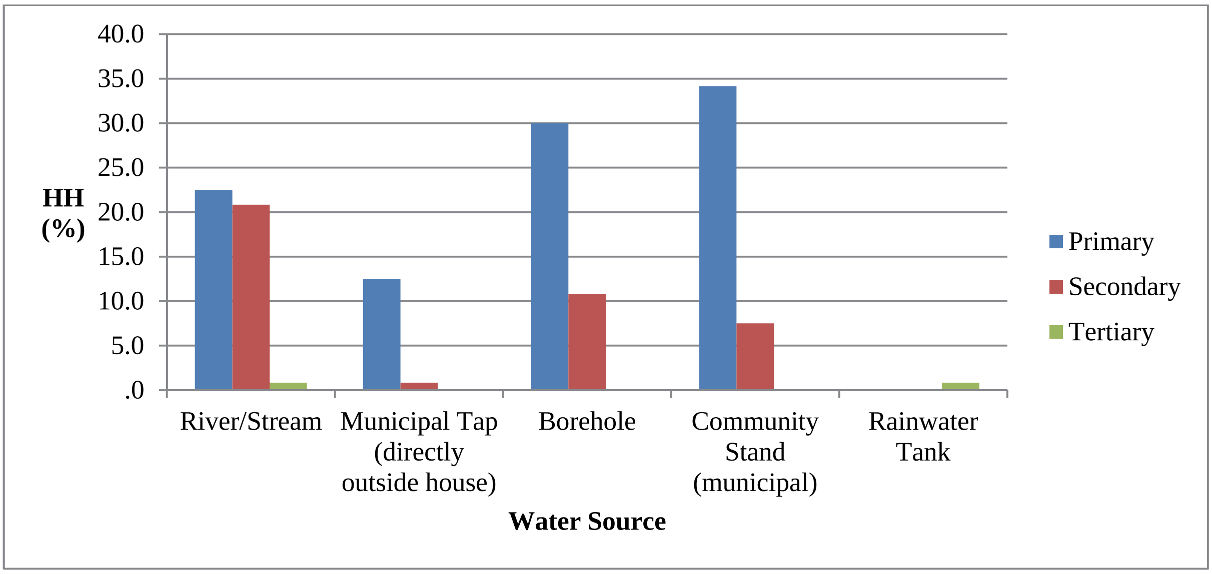


Figure 4-6: Percentage of households collecting water at different sources.

4.2.2.2 Details of Water Collection

The source of collection ranged from being 2 metres to 1 km away from the respondents' homes, with a mean distance of 309 metres (Table 4-3). The average amount of time spent collecting water was 25 minutes per day and the average quantity used per household was 62 litres per day. The average time spent collecting a 20 litre bucket of water is relevant to the assessment of time spent feeding a biodigester and was calculated at 8 minutes and 6 seconds (i.e. 8.1 minutes).

Table 4-3: Details of water collection.

DETAILS OF WATER COLLECTION				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**
Source distance (m)	2	1000	308.61	289.793
Time spent collecting per day (minutes)	1	120	25.29	20.324
Quantity used per day (litres)	10	140	61.93	22.960
Average time taken to collect 20 litres of water				**8.1 minutes**

4.2.3 Farming Practices

The results of the survey, summarised in Table 4-4, showed that over 84% of households grew their own vegetables, but only 3.3% of households grew fodder for cattle with, "not being able to afford it" being the most commonly quoted (36.7%) reason for not growing fodder for cattle. The use of fertiliser was prevalent, with all households that grew vegetables using some form of fertiliser and with 79.2%[1] of households buying chemical fertilisers. The most frequently used chemical fertiliser was NPK (321)[2] which was used by 84.2% of fertiliser buyers and DAP[3] which was purchased by 12.6% of buyers. The average quantity of fertiliser used across the sample group was 83.17 kg and the average cost of fertiliser used per year was R365.98.

Table 4-4: Details of standard farming activity and practice.

STANDARD FARMING PRACTICE	
Households that grow own vegetables (%)	84.17
Households that grow fodder for cattle (%)	3.33
Households that use fertiliser for growing crops (%)	84.17
Households that purchase fertiliser (%)	79.17
Mean quantity of fertiliser used per year (kg)	83.17
Mean cost of fertiliser per year (ZAR)	365.98

4.2.4 Suitable Households for Biodigester Installation

The strict suitability requirements for a household to be deemed worthy of having a biodigester are listed in section 2.2.5 of Smith (2011: 20). The adjusted suitability requirements are included in the results to display the number of potential biodigester using households in the area, if they are not required to own four or more cattle. These households are included for later discussion as it became clear in the survey process that even those households who do not have cattle, tend to collect cow dung on a regular basis.

Figure 4-7 indicates that 35% of the sample group is considered suitable for having and using a biodigester under the strict suitability requirements and 79% of the sample group are considered suitable households under the adjusted requirements. When extrapolated to the total area population[4] (Okhombe community), 411 households meet the strict suitability requirements and 931 households meet the adjusted suitability requirements.

1 One household bought 'compost', which is not considered a chemical fertiliser.
2 Nitrogen Phosphorus Potassium in the ration 3:2:1.
3 Diammonium phosphate.
4 Population of Okhombe community is calculated as 6 343 people (*section 2.1.3*) and 1 176 households (population divided by average number of people per household, see *section 5.2.2*).

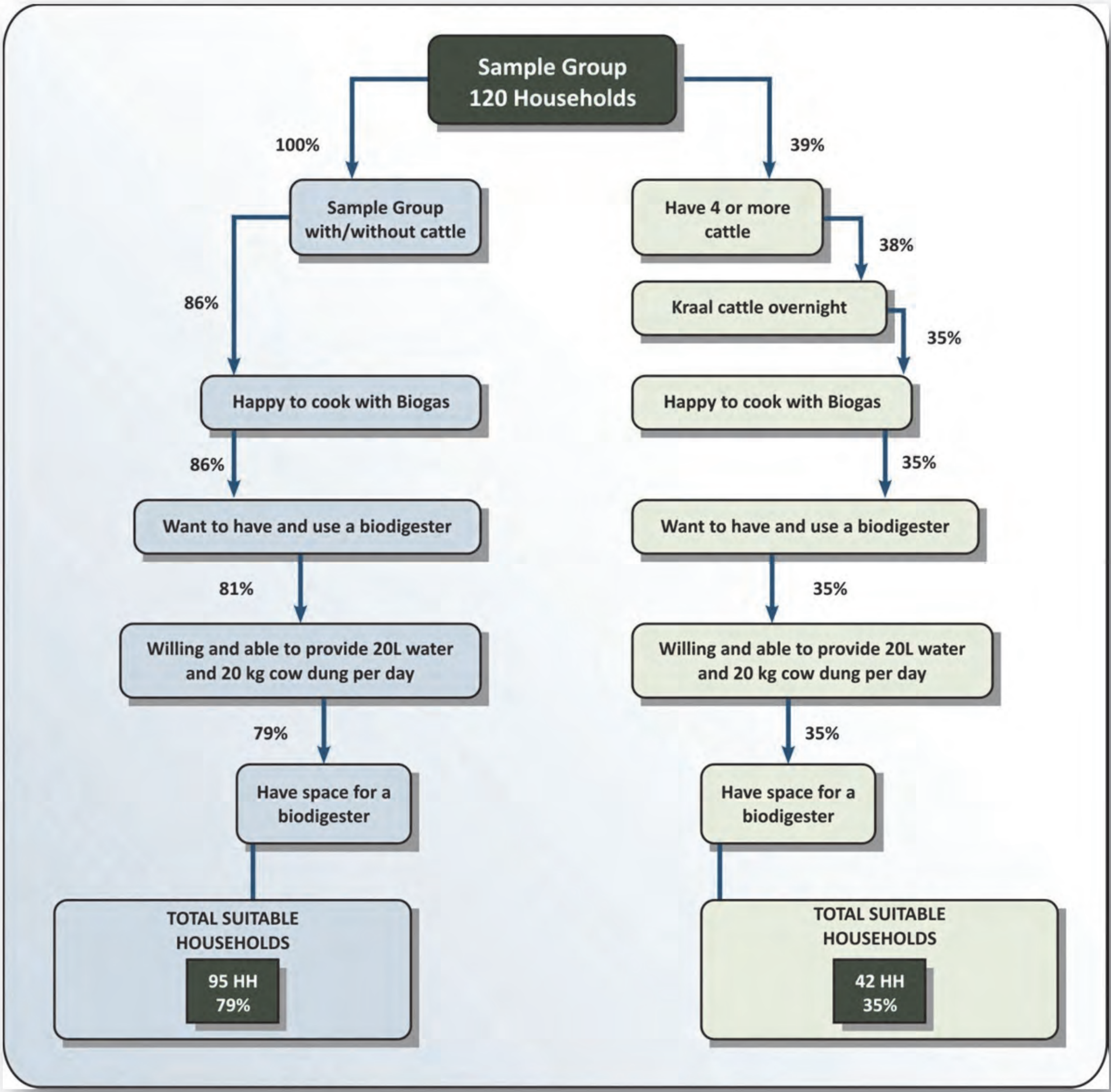


Figure 4-7: Flow diagram showing suitable households for biodigester use.

4.3 COMMUNITY ENGAGEMENT

The project team felt that a critical issue in completing the community engagement for the project was to standardize the process of obtaining community endorsement and selecting households across the three provinces. The following steps broadly outline the actions that were taken in each province (although the timeline differed slightly between each).

Step 1:

Presented project to the tribal authorities for permission to implement project within their area.

Step 2:

Developed selection criteria for pilot households.

Step 3:

Conducted various community meetings in the respective areas to introduce the project, the technology, and begin the process of household selection (see Figure 4-8). At this point partakers were provided with nomination forms (see Figure 4-9) and requested to nominate households that would meet the selection criteria for a pilot household.

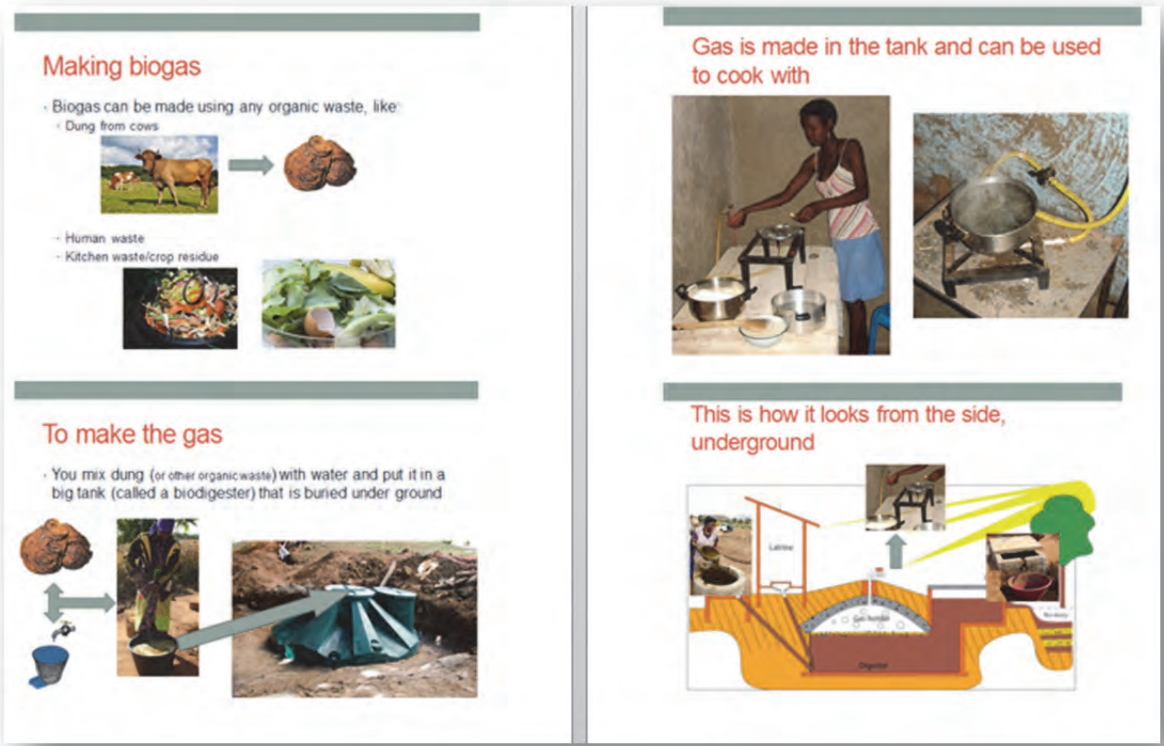
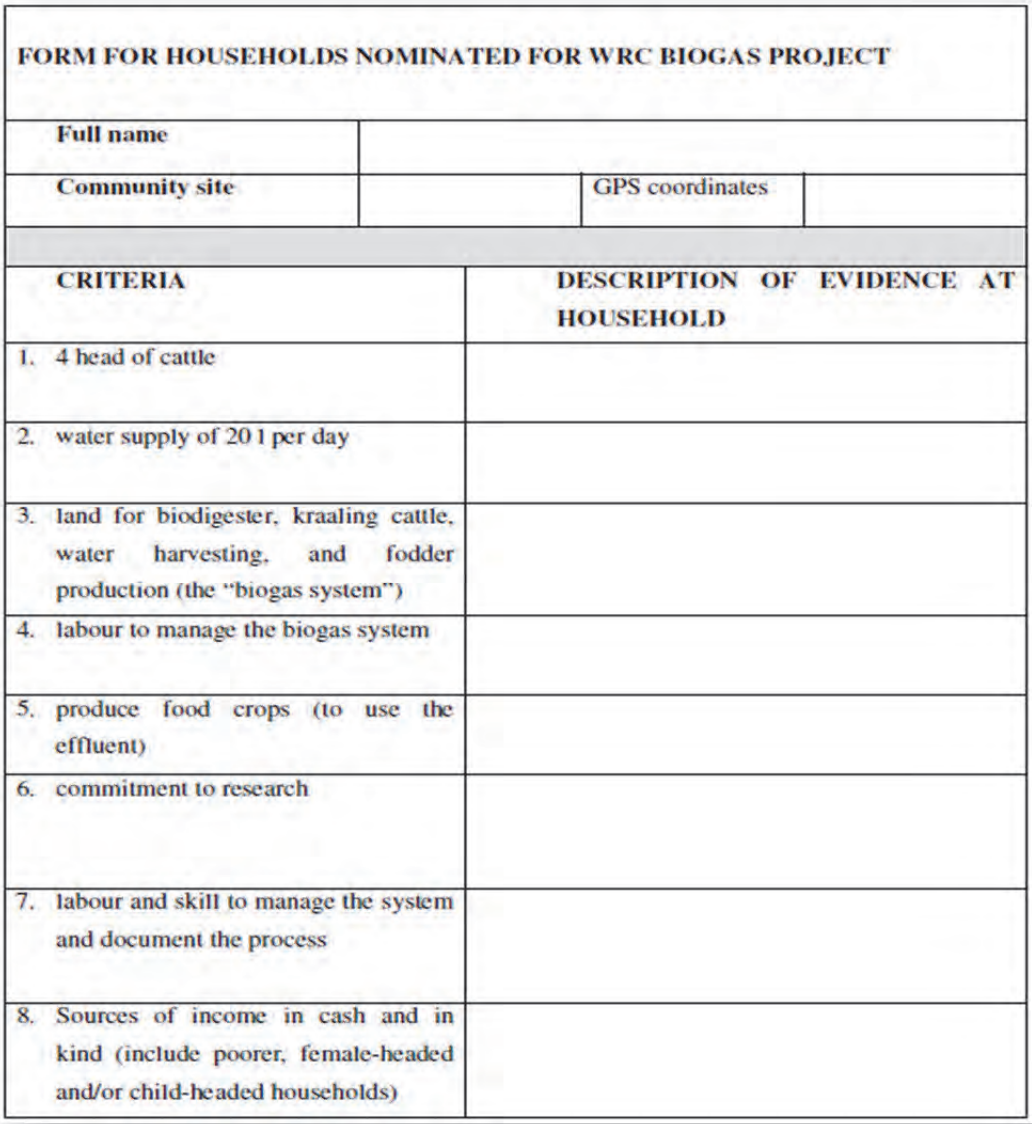


Figure 4-8: Slides from the presentation given at the initial community meetings.



FORM FOR HOUSEHOLDS NOMINATED FOR WRC BIOGAS PROJECT

Full name			
Community site		GPS coordinates	

CRITERIA	**DESCRIPTION OF EVIDENCE AT HOUSEHOLD**
1. 4 head of cattle	
2. water supply of 20 l per day	
3. land for biodigester, kraaling cattle, water harvesting, and fodder production (the "biogas system")	
4. labour to manage the biogas system	
5. produce food crops (to use the effluent)	
6. commitment to research	
7. labour and skill to manage the system and document the process	
8. Sources of income in cash and in kind (include poorer, female-headed and/or child-headed households)	

Figure 4-9: An incomplete nomination form from the household selection process.

Step 4:

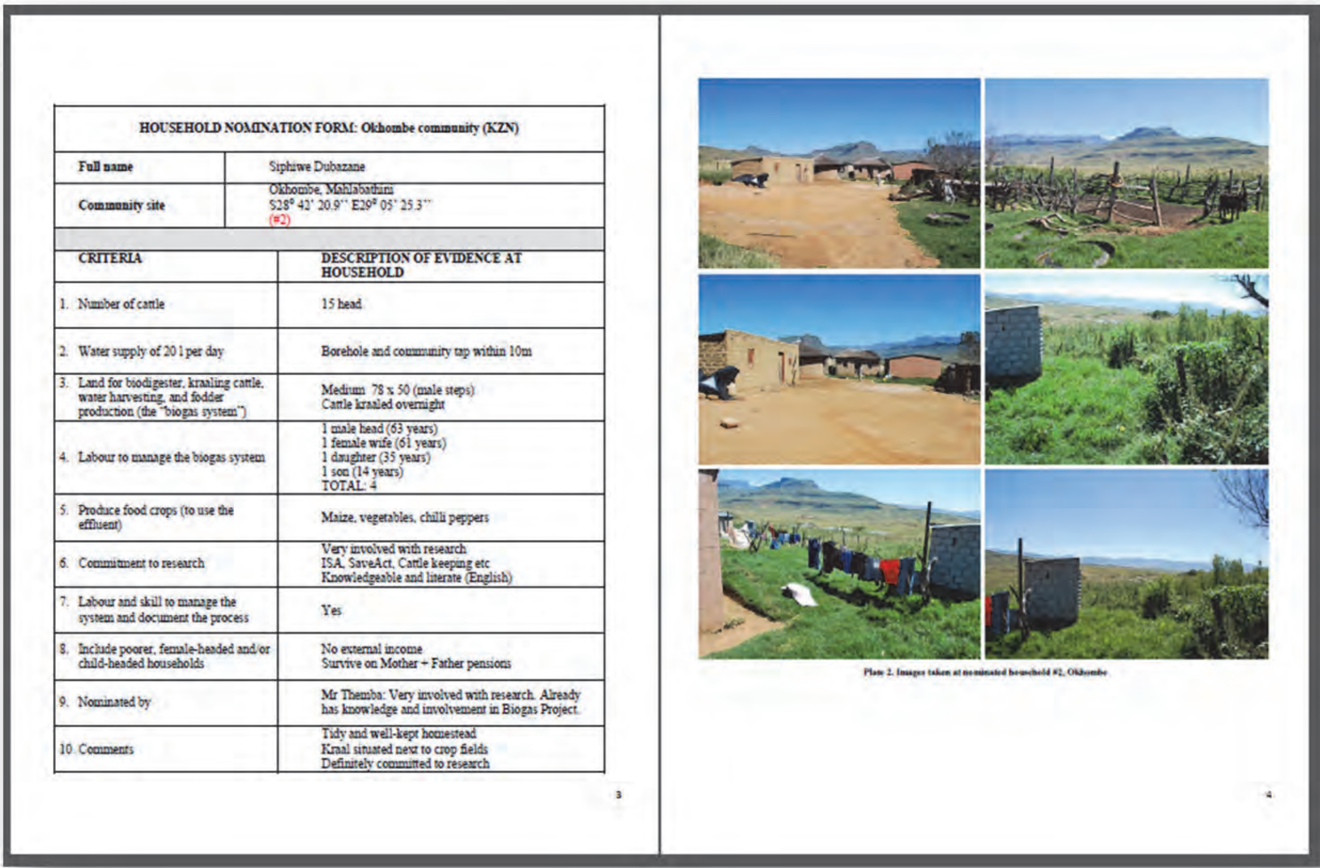
Received nominations from community members, selected approximately four top contenders from each community and notified those involved that a site visit would be made.

Step 5:

Conducted site visits to each household to authenticate stated information and take pictures for review.

Step 6:

Reviewed nominations as a team and selected what were considered to be the most appropriate households from each community.



HOUSEHOLD NOMINATION FORM: Okhombe community (KZN)	
Full name	Siphiwe Dubazane
Community site	Okhombe, Mahlabathini S28° 42' 20.9'' E29° 05' 25.3'' (#2)
CRITERIA	**DESCRIPTION OF EVIDENCE AT HOUSEHOLD**
1. Number of cattle	15 head
2. Water supply of 20 l per day	Borehole and community tap within 10m
3. Land for biodigester, kraaling cattle, water harvesting, and fodder production (the "biogas system")	Medium 78 x 50 (male steps) Cattle kraaled overnight
4. Labour to manage the biogas system	1 male head (63 years) 1 female wife (61 years) 1 daughter (35 years) 1 son (14 years) TOTAL: 4
5. Produce food crops (to use the effluent)	Maize, vegetables, chilli peppers
6. Commitment to research	Very involved with research ISA, SaveAct, Cattle keeping etc Knowledgeable and literate (English)
7. Labour and skill to manage the system and document the process	Yes
8. Include poorer, female-headed and/or child-headed households	No external income Survive on Mother + Father pensions
9. Nominated by	Mr Themba: Very involved with research. Already has knowledge and involvement in Biogas Project.
10. Comments	Tidy and well-kept homestead Kraal situated next to crop fields Definitely committed to research

3

Plate 2. Images taken at nominated household #2, Okhombe

4

Figure 4-10: An authenticated nomination form along with images taken at a site selection visit.

Step 7:

Notified all who had been involved with the process and conducted a community meeting to present and explain the choices made.

The community engagement process appeared to have been a great success which resulted in acceptance from the communities and support of the project. The process followed was developed further and included in the guidelines report.

4.4 QUESTIONNAIRE ASSESSMENT INTERVIEWS

4.4.1 Follow up surveys

Follow up baseline surveys were undertaken during the first half of 2013 to assess the change in the EC and KZN communities' level of awareness of biogas and related outputs when compared to 2011 (Deliverable 10, 2011)[5]. The questionnaire used in the follow-up survey was based on that which was used in the first round of this process (baseline surveys in 2011). Although the basic format and many of the questions were kept, the questionnaire was adapted to address some of the concerns expressed by the researchers after the first round of surveys.

The follow-up questionnaires were conducted in the EC (Figure 4-11) and KZN (Figure 4-12). In KZN digesters were installed at four locations (wards), namely Obonjaneni, New Stand, Postshini and Okhombe. These wards are similar in level of development and demographic profile, and are geographically located within a 40 km radius of each other. All surveys have been conducted in the Okhombe community in an endeavour to maintain a statistically significant sample size of 10 per cent or more.

In the EC a standardized questionnaire was administered to randomly selected households within each village. A total of 25 households were surveyed at both Boomplaas and Tschamazimba and 20 were surveyed at Plaatkop and Nkunkulu respectively. In KZN One hundred and twenty three questionnaires were administered in the Okhombe village. The randomization process was similar to that used in the first round of surveys, with random GPS points taken from the map produced after the first administration of the questionnaire (Figure 4-12).

[5] Limpopo was excluded from this assessment due the delays and necessary changes in study site location.

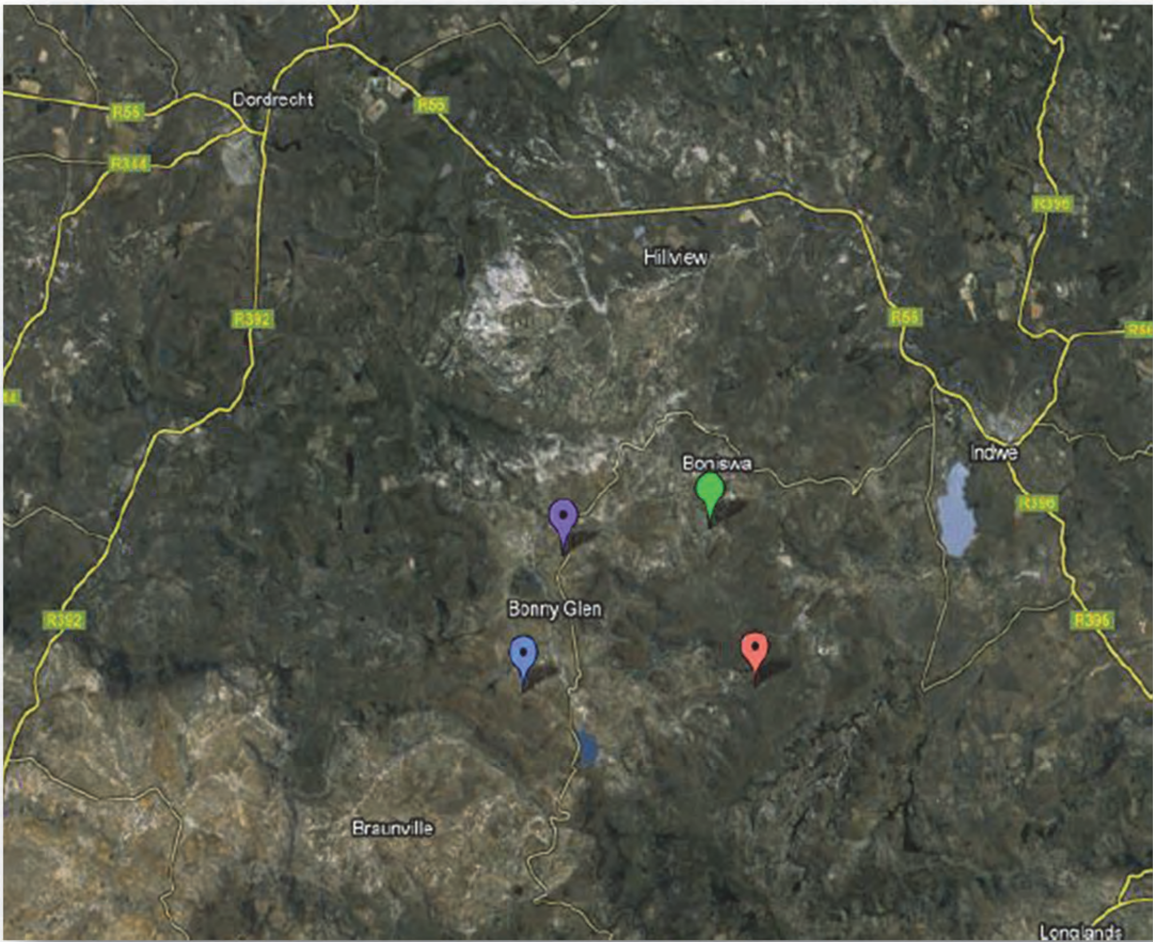


Figure 4-11: Location of the 4 villages in the EC - Boomplaas (purple), Tschamazmiba (blue), Plaatkop (red) and Nkunkulu (green).

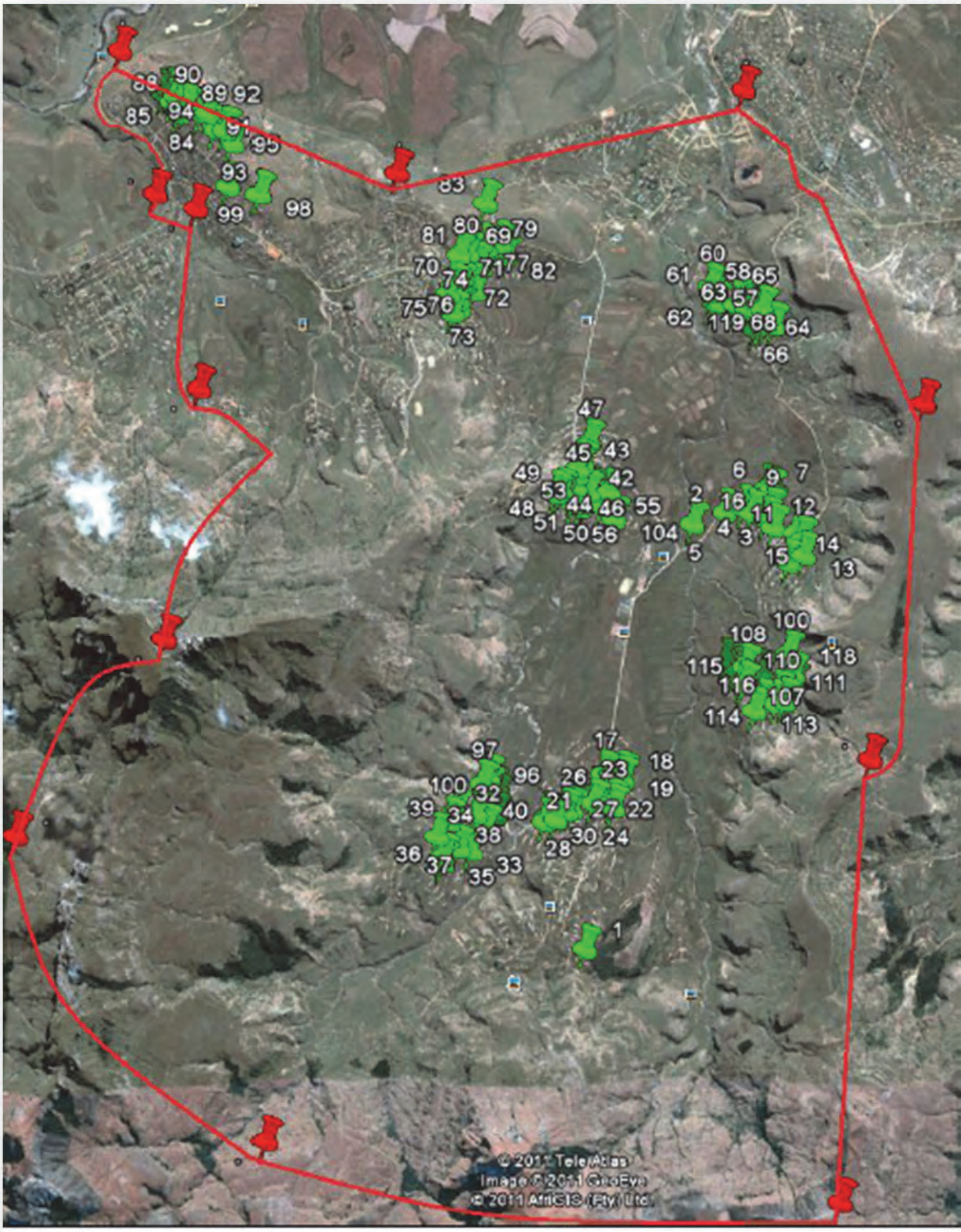


Figure 4-12: Distribution of surveyed households (round one) in the Okhombe study site.

The results of KZN and the EC were combined to gain an overall picture of the changed level of awareness across both study sties

Question	Change in awareness or situation from 2011 to 2013
H1. Have you heard of biogas?	An increase of 41% for positive responses, mainly coming from EC (86% increase) with only 3.5% increase in KZN.
H3. What experiences have you heard about biogas as a fuel (positives and negatives)?	There were 87 positive responses and 14 negative responses in 2013. This reveals a significant increase in awareness as there were only 4 combined responses in EC and KZN in 2011.
H4. Assuming equal prices of all energy sources, which would you buy to satisfy your household cooking needs?	Firewood increased by 4%, LPG increased by 9%, Biogas decreased by 28%, Paraffin increased by 2% and electricity increased by 12%.
H5. Would you be happy to use biogas for cooking?	There was a decrease by 3% in "yes" responses.
H6. How much would you be willing to pay for the outputs of a biodigester every month?	The average per household increased from R81 to R91 which appears to be in line with inflationary increases.
I1. If your household could run a biodigester that can give you biogas for cooking and fertiliser, would you want to have one?	The positive response decreased by 3%.
I2. Would your household be willing (and able) to feed a biodigester with water and manure on a daily basis?	The positive response decreased by 6% with a number of respondents stating that they had no cattle and this was the reason for their negative response.
I3. Does your household own cattle?	The number of households owning cattle decreased by 2%. There is an average of 5.2 cattle per household (average across cattle owning households) – 2013.

In the EC, there has been a significant change in the level of awareness in the target community. Initially there was absolutely no knowledge of biogas in this area (only 1% had heard of biogas whereas in 2013 it rose to 87%). It is noted that throughout the visit, residents constantly recognised the topic and in several situations were quite happy to expound upon the virtues of biogas and how similar it is to Liquid Petroleum Gas (LPG - considered to be one of the best sources of cooking energy). There were, however, also cases where households were adamant that electricity was the preferred method of energy supply. In many of these cases this was attributed to the fact that electricity could be used to light homes and power basic appliances as well as for cooking.

One major challenge identified by several households was the fact that cattle dung is scarce during winter, as many households send their cattle off to grazing camps in the nearby mountains. In addition to this the advanced age and frailty of many respondents was a limiting factor in their willingness to commit to the daily collection of cattle dung.

In KZN, The awareness of biogas in KZN increased only slightly by 3.5%. It should be noted, however, that there was a relatively high awareness of 21% in 2011 (compared to only 1% in the EC survey). Of those that have heard of or had experiences with biogas most responded with positive comments including one household that stating that “it is fast and easy to cook with, it was cheap and uses only manure and water”. Negative comments were that it “does not last” and that one needed access to cattle (manure).

When asked which energy source the household would buy to satisfy their cooking needs there was a significant drop in the number of households choosing biogas. Many more households stated that they would buy electricity compared to none in 2011. Some of the reasons for choosing biogas as a preferred source of energy included that they “liked the idea” and that biogas is “more environmentally sustainable”. The significant decrease in selection of biogas, and increase in electricity, as a preferred source of energy could be attributed (as stated previously) to interviewer bias and the omission of electricity as a stated option in the first round of questionnaires. Those that were willing to pay for biodigester outputs indicated a monthly payment that was slightly higher than that stated in 2011. Overall the survey of 2013 indicated that there was a drop in willingness to own, pay for or load a digester to result in biogas for cooking. Some of the reasons for not being willing, or able, to feed and run the digester included not having any cattle and the difficulty in collecting dung (especially in the mountains).

4.5 QUALITATIVE SURVEYS AT PILOT HOUSEHOLDS

Qualitative surveys were conducted at each of the pilot households to gather information about their use of the biogas technology and how it had impacted their lives. The following provides a brief summary of the key points ascertained through this process:

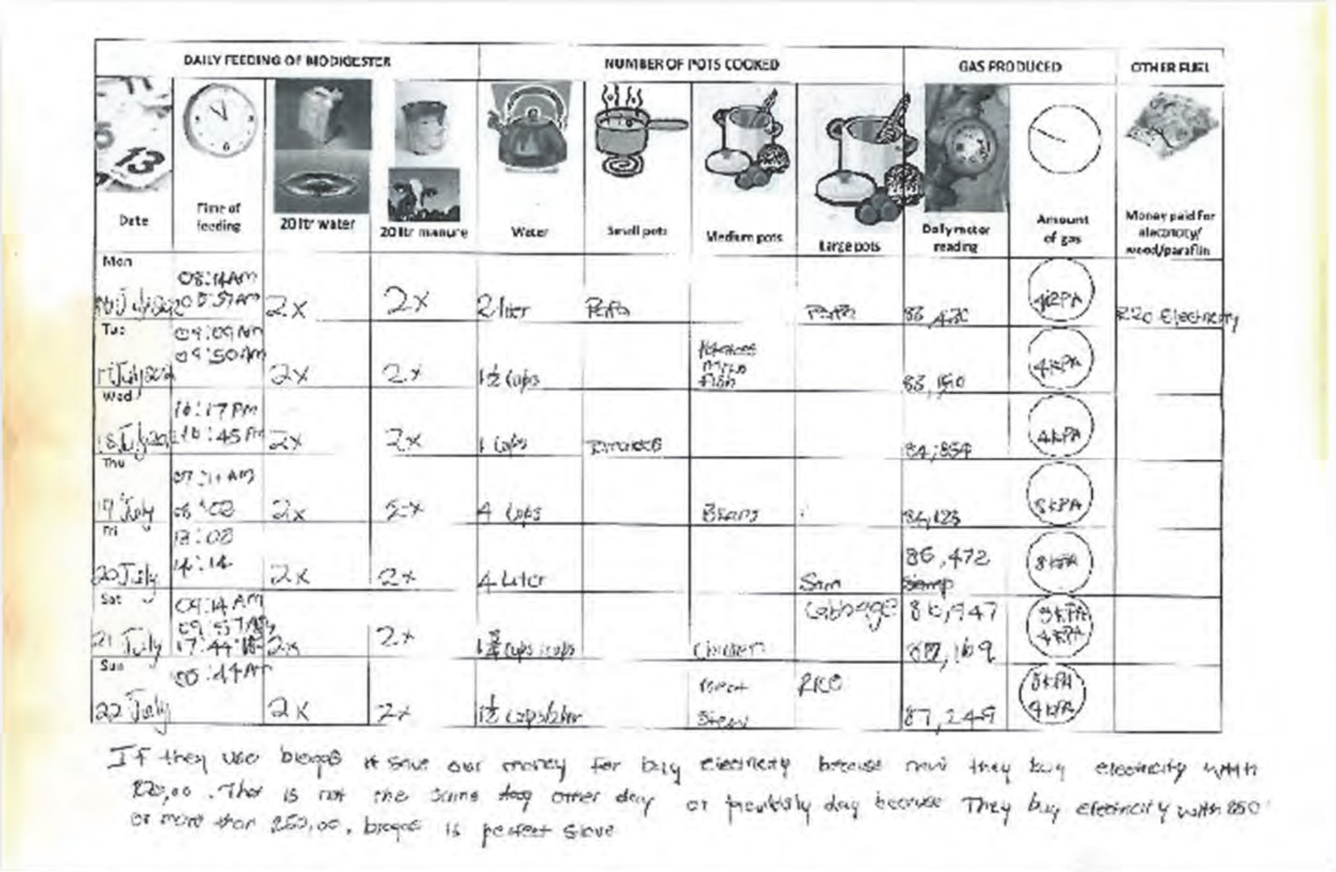
- Process of feeding:
  - The households had similar routines around feeding the biodigester. Typically manure was collected from the kraal in the morning and mixed with available water (often greywater from washing) before being fed into the digester. Mrs Khumalo (Obonjaneni) reported that they allowed the manure to soak for a day before mixing it and feeding the digester. This was interesting, given the good gas production/usage results from this site.
- Uses
  - Most households reported using the biogas for boiling of water and for breakfast. Apart from one, households reported using the biogas at least twice a day (morning and late afternoon). All households noted that there was insufficient gas for cooking certain foods (e.g. kidney beans), and as a result many used wood fires simultaneously or when required.

It was apparent that insufficient biogas was available for all cooking requirements at the pilot study households.

- Low gas production in winter
  - Households noted a marked difference in the quantity of gas available during winter and summer months – with cold winter months resulting in very little gas production.
- Electricity and wood savings
  - Households noted significant savings on expenditure for energy sources. In KZN, wood is purchased by bakkie load and it was noted that the need to purchase wood had decreased significantly and entirely in some cases. Electricity expenditure decreases were also noted by households.
- Require two plate gas cooker
  - All households noted the limitation of the biogas system having a single plate gas cooker and their need for at least two gas plates to cook an average meal.
- Choice of biogas as a cooking fuel
  - When asked what households would use for cooking, if all prices were equal, biogas was resoundingly chosen. Despite some concern that this might have been an interview bias, households provided plausible reasons for their choice including: (i) the simplicity of lighting and using biogas, (ii) the unreliability of electricity, (iii) LPG was seen as a comparatively unsafe gas.

4.6 BIOGAS MONITORING

Biogas systems were monitored in a number of ways including intermittent site visits by the project team to document the health of the biodigesters, and data capture by the households on a daily basis (see Figure 4-13).



DAILY FEEDING OF BIODIGESTER				NUMBER OF POTS COOKED				GAS PRODUCED		OTHER FUEL
Date	Time of feeding	20 ltr water	20 ltr manure	Water	Small pots	Medium pots	Large pots	Daily meter reading	Amount of gas	Money paid for electricity/ wood/paraffin
Mon [illegible] July 20[illegible]	08:14AM 08:57AM	2X	2X	2 liter	Pap		Pap	83,430	4,2KPA	R20 Electricity
Tue [illegible] July 20[illegible]	09:09AM 09:50AM	2X	2X	1½ cups		Potatoes [illegible] fish		83,150	4KPA	
Wed 18 July 20[illegible]	16:17PM 16:45PM	2X	2X	1 cups	Tomatoes			84,854	4KPA	
Thu 19 July	07:[illegible]AM 08:02	2X	2X	4 cups		Beans		86,123	5KPA	
Fri 20 July	13:08 14:14	2X	2X	4 Liter			Sam	86,472 Samp	8KPA	
Sat 21 July	09:14AM 09:57AM 17:44PM	2X	2X	1½ cups [illegible]		Chicken	Cabbage	86,947 87,169	3KPA 4KPA	
Sun 22 July	08:44AM	2X	2X	1½ cups [illegible]		Meat Stew	Rice	87,249	3KPA 4KPA	

If they use biogas it save our money for buy electricity because now they buy electricity with R20,00. That is not the same [illegible] other day or [illegible] day because They buy electricity with R50 or more than R50,00. biogas is perfect stove

Figure 4-13: A biogas data sheet filled in by Mrs Khumalo (Obonjaneni, KZN).

From this data, captured by the household members, the mean biogas production over a 34-week period expressed as litres per kg per household was calculated. The results showed mean values of 21.15 at Obonjaneni followed by 10.75 Potshini, 11.21 New Stand and 8.04 Okhombe (Figure 4-14).

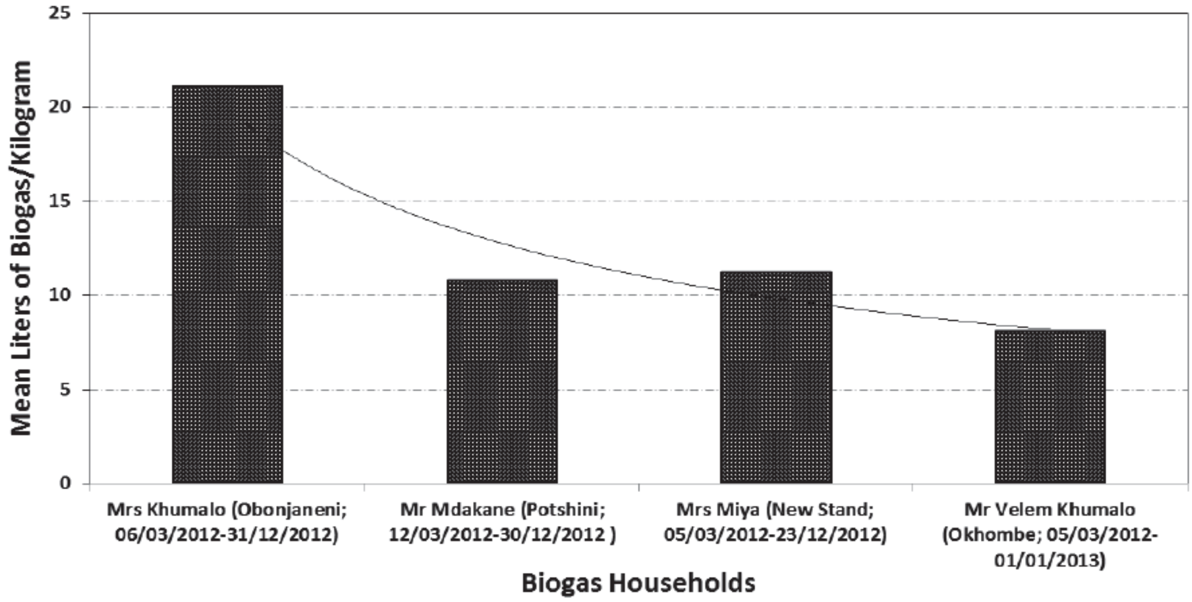


Figure 4-14: Mean biogas produced per kilogram by Agama Pro Biogas digesters in KZN.

It became apparent through the course of the project that there were two major problems with the physical capture of data by households. Firstly some households neglected their duties to capture data, and similarly others provided an inconsistent account of their system usage. Secondly, the data that was captured related directly to the use of gas, and not the production of gas by the system (i.e. the gas meter only registered gas used, not gas produced and potentially vented). The inconsistency of data can be seen clearly in Figure 4-15.

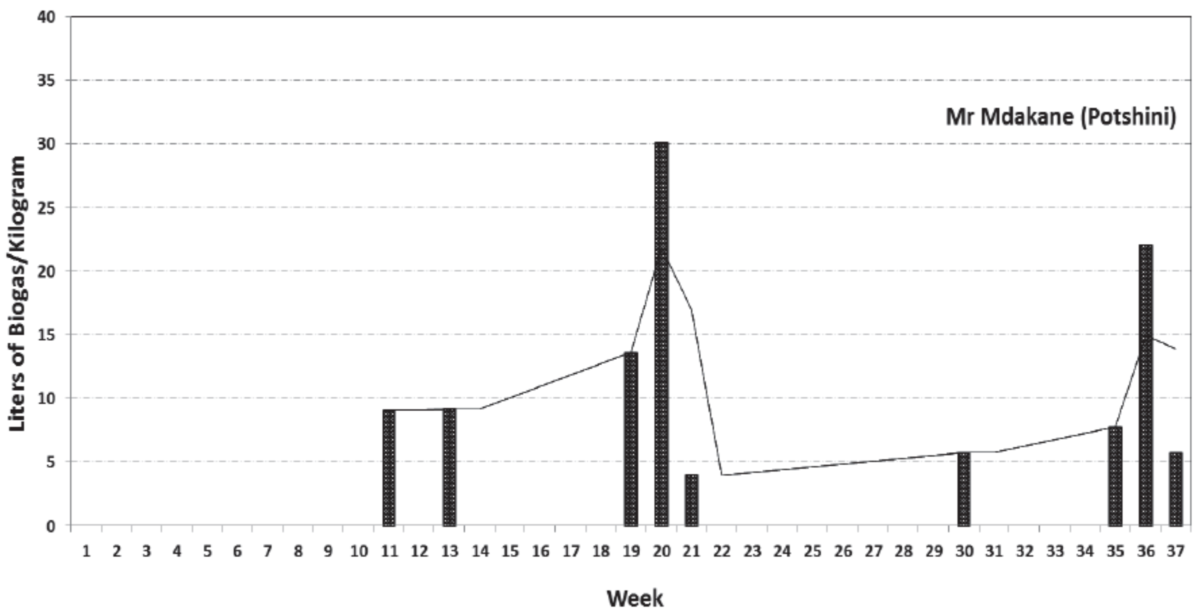


Figure 4-15: Presentation of results from data captured at Potshini pilot household, KZN.

The UKZN team was in consistent consultation with the installer of the biodigesters in KZN, Renen Energy Solutions, who recognised the need for a remote monitoring system to capture necessary biogas system information. Renen developed a solar powered, GSM Mobile network based monitoring station that was capable of recording and sending data including, (i) tank temperature, (ii) ground temperature, and (iii) gas pressure. From the gas pressure information and knowledge of the internal dimensions of the biodigesters gas chamber, Renen developed a model to estimate gas volume. The team was therefore able to record changes in gas volume within the tank, therefore developing a dataset of biogas usage and biogas production at the households.

Following installation of the monitoring system at Obonjaneni, there were some delays in obtaining data on the biogas production. The main reason for this was that the Obonjaneni biogas line was damaged when a household member struck it when installing a new fence pole, and the unexpected problem took a number of months to be identified (see Plate 4.10). There were also some initial developmental hitches with the prototype BiogasPro Meter system. Unfortunately this meant that the team was unable to capture a full year cycle of monitoring data, and has therefore been unable to determine the changes in gas production over the summer and winter months. The team has, however, recorded some insightful and meaningful data from the system.

Plate 4.10: Gas line damaged by a new fence pole inserted into the ground at Obonjaneni, KZN.

<u>BiogasPro Meter as an early warning device:</u>

Figure 4-16 displays an example of how a BiogasPro Meter identified a problem, remotely, and offers a potential solution as an early warning device. In this specific case, the problem was not known and identification of it took a number of months and many site visits by the project team. Only once the team had seconded the help of the biodigester installers, was it identified that the household had struck the gas line with a new fence pole (see Plate 4.10).

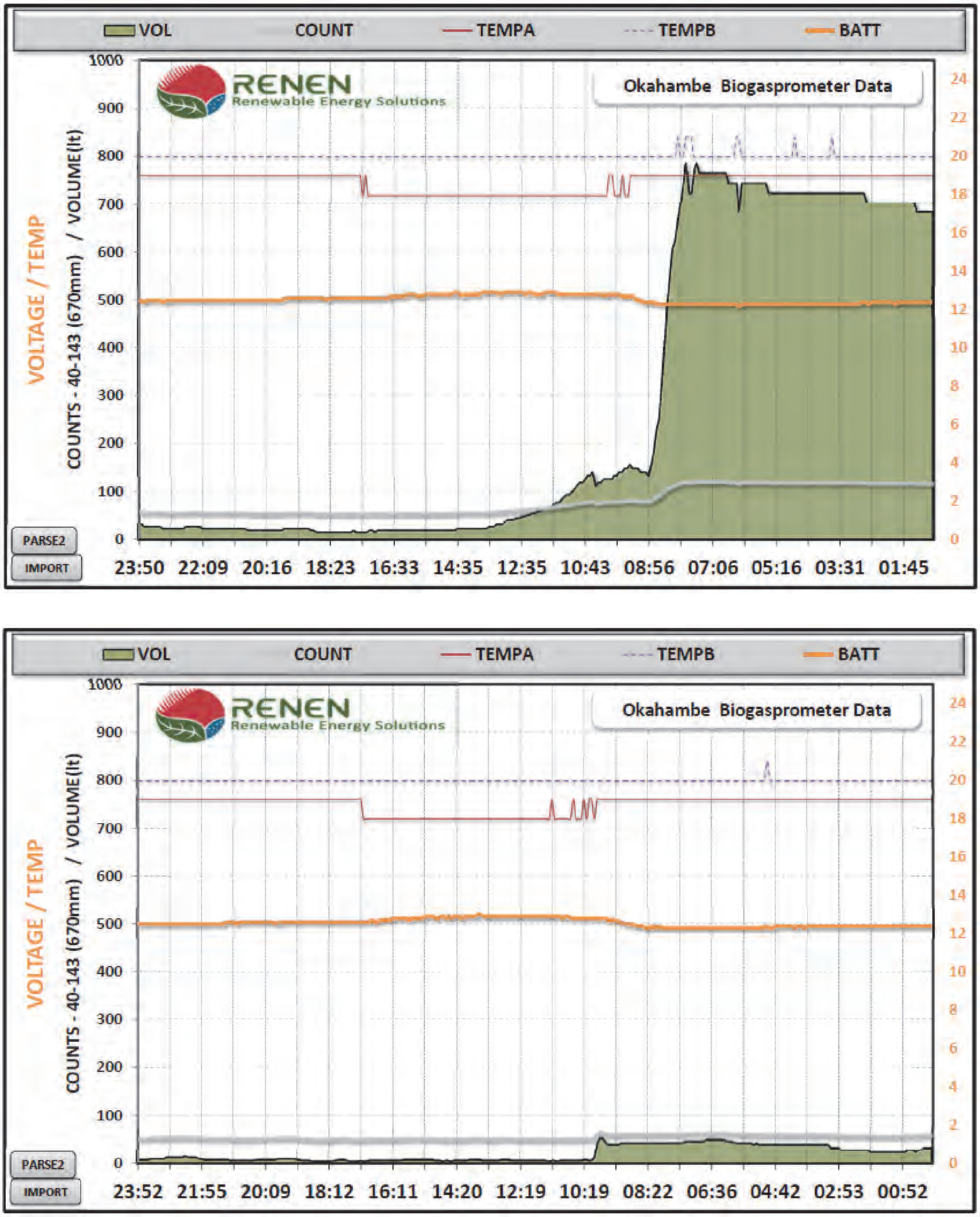


Figure 4-16: Example of problem identified by a BiogasPro Meter at Obonjaneni, KZN.

Daily usage cycles at Obonjaneni Pilot household:

Figure 4-17 shows 24 hour usage and production cycles across a five day assessment period, with an average cycle displayed in blue. Figure 4-17 displays usage as a dropping (negative) gas volume and production as a positive volume. It is clear from the eclectic graph that usage cycles change from day to day (week to week), although a general trend did start to become evident (see Figure 4-18).

The trend identified across the various days shows that morning usage generally takes place between the hours of 5:00 and 8:00 (breakfast). On only a few days, larger quantities of gas was used between 12:00 and 14:00 (lunch), while a small volume of gas was used consistently at approximately 11:00, which was likely to be for boiling water (i.e. tea making). Late afternoon / evening gas usage was consistent across the period of assessment with usage taking place at approximately 17:00.

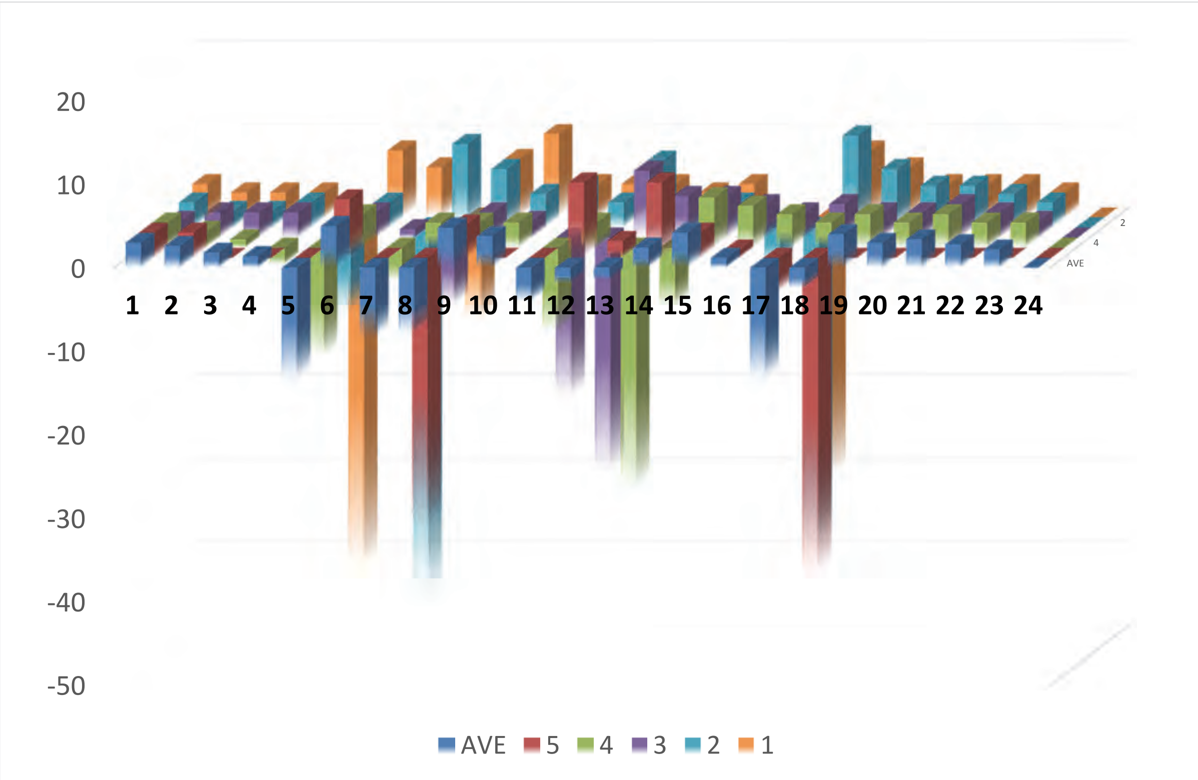


Figure 4-17: Usage cycles measured by a BiogasPro Meter on a 24 hour daily cycle for 5 weeks (X-axis = hours of the day; Y-axis = relative gas volume).

Average daily production and consumption:

Figure 4-18 displays the average daily usage cycle gleaned from the data as presented in Figure 4-17. The trend identified over the assessment period displayed that households typically used gas between 4:00 and 8:30 in the morning. The positive interlude shown at 6 on the X-axis is expected to be a time when the household fed the biodigester (i.e. increased the volume in the digester, showing a production spike while usage was likely still taking place). Small quantities of gas appear to have been used between 10:30 and 13:30 which are likely for boiling water for tea, and/or for re-heating of food (described by one pilot household). Late afternoon usage appears to be predominantly between the times of 16:00 and 18:00. Individual cases revealed that loading possibly took place in the early evening, identified by a number of volume spikes.

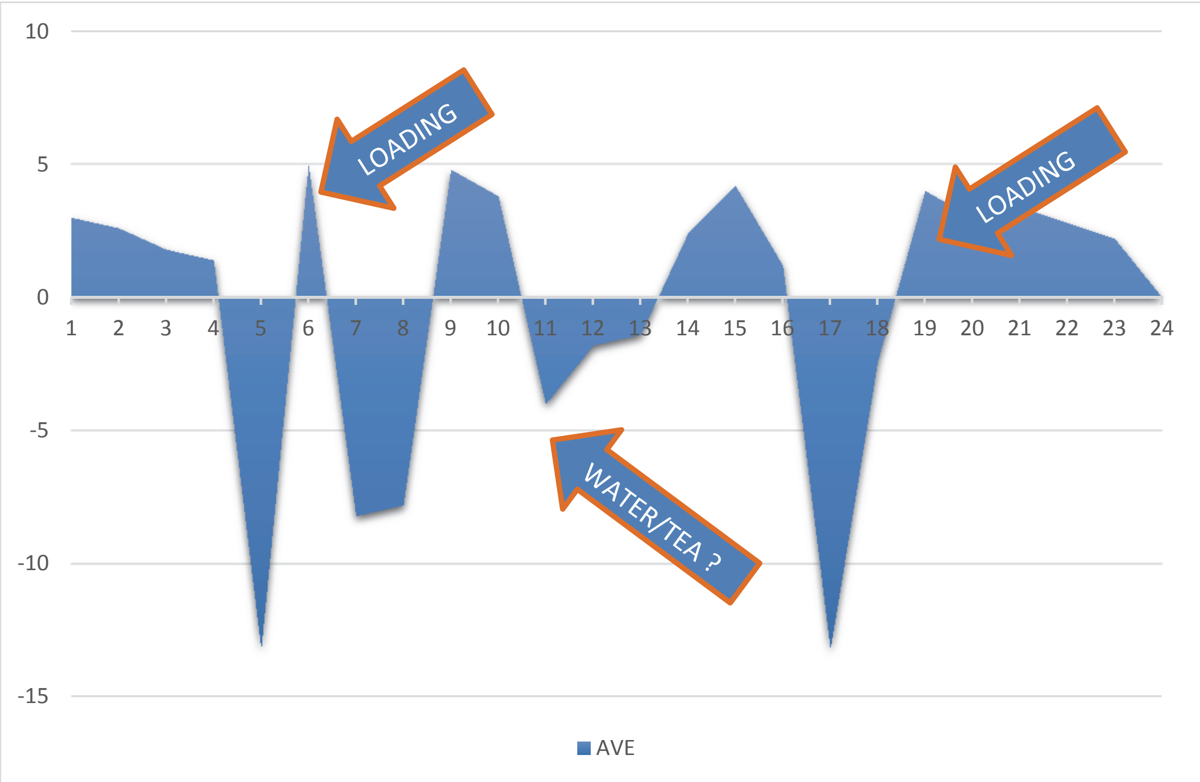


Figure 4-18: An average of the usage and production cycle over a 5 day period (X-axis = hours of the day; Y-axis = relative gas volume).

Monitoring

The implementation of a remote monitoring system for biogas production has proved to be a useful tool for interpretation of the data sheets kept by the community. The household captured usage data from the Obonjaneni biodigester (Figure 4-19) showed a marked reduction in biogas *usage* during winter months. The data from the remote monitoring system indicated the direct relationship between air temperature and biogas production. The problem of a significant decrease in biogas production in cold temperatures needs to be addressed in future research programs. One proposal is to store water for the biodigester in black drums during the day to increase the temperature of the water when it is input into the biodigester.

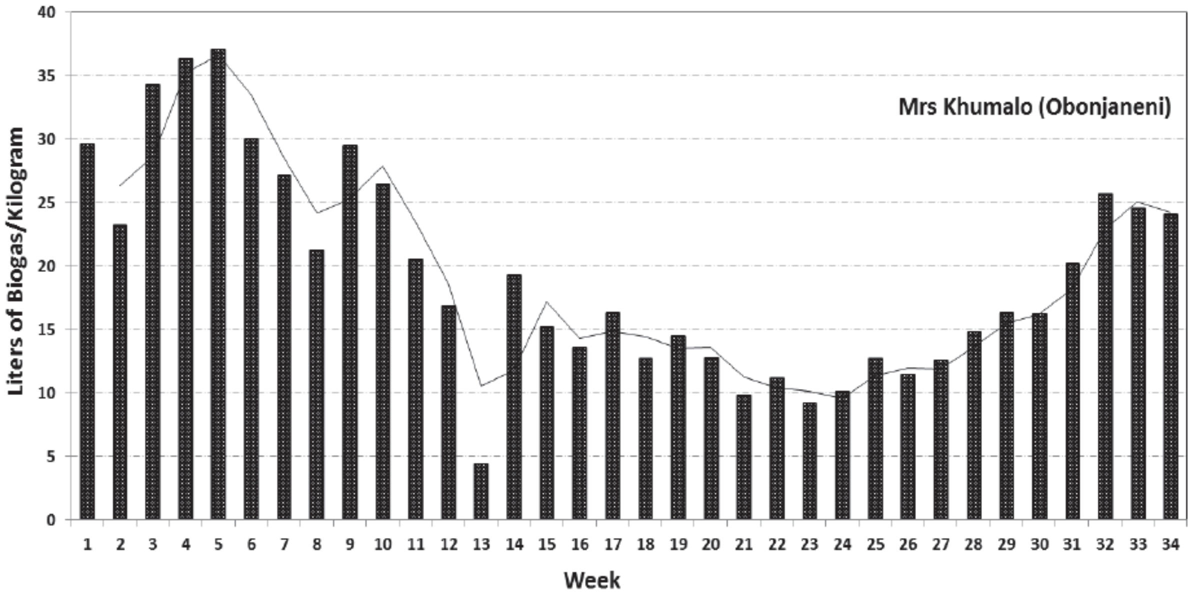


Figure 4-19: Biogas produced per kilogram by an Agama Pro Biogas digester at Obonjaneni (2012-03-12 to 2012-10-29).

CHAPTER 5: INTEGRATED MANAGEMENT – KWAZULU-NATAL

by Everson T, Everson C, Magagula L, Ngobo N and Zuma M.K.

Livestock production is generally poor in communal areas due to both low quantity and quality of feed for livestock. The aim of this study was to improve rangeland condition and livestock production in the Upper Thukela communal area of KwaZulu-Natal by developing strategies that promote sustainable management of rangelands and livestock. These strategies include the use of rainwater harvesting, fodder production and biogas technologies to assist in water, food and energy security. These integrated systems formed part of an overall management plan which was implemented in the communal areas.

Any intervention to improve rangeland management and livestock production should be founded on knowledge of local management practices. Information on local farmers' current rangeland management and rainwater harvesting practices were collected at each of the potential households to determine the following:

- Rainwater harvesting technologies that are currently used by each household (HH),
- Potential of infrastructure at the homesteads to implement RWH,
- Current fodder technologies used by the HHs
- Current livestock management strategies.

The first phase of the study involved a visit to each homestead in KwaZulu-Natal (4) to survey each site and draw a detailed plan of the homestead. The following information, which was considered necessary for the development of appropriate RWH, fodder and biogas technologies, was surveyed on to the maps (see Figure 5-1 as an example):

- Size of fields for fodder production
- Distance of fields from the homestead
- Potential position of the biogas digester
- Position of the kraal and distance to the biogas digester
- Position and area of buildings with potential for rooftop RWH
- Area and position of homestead gardens.

An example of a survey map with the above details for the development of the rainwater harvesting, food, fodder and biogas plans is presented in Figure 5-1.

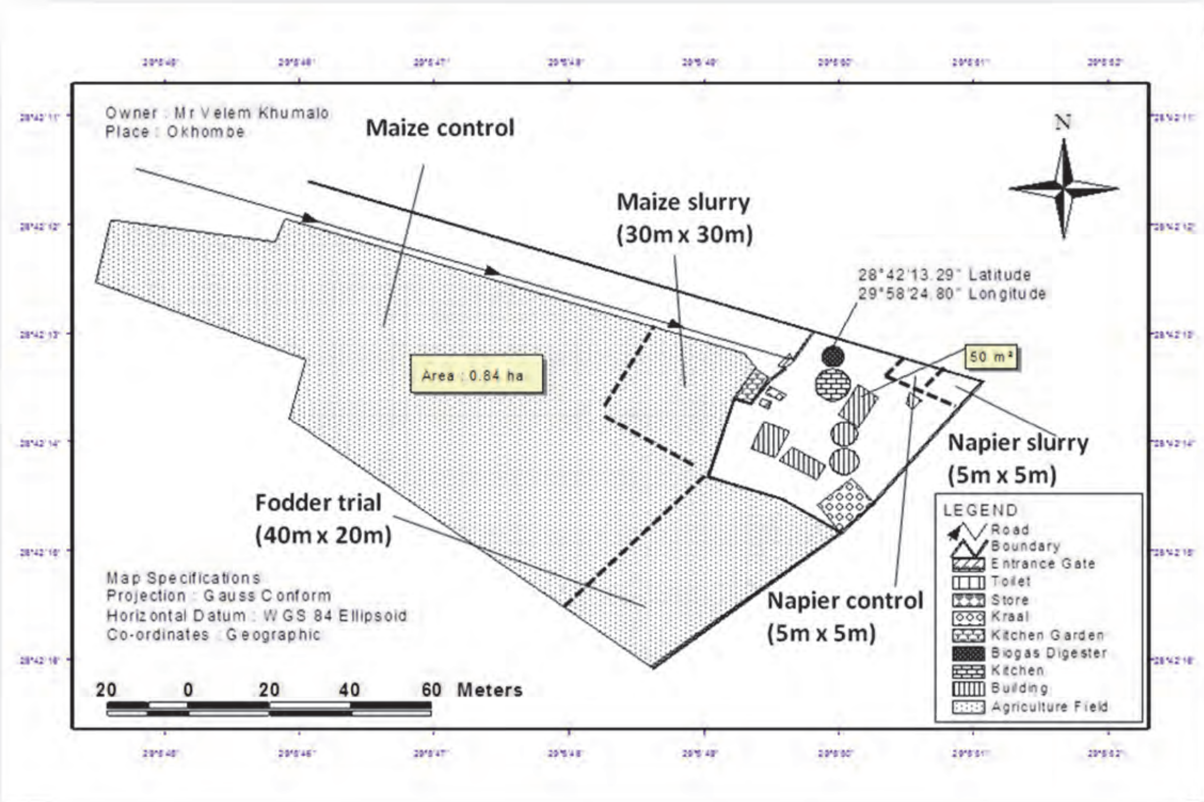


Figure 5-1: Plan of Mr Khumalo's household in KwaZulu-Natal.

The GPS co-ordinates were taken for all the selected households in KwaZulu-Natal (KZN). The area of each agriculture field (ha) and position of all attributes (i.e. homestead, kitchen, biogas digester, kraal, buildings, kitchen garden) were measured for the crop and fodder experiments. The landholding ranged between 0.18 ha to 1.12 ha in KZN. The area of roofs was also measured for harvesting the roof water in a rainwater tank for the biogas digester and household requirements. The roof area for harvesting the water ranged between 25 m^2 to 142 m^2 in KZN.

5.1 RAINWATER HARVESTING

One of the most critical factors in the operation of a biogas digester for biogas and bioslurry fertilizer is water. The digester has to be fed 20 litres a day to maintain biogas production. The total annual water use to run a biogas digester based on a daily usage of 20 litres per day is 7200 litres per year or 600 litres per month. However, access to water is a limiting factor for the households in this study. In the initial questionnaire survey carried out at the start of the study, 22% of households collect water from a river or stream, while 34% of households depend on a community tap for their primary source of water

(Figure 4-6). Only one percent of households use water from a rainwater tank on their homestead as a tertiary source. Since the collection of 600 litres of water per month will place a heavy burden on households operating biodigesters, there is a need to examine the potential of rainwater harvesting to relieve this burden. Another factor that needs to be considered is how the use of water in a biodigester rates against other competing uses of water in a household (e.g. drinking, washing, cooking, bathing). However, since greywater from these activities can be used to feed a biodigester it is unlikely that this will be a problem.

In order to address the water requirements of households it is necessary to identify the most appropriate rainwater harvesting (RWH) techniques. A simple and practical categorisation recommended by Dennison and Wotsheba (2009) was selected which was then adjusted according to the FAO (2003) categorisation (Figure 5-2). The classification is based on a scale and storage descriptor and adjusted for South African conditions (i.e. annual rainfall >300 mm). The relationship between the type of water harvesting, rainfall and scale (size) is shown in Table 5-1. Based on 13 rainwater harvesting techniques recognised for use in South Africa (Dennison et al., 2011) three possible appropriate techniques relevant for biogas and food production were identified (Table 5-2). These were rooftop, greywater and mulching. However, in the study areas there were no easily available mulching materials which limited the application of this technique. The research component of this project focused mainly on the scale of rooftop water harvesting (Figure 5-2, Table 5-1). Micro- and macro-catchment scale rainwater harvesting was not considered as the biodigester operates at a household level. For domestic rainwater harvesting, rainwater is collected from rooftops, courtyards, compacted or treated surfaces and it is stored in RWH tanks and used for domestic purposes as outlined by Kahinda et al. (2008) in WRC project K5/1563. Storage tanks can be located underground or above ground.

Since the size of storage tank will depend on the rainfall of the study area and rooftop area, the first step in the implementation of RWH tanks is to survey each site and draw a detailed plan of the homestead (Figure 5-1).

Table 5-1: Ratio of catchment, field size and flow type for water harvesting and conservation systems (taken from Denison and Wotsheba, 2009).

Type of WH	Kind of flow	Annual rainfall	Treatment of catchment	Size	Ratio
Micro-catchment	sheet and rill flow	> 200 - < 300 mm	treated or untreated	- 1000 m	1:1-10:1
Macro-catchment	turbulent runoff + channel flow	> 300 mm	treated or untreated	1000 m - 200 ha	10:1-100:1
Floodwater harvesting	flood water	> 150 mm	untreated	200 ha - 50 km^2	100:1-10,000:1

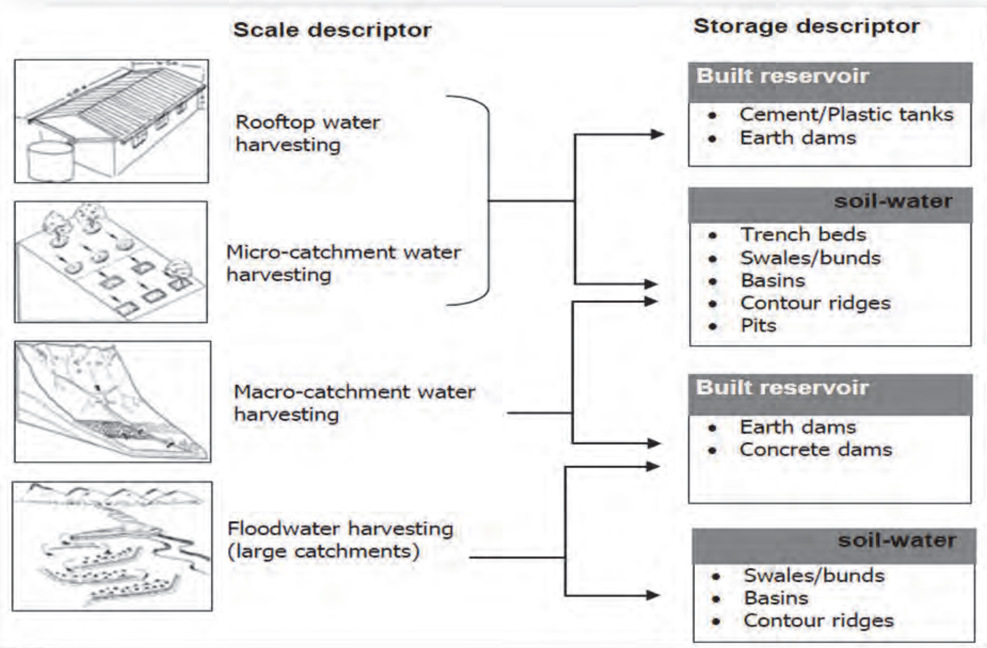


Figure 5-2: Categorisation of rainwater techniques (after Dennison and Wotsheba, 2009).

Table 5-2: Selection of suitable water harvesting techniques for biogas and food production.

Technique	Possible?	Reason	Relevance to biogas production	Tested
Roofwater harvesting	Yes	Available roof tops	High	Yes
Greywater harvesting	Yes	From domestic activities	High	Yes
Mulching	Yes but with difficulty	No material available	medium	No
Diversion furrows	Yes	Impervious runoff areas generally available at all sites	Medium	No
Trench beds	Yes	Small gardens	medium	No
Fertility pit	Yes	Any site	medium	No
Swales	No	Not suitable at homestead level		
Stone bunds	No	Not suitable at homestead level		
Tied ridges	No	Not suitable at homestead level		
Terraces	No	Not steep enough		
Ploegvore	No	Not suitable at homestead level		
Domewater	No	No suitable geological features		
Saaidamme	No	No floodplain or nearby ephemeral rivers		

The geographical locations of the four sites in the Upper Thukela which extend from Potshini in the south, past Okhombe in the centre, through to Obonjaneni near Royal Natal National Park in the north are presented in Table 5-3. For the climate and rainfall analysis Bergville was selected as the representative weather station as it is located in the most central position to all sites.

Table 5-3: Geographical locations of the biogas digesters, roof water harvesting and agriculture area in KZN.

Owner name	Place	Biogas co-ordinates	Agriculture area (ha)	RWH area (m^2)
Mrs Khumalo	Obonjaneni	28°41'18.84" Latitude; 28°59'34.83" Longitude	0.22	105
Mrs Miya	Newstand	28°41'37.07" Latitude; 29°18'41.39" Longitude	0.18	142
Mr Khumalo	Okhombe	28°42'13.29" Latitude; 29°58'24.80" Longitude	0.84	50
Mr Mdakane	Potshini	28°49'14.10" Latitude; 29°21'56.40" Longitude	1.12	25

The Upper Thukela lies in the summer rainfall area of South Africa. Its proximity to the Drakensberg results in cool dry winters and warm wet summers. The mean annual long-term temperature is 14.0°C and the area is characterised by mild to hot summer days (average 20°C) and cold winters (average minimum temperatures in June and July below zero) so that frosts are a frequent feature of the climate in the Upper Thukela (Figure 5-3). The annual average rainfall is 711 mm and the distribution is distinctly seasonal, being wet between January and December (± 100 mm $month^{-1}$) and dry in winter (<20 mm $month^{-1}$). The annual total PM Reference evaporation is 1219 mm and therefore 500 mm higher than the annual rainfall. Average daily PM varies between 6 and 4 mm day^{-1} in summer and winter (Figure 5-4). Being situated in a mild-temperate climate with warm summers and relatively low AED, the Bergville area is ideally suited to crop production.

5.1.1 Design rainfall analysis

Design rainfall analysis is a useful tool to calculate the size of rainwater tank and impervious area necessary for obtaining adequate rainwater for the biogas digesters. For the purpose of this project the design rainfall analysis was used to only determine the size of the rainwater tank needed to supply the needs of the biogas digester. However, if the budget allows, it is recommended that tank sizes should be designed to also include capacity for other household requirements.

For the development of rainwater harvesting technologies it is essential to understand the climatic characteristics of the different study sites within the various provinces which were selected to be representative of widely different climatic zones. The planning of water harvesting techniques for the study sites needs to account for the appropriate "design" rainfall, which is the ratio of "run on" to planted or "run off" area (Critchely and Siegert, 1991). According to the FAO (1991) design rainfall is defined as "the total amount of rain during the cropping season at which, or above which, the catchment area will provide sufficient runoff to satisfy the crop water requirements. If the actual rainfall in the cropping season is below the design rainfall, there will be moisture stress in the plants; if the actual rainfall exceeds the design rainfall, there will be surplus runoff which may result in damage to the structures". Design rainfall is also appropriate for determining the areas of roof tops that will be necessary to supply sufficient water to fill the capacity of the rainwater storage tanks that will be used to fill the biogas digesters. While the design rainfall analysis reported here only accounts for the quantity of water used in the biogas digester, it is advisable to design a tank size within the budget that has capacity for other competing water requirements of households.

In this study, the design rainfall was determined by means of a statistical probability analysis program (Smithers and Schulze, 2004). This program implements procedures to estimate design rainfall in South Africa and was run for the study area sites and surrounding areas, and can be used for designing water harvesting techniques in the study region. To determine the probability exceedance of the annual rainfall totals for the study sites, a graphical procedure of ranking the annual rainfall totals against their probability of occurrence and plotting on normal probability axes was applied to the long-term rainfall data. Long-term data series were required to make the data representative of the long-term rainfall patterns of the selected study sites (Critchely and Siegert, 1991). The probability of occurrence *P* (%) for each of the ranked observations was estimated from the equation:

$$P(\%) = \frac{m - 0.375}{N - 0.25} * 100$$

where:

P = probability in % of the observation of the rank *m*

m = the rank of the observation

N = total number of observations used

Logarithmic regression lines were fitted to the Upper Thukela data. From the curves it was possible to obtain the probability of occurrence or exceedance of a rainfall value of a specific magnitude. Inversely, it is also possible to obtain the magnitude of the rain corresponding to a given probability.

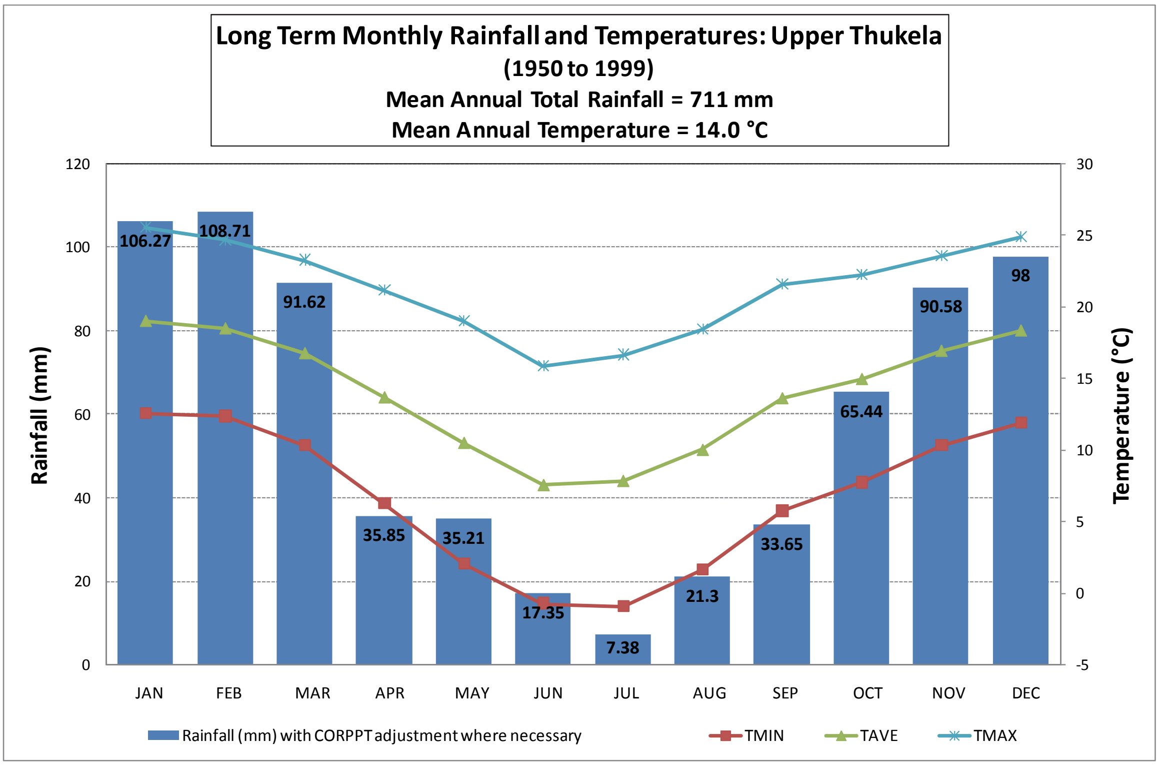


Figure 5-3: Long-term monthly rainfall and temperatures at Upper Thukela (KwaZulu-Natal).

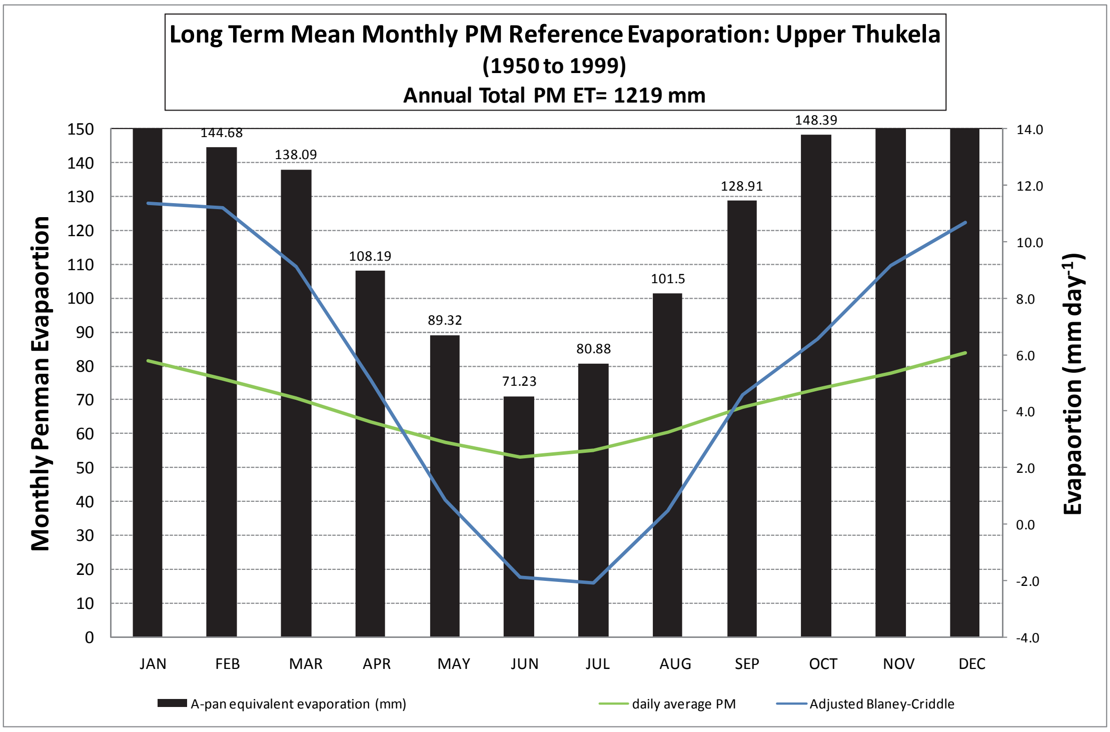


Figure 5-4: Long-term mean monthly and daily Penman-Monteith evaporation (Upper Thukela).

From the annual design rainfall statistics it was predicted that the sites will have a two out of three year probability (66%) of receiving 580 mm of annual rainfall and only a 33% probability of receiving the long-term average of 700 mm (Figure 5-5). Considering the driest month (July) it was apparent that there is no confidence in receiving rainfall in the winter months at the 66% probability level and only a 33% chance of receiving 10 mm (Figure 5-6). The monthly rainfall is particularly low in June and July. It was therefore considered important to allow for at least three months of storage following the average long-term May rainfall of 24 mm (2400 L on a 100 m^2 roof area). For these purposes a storage tank of 2500 L would be adequate to store the water for biogas generation based on an input of water to the digester of 20 L day^{-1}. The input from “greywater” from normal household activities such as washing and showering provides an additional source of water.

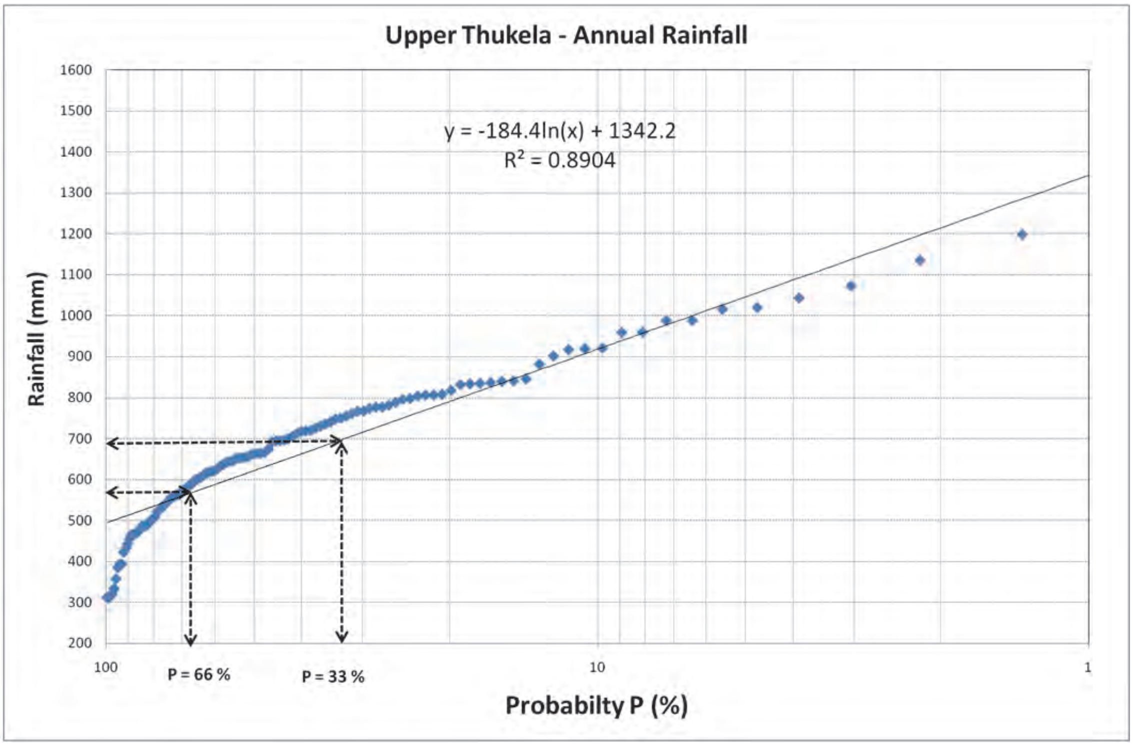


Figure 5-5: Probability diagram with regression line for an observed series of annual rainfall totals Upper Thukela.

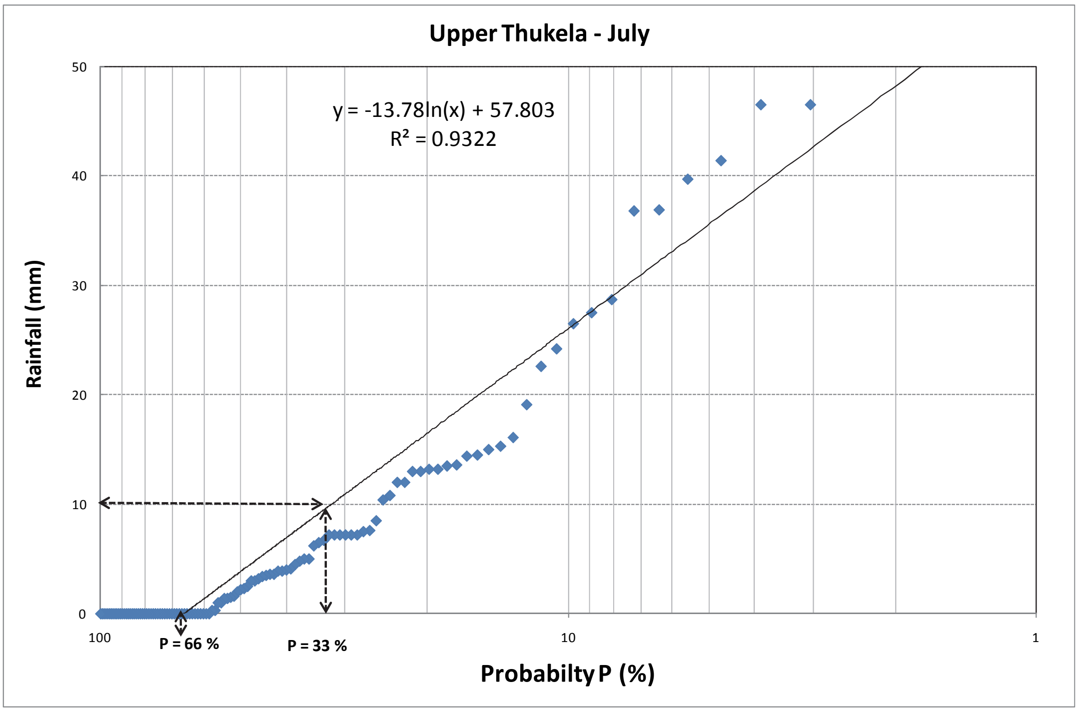


Figure 5-6: Probability diagram with regression line for an observed series of July rainfall totals Upper Thukela.

5.1.2 Rainwater harvesting implementation

Four field visits were made between 13/7/2012 and 30/10/12 to assess the implementation of the rainwater harvesting (RWH) systems of the four households in KwaZulu-Natal. On the initial visit it was observed that the contractor had installed the wrong size Jojo tanks (500 litres) at all the households. This was then corrected and replaced by 2200 litre tanks.

- Mr Sibusiso Mdakane (Potshini)

Mr Mdakane already had an operating RWH system. This comprised plastic pipes cut in half to form gutters that were attached to his thatched roof. The gutters fed into a Jojo tank. Mr Mdakane also has three underground water storage tanks.

- Mr Velum Khumalo (Okhombe)

The first inspection of the RWH system indicated that the system was not working as the down pipe was not operational. Mr Khumalo had prepared the base for the 2200 litre tank using his own frieze bricks. It was noted that the base was not adequate and at the back of the tank it was in danger of collapsing and urgently needed to be repaired. Mr Khumalo had placed a metal sieve on the opening of the Jojo tank which reduced the efficiency of harvesting rainwater. It was also noted that the position of the Jojo tank was not correct as it blocked the drain to the house which could result in flooding of the house if there is a big rainfall event.

The Jojo tank was then moved to the middle of the side wall of the house and two down pipes were installed which doubled the roof collection area. The base for the tank was rebuilt so that it could support the weight of a full tank. This enabled the system to function efficiently and safely.

- Mrs Miya (Newstand)

Mrs Miya paid R70 to a family member to build the base for the 2200 litre water tank. The team observed that this was a high quality. She reported that her RWH system was functioning well.

- Mrs Khumalo (Obonjaneni)

Mrs Khumalo reported that a family member built the cement bases for the 500 litre and 2200 litre water tanks. The project did not provide guttering as it was already there. Mrs Khumalo requested that the contractor leave the small water tank which she would pay for as water shortage was a major constraint for the operation of the household.

The installation of the RWH systems at the four households in KZN were completed and in operation by November 2012.

5.2 UTILIZATION OF HARVESTED RAINWATER

In 2015 a questionnaire survey was carried out with the four KZN household members to determine their use and management of water from the rainwater harvesting tanks. All the households ranked household use as their main use of water. This included cooking, washing clothes, bathing and building mud huts. None of the households used the harvested water for their maize crops. The reasons given were that the water tanks were too far from the maize fields, the pipe was too short and that their crops are planted in the wet season so they rely on rainfall. Only one household member planted fodder and he did not use harvested water as household use was a greater priority. None of the households used harvested water for their vegetable gardens. The reason for this was that they all used bioslurry which is a liquid fertilizer. All the households used greywater to feed the biodigesters. That way they saved water.

The interviews with the households confirmed the report by Bonten et al. (2014) that bioslurry generally has a high water content (more than 80%), which makes it difficult to store, handle and transport. Further studies are therefore needed to determine different storage mechanisms of bioslurry to promote its potential use on food and fodder crops.

5.3 SOIL WATER CONSERVATION

5.3.1 The effect of different mulch types on soil water content in maize crop systems of the Upper Thukela

Water scarcity in South Africa poses a problem for a large percentage of the population who rely on rainfed agriculture for food production. Maize *(Zea mays)* is the most important grain crop in sub-Saharan Africa and Latin America and it is used as a staple crop for food provision (Jones and Thornton, 2003). However, maize is a water-demanding crop which needs 450 to 650 mm of water per growing season (du Plessis, 2003). Climate variability which may result in prolonged dry spells is a major constraint to small-scale farmers who rely on rainfed maize production. This problem is common in the KwaZulu-Natal province and more specifically the Upper Thukela has high inter-annual rainfall variability (DEA, 2013). This region experiences mid-summer dry spells that occur in early January (Walker and Schulze, 2006). Dry spells hinder maize growth and grain filling leading to a decline in maize yield (Walker and Schulze, 2006). Therefore, ways need to be found to improve food security in water scarce areas where farmers are unable to afford irrigation and improved cultivars that can withstand dry spells.

One strategy that has been reported to reduce evaporation and conserve moisture is mulching, where organic or inorganic material is applied around the plant to prevent excessive evaporation or erosion, enrich the soil and inhibit weed growth (Ramakrishna, 2006). Mulching has an ability to improve productivity because of its potential to conserve soil moisture and increase soil fertility and consequently stabilizes and enhances crop yield. Mulching conserves water by reducing run-off and holding rainwater at the soil surface and thereby giving it enough time to infiltrate into the soil (Erenstein, 2003; Mupangwa et al., 2007). An ideal mulching material should be able to suppress weed growth, conserve water and it must be renewable, biodegradable, durable and permeable to water and irrigation water and it must be affordable (Haapala et al., 2014).

Mulch can either be inorganic or organic. Inorganic mulches refer to non-living mulches such as rocks and plastic mulches. Organic mulches are mulching materials made from organic materials such as grass clippings, compost or animal manure, crop residues from previous crops, live mulch, paper or woody material such as bark and sawdust (Merfield, 2002). Organic mulches are generally relatively cheap and locally sourced. Organic mulches are environmentally friendly because they don’t release toxic chemicals which are a threat to the environment. They can be fully decomposed into the soil, eventually improving soil organic matter. However, using crop residue mulch also has some limiting factors which include pests and diseases incidence (Erenstein, 2002) since a disease affecting the previous crop can get a chance to establish and become a problem to the current crop. Another example of organic mulch that is common in developing countries is live mulch (cover crops).

Live mulch refers to the use of a living plant for ground cover such as a low growing intercrop (Aladesanwa and Adigun, 2008). A common example of live mulch in rural areas is intercropping maize with pumpkins (*Cucurbita*). This type of an intercrop or mulch can increase yield per unit area, conserve water and control weeds (Li et al., 2011). However, there are reports of pumpkins in a maize-pumpkin intercrop system having an antagonistic effect by competing for water and nutrients with maize resulting in low maize yield.

Digested animal manure (known as bioslurry) can also be used as an organic mulch since it shows some characteristics of mulching material such as weed suppression and improving water holding capacity (No, 2012). Bioslurry is the effluent produced as a by-product of biogas production from the anaerobic digestion of organic material in a biodigester (Nasir et al., 2012). Bioslurry can be produced from cattle, pig and poultry manure and kitchen garbage (Arnott, 1985; Kumar et al., 2010). It is rich in micro and macro nutrients and it is therefore considered as a good source of soil nutrients (Nasir et al., 2012).

Bioslurry contains bulk and fibre which hold soil moisture and therefore it improves soil organic matter when it is incorporated into the soil (Arnott;5). Bioslurry can also form a mulch since after application it covers the soil surface and forms a hard cap of organic material which has potential to reduce soil evaporation. Conversely, the cap may reduce water infiltration and reduce soil water content. However, so far information on the effect of using bioslurry as a mulch on soil water content and infiltration is not well-documented.

The objective of the study was to compare the effect of bioslurry, grass clippings and live mulch (maize-pumpkin intercrop) on water conservation. In this study, it was hypothesized that bioslurry mulch could conserve more water than pumpkin live mulch and grass clippings mulch, thereby resulting in higher maize yield. This was based on the fact that when bioslurry is applied on the soil surface it forms a hard cap which could have the effect of minimising water loss through soil evaporation and hence conserve moisture and increase maize yield.

5.3.1.1 Materials and Methods

Maize seeds were sourced from the farmer (kept from his previous growing season) and pumpkin seeds were purchased (cultivar Flat White Boer). Flat White Boer was selected because it grows into compact bushes and this bush characteristic contributes to a large mulch canopy which has an ability to reduce soil evaporation and thus conserve soil moisture.

5.3.1.1.1 Experimental design

The experiment was set up as a 2 x 3 factorial treatment structure in the field and laid out using a randomized complete block design (RCBD) in a split-plot arrangement. In this scenario, pumpkin was considered as part of the cropping system. Cropping system (2 levels: sole maize and maize-pumpkin intercrop) served as the main plot treatments while mulching materials (3 levels: grass clippings, bioslurry and control) served as sub-plots treatments. The bioslurry treatment included the combined effect of moisture and nutrients when compared to the other mulch treatments. The treatments were replicated four times totalling 24 experimental units (5 m x 5 m plots).

The six treatments were as follows:

i) MC= Sole maize (no mulch)

ii) MB= Sole maize with bioslurry

iii) MG= Sole maize with grass clippings

vi) IC= Intercrop control (no mulch)

v) IB= Intercrop with bioslurry

vi) IG= Intercrop with grass clippings

To test the effect of pumpkin as live mulch compared with bioslurry and grass clippings, the experiment was analysed as a single-factor analysis with the following treatments as mulches applied to a maize crop: pumpkin, bioslurry, grass clippings (100% ground cover) and a control of no mulch. The experiment was replicated four times (Table 5-4) totalling 16 experimental units (5 x 5 m plots). In this case pumpkin was treated as live mulch and not as part of a cropping system.

Table 5-4: Experimental design of mulch trial.

Block 1	Block 2	Block 3	Block 4
MB IB	IG MB	MG IG	IB MB
MG IG	IC MC	MC IC	IG MG
MC IC	IB MG	MB IB	IC MC

5.3.1.1.2 Planting and management

The study was conducted on the cropping section of the homestead at Okhombe on 25th November 2014. Maize was planted according to Smith (2006) at an intra-row spacing of 0.4 m and 0.75 m between rows, which gave 84 plants per 25 m^2. In the intercrop treatment, maize and pumpkins were planted simultaneously where pumpkins were planted between two rows of maize. Pumpkin seeds were planted at 0.38 m between maize rows while the pumpkin seeds were spaced at 0.5 m within the rows. Two maize seeds were sown per station and three pumpkin seeds were sown per station. Both crops were thinned to one seedling per station at the first weeding. At planting, all sub-plots treatments (excluding bioslurry treatments) received nitrogen applied fertilizer based on the soil analysis, at the rate of 40 kg ha^{-1} as mono-ammonium phosphate (MAP 30%). At planting bioslurry was applied to respective plots as the source of fertilizer (Table 5-5) and it was incorporated into the soil. The bioslurry treatment was applied twice a month (fortnightly) as mulch until the maize was at 100% silking stage. This was to test if bioslurry could improve soil water content during flowering including tasselling, silking and pollination which are the most water demanding stages for maize and also to ensure that plants do not grow vigorously due to excess nitrogen applied by bioslurry. Each plot received 320 litres of bioslurry during the growing season as it was applied four times at the rate of 80 litres per plot. In terms of treatment application and management, bioslurry and grass clippings were applied to respective plots on the third week (16 December 2014) after planting to ensure that emerging plants were not buried by the treatments. Treatments were applied after the first weeding when manual weeding was practised. To simulate the farmer's practices, no additional water was applied to the experimental plots since the farmer relies on rainfed crop production.

Table 5-5: Chemical properties of bioslurry used.

Site	Soil moisture (%)	pH (%)	Total Nitrogen (%)	Total organic carbon (%)	Phosphorus (mg/L)	Potassium (mg/L)
Okhombe	96.69	7.18	1.78	39.74	16.53	36.02

Soil water measurements commenced two weeks after treatment application and every fortnight thereafter (before re-application of bioslurry). Soil water content was measured using a HydroSense II

Pole system (Campbell Scientific, Incl. Africa Pty. Ltd). Water content was measured at a depth of 12 cm in all plots to compare the effect of the different mulch treatments on soil water. The measurements were taken four times randomly in each plot and the mean was calculated.

5.3.1.1.3 Plant growth and yield parameters

The following maize growth variables were measured: maize plant height, maize stem circumference, maize leaf number and leaf area. Data on plant height and leaf number were collected fortnightly after treatment application until maize was at 50% tasseling. Maize leaf number, plant height, stem circumference and leaf area were measured from a repeated measures sample of five plants marked with tags. Five plants were randomly selected from the centre row of each plot to avoid the effect of border plants. The mean from five plants was then determined for each parameter.

- Maize plant height (cm) was measured from the soil surface up to the last leaf collar with a carpenter's tape measure.
- Stem circumference (cm) was measured with a tailor's tape measure.
- Number of leaves per plant was directly counted; leaf number per plant was recorded only for the green leaves on the main stem.
- Maize leaf area (cm^2) was determined by a non-destructive length and width method as described by (Onasanya, Aiyelari, et al., 2009) where maize leaf area is calculated as follows;

$$LA = 0.75 \, (L \times W)$$

Where LA, L and W are leaf area, leaf length and leaf width respectively, and 0.75 is a constant. Leaf area was determined from the five permanent marked plants in each plot. The youngest leaf or a flag leaf from the apex of the main stem of maize was used for leaf area measurement.

- Stover weight of five selected plants was recorded after oven drying at 60°C for 48 hours according to Pandey et al. (2000).
- After harvesting, the following yield components were measured; ear length and ear girth of dehusked cobs, weight of 1000 grain, grain yield and harvest index. These yield components were determined following shelling of the grain from the cobs. Grain samples were air dried for three weeks for moisture adjustment. Grain moisture content was measured using a digital grain moisture meter analyser (Zhejiang top instrument CO., LTD, China). Dry mass was determined when the grain reached a moisture content around 12%.
- Harvest index was determined by dividing the grain mass per plant by total biomass (stover weight and grain) after adjusting for moisture content (Unkovich et al., 2010).

5.3.1.1.4 Data analysis

Data were analysed using GenStat 16th version (VSN International, UK) at the 5% level of significance. A single factor analysis of variance was carried out with four levels of mulching treatments namely bioslurry, pumpkin live mulch, grass clippings mulch and control (no mulch). Pumpkins were treated as live mulch in the split plot design and not as part of the cropping system (intercrop). The tested assumptions of the

ANOVA showed that the distributions of the residuals were normal and the variances were equal. Contrasts were done to compare treatment means for the single-factor analysis at the 5% level of significance. Duncan's multiple comparison test was used to separate the means in GenStat at the 5% level of significance. Interactions were considered but reported only when significant

5.3.1.2 Results

5.3.1.2.1 Maize Yield and yield components

The data on grain yield showed that maize grain yield was highly affected by the mulching treatments (Table 5-6). The highest grain yield was obtained from the bioslurry mulch treatment (3498 kg ha^{-1}) which was significantly higher than the grass clippings mulch (3420 kg ha^{-1}), pumpkin mulch (1332 kg ha^{-1}) and the control (1017 kg ha^{-1}) Table 5-6).

The one thousand grain weight was significantly different in the different mulching treatments ($P<0.05$, Table 5-6). The maximum one thousand grain weight was observed in plots mulched with bioslurry (0.49 kg) and the minimum one thousand grain weight was recorded under control plots (0.22 kg). All mulching treatments showed significantly higher (0.34 to 0.49 kg) one thousand grain weight than the control (0.22 kg). There were also significant differences between mulching treatments in terms of harvest index which ranged from 0.55 to 0.79 (Table 5-6).

The results of ear length ear girth, and stover yield were analysed and presented in Table 5-6. The Duncan's multiple comparisons test indicated that the effect of the grass clippings on ear length was similar to those of bioslurry and pumpkin live mulch which ranged from 0.16 m to 0.17 m (Table 5-6). However, the control with no mulch was significantly lower (0.14 m) with respect to plant height. Mulching treatments had a significantly different ($P<0.05$) effect on ear length. The ANOVA indicated that there were no significant differences ($P>0.05$) in the effect of different mulching treatments with respect to ear girth which ranged from 0.14 m to 0.15m. The highest stover yield (1147 kg ha^{-1}) was observed in bioslurry which differed significantly from the control (633 kg ha^{-1}). However, there were no significant differences ($P>0.05$) between bioslurry, grass clippings and the pumpkins live mulch with respect to stover yield (Table 5-6).

Table 5-6: The effect of mulching materials on maize yield and yield contributing characters.

Treatments (Mulching material)	Ear length (m)	Ear girth (m)	Stover yield (kg ha^{-1})	1000-grain weight (kg)	Grain yield (kg ha^{-1})	Harvest Index (HI)
Bioslurry	0.17a	0.15a	1147a	0.49a	3498a	0.76a
Control	0.14b	0.14a	633b	0.22b	1017b	0.61b
Grass clippings	0.17a	0.14a	928ab	0.41ac	3420a	0.79a
Pumpkin live mulch	0.16a	0.14a	1073a	0.34bc	1332bc	0.55bc
SED	0.01	0.01	154.3	0.08	200.3	0.05
CV (%)	10.4	7.7	23.1	29.2	12.2	9.9

Notes: Means within columns not followed by the same letter are significantly different at P>0.05; SED= standard error deviation; CV = Coefficient of variation

5.3.2 Maize growth components

Growth parameters of maize plant including plant height, number of leaves, leaf area and stem girth are shown in Table 5-7. There were no interactions (P>0.05) between mulching treatments and time (weeks after planting) with respect to maize growth parameters. All mulching treatments were significantly higher (P>0.05) than the control (0.99 m) with regards to plant height. The Duncan's multiple comparisons test showed that maize plant height was similar to bioslurry, grass clippings and pumpkin live mulch which ranged from 1.18 m to 1.23 m. Pumpkin live mulch produced the tallest plants compared to the other treatments (Table 5-7). Bioslurry produced the maximum (9.45) number of leaves which differ significantly from other treatments. The least number of leaves (7.85) was recorded in the control plots (Table 5-7). There were highly significant differences (P<0.001) in number of leaves across the mulching treatments used.

Stem girth was significantly improved by mulching with bioslurry (0.082 m) followed by grass clippings (0.079 m), pumpkin live mulch (0.078 m) and control (0.074 m). Data showed that bioslurry was statistically different from control but statistically similar to other mulching treatments with respect to stem girth (Table 5-7).

The highest and lowest leaf area were recorded in plots treated with bioslurry (154.9 cm^2) and control (124.0 cm^2) respectively. There were significant differences (P<0.05) in mulching treatments with respect to leaf area. The leaf area was statistically similar in grass clippings, pumpkin live mulch and control while bioslurry mulch was statistically different from all other treatments (Table 5-7). The highest leaf area (248 cm^2) was recorded in bioslurry mulch at 13 weeks after planting (WAP) while the control (191 cm^2)

gave the lowest value of leaf area. Bioslurry was significantly higher than other treatments at 11 WAP and 13 WAP (Figure 5-7). There were no significance differences (P>0.05) observed in maize leaf area from different mulching treatments over time.

Table 5-7: Effect of mulching material on plant growth parameters.

Treatments (Mulching material)	Plant height (m)	Leaf number	Stem girth (m)	Leaf area (cm^2)
Bioslurry	1.21a	9.45a	0.082a	154.9a
Control	0.99b	7.86b	0.074b	124.0b
Grass clippings	1.23a	8.58c	0.079ab	133.2bc
Pumpkin live mulch	1.18a	8.35bcd	0.078ab	134.4bc
SED	0.10	0.30	0.003	7.51
CV (%)	24.0	9.8	12.5	15.6

Notes: Means within columns not followed by the same letter are significantly different at P>0.05; SED= standard error deviation; CV = Coefficient of variation

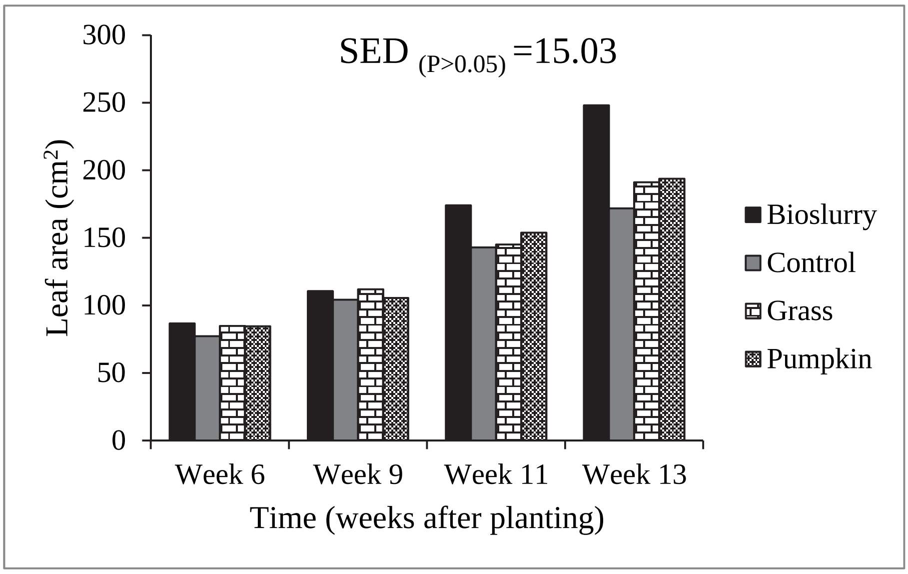


Figure 5-7: Leaf area of maize plants recorded during the weeks after planting (WAP).

5.3.2.1 Soil moisture

Significant differences were observed in the soil treated with different mulching materials. Soil water content was highest under the bioslurry treatment (21.55%) followed by pumpkin live mulch (21.30%), grass (19.88%) and the control with 18.39% (Figure 5-8). The soil water content in the bioslurry treatment was significantly different from the control ($P<0.01$) but not statistically different from the grass mulch and pumpkin live mulch treatments (Table 5-8). Pumpkin live mulch was statistically different from the control ($P<0.01$) but it did not differ significantly from the grass mulch (Table 5-8). The results showed that there was no significant interaction ($P>0.05$) between time and mulch with respect to soil water content. However, as expected, soil water was closely related to rainfall (Figure 5-8).

Table 5-8: Results of the analysis of variance for the soil water content in maize plots treated with different mulching materials (See Appendix for ANOVA).

Source of variation	d.f.	m.s.	Significance
Block stratum	3	510.23	
Block.*Units* stratum			
Date	4	663.29	<.001
Mulch	3	42.28	0.015
Bioslurry vs Control	1	99.23	0.004
Bioslurry vs pumpkin	1	0.63	0.814
Bioslurry vs grass	1	27.64	0.122
Pumpkin vs control	1	84.10	0.008
Pumpkin vs grass	1	19.95	0.188
Grass vs Control	1	22.13	0.166
Date. Mulch	12	8.78	0.666
Date. Bioslurry vs Control	4	8.95	0.532
Date. Bioslurry vs pumpkin	4	6.21	0.697
Date. Bioslurry vs grass	4	9.86	0.483
Date. Pumpkin vs control	4	7.52	0.616
Date. Pumpkin vs grass	4	9.21	0.517
Date. Grass vs Control	4	10.90	0.430
Residual	57	11.22	
Total	79		

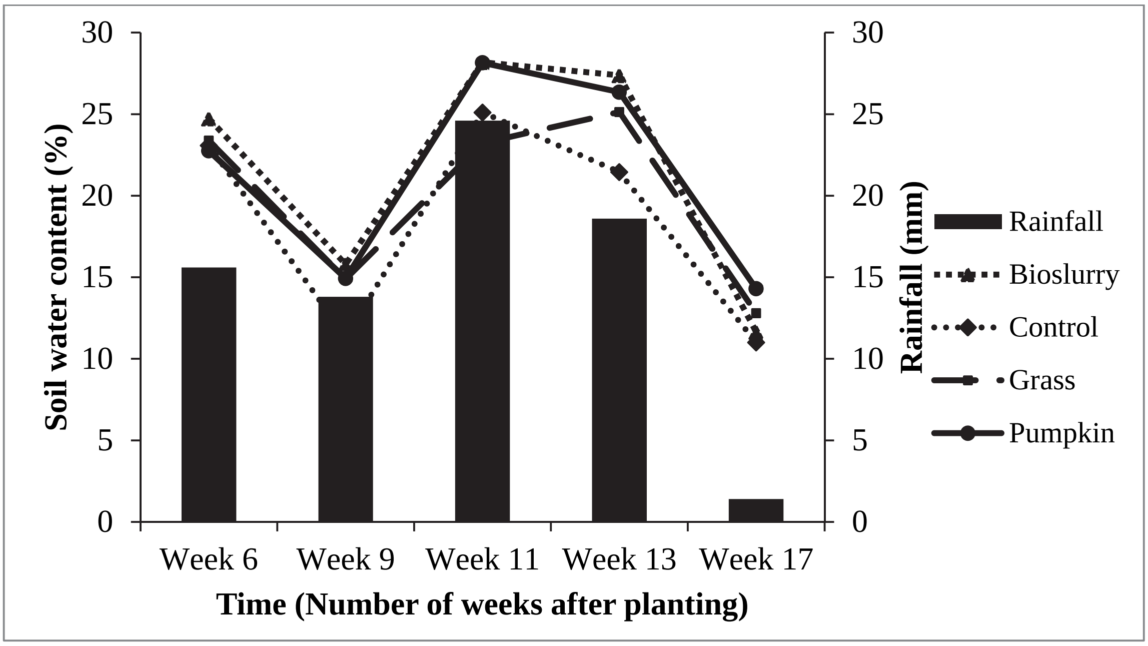


Figure 5-8: Effect of mulching treatments and rainfall on soil water content.

Box plots were used to describe the variability among mulches and blocks with respect to soil water content. Box plots were used to illustrate the variation in soil water content values between 25th and 75th percentile which represents the interquartile range and contains 50% of the data. Water content was normally distributed for all mulching treatments with the bioslurry and control treatments having the most variability (Figure 5-9). The variability in soil water across the maize field is apparent in Figure 5-10 which showed that blocks 3 and 4 were relatively wet compared to blocks 1 and 2.

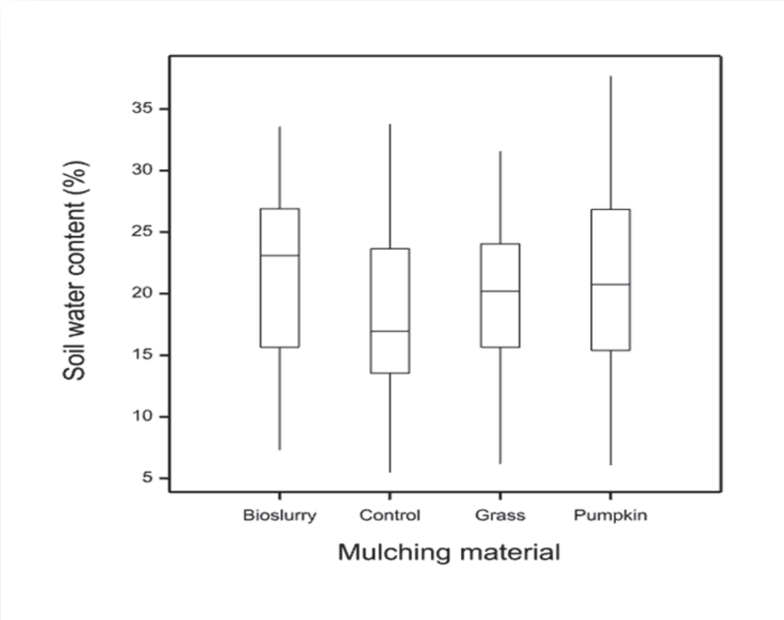


Figure 5-9: Box plots comparing the variability in soil water content in different mulching material.

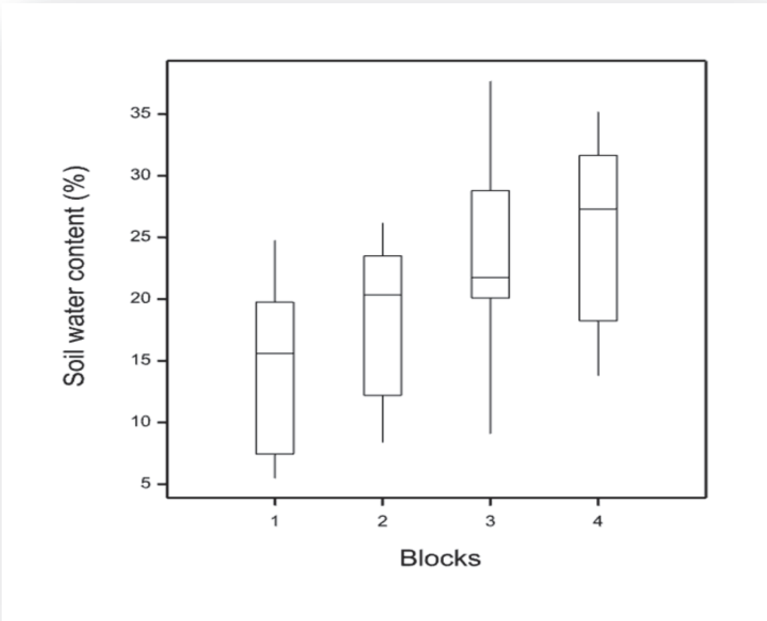


Figure 5-10: Box plots comparing the variability in soil water content in different blocks across the maize field.

There were highly significant differences ($P<0.001$) between mulching treatments for grain yield. Highest grain yield (Table 5-9) was recorded for maize plants mulched with crop residues (319.7 g m^{-2}), followed by the control (203.6 g m^{-2}) and bioslurry treatments (128.7 g m^{-2}). Least grain yield was obtained under bioslurry treatments. Mulching with crop residues also had a significant effect ($P<0.001$) on harvest index (HI). The HI of the crop residue treatment (0.35) had a significantly higher index than the bioslurry (0.28) and control treatment (0.31) which were not significant different from each other.

Maximum value of leaf area index (LAI) was recorded under the crop residue treatment (2.6) and minimum values were observed on the bioslurry (1.4) and control (1.5) treatments. Crop residue treatments were statistically higher than both the control and bioslurry treatments which were not statistically different to each other (Table 5-9).

Table 5-9: Effect of mulching material on harvest parameters and leaf area index of maize.

Treatments (mulching material)	Cob length (mm)	Stover Dry Wt (g m^{-2})	Cob Dry Weight (g m^{-2})	Grain yield (g m^{-2})	Harvest index	Leaf Area Index
Crop residues	173.8 b	585.1 c	433.2 c	319.7 c	0.35 b	2.6 b
Bioslurry	119.1 a	299.3 a	305.8 a	128.7 a	0.28 a	1.4 a
Control (no mulch)	133.8 b	395.3 b	337.9 b	203.6 b	0.31 a	1.5 a
SED	5.50	20.99	15.67	8.16	0.02	0.20
CV (%)	21.3	25.6	22.7	19.5	27.7	17.4

Notes: Means within columns not followed by the same letter are significantly different at P>0.05 by Duncan's multiple range test (DMRT); SED= standard error deviation; CV = Coefficient of variation

Longest cobs were observed under the crop residues treatment (173.8 mm) followed by the control (133.8 mm) and bioslurry treatments (119 mm). Stover dry weight was significantly higher on the crop residues treatment (585.1 g m^{-2}) than the control (395.3 g m^{-2}) and bioslurry (299.3 g m^{-2}) treatments (Table 5-9).

Grain yield was highly significant different ($P<0.001$) between cropping systems. Maximum grain yield was observed on maize planted in a sole cropping than those in an intercropping system. Intercropping and sole cropping systems had 185.4 g m^{-2} and 249.2 g m^{-2} grain yield respectively (Table 5-10). Cropping system also had an effect on HI; maximum HI was recorded for the sole cropping system (0.35) which was significantly higher ($P<0.001$) than that of the intercropping system (0.28,Table 5-10).

Table 5-10: The effect of cropping systems on maize grain yield (g m^{-2}) and Harvest Index.

Cropping system	Grain yield (g m^{-2})	Harvest index
Sole crop (maize)	249.2	0.35
Intercrop (maize and pumpkins)	185.4	0.28
SED	6.66	0.01
CV (%)	19.5	27.7

5.3.2.2 Discussion

The highest grain yield (3498 kg ha^{-1}) and yield components such as ear girth, stover yield, one thousand grain weight and harvest index (Table 5-6) were recorded from the plots mulched with bioslurry compared to other mulching treatments. This could be attributed to nitrogen supplied by the bioslurry which increases the leaf area in plots mulched with bioslurry (Table 5-7). Valadabadi and Farahani (2010) reported that nitrogen plays an important role in developing leaf area. Furthermore, maximum leaf area increases photosynthesis and hence increases crop yield (Valadabadi and Farahani, 2010). In addition, high yield and yield components observed under bioslurry may be ascribed to high soil water content observed in plots mulched with bioslurry as well as the high moisture content in the bioslurry (Table 5-5). These results are in agreement with those obtained by Gurung (1997) on a wheat trail where it was concluded that liquid bioslurry also provides moisture which is an important factor in crop yield in rainfed conditions. Bioslurry is reported to supply nutrients that are readily available for plant uptake (Karki and Expert, 2006; Islam et al., 2010) and this could be the one of the reasons why the bioslurry increased maize grain yield. Maize needs water and nutrients in order to grow and produce high yield.

The different mulching materials conserved more soil water than unmulched soil (control). This could be attributed to the fact that mulches prevent soil water evaporation thus increasing soil water content. In this study, it was observed that the amount of water conserved in the profile to a soil depth of 12 cm was significantly greater under the bioslurry mulch treatment than the control (Figure 5-8). This could be due to the high moisture content in the bioslurry since bioslurry contains 90% of water (Arnott, 1985). Therefore, adding bioslurry into the soil increased soil water content. The ability of bioslurry to have high moisture content compared to other mulching materials could be attributed to the effect of the high fibre found in bioslurry, which is reported to contribute to its ability to hold more water (Arnott, 1985). In addition, it is possible that the hard cap formed after bioslurry application could reduce evaporation from the soil surface.

Pumpkin live mulch conserved more water than grass although the differences were not significant (Figure 5-8). This could be due to the fact that pumpkins are living plants and have the ability to cover the ground rapidly and hence reduce soil evaporation, while grass clippings are inert and they decomposed faster. Results showed that pumpkin live much (maize-pumpkin intercrop) had higher soil water content than control (sole maize). These results are in agreement with those obtained by Olasantan (2007) who concluded that high soil water content in pumpkin live mulch is related to the rapid ground cover of pumpkin, which further reduced soil evaporation, hence increasing soil water. The results of pumpkin live mulch with regards to water content in this study also corroborate with the study conducted by Salau et al. (2015) in pumpkin-cassava intercrop. They concluded that creeping growth habit and the large canopy of pumpkin played a significant role in reducing soil evaporation by shading the soil and thus conserving soil water.

Grass clippings conserved less water than pumpkins and bioslurry (Figure 5-8) which could be attributed to the fact that grass decomposed faster and therefore lost its ability to reduce soil evaporation after decomposition. A study conducted by Sinkevičienė et al. (2009) showed that grass conserved less water than wheat straw, peat and sawdust and they concluded that grass decomposed before the end of growing season, allowing soil evaporation which further decreased soil water. The lowest soil water content recorded in the control treatment could be due to relatively higher evaporation from the bare soil compared to the mulch treatments.

The box and whiskers plots of the data indicated that the soil water data were normally distributed. However, in the grass and pumpkin treatments showed less variability than the bioslurry and control treatments (Figure 5-9). This indicates that control plots were more responsive to changes in rainfall meaning that the control treatments had higher moisture when the soil was wet and lower moisture when the soil was dry. The variability in bioslurry treatments could be due to the bioslurry concentration at application, the thin layer of bioslurry reduced the formation of hard cap in bioslurry eventually reduce water conservation. The variability in soil water across the maize field (Figure 5-10) could be due to soil textural differences with some blocks having more clay than other blocks.

The current study revealed that the highest ear girth, stover yield, one thousand grain weight, grain yield and harvest index were observed in plots treated with bioslurry mulch compared to those treated with grass clippings and pumpkin mulch. This could be attributed to an increase in leaf area in plots mulched with bioslurry (Table 5-6) resulting in increased light interception and thus high photosynthetic activity. In addition, maximum ear girth, the stover yield, one thousand grain weight, grain yield and harvest index was observed under bioslurry treatments (Table 5-9) This may also be attributed to the higher soil water content in this treatment which may be associated with the high moisture content in the bioslurry (Liu et al., 2009) or associated with reduced soil evaporation through the hard cap formed after bioslurry. These results are in agreement with those obtained on a wheat trail (Gurung, 1997). It was concluded that wet bioslurry also provides moisture which is an important factor in crop yield in rainfed conditions.

In conclusion, the findings of this study indicated that the use of organic mulches such as bioslurry and pumpkin live mulch increased soil water content more than the control of no mulch. Therefore, application of bioslurry as mulch can be implemented by small-scale farmers who rely on rainfall for maize production. Mulching using grass clippings, pumpkin live mulch and bioslurry can also reduce reliance on herbicides by suppressing weed growth. Results of this study may be used as an initial step towards the use of bioslurry as mulch. However, more studies are needed to assess if the ability of bioslurry to conserve water was due to the formation of the hard cap or if it was due to the high moisture content of bioslurry. From this study, it was clear that mulching materials such as bioslurry, grass clippings and pumpkins live mulch significantly improved maize growth and yield. Maize growth was therefore increased by mulching materials compared to the farmer's practice which was the control of no mulch. Growth was higher with bioslurry and grass mulches compared to pumpkin live mulch and the control. This was evident in the plant height, number of leaves, stem girth and leaf area produced. This may be due to the fact that the anaerobic digested bioslurry contains nutrients that are more readily available for plant uptake (Islam et al., 2010; Karki and Expert, 2006) than grass mulch which has to undergo decomposition to release nutrients. Although pumpkins may compete for water and nutrients with the maize, live pumpkin mulch resulted in a higher maize yield than the control. Since all mulching materials increased maize yield, the application of mulch should be highly recommended to farmers operating rainfed agriculture in this region.

5.3.3 The effect of bioslurry on soil water content in a Napier fodder crop system

Soil water is essential for plant life (Ritchie, 1998), and therefore affects yield production within an agriculture system. According to Bennie and Henseley (2001), the total biomass production of any crop is directly proportional to the amount of water taken up by the plant. As a result, in drought prone areas, the yield declines significantly. Water availability in the soil is largely dependent on the amount of precipitation, percentage drained into aquifers through gravity, the amount lost to evaporation and the remainder that is stored in the soil reserve that is taken up by the plant (Ritchie, 1998). There are different ways that farmers can maximize water conservation to increase the amount available to the plant. These include the use of mulches as well as working the soil to make it porous and thus improving infiltration rate (Bennie and Hensley, 2001). Addition of nutrients can improve soil chemical and physical properties and consequently also the water storage. In this study we investigated the effects of different applications of nutrients on soil water content.

5.3.3.1 Methods

Following land preparation, the different nutrients were applied into the soil of the Napier fodder trial. This trial had 3 cutting regimes at 8, 12 and 24 weeks, and four nutrient treatments. These included the application of chemical fertilizer (F), bioslurry worked into the soil (B), bioslurry-overlay where bioslurry was left to form a cap on the soil (BO), and the control (C) with no nutrients.

Fertilizers were applied to the soils following the recommendations by Cedara Soil Fertility and Analytical Services (CSFAS) based on soil sample analyses in January 2015 (Table 5-11). Ammonium sulphate (20:0:0) and single super phosphate (0:10.2:0) fertilizers were used to apply the recommended NPK (120-70-0) ratio. These fertilizers were therefore applied at 1.65 kg plot^{-1} and 0.926 kg plot^{-1} respectively (only in fertilizer treatment plots). The phosphorus was applied at establishment while nitrogen application was split into several applications: at planting it was worked into the soil as a top-dress after four and eight weeks after planting. The bioslurry used for this study had 1.48% nitrogen, equivalent to 0.108% per 100 ml. To meet the recommended 120 kg ha^{-1}, 304.19 L plot^{-1} was applied (3.13 L plant^{-1}). The bioslurry application was applicable for both uncapped and capped treatment plots.

Table 5-11: The different amounts of fertilizer (ammonium sulphate, 20:0:0) and bioslurry (1.14% Nitrogen) applied at different times.

Week of Nutrient application	Ammonium fertilizer (g/row)			Bioslurry (L/plant)		
	8*	12*	24*	8*	12*	24*
0	0.55	0.55	0.55	3.38	3.38	3.38
4	0.55	0.55	0.55	3.38	3.38	3.38
8	0.55	0.55	0.55	3.38	3.38	3.38

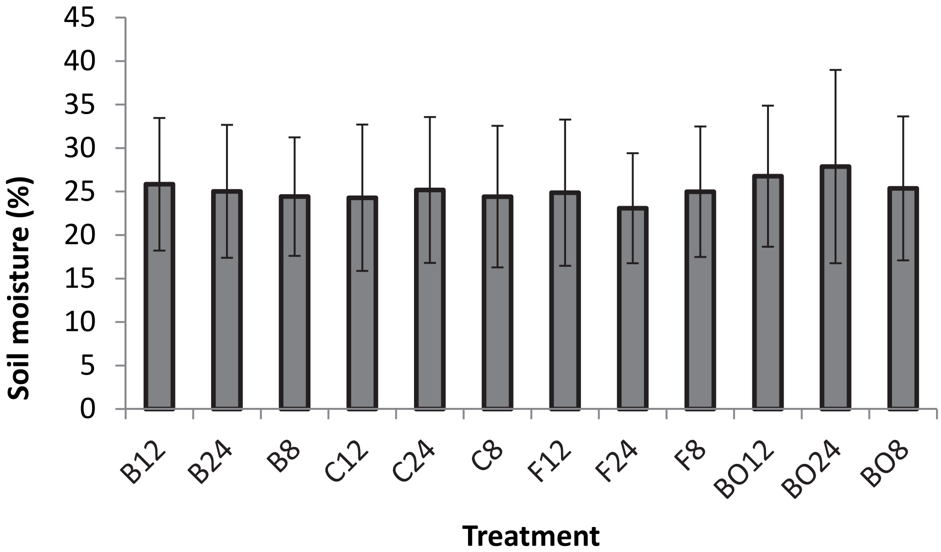
**where 8, 12 and 24 are the different cutting regimes in weeks for the different treatment plots*

Soil moisture measurements were taken on a monthly basis for the first three months when the grass was allowed a period to establish. We did not expect any variation in soil moisture because of the heavy rains during this period (December to March). From April onwards, bi-weekly measurements were taken at a 120 mm depth. For all soil moisture measurements, a HydroSense II Pole instrument (Campbell Scientific, Incl. Africa Pty. Ltd) was used which gives the volumetric water content as a percentage in the range from 0-50%. The data were analysed on SPSS using a one-way univariate analysis of variance (ANOVA), following testing of the assumptions of the ANOVA. The normality of the residuals was tested using the One-Sample Kolmogorov-Smirnov test and a Levene's test was done to determine the homogeneity of the variance of the residuals.

5.3.3.2 Results and discussion

The soil moisture content was similar across the different plots (Figure 5-11). While the highest water content was in the bioslurry overlay (BO) plots (27% ± 11.11), there was no statistical difference between treatments ($p = 0.84$, df= 11).

Figure 5-11: Mean soil moisture content (%) ± standard deviation across the four treatments (control (C), bioslurry worked into the soil (B), bioslurry-overlay (BO) and inorganic fertilizer (F) on Napier plots with cutting regimes at 8, 12 and 24 weeks).



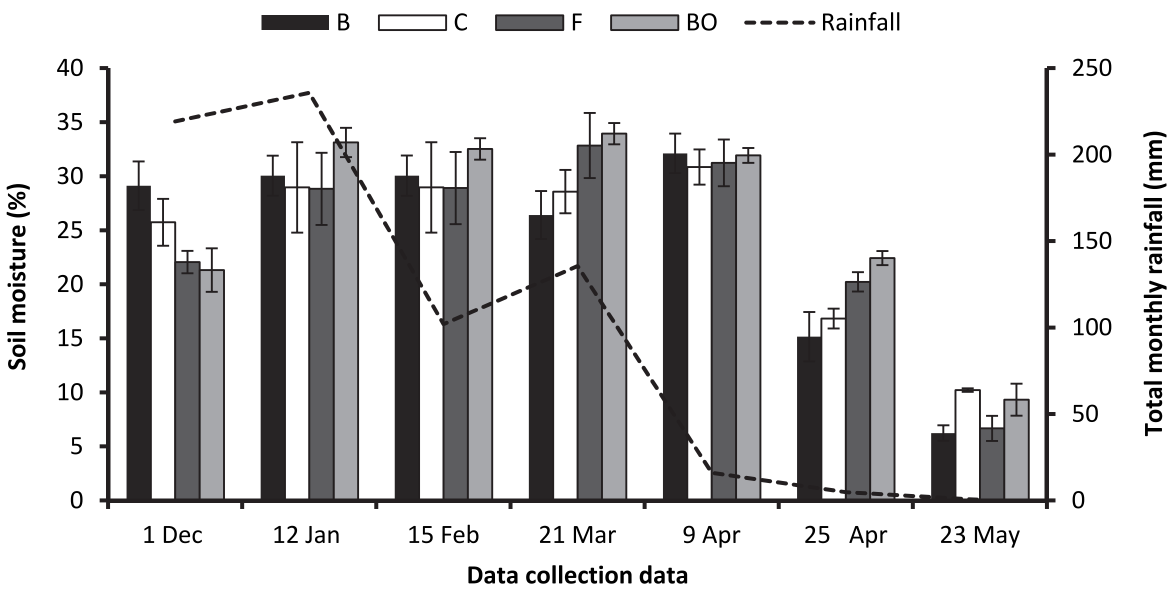


Figure 5-12: Mean soil moisture content (%) and total monthly rainfall across the four treatments control (C), bioslurry worked into the soil (B), bioslurry-overlay (BO) and inorganic fertilizer (F) were the Napier grass was cut at 12 weeks after planting.

According to Bennie and Hensley (2001) dry land production covers 11 million hectares in South Africa and it receives 600 mm rainfall. They reported that of this, only 12% of direct rainfall feeds into agricultural systems and the rest is lost as runoff or filters into underlying water bodies back into the sea. It is therefore important for farmers to effectively manage water in rain-fed systems to maximize production of water flow between the soil and the plant. In this study we measured water content where different nutrients were added. There was no difference in water content across the four treatments (Figure 5-11), which could be attributed to the fact that the study site falls within a sourveld grassland thus receiving high rainfall (Everson et al., 2012). Due to the high rainfall, the loss of water through evapotranspiration could be minimal, resulting in no differences in water content between the different treatments. The results of this study therefore indicate that in high rainfall areas soil moisture may not be a limiting factor for growth.

5.4 FODDER PRODUCTION

There are a number of challenges faced by livestock keepers in communal lands. The top ranked of these is the decline of nutrients in sourveld during the winter season (Kirkman and Moore, 1999; Morris et al., 1999), coupled with effects of land use changes and degradation, leading to fodder shortage. A number of alternative feeding strategies have been highlighted by van Zyl and Danhauser (2005) to address the problem of fodder shortage, including pastures, fodder crops and crop residues such as maize stalks. Since communal livestock owners are already utilizing crop residues, this study focused on the implementation of pasture and fodder crop species.

Prior to the establishment of the fodder trials, each household was visited and in-depth interviews were held to determine past and current practices in fodder and crop establishment. The quantity of lime delivered to each household was determined by the soil analysis results received from the Cedara Soil Laboratory.

Mr Sibusiso Mdakane - Potshini

Mr Mdakane would like to plant crops that do not use a lot of water as water is very short. He once planted a fodder crop – a bean crop that grew along the ground and everything was harvested. He did not have a definite recommendation for a suitable fodder crop. He has seen lucerne grown on the farms outside Winterton. He suggested rye grass, but this uses a lot of water. He did not know Napier Fodder. He was happy to try lablab if it was planted in November. When there is other fodder available the animals do not like it, but if fodder is short they will eat it. He queried why Napier Fodder is grown along fence lines and not in fields. It was explained that it was a good wind break and the idea was to use it on non-productive land so that it doesn't take up space that can be used for food crops like maize.

Mr Mdakane generally ploughs in November. He adds manure before ploughing. After ploughing he fertilizes with MAP, DAP and LAN. He last had soil samples taken years ago. He had not limed his fields for five years. When he did lime he planted maize a week later.

Mr Velumu Khumalo – Okhombe

Mr Khumalo has never grown fodder crops before. He doesn't have a place to grow fodder. He had no knowledge of fodder crops and could not recommend any. He did not know lablab and cow peas, but has seen fodder growing on farms near Bergville which may have been Napier fodder.

Mr Khumalo has never had soil samples done. He ploughs his fields in October. He uses MAP fertilizer and chicken manure (igroma) which has a bad smell. He plants from 25-30 November. He uses his own seed which he has used for years. He has never used lime.

Mrs Miya – Newstand

Mrs Miya had no knowledge of fodder crops and could not recommend any. She would like to grow fodder crops as she currently cuts grass to feed her cattle in winter. A huge heap of cut grass was evidence of this. She currently is not growing anything and is storing the bioslurry on a field which she will plant later. As Mrs Miya's fields are not close to her house it may not be possible to establish experimental fodder trials. She has soil samples done every year by Mr Mkhawnuleni Khumalo from DoA.

Mrs Khumalo - Obonjaneni

Mrs Khumalo has never grown fodder crops before and could not make any recommendations. She currently uses DAP and no lime. She ploughs and plants in the middle of November.

The in-depth interviews with the four households in KZN indicated that the implementation of fodder crops will be a new technology for the households. Only one of the households has had their soils analysed in the last five years. Three of the households had never applied lime which is regarded as essential in the area because of the acidic soils. Training of the households on the need for soil analyses and on the management of the fodder trials formed an essential component of capacity building of the household members.

The objectives of the fodder trial and proposed fodder species were discussed with each of the four households in KZN and permission was obtained to use part of the maize cropping field for fodder establishment. The three fodder species that were tested were: cow peas (*Vigna sinensis)* know in Zulu as isihlumaya, as it is a nitrogen-fixing legume crop which is drought tolerant, Forage Sorghum (*Sorghum bicolor*) because it grows quickly, has a high yield potential and is rich in nutrients and Napier Fodder *(Pennisetum purpureum*) which has a high yield and is hardy. All households were also given one kilogram of velvet beans to plant under non-experimental conditions.

5.4.1 Experimental on-farm fodder trials: sorghum fodder and cowpea

There is little information on the use of bioslurry for fodder production in South Africa and the effect on soil chemical properties. The aim of this study was to establish whether bioslurry could be used as a nutrient source for fodder production in KwaZulu-Natal and secondly, to determine whether this could contribute to sustainable livestock-crop production systems among smallholder farmers in the Upper Thukela. The specific objectives were (1) to conduct on-farm trials to determine the effect of bioslurry on growth, biomass and nutritive quality of cowpea and sorghum fodder; (2) to determine the N and P release patterns from bioslurry in two contrasting soils (acidic and non-acidic) sampled from two farms in the Upper Thukela and (3) to assess the impact of using cowpea and sorghum fodder for supplementary feeding on the current grazing carrying capacity (AU ha^{-1}).

5.4.1.1 Experimental design

The trials were established using a randomized complete design (RCBD) as a 3 x 2 factorial experiment in each farm with the following factors: fertilizer (3 levels – MAP, bioslurry and control) and fodder species (2 levels – cowpea and sorghum) replicated 3 times giving a total of 18 experimental units (plots measuring 5 x 5 m).

Bioslurry was collected from the biodigesters in the New Stand and Potshini homesteads, and applied biweekly at a rate of 20 litres per 5 x 5 m plot; slurry was diluted to a 1:1 ratio with water following recommendations by Gurung (1997). Prior to the experiment bioslurry from each digester was analysed to determine its nutrient content. Mono-Ammonium Phosphate (MAP) fertilizer was used following the recommendations of the Department of Agriculture (DoA) based on the results of soil analysis. MAP fertilizer was applied once during planting at 100 kg ha^{-1}.

5.4.1.2 Plant material, planting date and spacing

Cowpea and sorghum seeds were provided by the Southern African Cover Crop Solutions (SACCS). The cultivars used were mixed brown (cowpea) and forage sorghum. Cowpea seeds were planted at a row spacing of 90 cm apart and the inter-plant spacing was 10 cm following recommendation by Smith (2006). Forage sorghum was planted at a row spacing of 90 cm apart and the inter-plant spacing was 30 cm. The planting took place on the 10^{th} December (New Stand) and 14^{th} (Potshini) December 2013 and harvesting occurred in March/April 2013 at both sites.

5.4.1.3 Data collection

Five plants were randomly selected in each plot and the selected plants were tagged for repeated measurement purposes. Growth data for cowpea were collected biweekly, starting from 4 WAP to 10 WAP. However, sorghum data were collected biweekly from 4 WAP to 12 WAP. Different harvesting dates were used because of the different crop growing seasons. Cowpea was harvested in March (at 50% pods stage) and sorghum was harvested in April (milky grain head stage). A tape measure was used to measure the height of the plants. The height of both species was measured from the plant base to the growing point (apical meristem) of the plant. For sorghum the number of leaves was counted per plant and for cowpea the number of trifoliate leaves per plant was counted.

Cowpea was harvested in March while sorghum was harvested in April. A square meter (m^2) quadrat was placed in the centre of each plot and all plant material was clipped to 1 cm above ground level. Biomass harvested was weighed in the field as fresh weight and oven dried at 60^0C for 48 hours to determine dry weight. Biomass samples were analysed for nutrient content.

5.4.1.4 Agronomic practices

Prior to planting, soils samples were taken for soil fertility analysis in the Cedara laboratory (Fertilizer Advisory Service). Nutrients analysed were N, P, K, Ca, Mg, Zn, Mn, Cu, organic C and pH. Acid saturation was also included in the soil fertility test, to measure the soil acidity and the required lime. Post harvesting, samples were taken for similar soil fertility tests to compare differences prior to and after application of treatments. Routine weeding was done by hand. Bioslurry was analysed for nutrient composition prior to planting by Talbot and Talbot laboratories in Pietermaritzburg.

5.4.1.5 Statistical analysis

Differences between treatments were analysed using a 2-factor analysis of variance (ANOVA) using GenStat® Version 14 (VSN International, UK). Means were separated using the 5% level of significance (LSD= 0.05)

5.4.1.6 Results

5.4.1.6.1 Cowpea growth

With respect to number of cowpea trifoliate leaves results of the New Stand on-farm trial showed that there was no significant (P>0.05) effect of bioslurry on the mean number of leaves of cowpea when compared to other treatments (MAP and control) during the three month period of growth (Figure 5-13). At 10 WAP, the maximum height occurred in the control treatment (42.2 cm) whereas bioslurry (32.87 cm) had the lowest height.

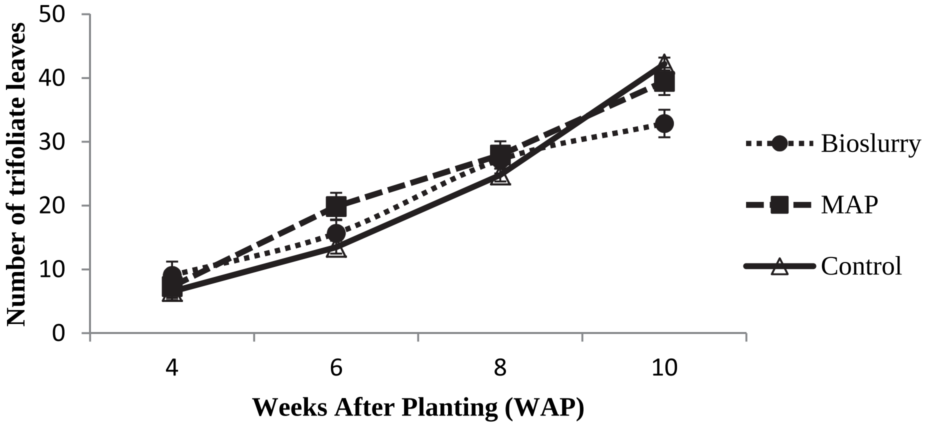


Figure 5-13: Mean number of trifoliate leaves for cowpea in the New Stand trial.

Results of the Potshini on-farm trial also showed significant effect (P<0.05) of the bioslurry on the mean number of cowpea trifoliate leaves when compared to the other treatments (Figure 5-14). At 10 WAP, the mean number of trifoliate leaves ranged from 38.47 to 54.4, with the control treatment having the highest mean and bioslurry the lowest.

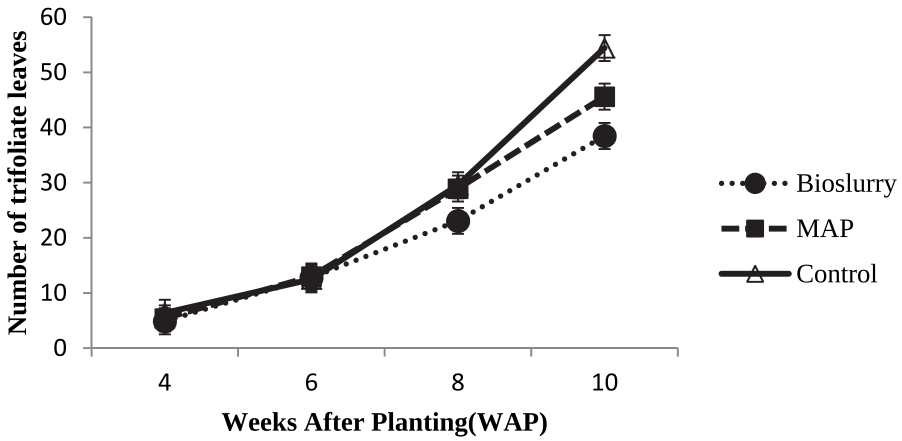
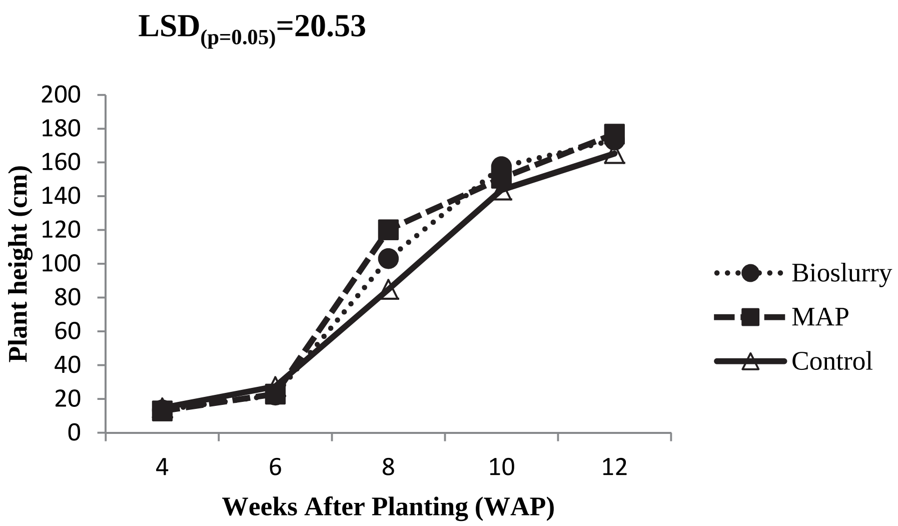


Figure 5-14: Mean number of trifoliate leaves for cowpea in the Potshini trial.

5.4.1.6.2 Sorghum growth

The applied treatments (bioslurry, MAP and control) had no significant effect (P>0.05) on sorghum height in the New Stand trial (Figure 5-15a). At harvest (12 WAP), maximum height occurred with MAP (176.8 cm), followed by bioslurry (173.3 cm) and the control (165.3 cm).

(a)



(b)

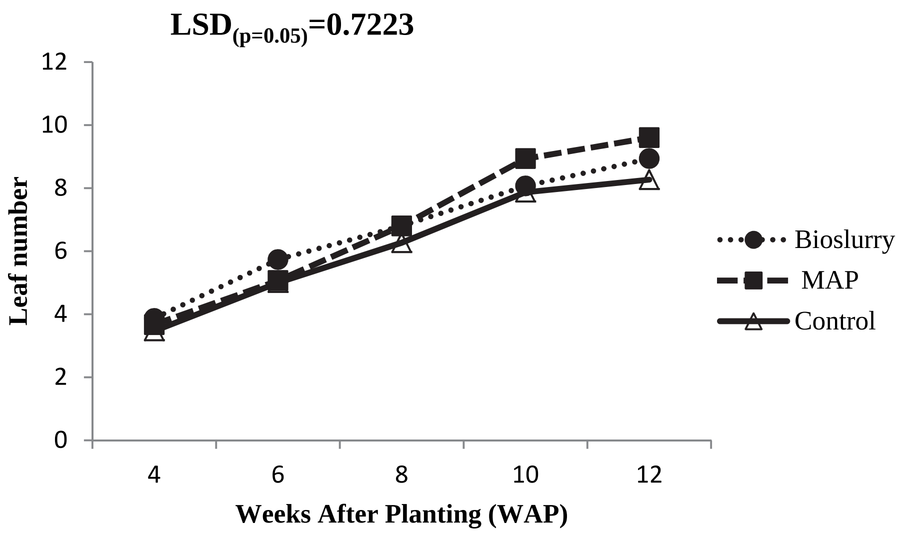


Figure 5-15: Mean height (a) and leaf number (b) of sorghum fodder grown on the on-farm trial in New Stand.

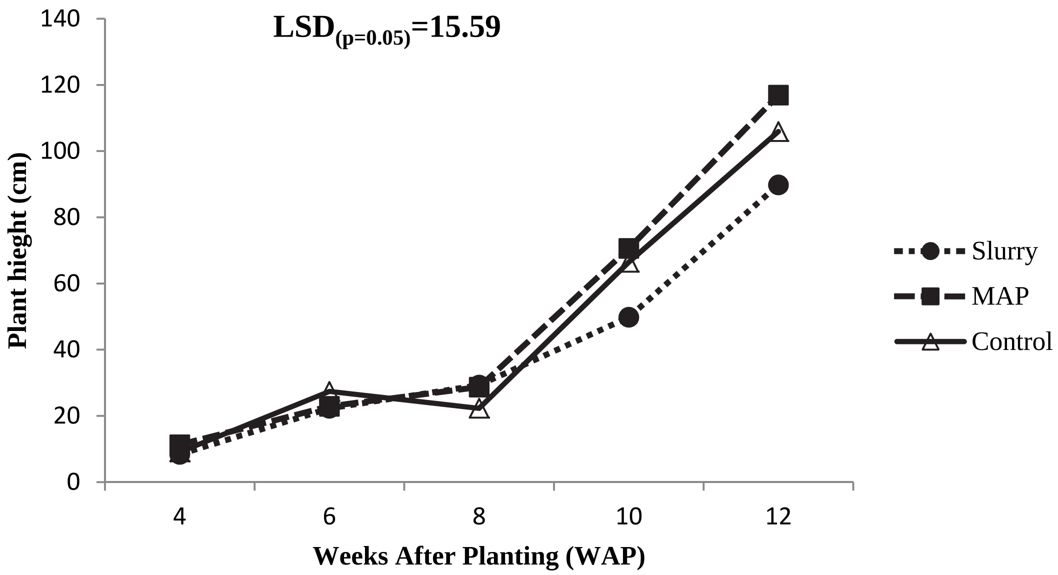
The mean number of leaves increased linearly during the growing season for all the treatments (Figure 5-15b). Maximum leaf number occurred at harvest (12 WAP), when the leaf number ranged from 8.26 in the control to 9.6 in the fertilizer treatment (Figure 5-15 b), However, there was no significant effect (P>0.05) of treatments on the leaf number during the growth period.

In Potshini, the growth pattern of sorghum showed that for all treatments there little increase in height until 8 WAP after which height increased exponentially until 12 WAP when plants were harvested (Figure 5-16a). From 8 WAP to 12 WAP, the number of leaves in the bioslurry treatment lagged behind the fertilizer and control treatments. At harvest, plant height ranged from 89.8 in the bioslurry treatment to 116.9 cm in the fertilizer treatment (Figure 5-16a). However, the application of fertilizer treatments on sorghum had no significant effect (P>0.05) on plant height. Treatments also had no significance effect (P>0.05) on leaf number in Potshini trial during the growth period.

5.4.1.6.3 Yield

At New Stand the average cowpea yield for the MAP treatment was significantly higher (6.73 ton ha^{-1}) than the control treatment which had the lowest yield of 4.97 ton ha^{-1} (Table 5-12). The bioslurry treatment (5.73 ton ha^{-1}) was not significantly different to the other treatments. For sorghum, there were no significance differences in yield between the three treatments (P>0.05). The mean yield ranged from 3.75 (control) to 5.47 ton ha^{-1} (MAP) treatment (Table 5-12).

(a)



(b)

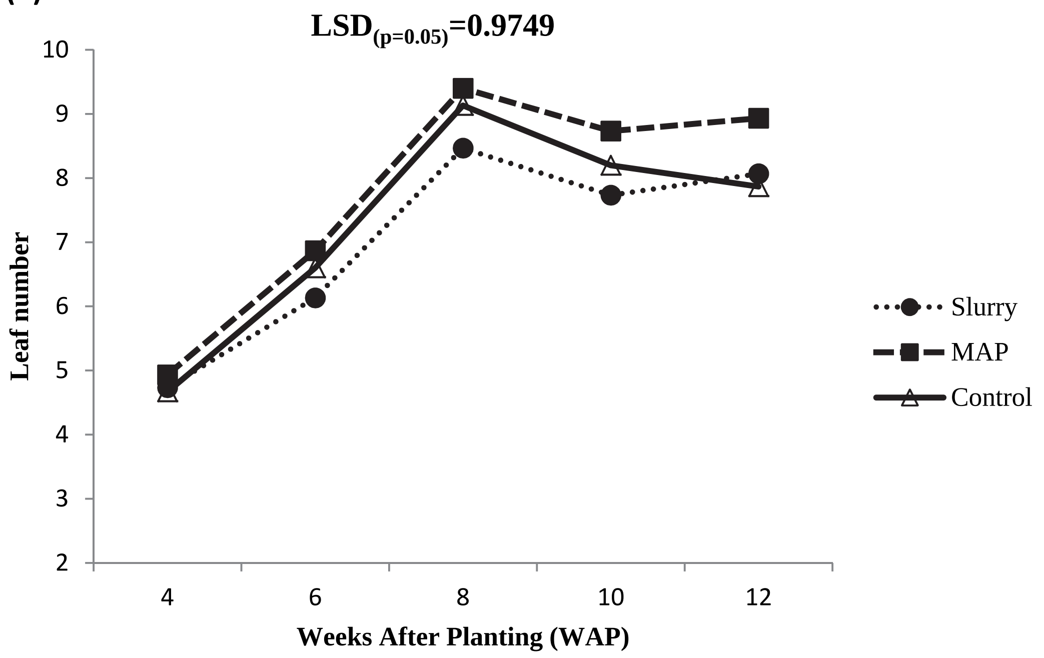


Figure 5-16: Means of height (a) and (b) leaf number of sorghum fodder grown on the on-farm trial in Potshini.

Table 5-12: Average biomass (ton ha^{-1} ±se) for cowpea and sorghum fodder in the New Stand trial.

Treatment	Cowpea (ton ha^{-1})	Sorghum (ton ha^{-1})
Control	4.97± 0.328^{b}	3.75±0.320^{a}
MAP	6.73±0.88^{a}	5.47±0.710^{a}
Bioslurry	5.73±0.348^{ab}	4.76±0.369^{a}

Means in the same column not sharing the same letter differ significantly at LSD (P=0.05)

In Potshini, the applied treatments had no significance difference (P>0.05) on both cowpea and sorghum yield (Table 5-13). Cowpea biomass yields ranged from 3.7 to 5.33 ton ha^{-1} with the control having the lowest yield and the MAP treatment the highest yield. For sorghum, the biomass ranged from 1.8 to 3.09 ton ha^{-1}, where the MAP treatment had the highest biomass and the control treatment had the lowest (Table 5-13).

Table 5-13: Average biomass (ton ha^{-1}±se) for cowpea and sorghum fodder in the Potshini trial.

Treatment	Cowpea (ton ha^{-1})	Sorghum (ton ha^{-1})
Control	3.7±0.819^{a}	1.8±0.947^{a}
MAP	5.33±0.120^{a}	3.09±0.374^{a}
Bioslurry	4.93±0.633^{a}	2.14±0.303^{a}

Means in the same column not sharing the same letter differ significantly at LSD (P=0.05)

5.4.1.6.4 Nutritive quality

The bioslurry used for the experiment was liquid, comprising about 80% moisture (Table 5-14). The pH of the bioslurry was alkaline at both sites. There was not much difference in terms of N for both slurries used in the experiment.

Table 5-14: Composition of the bioslurry collected from the trial sites.

	New Stand	Potshini
Moisture	92.67	92.16
pH	8.62	7.86
Total N (%)	1.48	1.39
K (mg/kg)	574	443
Total organic C (%)	20	22
NDF (%)	50.54	50.48
ADF (%)	42.5	41.7
Total Solids (%)	8	6
Volatile Solids (%)	80	78

At New Stand there was an increase in the soil organic carbon in the sorghum experimental site. Organic C increased from 3.8% prior to planting to a maximum of 4.67% after (post) experiment (Table 5-15). Organic C was higher in the sorghum plots (3.85 to 4.67%) than in the cowpea plots (2.93 to 3.1%). In both plots the bioslurry treatment had the highest organic carbon (Table 5-15).

Table 5-15: Soil macro nutrients prior to planting and post experiment in fodder (sorghum and cowpea) plots at the New Stand trial.

		N (%)	P mg/l	K mg/l	Organic C (%)
Prior planting		0.13	17	187	3.8
Post-Harvest					
	Bioslurry	0.17	14.67	108.67	4.67
Sorghum	MAP	0.18	17.33	132.33	4.53
	Control	0.17	13.33	145	3.85
	Bioslurry	0.18	19.33	101.33	3.1
Cowpea	MAP	0.18	12.3	96.67	2.93
	Control	0.18	11.5	112	3.03

At Potshini, soil nutrient changes were observed before and after the experiment. There was an increase in organic C after the trial experiment in both crop plots (Table 5-16). Changes were observed in the soil N; it decreased in the cowpea plots and slightly increased in the sorghum for all the treatments. Phosphorus decreased from 60 mg/l prior to planting to a low of 33.33 mg/l in the cowpea plot.

Table 5-16: Soil macro nutrients prior planting and post experiment in fodder (sorghum and cowpea) plots at the Potshini trial.

	Treatment	N (%)	P mg/l	K mg/l	Organic C (%)
Prior planting		0.34	60.00	1707.00	1.1
Post-harvest					
	Bioslurry	0.32	51.50	722.00	1.83
Sorghum	**MAP**	0.40	53.00	725.00	1.73
	Control	0.40	51.67	727.67	1.80
	Bioslurry	0.28	36.67	796.00	1.90
Cowpea	**MAP**	0.26	33.33	726.00	1.87
	Control	0.23	36.33	909.30	1.77

None of the fertilizer treatments affected the nutrient content of cowpea and sorghum in the New Stand trial (Table 5-17 and Table 5-18) and cowpea in the Potshini trial (Table 5-20). However, the K values of cowpea were significantly lower in the bioslurry and MAP treatment than in the control at the Potshini site (Table 5-19). Similar results were observed for P which was significantly higher in the control treatment.

Table 5-17: Plant nutrient content of sorghum in response to 3 treatments (bioslurry, MAP and control) in New Stand trial.

	Sorghum		
	Bioslurry	**MAP**	**Control**
N %	2.10^{a}	1.95^{a}	1.93^{a}
Ca %	0.21^{a}	0.18^{a}	0.19^{a}
Mg %	0.25^{a}	0.24^{a}	0.23^{a}
K %	1.32^{a}	0.97^{a}	0.95^{a}
Na mg/kg	40.40^{a}	40.40^{a}	47.39^{a}
Zn mg/kg	37.04^{a}	31.64^{a}	32.48^{a}
Cu mg/kg	5.86^{a}	4.17^{a}	4.13^{a}
Mn mg/kg	80.16^{a}	78.77^{a}	88.65^{a}
Fe mg/kg	699.70^{a}	577.65^{a}	463.59^{a}
P %	0.30^{a}	0.31^{a}	0.31^{a}
Al mg/kg	824.94^{a}	635.07^{a}	996.97^{a}

Means in the same column not sharing the same letter differ significantly at LSD (P=0.05)

Table 5-18: Plant nutrient content of cowpea in response to 3 treatments (bioslurry, MAP and control) in New Stand trial.

	Cowpea		
	Bioslurry	**MAP**	**Control**
N %	5.23^{a}	4.70^{b}	4.52^{bc}
Ca %	1.52^{a}	1.31^{a}	1.27^{a}
Mg %	0.51^{a}	0.53^{a}	0.50^{a}
K %	4.01^{a}	4.09^{a}	4.02^{a}
Na mg/kg	445.41^{a}	506.98^{a}	335.93^{a}
Zn mg/kg	73.36^{a}	58.34^{a}	54.89^{a}
Cu mg/kg	14.96^{a}	7.08^{a}	7.68^{a}
Mn mg/kg	230.15^{a}	190.92^{a}	184.40^{a}
Fe mg/kg	209.71^{a}	161.08^{a}	210.67^{a}
P %	0.57^{a}	0.62^{a}	0.57^{a}
Al mg/kg	137.73^{a}	111.09^{a}	122.81^{a}

Means in the same column not sharing the same letter differ significantly at LSD (P=0.05)

Table 5-19: Plant nutrient content of sorghum in response to 3 treatments (bioslurry, MAP and control) in the Potshini trial.

Sorghum			
	Bioslurry	**MAP**	**Control**
N %	1.32[a]	1.24[a]	1.44[a]
Ca %	0.21[a]	0.23[a]	0.26[a]
Mg %	0.26[a]	0.27[a]	0.29[a]
K %	0.76[b]	0.66[b]	1.00[a]
Na mg/kg	33.95[a]	27.14[a]	47.88[a]
Zn mg/kg	37.33[a]	38.00[a]	40.30[a]
Cu mg/kg	4.14[a]	3.66[a]	4.44[a]
Mn mg/kg	42.09[a]	44.78[a]	43.05[a]
Fe mg/kg	689.44[a]	658.10[a]	549.22[a]
P %	0.34[ac]	0.32[bc]	0.38[a]
Al mg/kg	787.58[a]	709.01[a]	582.06[a]

Means in the same column not sharing the same letter differ significantly at LSD (P=0.05)

Table 5-20: Plant nutrient content of cowpea in response to 3 treatments (bioslurry, MAP and control) in the Potshini trial.

Cowpea			
	Bioslurry	**MAP**	**Control**
N %	5.17[a]	5.16[a]	5.40[a]
Ca %	2.03[a]	1.83[a]	1.93[a]
Mg %	0.53[a]	0.54[a]	0.52[a]
K %	3.12[a]	2.94[a]	3.05[a]
Na mg/kg	294.88[a]	332.64[a]	352.53[a]
Zn mg/kg	48.01[a]	40.18[bc]	42.71[ac]
Cu mg/kg	10.70[a]	9.63[a]	10.44[a]
Mn mg/kg	192.11[a]	138.26[a]	138.99[a]
Fe mg/kg	211.16[a]	179.36[a]	236.64[a]
P %	0.47[a]	0.47[a]	0.45[a]
Al mg/kg	157.07[a]	116.27[a]	205.44[a]

Means in the same column not sharing the same letter differ significantly at LSD (P=0.05)

5.4.1.7 Discussion

Nutrients play a major role in plant growth and yield because the supply of enough nutrients to the plant enhances the development and production of the plant (Warnars and Openooth, 2014). However, the results from the current study showed that the three fertilizer treatments (bioslurry, MAP and control) had no significant effects on both sorghum and cowpea plant growth (i.e. plant height and number of leaves). These findings were contrary to those reported by Shahbaz et al. (2014) who, in their study on the effect of different N-fertilizer rates and bioslurry application on growth of okra, found that the application of bioslurry increased plant growth (plant height, branches per plant and fruit yield). Islam et al (2010) also reported that bioslurry stimulated maize growth (plant height, stem circumference and leaf area) at the optimum rate of 70 kg of slurry N ha^{-1}.

The fact that the sorghum and cowpea crops in the current study showed no significant response to the different fertilizer treatments may be due to the fact that other factors besides soil fertility affect plant growth. For example, plant growth is also dependent on season, genetic factors, plant type, climatic conditions, plant management and quantity of daylight.

The results of the present study showed that in New Stand the application of the treatments had a significant effect on cowpea fodder yield which ranged from 4.97 to 6.73 tons ha^{-1}. These findings were significantly lower than those of Islam et al. (2010) who observed that the application of bioslurry increased maize fodder yield from 34.67 to 54.12 tons ha^{-1}. They also reported that 70 kg N ha^{-1} was the optimum level to achieve maximum yield. By contrast, fertilizer treatment did not have a significant effect on cowpea fodder yield in Potshini which ranged from 3.7 to 5.33 tons ha^{-1}. There were no positive effects of treatments on sorghum yield at both trials. These results contrasted with those of Garg et al. (2005) who observed that bioslurry resulted in a high wheat yield of 6.21 tons ha^{-1} when 15 tons ha^{-1} of bioslurry was applied compared to 5.17 tons ha^{-1} wheat yield when 4.5 tons ha^{-1} bioslurry applied. One of the reasons for the lack of significant differences in yield between fertilizers treatments may be that fodder yield depends on the nutrient availability in the soils (Warnars and Opennoth, 2014). The timing and application of fertilizer treatments may also affect yield and further research should be carried out to determine the optimum application rate for maximizing yield in these areas.

Another reason for the lack of response of cowpea fodder yield may be due to the different release rates of the different fertilizers. Inorganic fertilizers are fast nutrient releasers and they contribute to optimum fodder yields (Ayub et al., 2002). For example, Ayub et al (2002) observed that the application of inorganic fertilizers at 120 and 180 kg ha^{-1} resulted in 59.38 and 59.69 t ha^{-1} sorghum fodder yield. Therefore it was expected that the application of MAP fertilizer of fodder would increase yield in the current study. However, the current findings showed no agreement with these results. Gutser et al. (2005) confirmed that bioslurry is a slow nutrient releaser and therefore the effects of bioslurry on fodder yield could be long-term. This may be the case in the current study where short-term benefits within one growing season after bioslurry application were not detected. Edmeades (2003) found that the use of organic manures relative to fertilizers have long-term positive effects on yields and lead to improved soil organic matter. However results from the current study do not support this, the application bioslurry and MAP had no positive effects on fodder growth and yield.

Treatments (bioslurry, MAP and control) increased the soil N in both the cowpea and sorghum plant plots after harvest in the New Stand trial. These findings were similar to those of Terhoeven-Urselmans et al. (2009) who observed an increase in soil inorganic N after the application of bioslurry in the fields. Different findings were obtained in the Potshini where the N increased in the sorghum plots specifically in fertilizer and control treatment plots, in the cowpea plots there was a decrease in N before and after harvest in all the treatment plots. Changes were observed in the soil P after harvesting in both trials. In Potshini, P levels decreased after harvesting.

Changes were also observed in organic C, for New Stand trial organic C increased for all the treatments after harvesting. However, in Potshini organic C decreased in all the treatments for both sorghum and cowpea plots. Significant differences in the plant nutrient content were recorded between sorghum and cowpea in the New Stand and Potshini trials. Except for Al and Fe, the nutrient content for cowpea was higher than sorghum (Tables 3.6 and 3.7). With respect to plant nutrient concentration, significant differences were observed for N between the treatments in both sorghum and cowpea. These findings agree with Islam et al., (2010) who observed that application of bioslurry on maize fodder had a significant impact on nutrient content. No significant differences were observed for all the other nutrients in sorghum (P, Ca, Na, K, Al, Fe, Mg, Zn, Cu and Mn) for both trial sites. These findings contrast with those of Islam et al. (2010) who observed that the application of bioslurry had a significant effect on P, K and S nutrient content of maize fodder.

Plant physical characteristics and yield components should increase when correct fertilizer application rates are practised (Reddy et al., 2003). In the current study the application of the inorganic fertilizer (MAP) and the organic fertilizer (bioslurry) treatment was expected to increase yield and growth. However, there were no significant differences between the fertilizer and control treatments in the growth and yield of sorghum and cowpea. According to Mutegi et al. (2010) inorganic fertilizers such as MAP should increase crop yield because when applied to the soils their minerals are easily made available unlike organic fertilizers (bioslurry) which undergoes the process of decomposition. However current results were contrary to those of Mutegi et al. (2010) because the application of MAP fertilizer did not have significant effects on growth and yield of the two crops (sorghum and cowpea).

Inorganic fertilizers release nutrients faster than bioslurry (Abubaker, 2012). Therefore MAP as an inorganic fertilizer was expected to have higher significant yields compared to other treatments. Lehamman et al. (2003) observed similar findings to the current study. These authors observed that in their study inorganic fertilizers and manure did not increase plant production. They suggested that either the amounts applied were low or that one or several nutrients limiting plant growth were not properly supplied by the fertilizers. This could suggest that in the current study the application rates were low or the fertilizers did not meet the crop's required nutrients.

Previous studies have shown that when bioslurry is applied at the soil surface ammonia could be lost in the atmosphere as NH_3 gas (Terhoeven-Urselmans et al.2009). The nitrogen in bioslurry is in the form of ammonia (NH_4-N) and it may be lost to the atmosphere through volatilization (Al Seadi, 2008).Terhoeven-urselmans et al. (2009) found that about 10% bioslurry NH_4 -N was lost in the atmosphere during application in the field. According to Al Seadi (2008) the best technique of the application of bioslurry is to apply it directly into the soils to avoid loss in the atmosphere.

In the current study the application of bioslurry did not have positive effects on fodder production. This may be related to the application rates of the bioslurry. In the current study the application rate followed recommendations by Gurung (1997), where bioslurry was applied at a rate of 20 litres per two weeks. Both Rahman et al. (2008) and Islam et al. (2010) found that different application rates (0, 60, 70 and 82 kg of slurry N ha^{-1}) of bioslurry application had a significant effect on maize fodder production. By contrast, the application rate used in this study (20 litres per two weeks) had no significant effect on growth and production. Islam et al. (2010) concluded that 70 kg of slurry N ha^{-1} was an optimum level for maize fodder production after they investigated the effects of different bioslurry application rates on maize fodder. Shahbaz et al. (2014) suggested that bioslurry should be incorporated with inorganic fertilizers for maximized yields and positive effects on okra yield. They also suggested that it should be applied at 600 kg ha^{-1} with 50% recommended rate of inorganic N fertilizer. Gurung (1997), Wannars and Oppenoorth (2014) suggested that 5 tons ha^{-1} of bioslurry may be enough to achieve significant yields in dry land farming systems. The current study findings suggest slurry was affected by application technique and slow nutrient release. Future research should be conducted to investigate the effects of bioslurry on fodder production under controlled environment conditions.

5.4.1.8 Conclusion

There were no significant effects of bioslurry and MAP on fodder crop yield except for cowpea at Newstand. MAP could be affected by the application rate, the soil pH and the acid saturation in the soil where crops were planted. The possible reasons for bioslurry not having a positive effect on fodder yield could be the application method of bioslurry, application rates and nutrient release patterns. As an organic fertilizer source, bioslurry is a slow nutrient releaser therefore the method of application and time frame need to be considered when applying into the soil as it can also be lost through volatization. Therefore, future studies are needed to understand the long-term effects of bioslurry application on different soil types and fodder plants. The information on the nutrient release patterns of bioslurry is scarce. Therefore a laboratory study was established to determine the application rate and nutrient release patterns (N, P and pH) of bioslurry in soils from the study site.

5.4.2 Experimental on-farm fodder trials: Napier fodder

The establishment of fodder banks (small plots of fodder crops grown close to the farmer's homestead) is another option for addressing the problem of fodder shortage. The choice of plants to grow in fodder banks is not restricted to legumes, but a variety of other fodder crops. It is essential that farmers develop innovative ways to select crops that require moderate input resources thus helping them capitalize on the use of low-cost natural resources to increase production. Napier grass (*Pennisetum purpureum*), also known as elephant grass, is an example of a fodder crop that is widely used. It is a tropical grass species native to eastern and central Africa, which has been successfully grown in Kenya for zero-grazing in dairy farming systems (Orodho, 2006). Zero grazing is an intensive production system, whereby the animals are kept in a pen or stall and forage and water are provided therein. In Nepal and Kenya, Napier grass has been recorded to be the most promising and productive fodder, giving higher dry matter yields (10-40 tons ha^{-1}) compared to other tropical grasses such as Rhodes grass (*Chloris gayana*), Setaria (*Seteria sphacelata*) and kikuyu (*Pennisetum clandestinum*) with yields of 15 tons ha^{-1} (Orodho, 2006). For these reasons, the potential of using this grass to address fodder shortage was worth investigating. However, it needs to be acknowledged that the high biomass production compared to other fodder crops is dependent on soil fertility (Orodho, 2006).

Although inorganic fertilizers have been shown to increase production (Orodho, 2006), they have been found to have negative cumulative effects on soils making them toxic to plants over time (Calugar and Morar, 2010). Furthermore they are expensive and economically not feasible in smallholder farmer systems. On the other hand, organic sources of nutrients such as plant residues and livestock dung (e.g. from sheep, cattle and poultry) are often readily available on-farm and are sustainable sources of nutrients. Benefits such as their being pollution-free and cheaper may outweigh the advantages of inorganic fertilizers especially with the current "go green campaigns". Bioslurry, a biogas plant by-product can be used as an organic fertilizer for both food and fodder crops (Islam et al., 2009). It is a by-product of cow dung which has been mixed with water and has undergone fermentation in a biodigester.

The aim of this study was to determine the effect of bioslurry as a fertilizer on Napier grass production to address the problem of fodder shortage in communal rangelands of the Upper Thukela region. The specific objectives were: (1) to implement on-farm field experiments to determine the effect of growing Napier grass with and without bioslurry, (2) to determine bi-weekly Napier grass production as growth per time unit, (3) to determine the impact of using Napier grass for supplementary feeding on the current carrying capacity (AU ha^{-1}), (4) to collect soil samples before and after bioslurry application and determine changes in soil chemical properties: organic carbon, macronutrients (% Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg),) and micronutrients (Manganese, Zinc, Copper), as well as soil pH and (5) to carry out a potted plant trial to determine the effect of bioslurry on Napier grass production when homestead is not a confounding factor (soil type, elevation, moisture and slope kept constant).

5.4.2.1 Materials and methods

The field experiment was conducted from January to May 2013. The soils are mainly well drained red Huttons forms and poorly drained grey Westleigh forms (Everson et al., 2012). The vegetation type is Bioresource group 12, moist tall grassveld which has been described as sourveld, producing palatable material for 6-8 months of the year (Kirkman and Moore, 1999; Everson et al., 2012). Intensive grazing, loss of basal cover and collection of firewood have contributed to degradation of the rangeland (Tau, 2005, Everson et al., 2007; Manssour et al., 2011).

Three homesteads were used for this study and were named Mrs N Khumalo, Mr V Khumalo and Mr S Mdakane, according to the homestead owner's initials; NK, VK and MD, respectively. For each homestead, soil samples were taken before and after the experiment from both the control and bioslurry treatment plots, to determine the effect of bioslurry on soil properties. Eight cores of 6.5 cm diameter and 15 cm depth were taken randomly within the entire field and bulked and sent to Cedara Soil Fertility and

Analytical Services (CSFAS). The chemical properties included organic carbon, macronutrients and micronutrients and soil pH. The soil pH level after testing was 3.98, 3.77 and 3.83 at NK, VK and MD respectively which was lower than permissible acid saturation levels for Napier grass which range between 4.8 to 8.2 (Schumach, 2002). Lime was therefore applied to the fields following recommendations of CSFAS. Following the results of the soil analyses, it was apparent that the three households could not be treated as true replicates because of the significant differences in their soil properties as well as the distance between them (approximately 30 km) which could result in different micro-climates. Homestead was therefore considered as a confounding factor.

The experimental layout was divided into two treatment blocks, a control and a bioslurry section (5.5 m x 5.5 m) to facilitate the application of the bioslurry by the homestead members and to simplify the day-to-day management. Planting was done in October 2012 following recommendations by MLD (1991). Each plant received 5 litres of water daily for two weeks until establishment. Bioslurry and water were mixed at a 1:1 ratio following recommendations by Gurung (1997a,b), making it up to five litres which was poured into a furrow made around the plant bi-weekly. This was then worked into the soil after drying.

To set up the greenhouse experiment, fifty black plastic bags (15 L) were each filled with 10 L of sterile garden refuse soil. One Napier grass sett (portion of the stem with three nodes) was planted in each bag, which was then randomly assigned to one of the two treatments. These were then placed 1m apart to avoid interference (e.g. shading) between adjacent plants and 0.9 m inter-row spacing approximating the same plant density as the field. Two litres of bioslurry were applied bi-weekly after establishment and worked into the soil once it had dried. The equivalent amount of water was added to the non-bioslurry treatments to eliminate the moisture effect on growth. The first weeding took place three weeks after planting, and thereafter it was done when necessary. Less weeding was required than the field trial since sterile potting soil was used.

Within each treatment plot, fifteen plants were randomly selected and tagged for repeated measures in the field. For both experiments, plant growth was measured as plant height (m), length of longest leaf (m) and number of tillers. Yield (above-ground dry biomass) was measured after harvesting. Plants were oven dried at 60°C for 48 hours and then weighed. Field plants were harvested after seven months when most plants were higher than one meter and the greenhouse plants were harvested after three months.

Generalized Estimating Equations Model (GEEM) was used to test whether bioslurry affected the growth of Napier grass. For plant height and longest leaf, a normal probability distribution was used which incorporates an identity link function. For the number of tillers which are count data, a poisson distribution with a log link function was performed. The working correlation matrix structure used was Auto-regression (AR, 1), which accounts for relationships between repeated measures. A generalized score Chi-square statistic was used instead of Wald since it is more conservative for small samples and fits best for repeated measures. Mean biomass production for the field experiment was compared using a randomized block one-way ANOVA, where homestead was the blocking factor. In addition, an independent two-sampled t-test was run to compare the difference between mean biomass production in the control and bioslurry treatment for the potted-plant experiment.

5.4.2.2 Results

Following planting in January, growth of Napier grass increased steadily in both the bioslurry and control treatments for all homesteads until the plants were harvested in May. The growth patterns were similar across the three homesteads, with the exception of MD whereby the control had higher growth and biomass (Table 5-21 and Table 5-22). The growth trend for the number of aerial tillers was similar across the three households, while plant height and leaf length were similar between homestead VK and NK. There was no difference in plant height between treatments (χ^2 = 0.869, df = 1, P = 0.351). Similar results were observed for the length of the longest leaf, number of basal and number of aerial tillers (χ^2 = 2.63, df = 1, P = 0.105,), (χ^2 = 2.055, df = 1, and P = 0.152) and χ^2 = 2.502, df = 5, P = 0.114, respectively. In the greenhouse experiment, the mean maximum plant height and length of the longest leaf were greater ($\chi^2_{0.5,\ 1}$ = 9.322 and p = 0.002) and ($\chi^2_{0.5,\ 1}$= 0.395 and p = 0.004) respectively, in the control than in the bioslurry treatment (Figure 5-17). However, the number of basal ($\chi^2_{(0.5,\ 1}$= 0.148 and p = 0.7) and aerial tillers ($\chi^2_{(0.5,\ 1}$= 1.003 and p = 0.317) did not differ significantly (Figure 5-18).

Table 5-21: Plant growth parameters measured at harvest (± standard error), across the experimental sites for the control and bioslurry treatments.

Site	Mean plant height (m)		Mean length of the longest leaf (m)		Mean No. Basal tillers		Mean No. Aerial tillers	
	Control	Bioslurry	Control	Bioslurry	Control	Bioslurry	Control	Bioslurry
MD	0,82 ± 0,06	0,74 ± 0,05	1,03 ± 0,03	0,99 ± 0,04	21,67 ± 2,63	27,00 ± 1,7	1,93 ± 1,01	0,43 ± 0,29
NK	0,59 ± 0,08	0,42 ± 0,07	0,78 ± 0,06	0,76 ± 0,05	15,20 ± 2,16	13,27 ± 1,53	2,8 ± 1,05	1,93 ± 0,69
VK	1,55 ± 0,11	1,6 ± 0,07	1.6 ± 0,03	1,34 ± 0,03	33,87 ± 2,37	32,6 ± 1,91	1,47 ± 0,56	1,73 ± 0,52
Green house	0,43 ± 0,03	0,34 ± 0,02	0,83 ± 0,03	0,70 ± 0,03	4,67 ± 0,45	5,87 ± 0,45	1,33 ± 0,19	2,00 ± 0,26

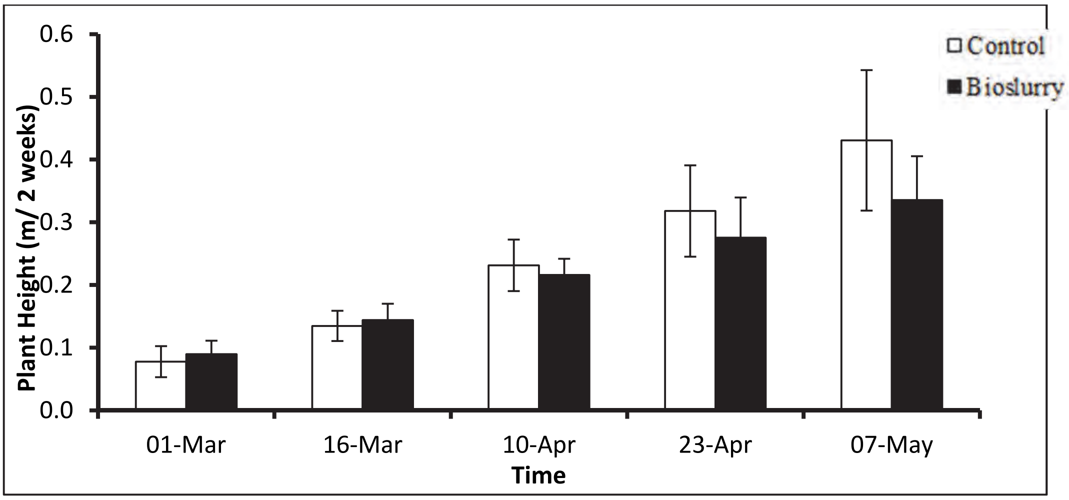
Where MD (Mdakane), NK (Nomusa Khumalo) and VK (Velum Khumalo) are the field sites.

At MD homestead, the biomass of the control (4.7 tons ha^{-1}) was 34% higher than that of the bioslurry treatment (Table 5-22). This was different from the other two homesteads whereby the bioslurry plot had a positive effect on biomass compared to the control. However, there was no significant difference in the overall mean biomass production between the two treatments across the three homesteads ($F_{1,\ 15}$ = 1.916, P = 0.178). In contrast to this, biomass of in the bioslurry treatment was significantly higher than that in the control (t 0.5, 24 = 2.688 and p = 0.015), producing about 75% more herbage.

Table 5-22: Total biomass production (tons ha^{-1}) in the control and bioslurry treatments at the different experimental sites.

Experimental site	Biomass (tons ha^{-1})	
	Control	Bioslurry
MD	4.7	3.1
NK	18.7	26.3
VK	33.9	48.2
Field mean	11.9	25.9
Greenhouse	9.4	37.0

a)



b)

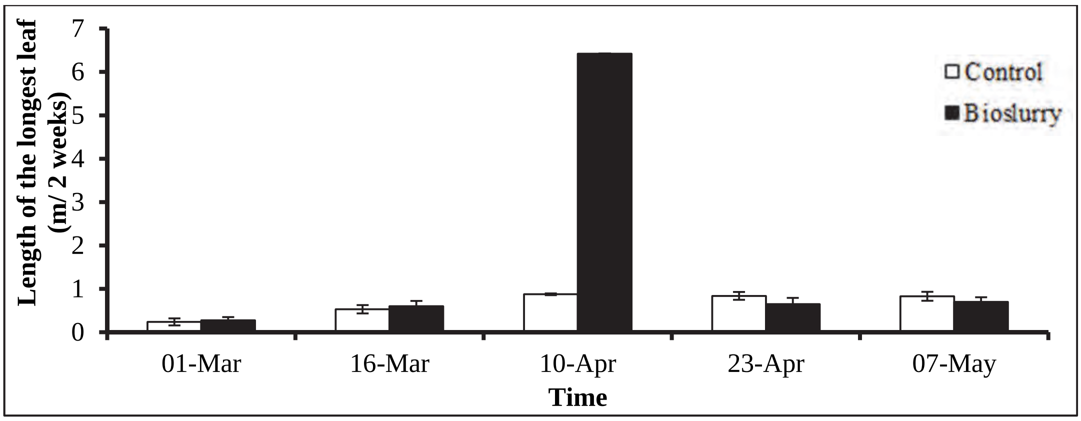
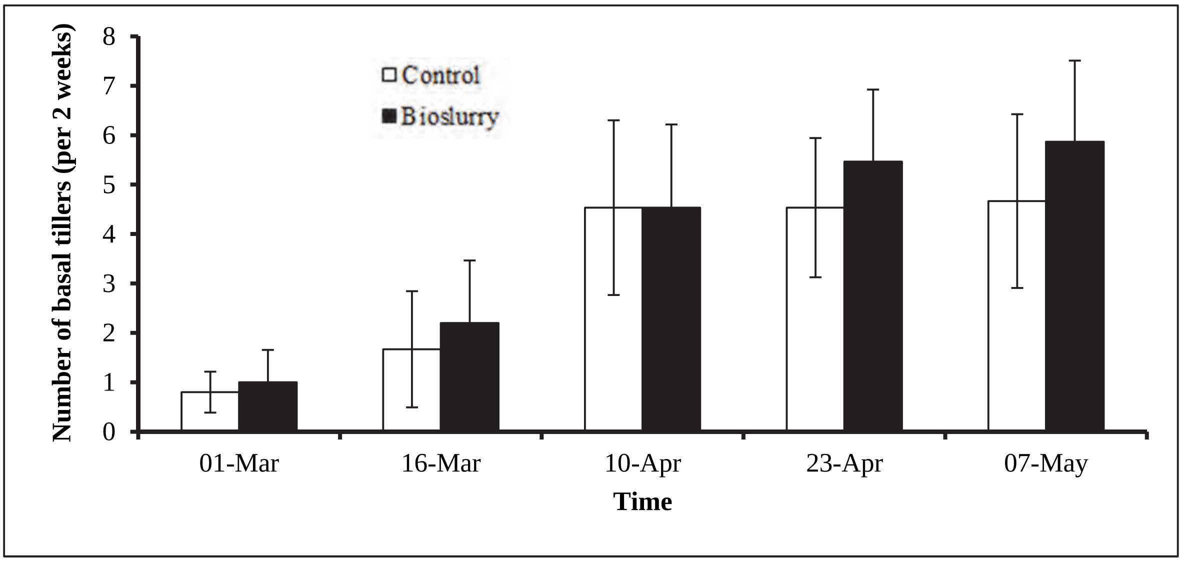


Figure 5-17: Plant height (a) and longest leaf (b) of Napier plants in the bioslurry and control treatments of the greenhouse experiment.

a)



b)

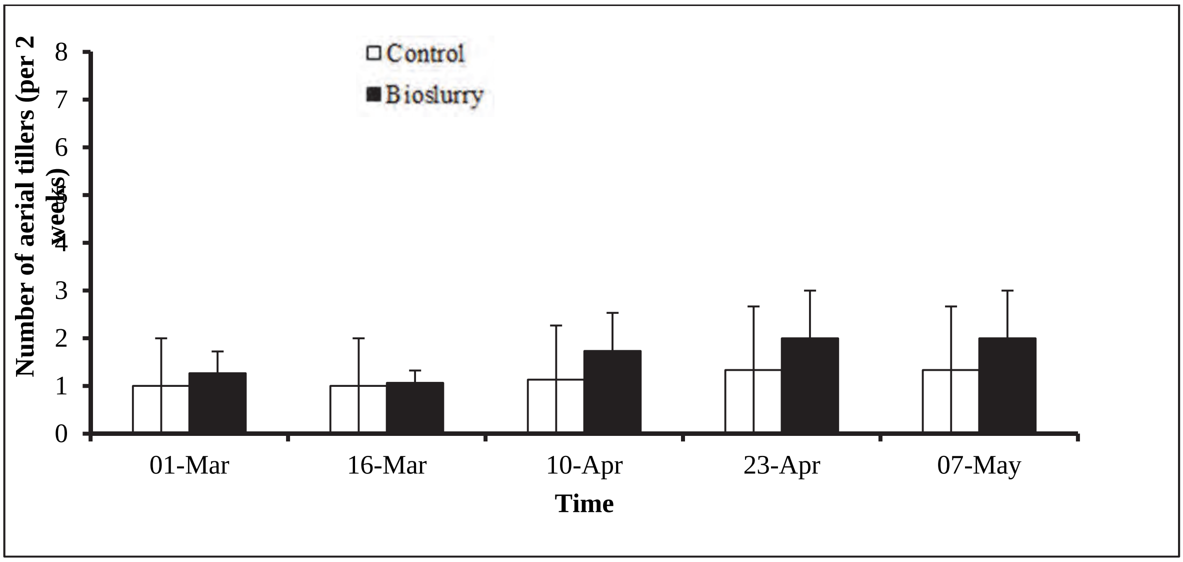


Figure 5-18: Mean number of basal (a) and aerial (b) tillers of Napier plants in the greenhouse bioslurry and control treatments.

With the exception of copper (Cu), there was no significant difference in the plant micro-nutrients and macro-nutrients between the bioslurry and control plots. For example, nitrogen was 0.18% in the bioslurry treatment compared to 0.17% in the control treatment.

Table 5-23: Concentration of soil micro- and macro-nutrients in the control and bioslurry plots at homestead MD, with statistical t-test results.

Units	Nutrients	Control	Bioslurry	t	p-value
$mg\ L^{-1}$	P	13.330 ± 0.882	14.670 ± 1.202	0.894	0.422
	K	108.670 ± 14.655	145.000 ± 25.697	1.228	0.287
	Ca	693.330 ± 118.442	827.000 ± 78.309	0.941	0.400
	Mg	228.330 ± 63.357	319.670 ± 22.806	1.358	0.246
	Zn	1.633 ± 0.285	2.500 ± 0.306	2.075	0.107
	Mn	3.000 ± 0.577	3.000 ± 0.000	0.000	1.000
	Cu	2.233 ± 0.033	2.700 ± 0.577	7.000	0.002
%	Organic C	1.833 ± 0.088	1.800 ± 0.577	0.316	0.768
	N	0.170 ± 0.010	0.183 ± 0.067	1.109	0.329

5.4.2.3 Discussion

Sufficient fodder production is important to match the livestock forage demand. Farmers can effectively reduce economic inputs associated with supplementary feeding, by producing enough fodder. In communal rangelands where the stocking rates are often twice the size of commercial farms (Vetter and Bond, 2012), feed shortage threatens survival of livestock and the livelihoods of people who depend on the animal products. According to Tainton (1999), farmers need to aim at increasing their farm-grown forages in order to minimize supplementation cost. This is a challenge in commonly shared land because people are confined to small pieces of land which they use for both livestock keeping as well as supporting their livelihoods. This raises a need for effective forage production systems that will allow small-scale farmers to optimize land-use and improve yields. This study investigated the potential of using napier fodder on marginal agricultural land for zero grazing to meet the forage demand and decrease the pressure on the natural rangeland. The use of fodder in zero grazing systems has potential where farm size is very restricted or where the natural grazing land is no longer available or highly degraded, as in the current study. Since farm size is not restricted in communal areas, semi-zero grazing, whereby livestock are grazed in the rangeland during the day and at night they are fed near homesteads (Magona and Musisi, 2002), has potential. In such cases, cattle can be fed on cultivated fodder and crop residues (Orodho, 2006). This ensures that while the amount and quality of forage varies seasonally, particularly in the sourveld during the winter period (Tainton, 1999), there is still enough forage to meet animal forage demands. This keeps livestock above the threshold where they can both maintain good health and reproduce (Fynn, 2012). In this study, the response to bioslurry varied across the growth parameters and the experimental sites. Plant growth parameters in the bioslurry treatment were not significantly different from the control (Table 5-14). Sugiyama (1995) found similar results to this study whereby biomass was not correlated to the number of tillers and leaf length. This may be explained by the plant available nutrients in the bioslurry (Pagliai et al., 2004). However, biomass production was higher in the bioslurry treatment (25.9 tons ha^{-1}) than in the control (11.9 tons ha^{-1}).

Bioslurry has been reported to be high in nitrogen (a yield limiting nutrient, essential for growth and development of living tissues), phosphorus (responsible for flowering and tiller growth), and other macro and micro-nutrients (zinc, calcium) which are essential for plant growth and metabolic processes (Islam et al., 2008; 2010). However, this study found no significant differences between the soil nutrients in the bioslurry and control treatments. Possible reasons for this could be that the bioslurry does not rapidly release nutrients, therefore only benefiting soils in the long-term. Cott cited in Gurung (1997) reported that application of bioslurry increased yield a year after application whereas in the first year no effect was observed. This supports a report by Orodho (2006) in Kenya, whereby bioslurry increased production of the same Napier setts for over a decade.

In addition to its effects on the soil chemical factors bioslurry also affects the soil physical factors. For example, the water holding capacity of the soil can be increased thereby improving the soil water conservation. However, according to Eldridge and Greene (1994) soil physical crusting decreases soil pores at the surface by forming a non-porous layer. This leads to reduced hydraulic conductivity consequently limiting water entry into the soil. After bioslurry application, soil crusting occurred which can lead to reduced soil pores which consequently reduce infiltration and aeration to the roots (Pagliai et al., 2004). It is therefore recommended that after application of bioslurry the soil should be loosened to prevent a hard cap from forming. This will also facilitate root penetration and increased storage and transmission of water and gases.

In this study, a high variability in Napier fodder biomass production was observed between the different homesteads (e.g. biomass ranged from 3.1 to 48.2 tons ha^{-1}, Table 5-22). According to Gurung (1997b), variability in yield production can occur due to different agro-climates and slurry storage and handling. This may hold for this study whereby the homesteads were 30 km apart and may have had different agro-climates. Although biomass was higher in the bioslurry plot (25.9 tons ha^{-1}) than in the control (11.9 tons ha^{-1}), this difference was not significant. However, the high biomass when compared to natural veld (1.195 tons ha^{-1}) has significant benefits for communal farmers. Since farmers are more concerned with the production ha^{-1}, the biomass at harvest reflects that bioslurry improved Napier grass production.

These results support findings by other studies (Islam, 2008; Schreuder et al., 1993 and Orodho, 2006) that showed an increment in plant yield with bioslurry application. For example, Islam (2010) reported that bioslurry caused an increase in cabbage biomass from 10 tons ha^{-1} in the control to 58.60 tons ha^{-1} in the bioslurry treatment. Reported yields of Napier fodder in Kenya varied between 10 to 40 tons ha^{-1} depending on soil fertility, climate and management practices (Schreuder et al., 1993).

Since Napier grass is easily accessible, it propagates vegetatively and can withstand heavy utilization (Orodho, 2006) it is suitable for communal farmers. The variability in the results obtained from the field and potted-plant experiment may be attributed to the different agro-ecological conditions and management practices. Further research is needed to determine the optimum bioslurry application rates and the impact of breaking the bioslurry crust on infiltration rate.

5.4.3 Impact of experimental fodder trials on the carrying capacity of communal rangelands

The carrying capacity for the area represents the maximum number of animal units (AU) that can be sustained without causing a downward trend in the range health (Tainton, 1999). If the stocking rate is exceeded the condition of the rangeland will decrease due to the lower herbage production and change in botanical composition (Edwards, 1980; Fynn and O'Connor, 2000). This will have a negative effect on the carrying capacity of the rangeland. This indirectly affects the economic returns of grazing systems by influencing production such as gain per animal and per hectare (Edwards and Mappledoram, 1979). These effects of stocking rate are exacerbated by the land shortage in communal systems, and highlight the importance of managing stocking rate for sustainable land-use to ensure long-term optimal forage and animal production.

5.4.3.1 Carrying capacity

The variables required to determine the effect of supplementary fodder on carrying capacity are:

5.4.3.1.1 The amount of forage produced

The yield data from the on-farm fodder trials were used to present a case study on the potential of supplementary fodder (sorghum, cowpea and Napier fodder) to address the problem of fodder shortage for livestock and assess its impact on the carrying capacity at Potshini. Biomass of sorghum, cowpea and Napier fodder (Table 5-22), were used for this study.

5.4.3.1.2 The grazing area

This value (218 ha) comprised the communal rangeland at Potshini which is available for grazing (Smith et al., 2005).

5.4.3.1.3 The number of livestock in the area

The number of livestock in Potshini was obtained from a participatory rural appraisal exercise carried out by Everson (Smith et al., 2005). Community members mapped the area indicating its boundaries and key resources (e.g. schools, streams, rivers, mountain, grazing land, crop field, homesteads). Each individual marked the location of their homestead and then selected bean seeds indicating the number of cattle at their homestead (Smith et al., 2005). The results indicated that there were 378 livestock in the Potshini village.

5.4.3.1.4 The amount of forage needed per animal unit

The amount of forage needed per animal unit was obtained from Camp and Smith (1997). However, this value is based on standardized biomass allocation and forage requirements of one animal unit under commercial production systems (i.e. 450 kg). However, the communal livestock in this study generally have a lower biomass and lower feed requirement compared to commercial animal units. It was therefore necessary to adjust Camp and Smith's (1997) forage values to those for communal livestock. Following the recommendation of Meissner (1982) an animal unit equivalent of 375 kg was used for this adjustment.

5.4.3.1.5 The veld condition of the rangeland

The veld condition of the Potshini rangeland was based on data collected by Everson (see Smith et al., 2005).The benchmark technique, whereby species composition of the study was compared to that of the veld in excellent condition, was used to calculate the veld condition score (Tainton, 1999).

Basal cover – According to Everson (see Smith et al., 2005) a metal spike was randomly placed 50 times in the veld at each site and the distance to the nearest tuft and diameter of the tuft were measured. The equation by Hardy and Tainton (2007) was used to calculate basal cover of the sample site:

$$\text{Basal Cover of sample site (BCS)} = 19.8+0.39(D)-11.87(\log_e D) +0.64(d) +2.93(\log_e d)$$

Where: D= mean distance to the tuft (cm)
d= mean diameter to the tuft (cm)

Stocking density - the stocking density is the number of animal units (AU) on a specific area for a specific unit of time (Vetter, 2005). For Potshini the stocking density in the 218 ha grazing area for the year was 378 AU.

Available forage resources – These were calculated from the forage requirements for each animal unit, the fodder supply of the natural veld (Camp and Smith, 1997; Everson et al., 2012), and the cowpea and sorghum fodder produced on the experimental farm trial at Potshini.

Current grazing capacity was calculated using the following equation (Tainton, 1999). This estimate is based on the current veld condition.

$$\text{CGC} = \text{PGC} * \text{numerical rating for the site} \qquad (1)$$

Where PGC = potential grazing capacity, and

$$\text{Numerical rating} = \text{CF} + \text{BCF} + \text{TF} + \text{SEF} \qquad (2)$$

Where CF (composition factor) = 0.25 [(veld condition score + number of units of Increaser (I) species in excess of the benchmark)/100]

$$\text{BCF (basal cover factor)} = -0.75 + 2\,(\text{BCS/BCB}) - (\text{BCS/BCB})\ 2 \qquad (3)$$

Where:

1. BCS = basal cover of the sample site (16.7) see Smith et al. (2005)
2. BCB = basal cover of the benchmark (12%)

TF (topographic factor) = 0.0 (slope is 0-5% and is not a drainage channel)
SEF (soil erodibility factor) = 0.13 (soil type range or gradient, with moderate erodibility rate).

Potential grazing capacity (PGC) = 0.7 AU ha^{-1} (Camp and Smith, 1997), veld condition score (VCS) = 41.4% (Smith et al., 2005) and Number of units of Increaser (I) species in excess of the benchmark = 0, (Tau, 2005).

Current grazing capacity calculation:

Numerical rating= CF+ BCF + TF + SEF= 0.104 + 0.097 + 0.0+ 0.13= 0.33

Current grazing capacity (CGC) = 0.7 AU ha^{-1} *0.33= 0.23 AU ha^{-1}

5.4.4 Results

To evaluate the potential value of supplementary fodder on the carrying capacity of the rangeland at Potshini it was necessary to determine the current fodder flow in the area. The grazing area at Potshini (218 ha) can support 50 AU (218*0.23AU ha^{-1}). If a 0.75 Animal Unit Equivalent (recommended for communal areas since the mass of an AU is 375 kg compared to that of a commercial livestock unit (450 kg) the area can support 68 AU (50/0.75). Actual stock density recorded for 34 livestock owners was 378 AU.

Forage requirements: Herbage consumption for a commercial LSU = 2.5 (tons AU^{-1} yr^{-1}). Assuming that a communal cow is 0.75 AUE, each cow consumes 1.88 tons (2.5*0.75). Therefore 378 AU will consume 710 tons (1.88 tons*378 AU) in 218 ha yr^{-1}.

Forage supply: The natural veld Bioresource Group (BRG) 8 (Moist Highland Sourveld) at veld condition of 40% produces 1.195 tons ha^{-1} (Everson et al., 2012). Therefore the total land area produces 260 tons (1.195 tons ha^{-1}*218 ha yr^{-1}).

Forage shortage: Biomass required by 378 AU (710 tons) – biomass of natural veld (260 tons) = 450 tons. This indicates that the veld was overstocked at 1.7 times more than its carrying capacity. However, with supplementary feeding of cowpea and sorghum there is potential for reduction in forage shortage.

Potential impact of cowpea, sorghum and Napier fodder under bioslurry production in Potshini

The yield values of cowpea, sorghum and Napier fodder were used to determine the potential impact of fodder production on the current carrying capacity of Potshini. Dry matter yields of the fodder crops were used to calculate the area required for producing sufficient fodder for a year at the current stocking density (Table 5-24).

Cowpea yield increased from 3.70±0.82 to 4.93±0.63 ton ha^{-1} in the bioslurry treatment and to 5.33±0.12 ton ha^{-1} in the fertilizer treatment. The corresponding area of land required to fill the fodder shortage was 121.6, 84.4 and 91 ha. The most productive fodder crop was cowpea fertilized with bioslurry which yielded 4.93 ton ha^{-1}. The production of sorghum fodder was significantly lower yielding

2.14 ton ha^{-1} in the bioslurry treatment. To meet the fodder shortage approximately 91-121 ha of land is required for cowpea fodder depending on the treatment, with the bioslurry treatment requiring 30 ha less than the control. The area of land planted to sorghum fodder to meet the fodder shortage will be 145-250 ha (Table 5-24). The results of the Napier fodder trial indicated that yield varied between 11.9-25.9 tons ha^{-1}. Thus 17-38 ha will be required to support the current stocking rate of 378 AU.

Table 5-24: Total dry matter yield (ton ha^{-1}±se) of cowpea and sorghum and corresponding area required to meet fodder shortage in Potshini.

	Cowpea		Sorghum	
	Yield (ton ha^{-1})	Area req. (ha)	Yield (ton ha^{-1})	Area req. (ha)
Control	3.70±0.82^{a}	121.6	1.8±0.96^{a}	250
MAP	5.33±0.12^{a}	84.4	3.09±0.37^{a}	145.6
Bioslurry	4.93±0.63^{a}	91	2.14±0.30^{a}	210

5.4.4.1 Discussion

In the current study site (Potshini), cattle are continuously grazed in the rangeland throughout the year. In Potshini, there is a critical forage deficit caused by grazing too many animals in the communal rangeland that does not have enough grass biomass to support them. The current stocking density was 378 AU which was significantly higher than the current carrying capacity (68 AU). The overstocking and continuous grazing regime has resulted in poor veld condition (41.4%) and low production (1.195 tons ha^{-1}) which has a negative impact on livestock production. Therefore it is essential that an alternative grazing system to continuous grazing is put in place to ensure that the quality and quantity of forage meet the forage deficit in Potshini.

Rotational grazing is a grazing system whereby specific camps are rested long enough for the plants to recover vigour after intensive grazing (Tainton, 1999). However, due to limited fencing facilities and theft smallholder farmers would struggle to implement the rotational grazing system in the rangeland (Bennett and Barrett, 2007; Salomon, 2011). Another option is to purchase hay (e.g. lucerne and ryegrass). Communal farmers who are termed “resource poor” are unlikely to have the income to purchase and transport hay fodder given their financial status and poor sources of income (Ngongoni et al., 2006). Results from the baseline survey in the study area showed that the average monthly household income was R1090 and 40% of it was spent on firewood. Therefore, farmers in communal areas are forced to use other cheaper alternatives to provide fodder for their livestock.

Another grazing management system that could be put into practice by farmers is zero grazing. In zero grazing livestock are fed without grazing in the rangeland and involves the cutting of grass and feeding it directly to livestock (Haskell et al., 2006). The challenges with the implementation of a zero grazing system in communal areas involve the cost of inputs such as grass cutters, labour and transport. This system can be adapted to a semi zero grazing where livestock are grazed in the rangeland during the day and at night they are fed near homesteads (Magona and Musisi, 2002).

Semi zero grazing system can be introduced as an alternative grazing system to continuous grazing currently practised in Potshini. In this type of grazing system, forage is grown near the homestead and fed to cattle to supplement their diets during winter when the grasses in the rangeland are dormant (Magona and Musisi, 2002). Supplementary feeding with quality fodder has the potential of reducing pressure on the natural rangeland in Potshini. The current natural rangeland production is 1.195 tons ha^{-1} and for the current study the cowpea yield ranged from 3.7 to 5.33 ton ha^{-1} for three different fertilizer treatments. These results indicate that when planting cowpea about 91-121 ha of land, depending on fertilizer treatment, would be required to produce sufficient fodder to meet the fodder requirements in the study area. For sorghum the yields ranged from 1.8-3.09 ton ha^{-1} and 145-250 ha is required to produce sufficient sorghum fodder. Napier fodder was the most productive crop producing 11.9-25.9 tons ha^{-1} which would require 17-38 ha to support the current carrying capacity. One of the main challenges facing smallholder farmers is a shortage of land available for fodder production. Since Napier fodder requires the least land, it is a hardy crop that was productive on the marginal sites of this study and it produces vegetatively resulting in low input costs, it is strongly recommended for supplementation in semi-zero grazing systems in Potshini.

5.4.5 Nitrogen and phosphorus release patterns from bioslurry in soils collected from farmer's fields at two homesteads in the Upper Thukela

Contrary to reports in the literature that bioslurry has proven to have positive effects on yields of grains, vegetables and fruit compared to not using any soil amendments (see review by de Groot and Bogdanski, 2013), the results of this study showed no significant effects of bioslurry on food and fodder crop yield. One reason for this may be the slow release patterns of nutrients from bioslurry when compared to inorganic fertilizers (Islam et al., 2010). Despite the potential importance of bioslurry as an organic fertilizer there is little understanding of the nutrient release patterns from bioslurry and the factors that affect its mineralisation after application in the soils.

Bioslurry nitrogen is disposed to different processes which include mineralization, denitrification and nitrification as well as volatilization of ammonia (NH_3) and leaching (Möller and Stinner, 2009). Nitrogen in the bioslurry is in the form of ammonia. During the application of bioslurry to the land, about 15% of the applied N is lost to the atmosphere as gaseous ammonia (Möller and Stinner, 2009). However, the loss may vary with the storage, application rate and method of application of bioslurry (Goberna et al., 2011). Some plants uptake N in the form of nitrate, therefore for ammonium to be accessible to plants as nitrate it has to undergo the process of nitrification (Möller and Stinner, 2009). Phosphorus is also an essential nutrient for both crops and livestock (Tambone et al., 2010). However the information on the phosphorus release patterns and application rates of bioslurry is scarce (Chiyoka, 2011). The objective of this study was to carry out an incubation study to determine the N and P release patterns from bioslurry in two contrasting soils (acidic and non-acidic) sampled from two farms in the Upper Thukela.

5.4.5.1 Materials and Methods

Soil samples were collected from Okhombe (23% acid saturation) and New Stand (3% acid saturation). The soil used was Okhombe (acid, unlimed and limed) and New Stand (non acid). Bioslurry at the following nitrogen (N) rates recommended by the Cedara fertility analysis (0, 2.1 (recommended), 4.2 (double recommended) and 10.5 g kg^{-1} (five times recommended rate) was applied to the three soils. Water was added to each tub containing 1kg soil with the treatment and it was maintained at 70% field capacity. Moisture corrections were made weekly after calculating weight loss to maintain the water content at 70% field capacity throughout the experiment. The incubation temperature was maintained at 25^0C. Inorganic nitrogen (ammonium-N and nitrate-N), phosphorus (P) and pH were analysed during the incubation period for the following samplings days: 0,1,2,4,7,14,21,28,35,42,49,56,63,70. Nitrogen was analysed using a discreet analyzer (Thermo Gallery, Thermo Scientific) after extracting with 2M KCl. Phosphorus was analysed using the molybdenum blue method after extracting with AMBIC solution. Soil pH was extracted using 1M KCl and water using a 1:5 soil: KCl/water ratio. pH was analysed using a PHM210 pH meter.

5.4.5.2 Results

During the incubation period ammonium-N concentration decreased for all the bioslurry application rates (2.1, 4.2 and 10.5 g kg^{-1}) in all the soils (e.g. Okhombe limed soil, Figure 5-19). There were no significant differences in ammonium-N concentration ($P>0.05$) between the different bioslurry rates applied on the soil samples during the incubation period of 70 days.

The nitrate-N release pattern showed no constant increase during the incubation period for all the soils (e.g. Okhombe limed soil, Figure 5-20). The highest nitrate-N concentration recorded was 1.34 mg kg^{-1} on day 2 for the control treatment (no bioslurry) (Figure 5-20). Following this, there was a rapid decline in nitrate-N concentration followed by fluctuating low concentrations from day 7 to 70 of the incubation period.

Phosphorus increased with time during the incubation study for all the three soils (Figure 5-21). The maximum P recorded on day 70 at an application rate of 10.5 g kg^{-1} was 49.89 mg kg^{-1} in the New Stand soil. For the Okhombe unlimed soil the maximum P was recorded on day 70 at an application rate of 10.5 g kg^{-1} (21.154 mg kg^{-1}). Similar findings were observed for the unlimed soils, the maximum P was 20.193 mg kg^{-1} at 10.5 g kg^{-1} bioslurry application rate on day 70. Phosphorus increased with the increase in the application rate.

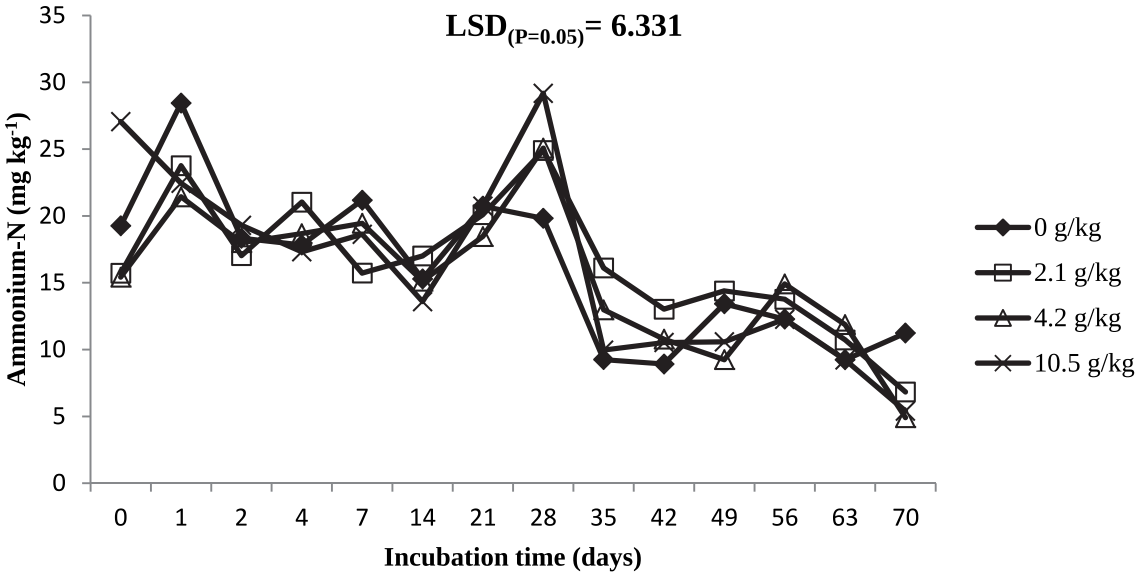


Figure 5-19: Ammonium-N concentrations (mg kg^{-1}) during the incubation of non-acidic soil at different application rates of bioslurry.

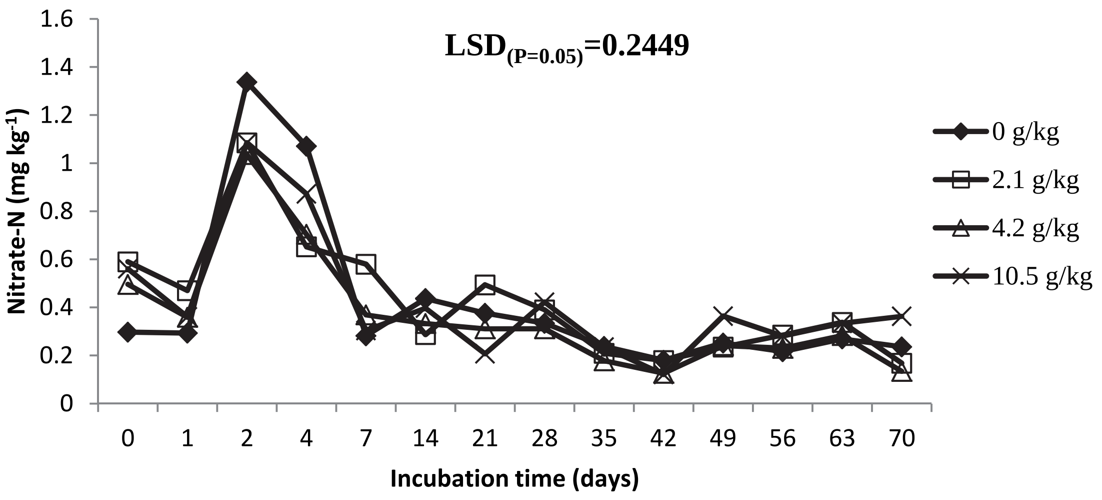


Figure 5-20: Nitrate-N concentrations (mg kg^{-1}) in non-acidic soil during the incubation period at different bioslurry application rates.

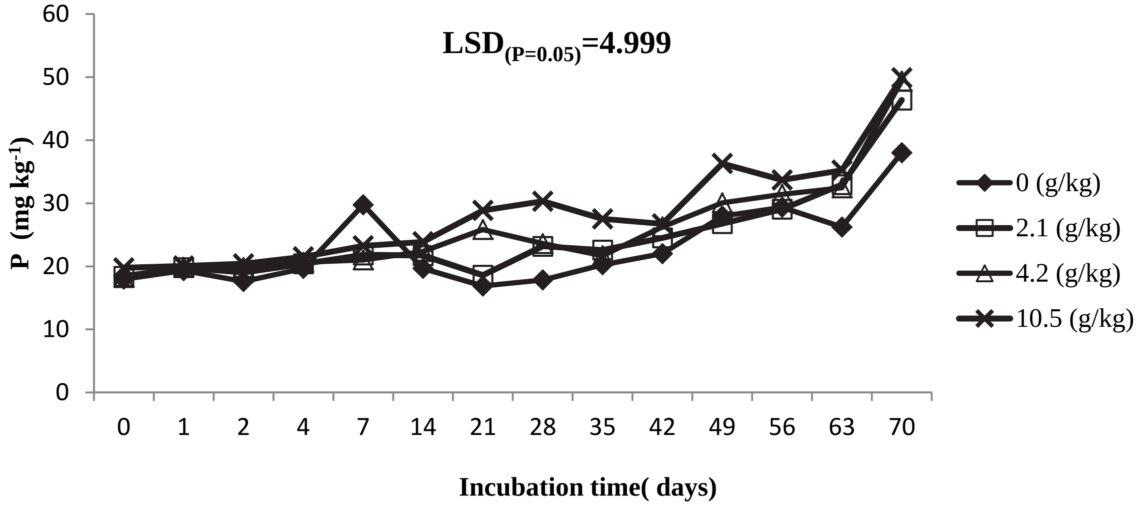


Figure 5-21: Phosphorus concentration (mg kg^{-1}) in non-acidic soil following different bioslurry application rates during the incubation period of 70 days.

5.4.5.3 Discussion

The application of organic fertilisers increases the soil N status depending on the N levels in the applied fertilisers and the application rates (Islam et al., 2010). In the current study bioslurry was applied at different recommended rates on different soils under laboratory conditions. The increasing levels of bioslurry applied presumably increases the availability of soil N and P. In the current study the ammonium-N concentration levels decreased over the 70 day incubation period for the entire application rate in all the soils (non-acidic, acidic unlimed and limed) (Figure 5-19).This decrease suggests that the ammonium-N of the bioslurry was nitrified in the soil during the incubation study. Little information could be accessed on the nutrient release patterns of bioslurry for comparison with this study. However, Möller and Stinner (2009) suggested that a decrease in ammonium-N after the application of bioslurry may not always mean that ammonium N is nitrified; ammonium-N decrease in soils could be caused by ammonia volatilization. These authors also observed that ammonia volatilization rate was significantly higher in digested slurry during the early hours after the application to soils in a field experiment.

Generally, when the ammonium-N concentration decreases during the incubation period, nitrate-N is expected to increase and this process is called nitrification (Daudu et al., 2012). However, the results from the current incubation study did not support this theory. In the current incubation study the nitrate-N concentration levels showed no consistent release patterns and this was observed across all the soils used for the incubation study (Figure 5-20). However, it was notable that nitrate-N concentration on the last day of incubation was lower than day 0 for all the soils and this could be due to immobilization. Kader et al. (2013) suggested that immobilization is responsible for reducing inorganic N.

The normal relationship between ammonium-N and nitrate-N is that their concentration levels are vice versa to each other following the application of organic fertilizers to soils. Therefore, a similar relationship was expected for the current incubation study. However, during this study ammonium-N followed a similar trend to nitrate-N suggesting that no nitrification occurred during the incubation period. Hence ammonium-N was lost without any track of where it went to during the incubation for all the soils. However, both Moller and Stinner (2009) and Terhoeven-Urselmans (2009) reportedly found that bioslurry was susceptible to volatilization leading to low inorganic N mineralization in the soils in their respective studies. No literature could be accessed to compare the inorganic N release patterns of bioslurry after different application rates with the findings of the current incubation study. Moreover, Chiyoka (2011) suggested that not only volatilization and di-nitrification affects the mineralization of inorganic N in the soil, but other factors such as N_20 emission and pH changes in the soil can also be attributed to low N mineralization.

The current findings show that P concentration increased with time (day 0 to 70) for all the soils although the concentration levels were not the same for each soil. Chiyoka (2011) suggested that the increase in P during the incubation is likely due to the decomposition of organic fertilizers in the soil, which in this case was bioslurry. The author further concluded that the decomposition resulted in P sorption being reduced by an increase in organic acids therefore resulting in increased P availability. This could be the case with the current findings where P gradually increased from day 0 to 70 for the study soils. It is worth noting that the non-acidic soil, was the soil that needed no liming because of it acid saturation levels and pH. This soil had higher P release concentrations when compared to the other two soils. The results of this study indicate the need for long-term field studies to test the impact of different application rates of bioslurry on soil nutrients.

CHAPTER 6: INTEGRATED MANAGEMENT – EASTERN CAPE

by Gambiza J, Langley K, Zondi L and Mapeyi M.

6.1 RURAL HOUSEHOLDS' EXPERIENCES IN USING BIOGAS DIGESTERS

6.1.1 Introduction

Overall there has been a significant change in the level of awareness of biogas in the target community. Initially there was absolutely no knowledge of biogas in this area (with less than 1% of respondents having heard of it). By the end of the project over 87% of respondents surveyed had heard of biogas and many were familiar with the numerous benefits provided by the technology due to extensive social learning having taken place. Residents consistently highlighted the ease of use and similarities between biogas and LPG gas.

Despite this positive reaction, many households remained adamant that electricity was the most suitable energy source, especially as it assisted in cooking, provided light and powered various appliances. One major challenge identified by several households was the manner in which cattle dung becomes scarcer during winter, as many households send their cattle off to grazing camps in the nearby mountains. Another concern is that the advanced age and frailty of many respondents was a limiting factor in their willingness to commit to the daily collection of cattle dung. Cultural preference for firewood for the preparation of certain dishes was also highlighted as a barrier for more widespread adoption.

Anaerobic biodigesters are relatively simple and most designs have few moving parts, requiring minimal maintenance. The modular nature of biodigester technology allows for rapid installation at both the household and village scale with minimal design changes, saving time, materials and money. Within the context of South Africa, several studies have concluded that numerous benefits can be accrued through the implementation of biogas technology (Karekezi, 2002; Austin and Blignaut, 2008; Amigun and von Blottnitz, 2010; Murphy et al., 2011; Smith et al., 2014). There are challenges, however, that remain regarding its widespread implementation (Figure 6-1).

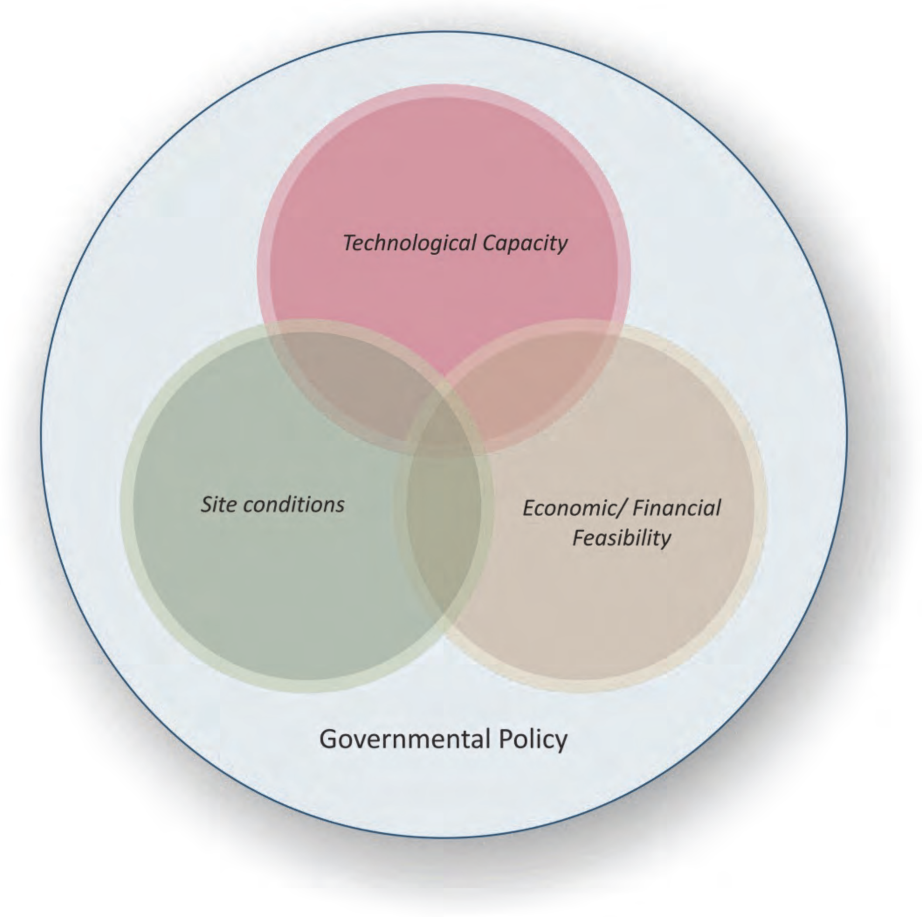


Figure 6-1: Interlinking factors influencing implementation of biogas technologies.

The technological capacity of the communities involved, specific site conditions, and the economic and financial feasibility of the biodigesters installed are three of the most common challenges encountered regarding the suitability of any new technology (Barry et al., 2011).

6.1.2 General characteristics of the biodigester systems installed

Anaerobic biodigesters come in a variety of shapes, sizes and designs. They can be constructed from an array of materials ranging from extruded plastics and polymers to concrete (Hilkiah Igoni et al., 2008). Two of the most commonly used designs are the fixed dome and floating drum biodigesters (Figure 6-2). These biodigesters are usually designed to operate on human and animal waste from a single household and to deliver sufficient energy to satisfy the cooking demands of a household. An average household biodigester has a volume between 2 m^3 and 10 m^3. It produces about 0.5 m^3 biogas per m^3 biodigester volume (Akinbami et al., 2001; Omer and Fadalla, 2003; Jiang et al., 2011). Floating drum biodigesters are normally made from concrete and steel, whereas fixed dome biodigesters are constructed with various available materials, such as bricks.

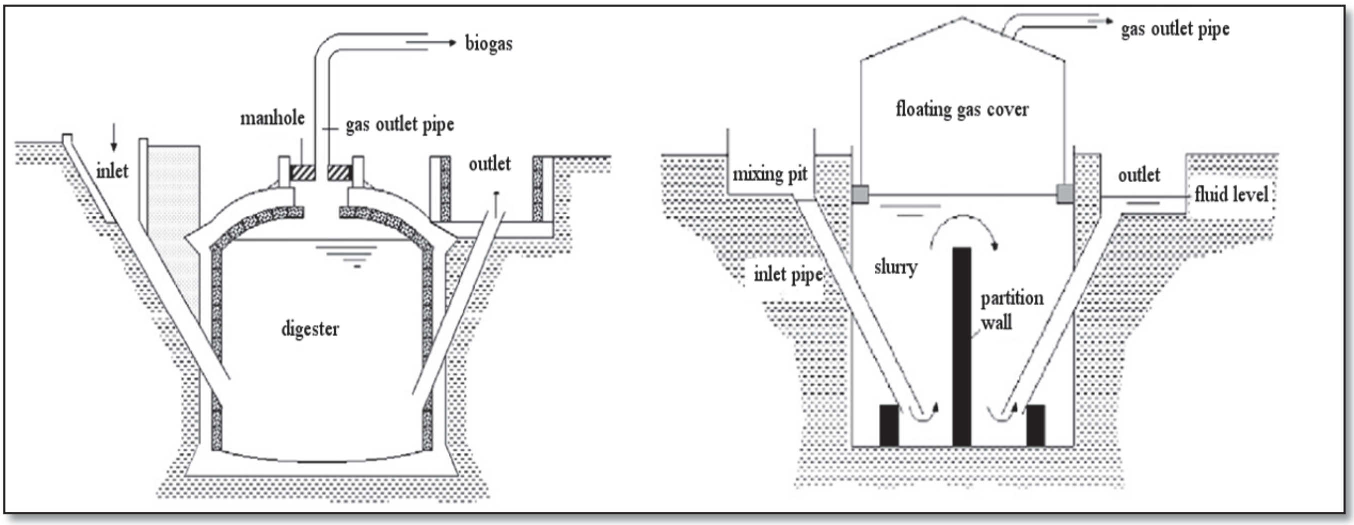


Figure 6-2: Left: fixed dome biodigester, and right: floating drum biodigester. Source: Bond and Templeton (2011).

Regardless of the biodigester design, the fundamental principle is similar with feedstock entering the system via an inlet pipe either directly or after going through a mixing pit. This substrate is then retained and 'digested' for a period ranging from 20-100 days (Sasse, 1988). The actual biogas is collected above the slurry before leaving through an outlet pipe for utilisation.

6.2 CHALLENGES EXPERIENCED WITH BIODIGESTERS

6.2.1 Technological and operational challenges

Ensuring that biodigesters deliver sufficient flammable gas for daily cooking is a critical factor in determining households' adoption of the technology (Brew-Hammond, 2010; Barry et al., 2011; Bruce et al., 2011). The technological capacity to repair or replace gas lines and fittings is sorely lacking within the Machubeni community and is a problem shared by other projects on the African continent (Brew-Hammond, 2010; Amigun et al., 2011; Black et al., 2011; Bruce et al., 2011; Okello et al., 2013; Orskov et al., 2014).

One of the most common faults reported by biogas users is low pressure or reduced gas production. This is often caused by either a leak within the gas chamber of the biodigester or pipes between the biodigester and gas appliance (Cheng et al., 2014). Luckily this was not the case in Machubeni because numerous tests were done after installation to ensure that there were no leakages. However, in the event of gas leaks, households have no recourse to rely upon for the repairs. Lack of maintenance support needs to be addressed in any large scale implementation of the technology.

Biodigesters require a constant addition of feedstock in the form of organic matter with a suitable ratio of water to ensure hydrolysis (Zuo et al., 2013). The retention time of biodigesters creates an initial period when little or no gas is produced as the microbes responsible for gas production reach critical mass. Ensuring that households continue to consistently feed the biodigester with sufficient biomass daily is the primary operational challenge associated with biodigesters (Austin and Morris, 2012). Households initially fed biodigesters daily. In the long run households, however, skipped some days and then added extra feedstock to compensate for those days. Evidence of overfeeding and insufficient water being added to the feedstock was evident at several digesters over time, with very thick slurry at the outflow point, coupled with low hydraulic movement from the reactor chamber.

6.2.2 Site specific challenges

Site specific conditions, both biophysical and social, are key factors influencing the success of biogas technology. Attitudes and cultural practices of communities utilizing biogas have been recognised as critical for the adoption of the technology (Mwirigi et al., 2009; Msimanga and Sebitosi, 2014). The gradual shift of households away from their traditional energy sources in rural communities is still not fully understood and involves numerous factors ranging from financial feasibility and availability to cultural significance and individual preference (Madubansi and Shackleton, 2006; Shackleton et al., 2007).

The most important biophysical characteristics of the site are the availability of feedstock, access to water and ambient air temperature (Harmon et al., 1993; Bohn et al., 2007; Amigun et al., 2011; Gao et al., 2012; Zhang et al., 2012; Kundu et al., 2013; Khan et al., 2014). Ideal operating conditions for a biodigester lie between 35° - 40°C. Biogas production, however, can take place at temperatures as low as 12°C. Machubeni lies within the lower range of this temperature spectrum.

With regards to access to feedstock, all households reported that they were able to access sufficient cattle dung in less than 20 minutes every day. Access to water was also not cited as a major concern, with all households being within 100 meters of a community stand tap, in addition to their rainwater tanks.

6.2.3 Comparative biodigester performance

The use of three biodigester designs at Machubeni allowed us to evaluate their relative performance (Figure 6-3). Initially the Biogas Pro units at Tschamazimba and Boomplaas performed significantly better than the other digesters. However, over time the Smart Top units increased gas production to comparable levels.

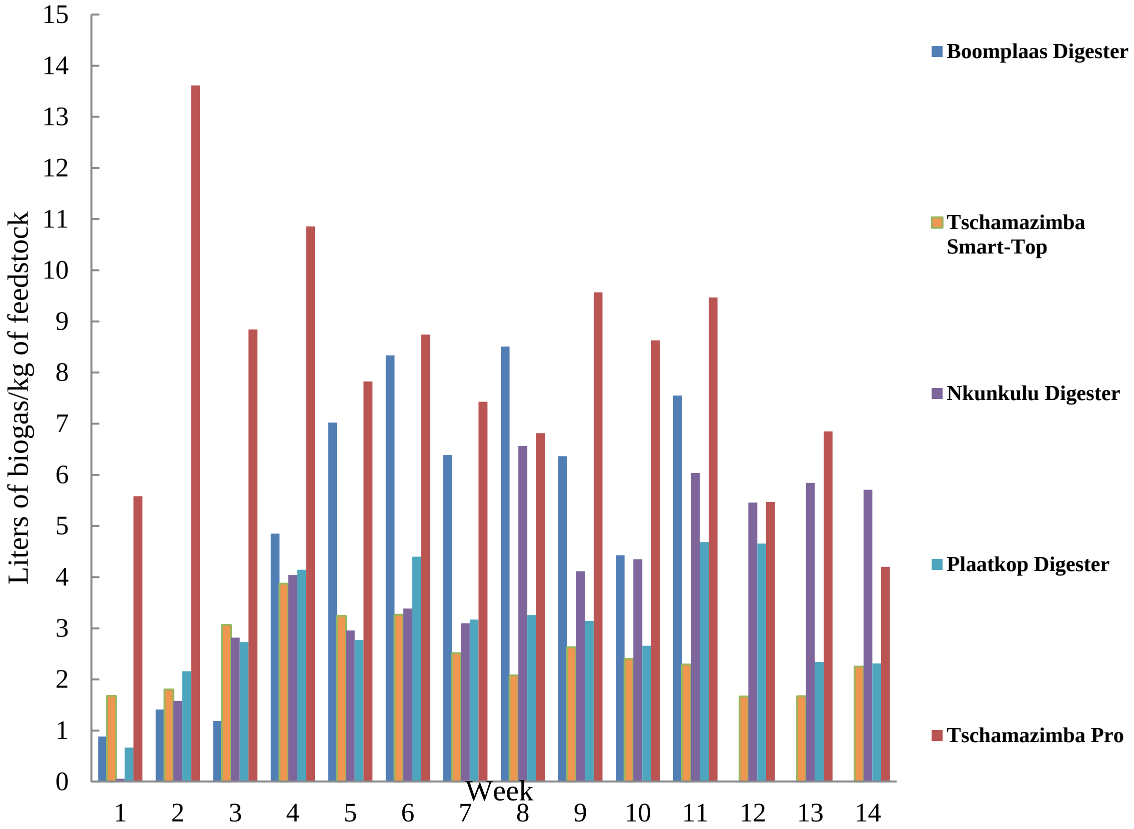


Figure 6-3: Comparative performance of biodigesters at five sites in Machubeni.

Despite low ambient air temperatures recorded in Machubeni, the internal temperatures of the biodigesters remained within the operational guidelines (Figure 6-4). These measurements were taken at dawn each day, establishing that the earth insulation prevented significant temperature losses overnight.

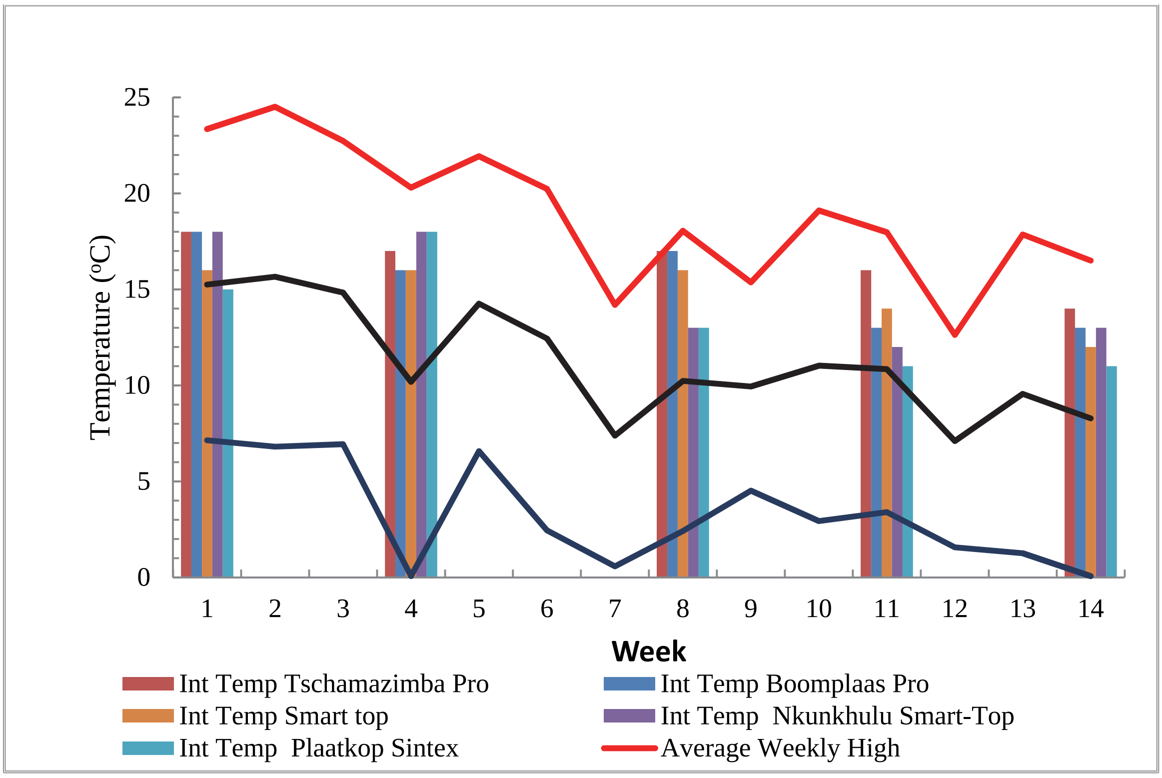


Figure 6-4: Internal temperatures of biodigesters compared to ambient air temperature.

6.2.4 Examples of challenges that households experienced in Machubeni

The following text boxes (1-4) show examples of challenges that households experienced.

Box 1: Case study: reduced gas capacity at Ngeka, Sotuko and Nyiki households in Machubeni due blockages in the gas chamber.

Problem: Households reported insufficient gas, despite their gauges indicating full gas chambers.

Action: Gas chambers were inspected. A fine ligneous material was discovered. The material was incredibly fibrous and porous with low moisture content. It did not have the strong smell of either the raw feedstock (manure or the bio-slurry). It was removed and the gas chambers resealed.

Cause: Inadequate mixing of feedstock (cow manure and water) and over-feeding the digesters probably caused the build-up of the ligneous material. This was compounded by the low digestion rate during the cold winter months.

Solution: Feedstock should be mixed thoroughly. Mixing the feedstock in a separate container and allowing it time to settle could assist. The Nkiti household at Tschamazimba that pre-mixed the feedstock did not experience any problems with blockages of the gas chamber.

Plate 6.1: Clockwise from top left: (a) High gas pressure, minimal gas, (b) opened gas chamber, (c) solid mass of ligneous material, and (d) light fluffy consistency of the ligneous material

Box 2: Extreme weather conditions.

Problem: High rainfall events made transportation and installation of biodigesters difficult. Additionally low temperatures during winter reduce the performance of biodigesters.

Solution: Careful planning must be done to ensure installation is conducted during summer, to take advantage of drier conditions and higher temperatures. This is especially useful for a speedy commissioning of the biodigesters, allowing microbes to reach critical mass faster. Biodigesters should be buried to insulate and regulate internal temperatures. Additionally, mixed feedstock can be allowed to stand in the sun for the duration of the day to increase its temperature.

Plate 6.2: Clockwise from top left: (a) Typical road conditions after a major rainfall event, (b) numerous rivers in the area flood on a regular basis, (c) overnight temperatures plummet below zero, and (d) burying the biodigester insulates it.

Box 3: Case study: Irregular loading and overloading of biodigesters.

Problem: Biodigesters have sluggish gas production and produce a thick bioslurry.

Action: The daily feeding regime of each household was monitored over a 14 week period.

Cause: Whilst feedstock was abundant, the labour to collect it and mix it was not always available to these households, particularly over weekends, holidays and cultural events (funerals). Households compensated for this by doubling the amount of feedstock they added. Additionally the feedstock to water ratio needs to be further investigated.

Solution: Further study into the best feedstock loading ratios needs to be conducted, taking into account temperature variations between summer and winter.

Plate 6.3: Clockwise from top left: (a) cattle dung serves as the primary feedstock, (b) additional mixing of feedstock within the biodigester, (c) consistency of the feedstock is very thick and additional water is added and (d) evidence of overloading the digester.

Box 4: Case study: Bioslurry outflow and hydraulic motion.

Problem: If the slurry outlet is not correctly placed so that the bioslurry freely and continuously exits the digester, digestate backs up into the system. A very thick bioslurry outflow and low hydraulic motion are two symptoms of this problem.

Cause: Insufficient slope between the outlet and the bioslurry pond, alternatively the pond overfills and material flows into the biodigester.

Solution: Households are encouraged to empty the bioslurry pit on a regular basis. A deeper pit was dug some distance away from the biodigester outlet, ensuring that it was well below the outlet's level to prevent backflow. Additionally the feeding regime could be adjusted to add more water to the feedstock.

Plate 6.4: Clockwise from top left: (a) Initial outflow pipe, with no bioslurry retention capacity, (b) evidence of slurry accumulation, (c) biodigester location in relation to field, and (d) new outlet constructed using rocks and cement to increase slope and ensure no backflow.

6.3 USE OF BIOGAS SLURRY FOR FODDER PRODUCTION

6.3.1 Challenges in livestock production

Overgrazing by livestock has resulted in decreased total vegetation cover, bush encroachment, high levels of soil erosion, low primary production and reduced biodiversity (Fynn and O'Connor, 2000; Hahn et al., 2005; Kassahun et al., 2008; Shackleton and Gambiza, 2008). Persistent heavy grazing has also been found to negatively affect seed production of palatable grass species (O'Connor and Pickett, 1992). The problem of overgrazing is a major challenge in communal rangelands (Hoffman and Ashwell, 2001).

Nefzaoui and Salem (2002) discuss the need to provide livestock with alternate feed sources when rangelands deteriorate as a result of overstocking and overgrazing. Rosati et al. (2009) aver that scarcity of feed is one of the main challenges in most livestock systems. The unavailability of good quality forage is a major factor that decreases the productivity of livestock (Dhyani et al., 2011). Poor nutrition in livestock often caused by insufficient quantity and poor quality of feed is one of the major causes of low livestock productivity in the smallholder sector (Mapiye et al., 2009). Negative effects associated with the shortage of feed include increased livestock mortality, decreased calving and reduced animal productivity (Kassahun et al., 2008).

Gambiza et al. (2010) suggest that one possible method of improving rangeland condition thus improving the quantity and quality of feed for livestock is through fodder production. The growing of fodder comes with a positive benefit such as relieving pressure on grazing areas allowing the land to recover.

6.4 CURRENT FODDER PRODUCTION PRACTICES IN MACHUBENI

There is a dearth of information on fodder production in smallholder systems. The opportunities, challenges and constraints that smallholder farmers in Machubeni face when growing fodder were investigated. Fodder production was defined as the deliberate planting of crops to be used as animal feed. The study addressed the following four key questions: (1) what is the proportion of smallholder farmers growing fodder? (2) which species are being grown as fodder? (3) what are the attitudes, knowledge and current practices of the farmers that grow fodder? (4) what are the challenges and constraints influencing fodder production? The main findings are summarized below.

6.5 PROPORTION OF FARMERS GROWING FODDER

Only 24% of the smallholder farmers sampled grew fodder despite 66% of them owning livestock. There was a positive relationship between the number of people who owned livestock and grew fodder. It appeared the bigger the village the smaller the number of people growing fodder in the village (Figure 6-5). The may be explained by the decrease in the area available for grazing as village size decreased.

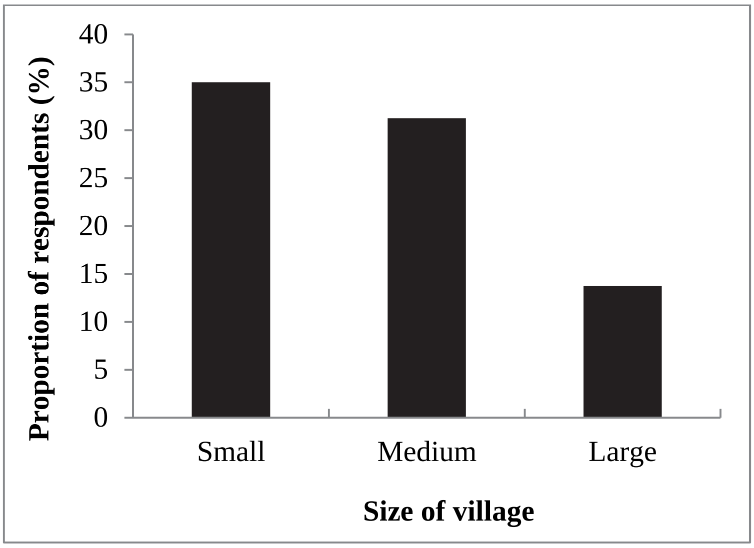


Figure 6-5: Proportion of farmers who grew fodder across different sized villages.

Those who did not grow any fodder were asked how they fed their livestock and most (29%) of the respondents just allowed their livestock to graze in the rangeland. Others bought lucerne (*Medicago sativa*) bales (49%) or fed their livestock crop residues (44%) in addition to rangeland grazing.

Most of the people who did not grow fodder were those who did not own livestock (Figure 6-6) with 43% of the respondents not owning livestock. The next commonly stated reason for not growing fodder was lack of money (30%) followed by poor rainfall (8%). Respondents gave other minor reasons for not growing fodder.

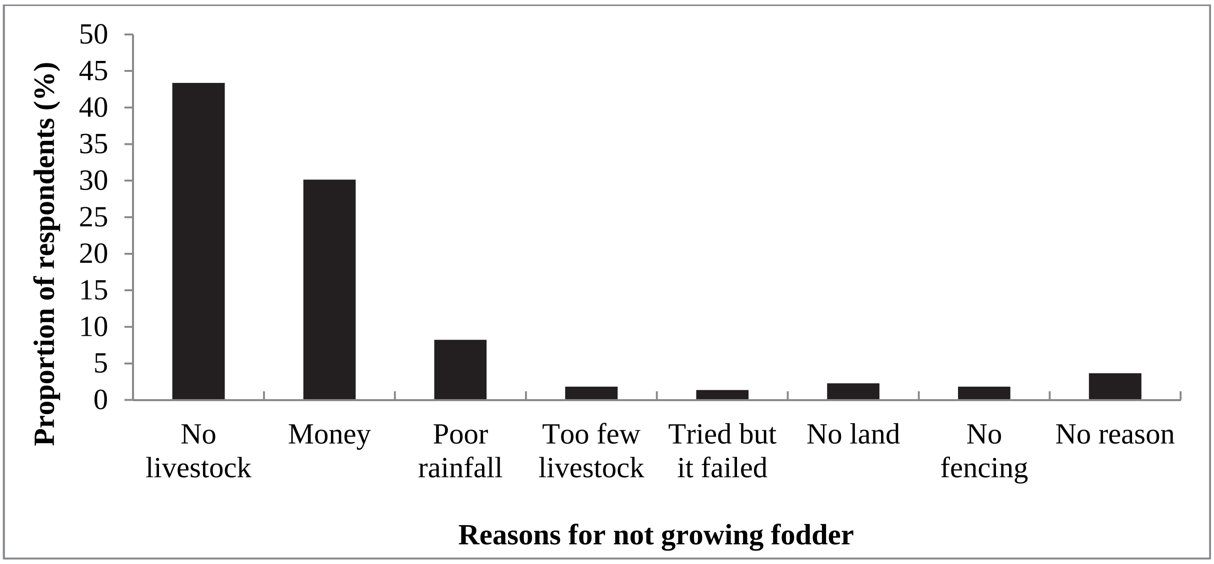


Figure 6-6: Reasons why farmers did not growing fodder.

6.6 PLANT SPECIES THAT WERE GROWN AS FODDER

All the respondents grew fodder grew oats (*Avena sativa*) with only two respondents also growing lucerne in addition to the oats. Most of the respondents bought seeds (95%). Five percent of the respondents used seeds from the previous year's crop.

About 26% of the growers chose oats because it was best suited for the area with the plant said to provide a range of benefits. Twenty-one percent of the respondents chose oats as a fodder species because they did not know any other species. A number of respondents (17%) said they chose oats because lucerne, being the only other species they knew, was unsuitable for the area. Other respondents chose oats because it was seasonal (7%), could withstand winter conditions (6%) and it was easy to obtain (4%). Fifty percent of the respondents had been growing fodder for longer than 30 years with 40% of them having been growing fodder since childhood. The oats were fed to cattle, sheep and lambs mainly during the dry season.

Most of the fodder growers (95%) also grew food crops. Maize was the most popular (94%), followed by pumpkins (63%) and beans (44%). Most of the respondents (80%) said their food crops were affected by pests. However, none of them stated a pest problem with the oats.

The main factor that influenced people to grow fodder (Figure 6-7) was their family members (72%). Other people also started growing fodder because they either saw people in the village (15%) or commercial farmers (5%) growing it or as a result of personal experiences such as death of livestock.

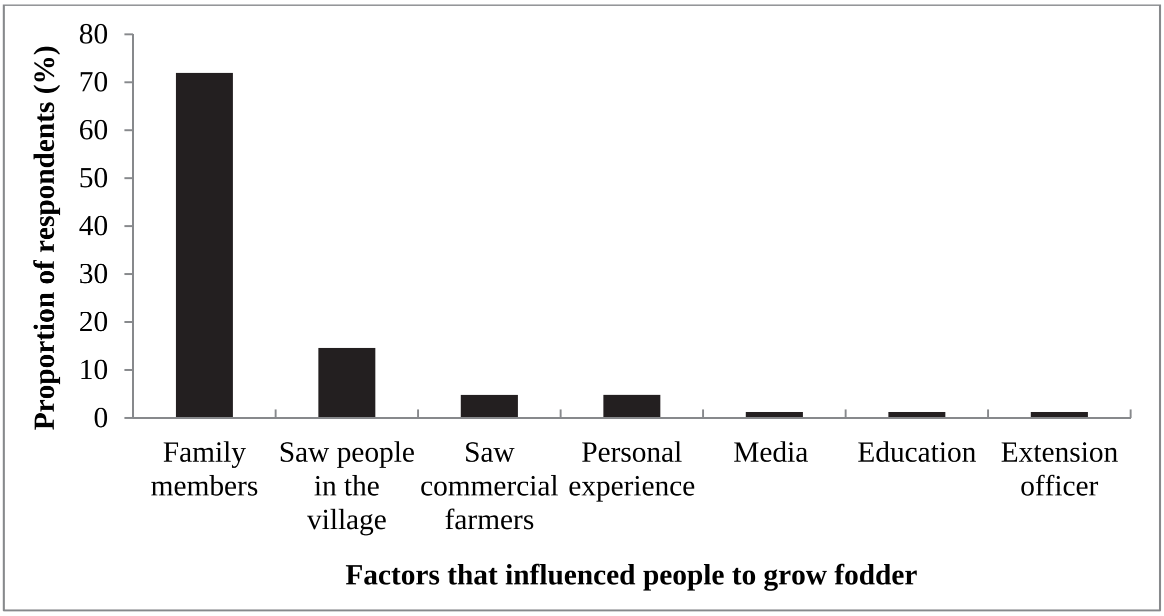


Figure 6-7: Factors that influenced farmers to grow fodder.

6.7 KNOWLEDGE, ATTITUDES AND CURRENT PRACTICES OF THE FARMERS

Most respondents (68%) did not know if the species they used had any adverse effects on livestock. The remainder said it could have adverse effects stating problems such as bloat, diarrhoea, and miscarriage. Although males (69%) were more knowledgeable of the adverse effects that oats caused than women, there was insufficient evidence to show that gender of the respondents and knowledge about the adverse effects of the oats were significantly dependent.

About 38% of the respondents stated they were not sure what knowledge was needed to grow fodder. Twenty-six percent of the respondents said you needed to know the correct time of the year for planting, 16% said you needed to have good knowledge on the weather and rainfall patterns. The rest of the respondents gave a variety of reasons such as knowing how to prepare the land before you plant, knowing the right time to start feeding your animals and knowing different seed varieties and seeding rates.

The majority of respondents (86%) knew from experience how much fodder each animal required. Of the remainder, 7% said they did not know, 2% said they observed their neighbours and only 1% were told by the extension officer how much fodder an animal would require.

Eighty seven percent of the respondents said they would recommend growing fodder to people who did not currently grow it whereas 11% said they would not recommend it to other farmers. Reasons stated by farmers who would not recommend growing fodder was that the soil in the area was not fertile enough and that growing fodder required money which people often complained about not having. The farmers who said they would recommend it stated the benefits of fodder as the reason they would recommend growing fodder to other farmers. Stated benefits included increased milk production, increased survival rate of new born livestock, an increased food source in winter, increased fertility of livestock and resultantly an increased number of livestock. Respondents stated that oats also had some environmental benefits. The most commonly stated environmental benefits were that it improved soil fertility (61%) followed by killing weeds (40%), loosening the soil (18%) and reducing erosion (2%).

Most of the respondents (92%) were very positive about the sustainability of growing fodder. Only 6% of the respondents did not think it was sustainable with 60% of those who did not believe it was sustainable stating that it was due to the decreasing interest in agriculture and the keeping of livestock. They stated that it could only be sustainable if the youth were encouraged to stay involved in agriculture.

Most of the respondents who grew oats, planted seeds in the first quarter of the year (Figure 6-8) with the largest number of people planting in February (34%) followed by March (22%) and April (18%). There were some respondents who planted seeds later in the year.

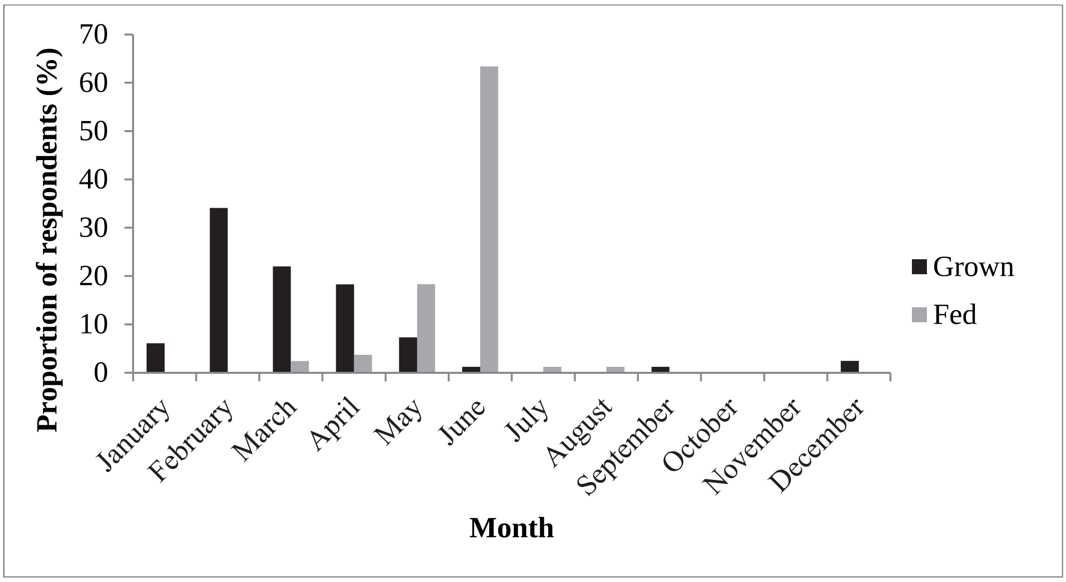


Figure 6-8: Time of the year when fodder species were grown and fed to livestock.

Most of the respondents allowed their livestock only to feed on the fodder in May (18%) and June (63%). Livestock were mostly allowed to graze on the area where the fodder was grown except for a few respondents (5%) who preferred to cut and feed the oats. For the two respondents who grew lucerne, they stated that lucerne could be grown at any time as it was a perennial plant but it had to be cut, baled and only be fed after it had been dried.

Only a few of the respondents (7%) irrigated their fodder, with scarcity of water in the area or distance of fields being the reason they did not irrigate. Most of them (72%) used organic manure from their livestock. Only a few of the respondents used fertiliser (6%) and pesticides (2%). Twenty two percent of the respondents did not use any of the stated inputs.

6.8 CHALLENGES INFLUENCING FODDER PRODUCTION

Obtaining tractors was the most commonly stated challenge when growing fodder. Respondents stated that there were often delays in getting tractors as there were only a few tractors available in the village. A number of respondents also stated that tractors were too expensive. The issue of expense was also another commonly stated challenge with many respondents (85%) stating that the costs related to growing fodder such as seeds and tractors were too expensive. Another challenge was the lack of water. A number of respondents (66%) stated that the area was prone to droughts and unreliable rainfall often contributed to poor growth or failure of the crop. Lack of fencing was another problem with respondents (51%) stating that this often allowed other people's livestock to graze their fodder. Forty-six percent of the respondents said obtaining seed was also difficult at times as shops were sometimes out of stock.

With most of the respondents having stated the many benefits that growing fodder provides, 71% of the farmers thought that growing fodder was a good practice for the government or external sponsors to support. Respondents stated that support in growing fodder would make a real change as the health of the livestock and the efficiency of livestock production would improve thus increasing profits. They further discussed that it would help improve people's livelihoods and help alleviate poverty. The rest of the respondents (29%) had a very negative attitude towards external funders or government with farmers stating that they were unreliable and made false promises. Government projects were said to be too short, unreliable and lacked longevity.

6.9 USE OF BIOGAS SLURRY FOR FODDER PRODUCTION IN MACHUBENI

Experimental design

Fodder plants were grown at four homesteads with biogas digesters. The annual grass species *Avena sativa* (oats) was grown together with the annual legume species *Trifolium vesiculosum* (arrow leaf clover) in a plot. The mixture of these annual species is referred to as the annual grass and legume (AGL). The perennial grass *Fescue arundinanceae* (tall fescue grass) was grown together with the perennial legume *Trifolium repense* (white clover). The mixture of the perennial species is referred to as the perennial grass and legume (PLG). Biogas digester slurry was applied to some plots while others received only water. Each homestead had 12 fodder plots each 5 x 5 m. The seeding rates per plot in 2012 and 2013 were as follows: for the oats 1.5 kg, 1.2 kg for tall fescue, 2 g for arrow leaf clover and 2 g for white clover. Superphosphate (750 g) was applied to each plot except at the Kiti site where double the amount was applied as per recommendation following soil analysis.

Planting was done in late February 2012 and early March 2013 and 2014. In 2012, 40 kg of slurry were applied per plot every month while control plots (no slurry) received 40 L of water. Slurry was applied on the soil surface in 2012. In 2013 the same amounts of slurry and water were applied per plot. However, the slurry was incorporated into the soil by digging holes and then covering them with soil after the slurry had been applied. Forty litres of water were also added to the slurry plots in 2013. The control plots received 80 L of water. In 2014, 40 kg of slurry plus water "*ad libitum"* were added per plot. The same amount of water was added to the control plots. Forage was cut in May, July and September.

Forage yields and crude protein content

In 2012 plots that had no slurry (i.e. control plots that were only watered) had higher dry matter yields than those where slurry had been applied (Table 6-1). This trend applied to both annual and perennial forage species. This suggests that slurry had a negative effect on dry matter yields. In sharp contrast, application of slurry resulted in a slight increase in crude protein content of annual species while it had no effect on crude protein content of perennial species. The results suggested that application of water in 2012 had a greater effect on dry matter yield than application of nutrients through slurry.

Table 6-1: Fodder trail details at Eastern Cape study sites.

2012	First cut				Second cut				Third cut			
Grass/Legume mixture	DM yield (kg/ha)	SD	CP (%)	SD	DM yield (kg/ha)	SD	CP (%)	SD	DM yield (kg/ha)	SD	CP (%)	SD
ALG_0	4076.5	424.63	11.0	1.83	2660.3	1459.56	7.0	2.77	782.5	299.64	7.1	2.76
ALG_s	2803.0	865.25	13.5	3.42	1874.3	720.95	8.0	3.39	439.3	189.89	8.1	3.31
PLG_0	3826.8	324.37	15.6	3.48	2166.8	537.06	10.7	2.29	599.8	246.73	10.8	2.18
PLG_s	2531.3	692.48	17.0	3.64	2758.0	1419.40	10.4	1.50	565.0	207.74	10.3	1.58
2013	**First cut**				**Second cut**				**Third cut**			
Grass/Legume mixture	**DM yield (kg/ha)**	**SD**	**CP (%)**	**SD**	**DM yield (kg/ha)**	**SD**	**CP (%)**	**SD**	**DM yield (kg/ha)**	**SD**	**CP (%)**	**SD**
ALG_0	4285.5	1030.33	15.4	4.44	4419.3	853.43	10.0	3.76	5228.8	528.04	8.3	1.21
ALG_s	4446.3	651.82	18.5	2.70	4503.8	1889.42	12.3	5.80	4425.3	455.18	9.1	1.71
PLG_0	3219.3	263.38	8.6	2.14	4581.5	2075.04	7.3	2.46	5015.5	550.24	11.0	1.67
PLG_s	2641.8	567.73	8.6	3.84	4060.5	878.65	7.8	2.89	4895.3	574.08	11.4	3.05
2014	**First cut**				**Second cut**							
Grass/Legume mixture	**DM yield (kg/ha)**	**SD**	**CP (%)**	**SD**	**DM yield (kg/ha)**	**SD**	**CP (%)**	**SD**				
ALG_0	2496.0	919.59	9.6	1.22	4509.8	1181.51	7.0	0.97				
ALG_s	2486.0	525.43	7.7	1.20	4083.5	469.88	8.7	1.25				
PLG_0	2677.8	501.38	11.0	1.70	4323.8	680.29	5.1	1.29				
PLG_s	1940.5	343.55	11.4	3.05	4419.3	937.13	6.4	1.50				

Dry matter (DM) and crude protein (CP) content of forage grown at four homesteads in the Eastern Cape. ALG_0 refers to annual legume and annual grass mixture with zero application of slurry, ALG_S refers to annual legume and annual grass mixture with slurry application. PLG_0 refers to perennial legume and perennial grass mixture with zero slurry. PLGs refers to perennial legume and perennial grass mixture with slurry.

During 2013 and 2014 there were no differences in dry matter yields of plots that received slurry and those that only received water. Again, application of slurry generally resulted in higher crude protein of forage than application of water.

Three general conclusions can be drawn from these results. First, application of slurry had no effect on dry matter yields whereas it increased the crude protein content of forage. Second, harvesting rainwater for forage production could result in significant feed reserves for livestock. Third, we need to investigate the optimum level of slurry application as well as the method of its application.

6.10 RANGELAND DYNAMICS AND MANAGEMENT

6.10.1 Conceptual overview of rangelands and their management

6.10.1.1 Rangelands as social-ecological systems

Evidenced-based management of rangelands requires a good understanding of the key drivers of their dynamics. It is now generally accepted that rangelands should be viewed as complex social-ecological systems (Boyd and Svejcar, 2009; Ostrom, 2009). Complex systems are characterized by non-linearity, unpredictability and multiple factors that interact to influence their dynamics. Ostrom (2009) proposed an analytical framework that should be used to manage complex social-ecological systems (SESs). SESs consist of four interactive subsystems (Figure 5-10). These are: (1) resource system, (2) resource units, (3) users, and (4) governance. It is important to note that external factors such as the social, economic and political settings and other related ecosystems also influence the subsystems.

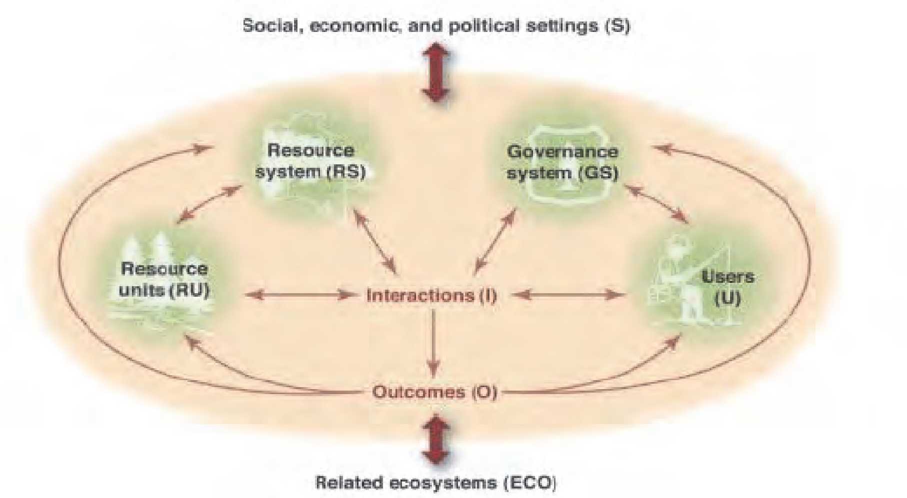


Figure 6-9: A conceptual framework of a social-ecological system. Source: Ostrom (2009).

For communal rangelands such as those in Machubeni, the resource system consists of the grazing area and arable fields. The resource units are the grasses, browse, crop residues and fodder crops. Users are the stakeholders that harvest or use different resources that are found on rangelands. These include livestock farmers, fuel wood collectors, medicinal plant harvesters and craft makers. We used Etienne et al.'s (2011) mental modelling technique to elicit local people's mental models of their SES.

6.10.1.2 Promoting the resilience of rangelands

Top-down command and control practices (Holling and Meffe, 1996) that promote destocking and rotational grazing management have failed in communal areas that are characterized by open access to grazing areas. Viewing communal grazing areas as complex SESs has been proposed as the way forward in promoting their sustainable management and resilience (Gunderson and Holling, 2002).

Insights from resilience theory can be used to promote sustainable management of rangelands. According to Allyson Quinlan and the Resilience Alliance (www.resiliancealliance.org) (cited in Fabricius et al., 2014) these insights are:

1: *Most SESs can exist in multiple states*. For example, savannas can exist in grassy or woody states. In Machubeni local people identified three states of their rangelands.

2: *Many SESs change gradually yet they quickly change to a new state when a threshold has been crossed*. In savannas grassy states can abruptly change to woody states once woody cover exceeds 30% (Scholes, 2009). This has been referred to as bush encroachment.

3: *Once a threshold has been crossed, it is difficult to revert to a previous state*. In Machubeni, grassy states where replaced by shrubs (*E. floribundus*). Attempts to eradicate the shrub have been unsuccessful.

4: *The adaptive cycle is a recurring pattern of change in SESs*. The cycle consists of four phases: (a) growth, (b) conservation of resources, (c) collapse and (d) re-organization.

5: *Systems are linked across scales in ways that can constrain or encourage innovation and reorganization*. For example, changes in global oil prices have effects that influence processes up to local and individual scales.

6: Institutional and governance arrangements that allow redundancy and thus ways of responding to change and that work with a mix of common and private property rights can promote the resilience of SESs.

7: *Sustaining diversity and working with ecological variation as opposed to attempting to control natural variation contributes to resilience*. Woody and herbaceous plants co-exist in savannas. Removal of woody plants has been shown to lead to up to a 300% increase in grass yields in semi-arid savannas. Grass production in these areas, however, is largely determined by annual rainfall. During drought years grass production is extremely low. Woody plants are more tolerant of drought than herbaceous plants. Thus during droughts woody plants are a key resource that provides browse for livestock thereby reducing the collapse of the rangeland system.

8: *Including ecosystem services that are either unpriced or have no market value in decision making can help to make trade-offs more apparent*.

9: *Social capital in the form of trust, strong networks, leadership and other aspects is linked to the capacity of people to respond effectively to change or disturbance and thus promote resilience of SESs*.

6.10.1.3 State and transition models (STMs) of rangelands

The traditional rangeland model views vegetation dynamics as a function of successional factors and grazing intensity (Figure 6-10). Successional factors are thought to drive vegetation towards the climax community while intense grazing is seen as opposing succession by driving vegetation towards early successional stages. Early successional stages are viewed as being in poor range condition while later successional stages are seen as being in excellent condition (Westoby et al., 1989). Rangeland health is hypothesized to follow a similar pattern to range condition. It has been shown that the traditional model fails to account for observed changes in vegetation especially in arid and semi-arid areas where alternative states to the climax state exist (Westoby et al., 1989; Briske et al., 2005). State and transition models (STMs) offer a plausible explanation for the observed changes in vegetation.

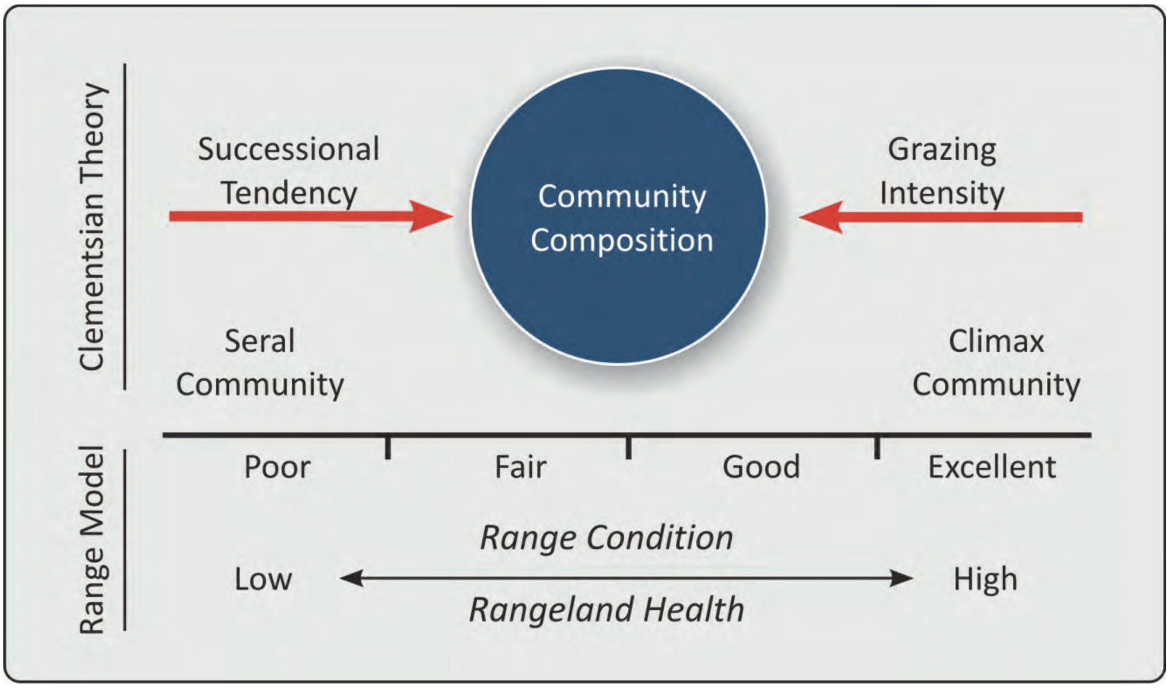


Figure 6-10: The traditional model of rangeland dynamics. Source: Briske et al. (2005).

The STM argues that vegetation can exist in different states within a given location. Vegetation can move from one state to another. It is important to understand the factors that cause transitions among states. STMs account for greater complexity since they accommodate multiple factors that drive vegetation dynamics (Briske et al., 2005). The states (represented by circles) are characterised by different vegetation structural and functional attributes (represented by arrows) (Figure 6-11). The desirable state depends on land users' management objectives.

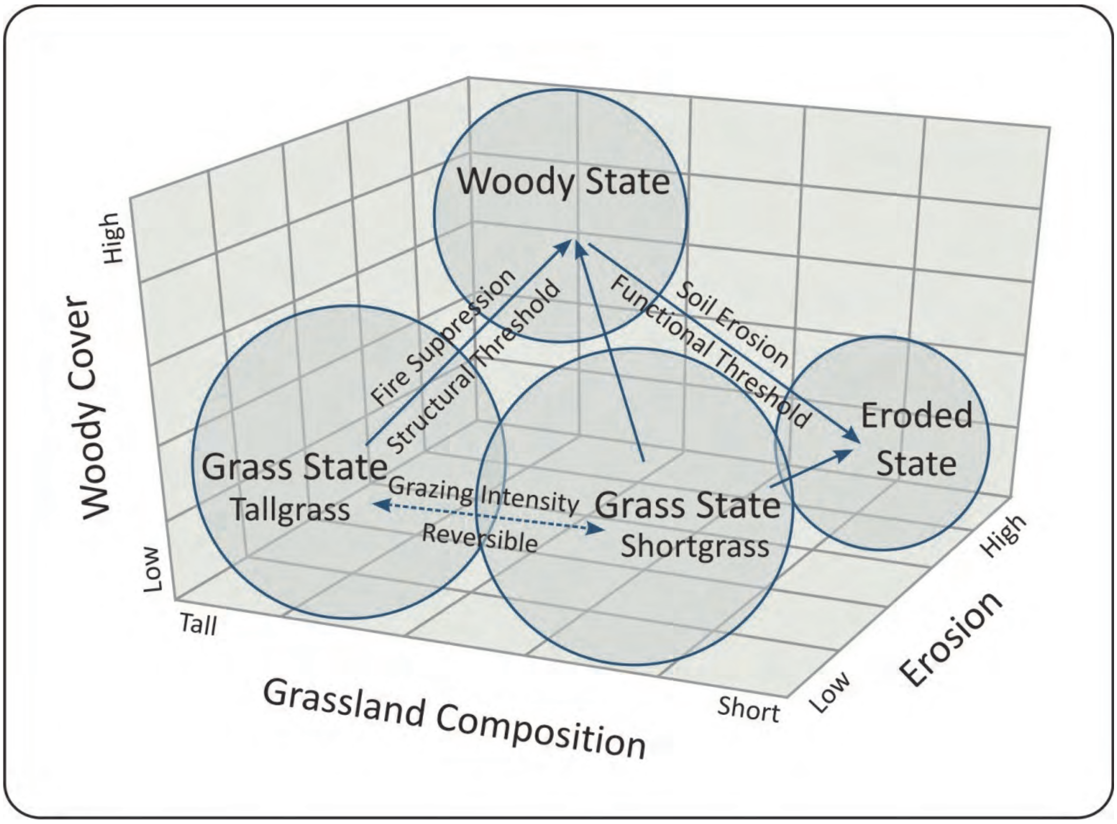


Figure 6-11: Example of multiple stable states that may exist in one area. Circles depict the states and arrows the transitions. Dashed arrows depict reversible transitions while solid arrows show irreversible transitions. Source: Briske et al. (2005).

Local people in Machubeni identified different examples of vegetation states (Plate 6.5). These ranged from bare areas to dense shrublands dominated by the invasive shrub *Euryops floribundus*. These vegetation states differed in important ecosystem functional properties such as nutrient cycling, water infiltration and soil nutrients (Figure 6-12).

Plate 6.5: Clockwise from top left: (a) extensive gullies in the grazing area; note the grave (next the fence) that is threatened by these encroaching gullies; (b) another view of extensive erosion and gullies; (c) gullies showing extensive vegetation regrowth, and (d) grazing area showing extensive *Euryops floribundus* invasive shrubs in the background.

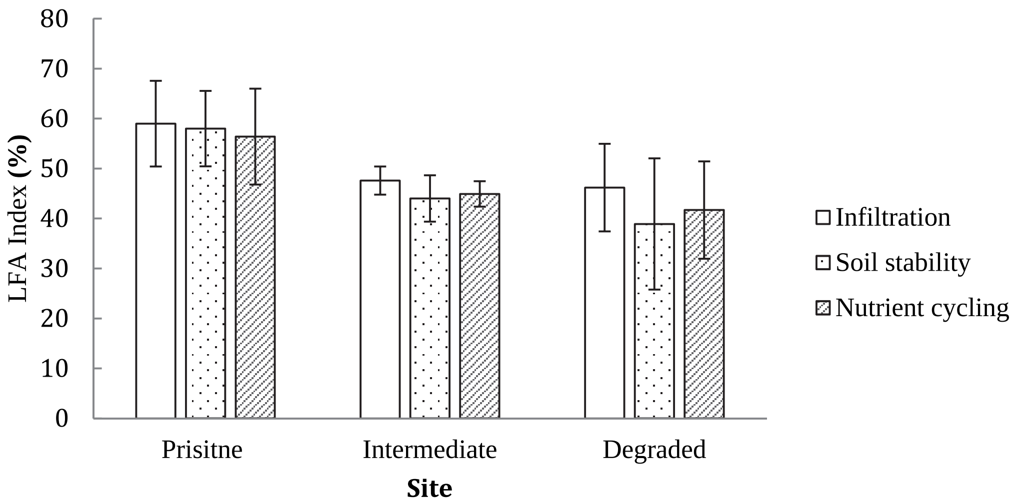


Figure 6-12: Landscape function indices at three site conditions in Macubeni. Bars indicate ± 1 SD.

6.10.2 Farmers' mental models of rangeland dynamics and condition

There are increasing attempts to understand stakeholders' behaviour, preferences, attitudes and values in natural resource management (Abel, 1998; Biggs et al., 2011; Jones et al., 2014). These social concepts are linked to understanding how a particular group interacts with natural resources within their community (Jones et al., 2011). A shared understanding of natural resource dynamics is necessary for any collective decision making. People use internal representations of real world interactions (i.e. cause and effect) to influence how they relate to situations. These representations or cause-and-effect diagrams constitute people's mental models (Jones et al., 2014).

Mental models are based on an individual's personal perceptions and general worldviews. The models are therefore limited and incomplete (Lynam et al., 2012). Mental models form the basis for people's behaviour, reasoning and decision-making. Mental models have a more social cognitive component, which means that as time passes people internalize and take in their experiences, and share them within their different social groups to create cultural meaning which in turn creates a shared mental model (Stone-Jovicich et al*.,* 2011). Researchers working in the natural resource management sphere need to understand the similarities and differences within and among certain groups to devise the most appropriate management plans.

The initial problem with mental models is that they exist within the mind. The challenge lies in how one is able to elicit this information from a group of stakeholders (Lyman and Brown, 2011). Several techniques can be used to elicit information from mental models with each technique having its own strengths and weaknesses (Jones et al., 2011). We used Etienne et al.'s (2011) method to elicit stakeholders' mental models.

6.10.2.1 Initial workshop session

At the inception workshop, the roles of the facilitator and observer were explained to participants. The facilitator was actively involved in the creation of the mental model whereas the observer served as a translator and took notes. We explained the aim of the study. Rhodes University ethical considerations were explained to participants. Participants had to give their consent to participate. They had rights to withdraw at any time or not to answer any questions. The rules of engagement were discussed and debated amongst participants and the facilitator.

6.10.2.2 Second workshop session

At this session, participants answered the question: "*Who are the main stakeholders that interact with the communal rangelands?*" Questions were asked in the vernacular language (Plate 6.6). The responses to the questions were written on cards and used to construct an actor's diagram (Figure 6-13). Only after approval from the whole group did this process continue.

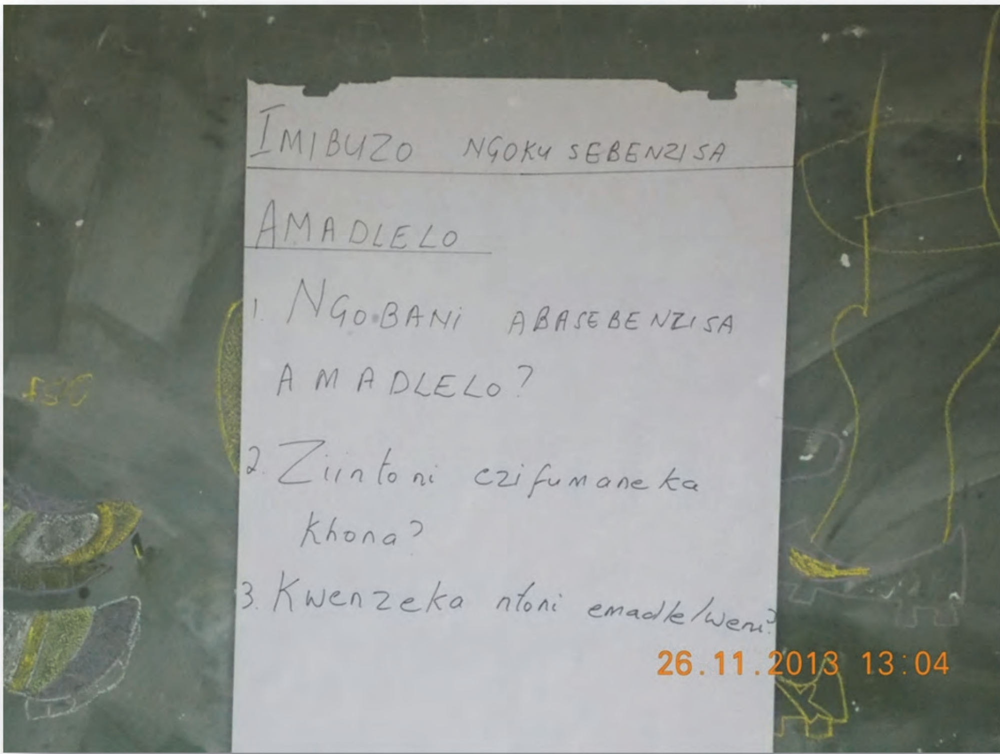


Plate 6.6: Questions that were posed (in the vernacular) as part of the Etienne et al.'s (2011) ARDI method to elicit users' mental models of rangelands.

Local community	*Smallholder farmers*
Local farmer's organisations	Commercial farmers
Non-governmental organisation	Farming groups
Local quarrymen	Traditional healers

Figure 6-13: The first stage of the ARDI process in Machubeni, Eastern Cape: "Who are the main stakeholders that interact with the Machubeni rangeland?" The concepts that are italicised are those suggested by the facilitator in order to break a deadlock. The concepts that are in bold are those added by the facilitator. Concept in orange font was added at a later stage in the ARDI process.

6.10.2.3 Third workshop session

At this session, participants answered the question: "What are the main resources obtained from the Machubeni rangeland?" The participants were asked to first list down the resources that they obtained from the rangeland (Plate 6.7). The list was discussed and debated amongst the participants for consensus. If after this process the list was too long the participants were asked to rank the resources and the top 10 were selected. Then a resource diagram was produced (Figure 6-14).

Plate 6.7: Participants filling in information on cards as part of the ARDI method.

Figure 6-14: The second stage of the ARDI process in Machubeni, Eastern Cape: "What are the main resources obtained from the Machubeni rangeland?"
Numbers rank the items from the most (7) to the least important (1).

6.10.2.4 Fourth workshop session

Participants answered the question: *"What are the main processes that cause rangeland condition to change?"* Participants identified things that they thought changed rangeland condition (Figure 6-15). The rationale behind these choices was also noted and used to create a frequency of justification graph. These were obtained in general terms and then the facilitator translated them into more scientific terms and added any glaring omissions (Figure 6-16).

OH	Overharvesting
OG	Overgrazing
TL	Topsoil loss
SD	Soil Degradation
NL	Nutrient loss
CSC	**Compaction, sealing and crusting**
WE	Water erosion

Figure 6-15: Stage three of ARDI in Machubeni, Eastern Cape: "What are the main processes that cause the condition of the rangeland to change?" The facilitator added the concepts that are bold.

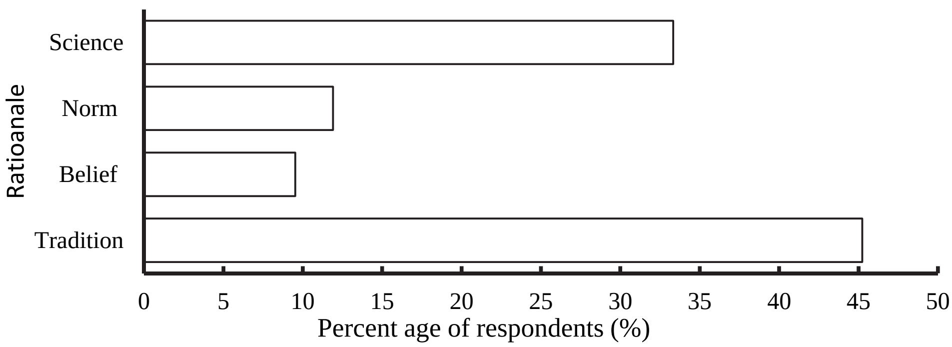


**Figure 6-16: Frequencies of rationale behind the choice of processes each participant chose from
step 3 of the ARDI method in Machubeni, Eastern Cape.**

Most participants based their responses on traditional local knowledge and science. This shows the importance of incorporating both types of knowledge in natural resource management.

6.10.2.5 Fifth workshop session

The last workshop was used for participants to examine the list of actors and resources, and then fill in the processes between each resource and actor. This activity produced the participants' mental model of rangeland dynamics (Figure 6-17). Researchers and participants shared meals during these intensive workshops (Plate 6.8).

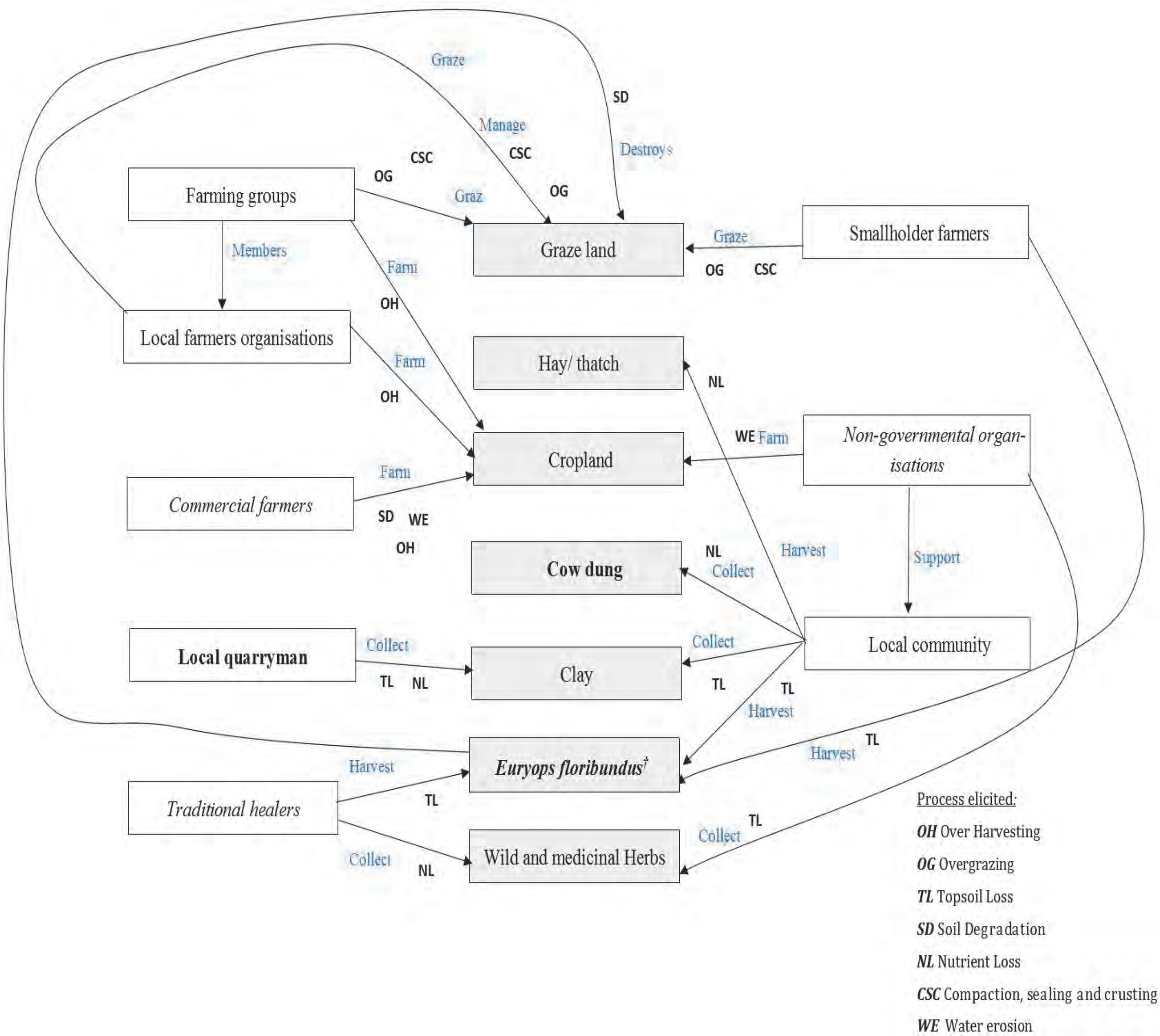


Figure 6-17: ARDI stage 4 in Machubeni, Eastern Cape.

"How does each stakeholder use the resources and modify the process?" White boxes indicate the stakeholders, the grey boxes indicate resources, boldfaced letter codes indicate processes, and grey text indicates actions. Words and concepts written in bold were input by the facilitator and those that are italicized were used to settle a deadlock during the construction phase.

Plate 6.8: Participants having a lunch after a hard day's work at an ARDI workshop in Machubeni, Eastern Cape.

6.10.3 Best practice in range management: Village Resource Management Plans (VRMPs)

Rangeland management plans should draw on concepts on SESs, resilience, STMs and local people's mental models. Fabricius et al. (2014) proposed VRMPs as a tool to promote rangeland management practices that are designed together with local people. VRMPs are based on key resource areas within each village. Key resources are important landscapes within each village such as forest patches, river valleys and springs. All key resources should be mapped as part of a VRMP. According to Fabricius et al. (2014) a VRMP should consist of: (a) an overall description of all key resource areas, (b) the management institutions and roles and responsibilities for managing them, (c) a collection of mini management plans with one for each key resource. Fabricius et al. (2014) listed seven steps for producing a VRMP.

1: *Describe the key resource*. Where is it located? What is its importance? What are its biophysical features?

2: *Production*. What is produced? How much and when? What are threats to production?

3: *Rights of access*. Who has right of access? Who can mediate in the event of conflicts?

4: *Responsibilities*. What are users' responsibilities? For example, what are the responsibilities of village people, traditional leaders and interested parties (e.g. government departments, municipalities)?

5: *Rules and regulations*. Clearly spell out general and specific rules.

6: *Management recommendations*. Specific management recommendations should be made such as when to utilize the resource, monitoring, administrative meetings, revisiting the rules annually and community structures (i.e. specific committees).

7: *Revision*. The rules may be reviewed annually.

Command and control management practices have failed to promote sustainable rangeland management. Active involvement of local communities in designing and managing their natural resources is the way forward.

6.11 LOCAL PEOPLE'S PERCEPTIONS OF RANGELAND INVASION BY *EURYOPS FLORIBUNDUS*

6.11.1 Introduction

Invasive species are a major driver of land degradation. Invasive species such as *E. floribundus* threaten land productivity and reduce the supply of essential ecosystem services (Shackleton and Gambiza, 2008). In 2005 the Department of Environmental Affairs funded a US$1 million project to clear the invasive *E. floribundus* in Machubeni. The aim of this project was to stop land degradation and erosion processes to improve agricultural production and conserve rangeland.

The aim of our study was to assess local people's perceptions and their views towards *E. floribundus* whilst at the same time identifying the effectiveness of the previous clearing project. Our objectives were to: (a) measure the extent of rangeland re-invasion by *E. floribundus*, (b) assess the use of *E. floribundus* as well as the trade-off which may exist between grazing land and *E. floribundus* invasion, and (c) find out why if previously cleared sites have been re-invaded – the local community has not continued to clear the sites. Findings from this study are important in helping us develop rangeland management practices that local people are likely to support and implement.

6.11.2 Findings

E. floribundus has re-invaded areas that were cleared in 2005 (Figure 6-18). Mean cover of *E. floribundus* ranged from 9-28% in 2014. In contrast, the mean cover of *E. floribundus* in uncleared sites varied between 46% and 55%.

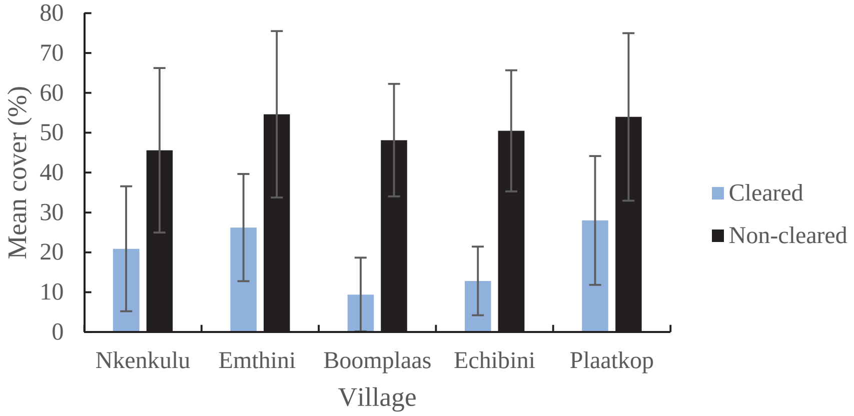


Figure 6-18: Mean cover of E. floribundus in cleared and non-cleared sites in Machubeni.

Local people highlighted several costs and benefits of *E. floribundus* invasion. About 97% of households used *E. floribundus*. This showed the importance the plant has on the local way of life. An interesting comment that kept being brought up was that “we need it (*E. floribundus*) but we hate it”. This highlights the trade-off present in the decision to remove the plant from the rangelands.

E. floribundus is used for several purposes including fuel for cooking, medicinal purposes, fencing for construction of livestock kraals, traditional ceremonies, shelter for chickens from predatory birds, aesthetic appeal and finally saves money in the household. About 90% of the respondents estimated savings per month to be R329 ± R180. This is an important saving considering the high unemployment rate in the area. It is therefore not surprising that 89% of the respondents agreed that *E. floribundus* contributed positively to their livelihoods and way of life, in light of the range of benefits.

According to local people, the costs of *E. floribundus* include: loss of water, loss of soil fertility, destruction of grasses leaving bare soil between individual *E. floribundus* shrubs, the destruction of roads, and the negative impact of smoke and bad odour from burning *E. floribundus* when it is used as a fuel.

Considering that there are costs and benefits associated with the invasion of *E. floribundus,* an ideal solution to this complex trade-off could be to manage the land by allocating specific zones.

CHAPTER 7: INTEGRATED MANAGEMENT – LIMPOPO PROVINCE

by Baloyi J, Tinarwo D, Lubisi M, Mzezewa J, Katsande S.

In most rural areas, ruminant animals depend on veld with poor nutritional value for their basic feed. Feed shortage and poor quality during the dry season are perceived by smallholder livestock farmers as the most production constraint. These farmers cannot afford purchasing conventional feed supplements. Maintenance of organic matter of the soil is a topical issue both for the farmers and agricultural scientists. Recycling of organic matter could be essential for maintaining soil fertility for crop or pasture production to feed the animals. Subsequently, there is a need to select a crop that will provide adequate and reliable fodder to ensure livestock sustainability. Yield increase due to bio-digester slurry application has been reported in many crops (Krishna, 2001). Vegetable crops produced with bio-digester slurry have better quality in nutrients as compared to those produced with chemical fertilizer (Krishna, 2001). The use of bio-digester slurry on the production of fodder can improve production and nutritional quality as shown where the slurry was used for irrigation in the field crops.

Decomposition of the cow dung and water mixture inside a bio-digester produces methane gas and the remaining portion of the mixture is sent through the outlet in bio-digester slurry. This slurry contains 93% water and 7% waste, which is an almost ready-made fertilizer containing macro and micro nutrients (nitrogen, phosphorous, calcium and magnesium) needed by the plants (Gurung, 1997). The slurry can be applied directly in the fields to grow crops more effectively than when using other fertilizers. There is evidence supporting the fact that the productivity of agricultural land can be increased dramatically with the use of manure produced from biogas (Krishna, 2001). The use of decomposed bio-digester slurry manure in fodder production has not been tested in many pasture growing areas. Therefore, there is a need to investigate the potential use of decomposed bio-digester slurry manure to enhance fodder yield and nutritional quality of livestock feed in communal areas of the Limpopo province in South Africa. The objectives of the study were to determine growth and yield, nutritional composition and quality of silage made from Napier and Panicum grass irrigated with biodigester slurry.

7.1 THE EFFECT OF BIOGAS SLURRY ON THE MINERAL AND CHEMICAL COMPOSITION OF NAPIER FODDER AT DIFFERENT GROWTH STAGES

7.1.1 Introduction

Shortage of feed and its nutritional quality are two most important constraints faced by smallholder livestock farmers during the dry season. These farmers cannot afford purchasing conventional feed supplements. Irrigation of crops with biogas slurry has gained popularity in many countries around the world (FAO, 1992) to enhance fodder production.

Slurry is a waste product of biogas plant and considered a potential source of soil nutrients. It contains substantial amounts of (N), potassium (K) and phosphorus (P) (Zhang, 2003). Mikled et al. (2002) stated that application of fermented slurry (FS) which is a by-product of anaerobic fermentation of animal excreta in biogas digester slurry significantly increased the yields of baby corn, corn stover and nutritive value. Slurry increases soil organic matter. Recycling of organic matter is essential for maintaining soil fertility for crop or pasture production to feed the animal. The slurry contains 93% water and seven percent waste, which is an almost ready-made fertilizer containing macro and micro nutrients (nitrogen, phosphorous, calcium and magnesium) needed by the plants (Gurung, 1997).

Yield increase due to biodigester slurry application has been reported in some crops. Vegetable crops produced with biodigester slurry have better quality in nutrients as compared to those produced with chemical fertilizer (Krishna, 2001).There is evidence supporting the fact that the productivity of agricultural land can be increased dramatically with the use of manure produced from biogas (Krishna, 2001). Yield responses of vegetable crops to biodigester slurry manure application have been reported in different crops including okra (Shahbaz, 2011) maize and cabbage (Karki, 2001).

The present study was conducted to determine the potential use of decomposed biodigester slurry manure to enhance fodder yield and nutritional quality of livestock feed in communal areas of Limpopo province in South Africa. The objective of the study was to determine the suitability of biodigester slurry as a nitrogen fertilizer in Napier fodder cultivation by analysing chemical composition in Napier grass harvested at different stages of maturity.

7.1.2 Materials and methods

7.1.2.1 Site description

The Napier fodder was grown at Maila (22.933°S and 30.467°E) and Nthabalala (23.26°S and 29.97°E) in Elim, 35 km south of Louis Trichardt in the Limpopo province in South Africa. Daily average temperature in summer at both sites ranges between 20 and 22.5ºC in summer 10°C and 15°C in winter. Maximum daily temperatures can reach as high as 35ºC at Maila and Nthabalala. Annual average rainfall at Maila and Nthabalala is 401 and 600 mm respectively. Rainfall is highly seasonal and 95% of it falls between October and March (Mmarete, 2003). Mid-season dry spell are often during early and intermediate stages of growth (FAO, 2009).

7.1.2.2 Experimental design and procedures

Two treatments of irrigation with poultry/cattle biodigester slurry and no slurry were used in a complete randomised block design. At both sites Maila and Nthabalala six plots of 5 x 4 m were demarcated, two plots per block were replicated three times. Soil samples were taken randomly in each plot using a 20 inch soil auger for mineral analyses. Napier cuttings with three nodes were planted, two nodes in the ground and one above ground level at an angle of about 30 - 45° (Tainton, 2000) and spacing was 75 cm between the inter row and 75 cm intra row. The Napier fodder per each block was irrigated with either biodigester slurry or only rain harvested water. Before irrigation, poultry and cattle slurry samples were collected in 50 ml containers for mineral analyses. The irrigation was done weekly using 10 litre watering cans at a rate of 5 litres per row in both treatments.

7.1.2.3 Characteristics of the experimental soil and slurries

The two sites were independent from each other. Therefore the soils at Maila were characterised by moderate acidity whilst soils at Nthabalala showed neutral reaction respectively. Calcium level was the highest mineral in the soil at both sites (Ca>K>Mg>P). Potassium was the most abundant mineral in poultry slurry compared to other nutrients. The order of nutrient content level in cattle slurry was N>K>Mg>P>Ca. The same trend was observed in cattle slurry. The order of nutrient content was similar for the two sites. Micronutrients were significantly ($P<0.05$) low (<30 ppm) in both soils and slurry, but high amount of nitrogen was in slurry at both sites. However, iron was the most dominant micronutrient in all cases.

7.1.2.4 Measurements of growth performance

During the experimental period, growth was measured by recording number of tillers per plant, number of leaves per plant, the height of the grass and the longest leaves length (in cm) every two weeks up to 16 weeks when the grasses were harvested.

7.1.2.5 Determination of Napier fodder chemical composition

The moisture content was obtained by subtracting dry weight from the wet weight of the sampled leaves. The Napier fodder leaves samples harvested at different stages of maturity were oven dried to determine moisture and dry matter (DM). The dried leaves samples were then analysed for crude protein (CP). Ash content was then also determined from the dried leaves samples by burning the samples in a muffle furnace at 550°C overnight following procedures by (AOAC, 2000). The organic matter (OM) was obtained by subtracting ash weight from the dried sample. Neutral detergent samples following Goering and Van Soest (1970) procedures.

7.1.2.6 Determination of Napier fodder mineral composition

The Napier fodder leaves samples harvested at the different stages of maturity were dried in an oven at 105°C for 48 hours following procedures by (AOAC, 2000). The minerals in the leaves and extracts from soil and slurry (P, K, Ca, Mg, B, Cu, Fe Mn and Mo) were determined using Inductively Coupled Plasm Optical Emission Spectrometry (ICP-OES) (SOP, 2005) and they were recorded in parts per million.

7.1.2.7 Statistical analysis

1. Statistical Model for growth parameters of fodder at different stages of maturity of Napier from Maila and Nthabalala respectively was as follows:

$$Y_{ij} = \mu + T_i + + \varepsilon_{ij}$$

Where Y_{ij} is the j^{th} sample of the i^{th} treatment

Y_{ij} = Observation, e.g. Tiller number per plant, number of leaves per plant, the height of the grass and the longest leaves length (in cm)

μ = Overall mean

T_i = Effect of the i^{th} treatment (biodigester slurry and no biodigester slurry)

ε_{ij} = Random error

2. Statistical Model for nutritional composition of Napier forages from Maila and Nthabalala respectively at different stages of maturity was as follows:

$$Y_{ijk} = \mu + T_i + S_j + (T \times S)_{ij} + \varepsilon_{ijk}$$

Where Y_{ijk} is the k^{th} sample of the i^{th} treatment in the j^{th} stage of maturity

Y_{ijk} = Observation, e.g. Chemical composition (g/kgDM) and macro and micro-minerals (ppm)

μ = Overall mean

T_i = Effect of the i^{th} treatment (biodigester slurry and no biodigester slurry)

S_j = Effect of the j^{th} stage of maturity

$(T \times S)_{ij}$ = Interaction between treatment and stage of maturity

ε_{ijk} = Random error

7.1.3 Results

7.1.3.1 Growth performance of Napier fodder at Maila site

The number of tillers for the first two weeks were did not differ significantly. The number of tiller count dropped in the 16^{th} week and it observed more in no biodigester slurry than in biodigester slurry treated Napier grass. (Figure 7-1)

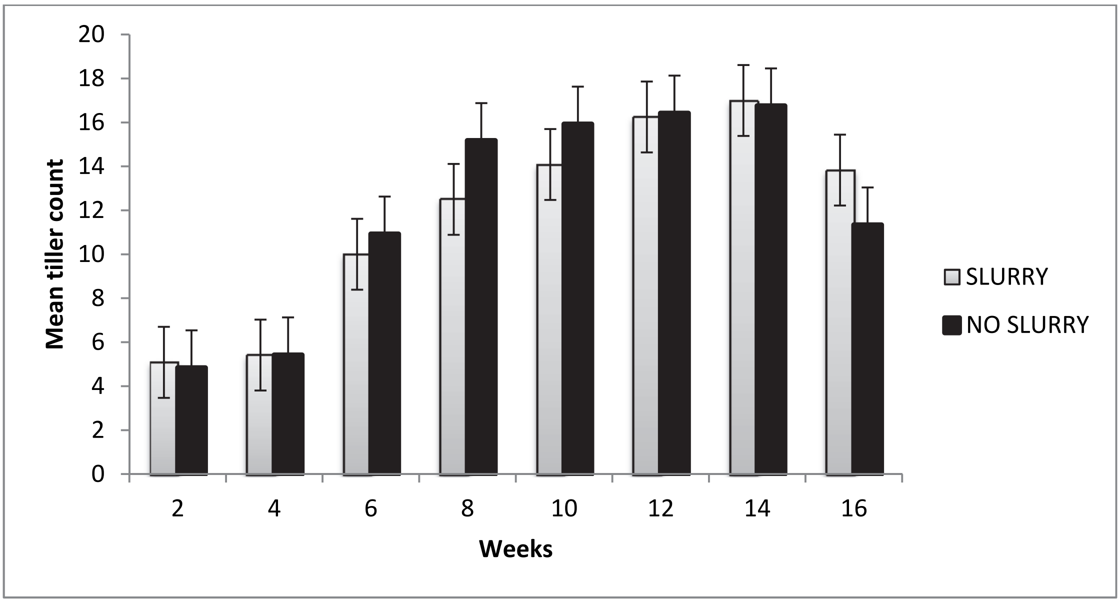


Figure 7-1: Mean tillers per plant of Napier grass under the treatments of poultry biodigester slurry and no biodigester slurry for a period of 16 weeks at Maila.

The number of leaves per plant was higher in biodigester slurry than no biodigester slurry treated Napier grass from week 2 until week 16. Growth difference in leaves per plant was observed more on the sixteenth week. (Figure 7-2)

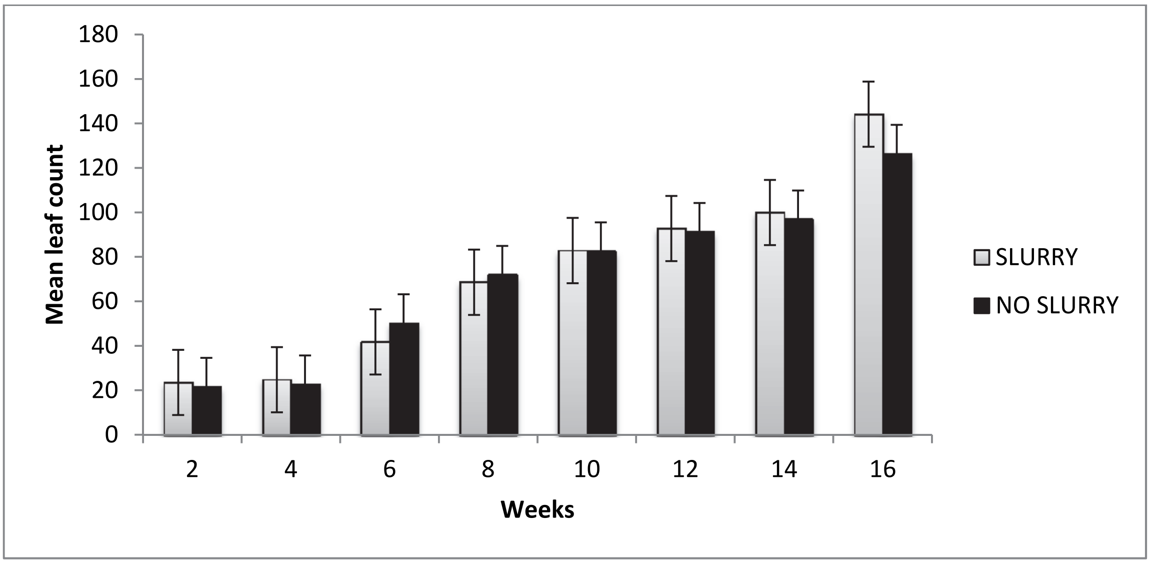


Figure 7-2: Mean number of leaves per plant of Napier grass under the treatments of poultry biodigester slurry and no biodigester slurry for a period of 16 weeks at Maila.

The plant height of the Napier grass showed a similar growth trend in biodigester slurry from week two to the sixteenth week. (Figure 7-3)

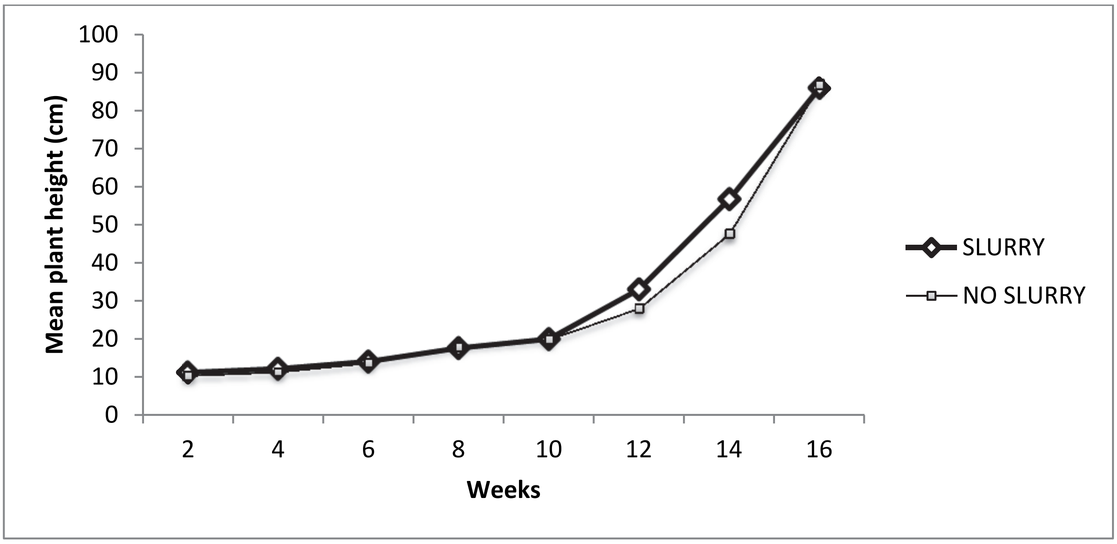


Figure 7-3: Mean plant height of Napier grass under the treatments of poultry biodigester slurry and no biodigester slurry for a period of 16 weeks at Maila.

Leaf length of Napier fodder was longer in no biodigester slurry than biodigester slurry for the first ten weeks and a change was observed from the twelfth week until the sixteenth week where it became higher in biodigester slurry. (Figure 7-4)

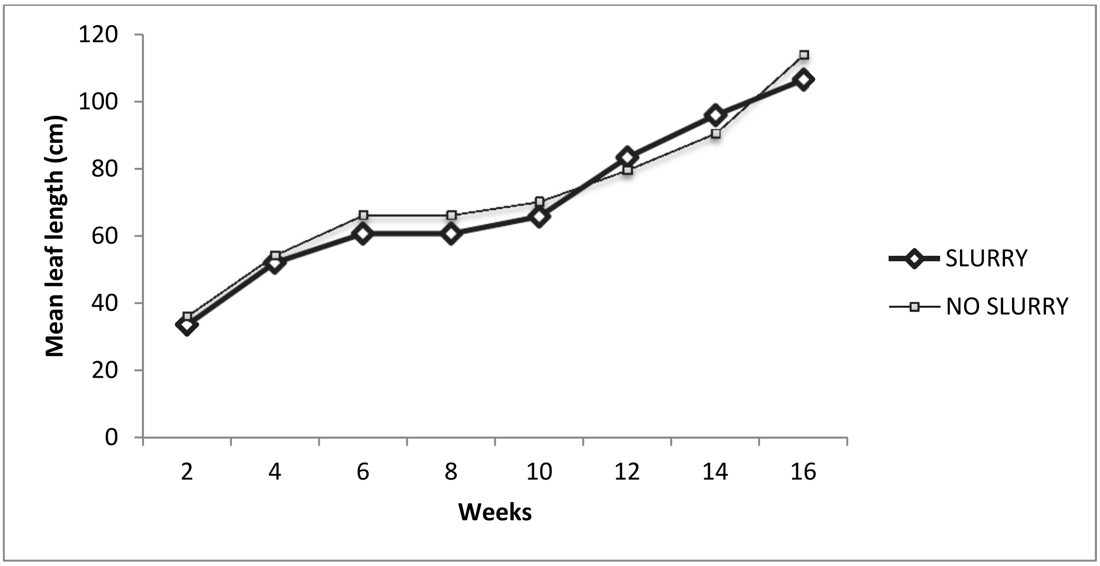


Figure 7-4: Mean plant height of Napier grass under the treatments of poultry biodigester slurry and no biodigester slurry for a period of 16 weeks at Maila.

The numbers of tillers increased in both treatments from week 2 up to week 10. Stable increase was observed from the tenth to the fourteenth week for no biodigester slurry for the Napier grass. (Figure 7-5)

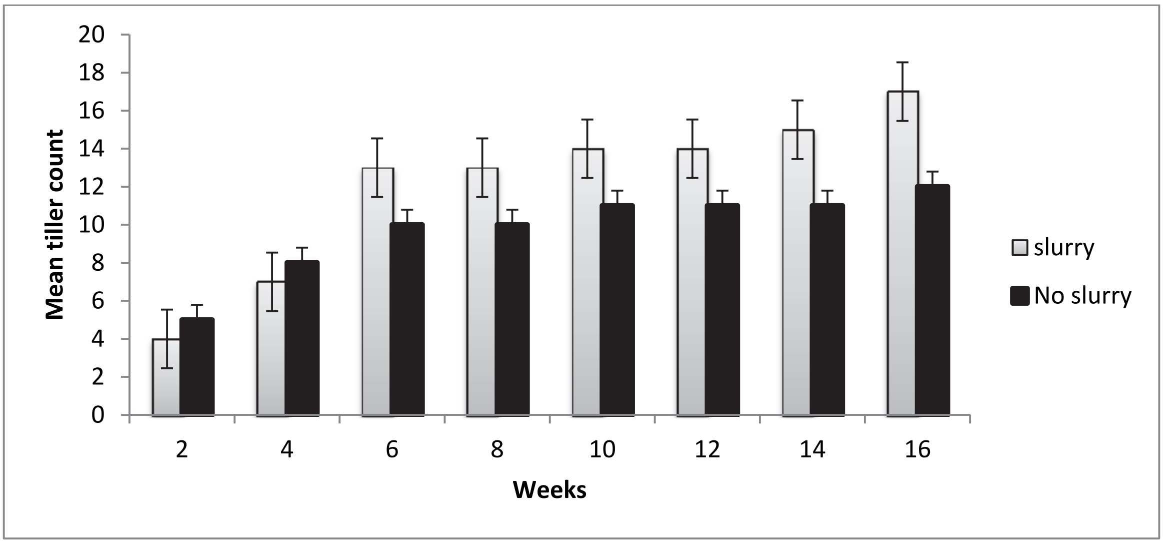


Figure 7-5: Mean tillers per plant of Napier grass under the treatments of cattle biodigester slurry and no biodigester slurry for a period of 16 weeks at Nthabalala.

The number of leaves per plant were high on biodigester slurry than no biodigester slurry treated Napier grass from week 2 until week 16 and the difference increased in week sixteen. (Figure 7-6)

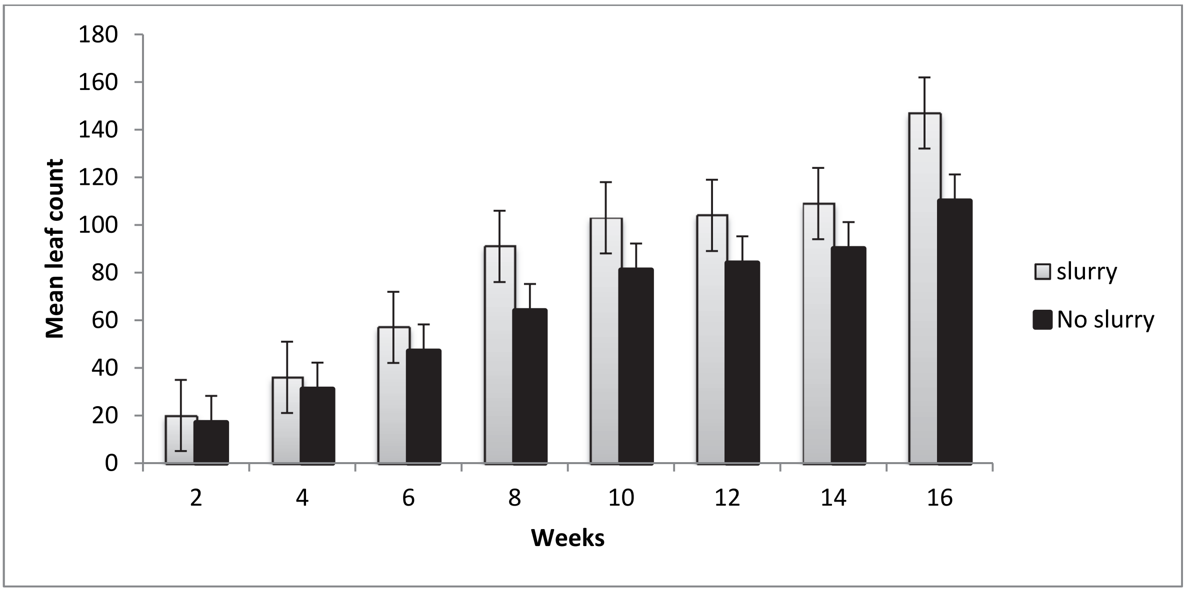


Figure 7-6: Mean number of leaves per plant of Napier grass under the treatments of cattle biodigester slurry and no biodigester slurry for a period of 16 weeks at Nthabalala.

The height of the grass increased from week two to week sixteen but Napier grass treated with biodigester slurry was taller than in no biodigester slurry but there was no significant different (P<0.05) observed (Figure 7-7).

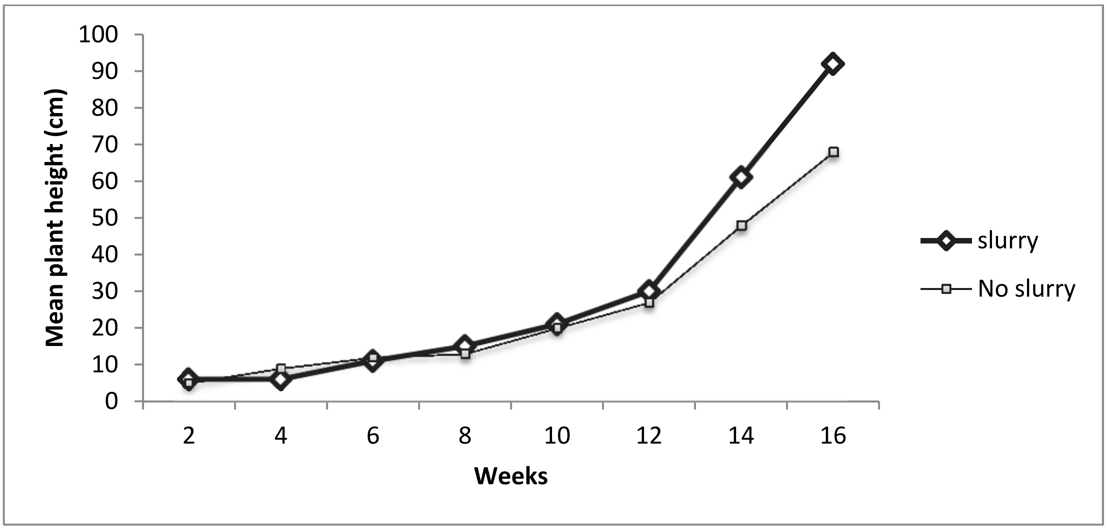


Figure 7-7: Mean plant height of Napier grass under the treatments of cattle biodigester slurry and no biodigester slurry for a period of 16 weeks at Nthabalala.

The leaf length was longer in biodigester slurry than in no biodigester slurry from the second week until the sixteenth week and no significant difference (P>0.05) were observed between treatments for each growth characteristics that were measured. (Figure 7-8)

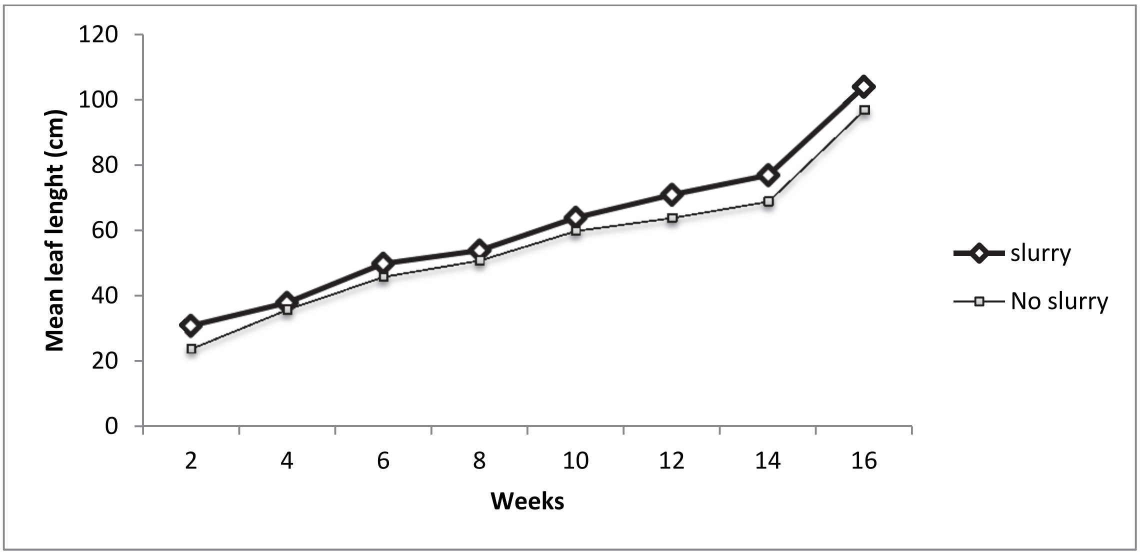


Figure 7-8: The highest leaf length of Napier grass under the treatments of cattle biodigester slurry and no biodigester slurry for a period of 16 weeks at Nthabalala.

7.1.3.2 Biomass yield of Napier fodder

Table 7-1 shows the two sites where application of biodigester slurry did not increase (P>0.05) fodder dry biomass yields when compared to the treatment in which no biodigester slurry was used.

Table 7-1: Effect of biodigester slurry fertilizer on Napier fodder yield at Maila and Nthabalala sites respectively.

Site	Treatment	Yield t/ha	Standard deviation
Maila	Poultry biodigester slurry	17.0[a]	±6.0
	No biodigester slurry	15.6[a]	±0.5
Nthabalala	Cattle biodigester slurry	16.0[a]	±0.0
	No biodigester slurry	15.5[a]	±2.0

[a] Mean values with same superscript letters in the same column are significantly (P>0.05) different.

7.1.3.3 Chemical composition of the Napier fodder harvested at different stages of maturity

Table 7-2 shows that moisture content of Napier fodder decreased with maturity. DM increased with maturity and it dropped at late stage. CP increased ($P<0.05$) at the late stage where the value of CP showed a significant difference between biodigester slurry and no biodigester slurry. NDF and ADF were constant in all the stages of maturity though the values vary, but they were not significant ($P>0.05$).

Table 7-2: Chemical composition (g kg^{-1}DM) of Napier grass irrigated with or without poultry biodigester slurry at different growth stages at Maila.

Stage of maturity	Treatment	DM(g kg^{-1})	ASH	CP	NDF	ADF
Early stage	Biodigester slurry	220^{c}	140^{a}	170^{a}	700^{ab}	410
	No biodigester slurry	200^{c}	60^{b}	170^{a}	710^{ab}	420
Intermediate stage	Biodigester slurry	430^{a}	100^{a}	120^{c}	650^{b}	440
	No biodigester slurry	470^{a}	120^{a}	120^{c}	690^{ab}	420
Late Stage	Biodigester slurry	360^{b}	100^{a}	150^{b}	730^{a}	440
	No biodigester slurry	380^{b}	140^{a}	140^{c}	710^{ab}	310
		Treatment means				
	Biodigester slurry	340	110	140	700	430
	No biodigester slurry	350	110	140	700	380
	SE	1.4	1.9	0.4	1.2	3.4
		Stage of maturity means				
Early stage		210^{c}	100	170^{a}	700^{ab}	410
Intermediate stage		450^{a}	110	120^{c}	670^{b}	430
Late stage		360^{b}	120	140^{b}	720^{a}	370
SE		2.1	2.3	0.5	1.4	3.4
Significance						
Treatment (T)		ns	ns	ns	ns	ns
Stage of maturity (S)		**	ns	**	*	ns
T x S		ns	ns	ns	ns	ns

*[a b c] Mean values with different superscript letters in the same column differ significantly (P<0.05) SEM = Standard error Mean; SM = Stage of maturity; DM = Dry matter; NDF = Neutral detergent fibre; ADF = Acid detergent fibre; CP = crude protein; ns = Not significant; * = Significant; ** = Strongly significant*

Table 7-3 shows that DM increased (P<0.05) with maturity and it dropped at the late stage with no significant difference to the intermediate stage without biodigester slurry treatment. CP decreased (P>0.05) with maturity. NDF increased (P<0.05) with maturity.

Table 7-3: Chemical composition (g kg^{-1}DM) of Napier grass irrigated with or without poultry biodigester slurry at different growth stages at Nthabalala.

Stage of maturity	Treatment	DM(g/kg)	ASH	CP	NDF	ADF
Early stage	Biodigester slurry	190^{d}	200^{a}	190^{a}	640^{b}	370^{c}
	No biodigester slurry	190^{d}	150^{b}	180^{a}	660^{b}	370^{c}
Intermediate stage	Biodigester slurry	410^{a}	110^{a}	130^{b}	760^{a}	420^{b}
	No biodigester slurry	440^{a}	70^{a}	140^{b}	750^{a}	430^{b}
Late stage	Biodigester slurry	380^{bc}	110^{a}	100^{c}	780^{a}	480^{a}
	No biodigester slurry	390^{ab}	100^{a}	100^{c}	780^{a}	480^{a}
		Treatment means				
	Biodigester slurry	330	140	140	730	420
	No biodigester slurry	340	110	140	730	430
	SE	1.0	2.2	0.5	0.7	0.6
		Stage of maturity means				
Early stage		190^{c}	170^{a}	180^{a}	650^{b}	370^{c}
Intermediate stage		420^{a}	90^{b}	140^{b}	760^{a}	420^{b}
Late stage		390^{b}	110^{b}	100^{c}	780^{a}	480^{a}
SE		1.2	2.4	0.7	0.8	0.7
Significance						
Treatment (T)		ns	ns	ns	ns	ns
Stage of maturity (S)		**	*	**	*	**
T x S		ns	ns	ns	ns	ns

*[a b c d] Mean values with different superscript letters in the same column differ significantly (P<0.05) SEM = Standard error Mean; SM = Stage of maturity; DM = Dry matter; NDF = Neutral detergent fibre; ADF = Acid detergent fibre; CP = crude protein; ns = Not significant; * = Significant; ** = Strongly significant*

7.1.3.4 Mineral composition of the Napier fodder harvested at different stages of maturity

Table 7-4 show no significant difference for K, B, Cu, Fe, Mn, Fe and Mo though the values have some increase in all the stage of maturity. Mg and Ca had differences between treatments at an early stage.

Table 7-4: Means of macro and micro-minerals (ppm) contained in the Napier leaves treated with or without poultry biodigester slurry at different growth stages at Maila.

Stage of maturity	Treatment	P	K	Mg	Ca	B	Cu	Fe	Mn	Mo
Early stage	Biodigester slurry	3[b]	17	84[a]	323.5[a]	37	55	69	50	57.3
	No biodigester slurry	2.3[b]	77	0	192.3[b]	44	6.2	63.4	50.3	49
Intermediate stage	Biodigester slurry	3[b]	54	15[b]	192[b]	41	21.3	59	50.1	46.3
	No biodigester slurry	5[b]	57	14.3[b]	202.4[b]	43	36	63	50.2	48.2
Late stage	Biodigester slurry	33[a]	66.4	46.3[b]	263.1[a]	43	29.3	65	50.3	52
	No biodigester slurry	35.2[a]	90.3	11[b]	248[a]	53	44	61.1	50.3	54
SE		1.2	34	25.3	34.2	9	18	7	0.2	13
		Treatment means								
	Biodigester slurry	15	46	48[a]	259	40	35	64	50	52
	No biodigester slurry	12	75	8[b]	214	46	29	62	50	50
	SE	3.4	20	14	40	5.1	10.3	4.2	0.1	7.3
		Stage of maturity means								
Early stage		3[b]	47	42	259	40	31	662	50	53
Intermediate stage		6.2[b]	55	14	197	42	29	61	50	47
Late stage		32[a]	78.4	28	255	48.3	36.4	63	50.3	53
SE		3.2	24	18	24.2	6.3	13	4	0.1	9
Significance										
Treatment (T)		ns	ns	*	ns	ns	ns	ns	ns	ns
Stages of maturity (S)		*	ns	*	*	ns	ns	ns	ns	ns
T x S		ns	ns	*	ns	ns	ns	ns	ns	ns

*[a b] Mean values with different superscript letters in the same column differ significantly (P<0.05), SE = Standard error, * = Significant; P<0.05, ns = Non significant (P>0.05), Phosphorus (P), potassium (K), calcium (Ca), Magnesium (Mg), Sulphur (S), Boron (B), Copper (Cu), Iron (Fe), Manganese (Mn) and Molybdenum (Mo)*

Table 5 shows macro-nutrients and micro-nutrients content showed no significant (P>0.05) difference for K, B, Cu, Mn and Mo in all the stage of harvest. P, Mg, and Fe showed significant (P<0.05) difference between treatments at an early stage. Ca was significant (P<0.05) different between the treatments at late stage of maturity.

Table 7-5: Means of macro and micro-minerals (ppm) contained in the Napier grass leaves treated with or without cattle manure biodigester slurry at different growth stages at Nthabalala.

Stage of maturity	Treatment	P	K	Mg	Ca	B	Cu	Fe	Mn	Mo
Early stage	Biodigester slurry	4^{a}	84.1	55.4^{b}	107^{c}	43	32.3^{a}	65.2^{a}	51.4	44.2
	No biodigester slurry	1.3^{b}	85.3	0	159.3^{b}	62.3	42^{a}	50.1^{b}	50.2	40
Intermediate stage	Biodigester slurry	4.1^{b}	65.3	20.4^{b}	191.2^{b}	43.3	13.4^{b}	56^{b}	50.4	34.2
	No biodigester slurry	8.2^{b}	85.4	110.2^{a}	158^{b}	45.2	27.4^{a}	64.4^{a}	50.1	47.4
Late stage	Biodigester slurry	37^{a}	17.3	50^{b}	314.4^{a}	56.4	10.3^{b}	67^{a}	50.4	45.1
	No biodigester slurry	27.1^{a}	43.2	28.3^{b}	228.4^{b}	47.4	11^{b}	65.4^{a}	50.2	45.1
SE		5	29.3	39.4	41.02	11	10.4	5	0.2	8
		Treatment means								
	Biodigester slurry	15	29	42.3	204^{a}	62	18.2	48.3	50.4	41
	No biodigester slurry	12.2	71	46	182^{b}	60	27.4	51.3	50.2	44.1
	SE	2.6	17	18.3	24.2	3.3	6.1	6.3	0.1	5.4
		Stage of maturity means								
Early stage		2.4^{b}	45	28.1	133.3^{b}	57.3	37.1^{a}	55.4	50.3	42.1
Intermediate stage		6.2^{b}	75	65	174.3^{b}	60.1	20.1^{a}	44.2	50.2	41.3
Late stage		32^{a}	30.2	39.1	271.4^{a}	66.2	10.3^{b}	62.1	50.2	45
SE		3.2	20.2	22.4	29	3.3	7.4	8.4	0.1	6.0
Significance										
Treatment (T)		ns	ns	*	*	ns	*	ns	ns	ns
Stages of maturity (S)		*	ns	ns	*	ns	ns	ns	ns	ns
T x S		ns	ns	ns	ns	ns	ns	ns	ns	ns

*[a b] Mean values with different superscript letters in the same column differ significantly (P<0.05), SE = Standard error, ns = Non significant (P>0.05), * = Significant; Phosphorus (P), potassium (K), calcium (Ca), Magnesium (Mg), Sulphur (S), Boron (B), Copper (Cu), Iron (Fe), Manganese (Mn) and Molybdenum (Mo).*

7.1.4 Discussion

7.1.4.1 Growth and yield of the Napier fodder irrigated with biodigester slurry

Terhoeven-Urselmans et al*.,* (2009) observed the impacts of biodigester slurry obtained from biogas plant on soil microbial biomass. In this study, as presented by Figure 7-1 to Figure 7-4 and Figure 7-5 to Figure 7-8 respectively results showed that the application of biodigester slurry improved growth of fodder when compared to the no biodigester slurry but statistical no significant difference (P>0.05) observed. Moreover, a rapid increase in number of leaves was observed on plots treated with biodigester slurry although statistically there was no significant difference (P>0.05). Comparisons also revealed that leaves and tillers were higher in biodigester slurry treatment grasses than those which were not treated with biodigester slurry. This can be attributed to the fact that biodigester slurry (composted from cattle/poultry manure) supplied other nutrients, such as calcium and potassium, all of which had an influence on the growth of fodder grass (Chadwick et al*.,* 2000). In addition to supplying nutrients, biodigester slurry affect plant growth indirectly by improving the physical, chemical and biological properties of soil, aeration, pH, cation exchange capacity and microbial activity and diversity (Cooperband, 2002). Reddy et al*.,* (2000) observed that biodigester slurry has buffering capacity on pH and increases the levels of P in the soil available to crops compared to inorganic fertiliser P application at the same rate.

Biomass yield in fodder depends on the number of leaves, leaf area, and fodder height and stem circumference. As stem circumference increases, fodder production increases (Rahman et al*.,* 2008). In the case of biomass yield as presented in

Table 7-2, the high yield of Napier fodder was obtained in both biodigester slurry and no biodigester slurry treatments. Biomass yield was not significantly different between biodigester slurry and no biodigester slurry. Biomass depends on the growth parameters and the growth parameters showed no significant difference. Similarly, Dauden and Quilez (2004) concluded that using different levels of pig biodigester slurry had no significant effect on plant height or biomass yield. Nonetheless, in terms of numerical values biodigester slurry proved to yield more biomass than no biodigester slurry.

7.1.4.2 Chemical composition of Napier fodder harvested at different stages of maturity at Maila and Nthabalala respectively

The moisture content defined from the fresh samples of the forage's at both sites as presented from

Table 7-2 and Table 7-3 respectively decreased with maturity and it was highest at the late stage of maturity. Dry matter increased with maturity and it dropped at the late stages of growth at Maila. At Nthabalala DM, NDF and ADF increased with maturity. There was no significant difference in NDF content among the treatments. As forages mature, DM yield tend to increase, concentrations of DM and residual water soluble carbohydrates increase. While concentrations of starch, neutral and acid detergent fibre and crude protein decrease, however in vitro DM digestibility is not affected by maturity (Adesogan, 2005). NDF and ADF values indicate how much substrate will be available for fermentation. Ramanurthy and Shivashankar (1996) reported that the application of organic waste decreased ADF content of maize fodder. Dry matter content may vary according to variety, stage of fodder maturity, soil topography, season, temperature and climatic conditions. Fodder DM content is also an indicator of its quality (Islam et al*.,* 2009). Significantly, higher DM content of forage crop with application of fermented biodigester slurry was reported by Mikled et al*.,* (1994). In the current study, the biodigester slurry had no effect as compared to the non-biodigester slurry irrigated plots. Gonet and Stadejek (1992) stated that average DM content of maize fodder increased with an application of nitrogen fertilizer. In this study, the DM was highly influenced by the stages of maturity. However, the results found in this study for DM are similar to those reported by Azim et al*.,* (1989). They reported that values of DM were higher in younger plants as compared to the matured ones.

The CP content of fodder is the most important indicator of its quality. It has a direct effect on milk production in dairy animals and body growth in cattle (Rahman et al*.,* 2008). Higher crude protein values were found in leaves harvested at early stages of growth from both sites and this was also supported by Azim et al*.,* (1989). The CP proved to be influenced by the application of biodigester slurry and that was observed in the late stages of growth where the value of CP showed a significant difference between biodigester slurry and no biodigester slurry. Beckwith et al*.,* (2002) reported that increasing levels of cattle biodigester slurry on grass increases the crude protein content. Similar results were obtained by Sarker (2000) in bamboo fodder.

Ash content was significantly different at early stages between biodigester slurry and no biodigester slurry. The outcome is different from the outcome reported by Khan et al*.,* (1996) who observed decreased ash content of oat fodder under N fertilizer application.

7.1.4.3 Mineral composition of the Napier fodder harvested at different stages of maturity at Maila and Nthabalala respectively

There was no significant difference in K, B, Cu, Fe, Mn, Fe and Mo content although the trend showed increase with maturity (Table 7-4 and Table 7-5). Macro-nutrients and micro-nutrients content showed no significant difference in K, B, Cu, Mn and Mo content in all the stages of growth. According to biphasic model of crop growth response to salinity stress (Munns, 1993), salinity limits plant growth due to osmotic effect during early stages, while at the intermediate stage of maturity it is due to accumulation of toxic ions (ion toxicity) this occurred only at Nthabalala with one plot at the far corner where biodigester slurry was not applied. The P, Mg, Ca and Fe content was significantly different between treatments during the early stages of growth. Phosphorus might have been bound with the acid forming cations, once the phosphorus is bound, it is very difficult to be released or be available to the plants unless lime application is made in order to ameliorate the soil (Krishna et al., 2001).

7.1.5 Conclusion

The chemical and mineral composition of Napier fodder was mostly affected by the stages of maturity compared to the treatments. However, CP content in the Napier fodder at the late stage of maturity was significantly increased by irrigating with biogas slurry. Moreover, the use of biogas slurry may result in an increase of vegetative growth of Napier fodder and a balance in mineral and chemical composition.

7.2 GROWTH PERFORMANCE, CHEMICAL AND MINERAL COMPOSITION OF *Panicum maximum* FODDER IRRIGATED WITH BIODIGESTER SLURRY AT DIFFERENT STAGES OF MATURITY

7.2.1 Introduction

Soil fertility problems are found in most tropical pasture situations (Aderinola, 2007). The forages are generally of lower nutritive value than those in the temperate regions (Akingbade et al., 2004) because native grasses are grown on low fertile soil which is not well suited, for cropping (Humphreys and Partridge, 1995). Herbage yield of the native *Panicum maximum* during the raining season could be somewhat high; the productivity however declines sharply during the dry season when they are dry and coarse with low feeding value (Aderinola, 2007). Sabiiti (1992) noted that during the dry season, forage quality especially of grass declined to three percent crude protein which is below the critical level of seven percent recommended by NRC (Minson, 1982). This limits feed intake and digestibility with subsequent low animal productivity. *Panicum maximum* (Guinea grass) is indigenous to subtropical areas of southern Africa. It is tolerant of shade and fire and produces high yields of palatable fodder during the warm season, but the nutritive value declines rapidly with increasing stages of maturity (Aganga and Tshwenyane, 2004). It has been reported that *Panicum maximum* dry matter yield per cutting may vary from less than 100 to 5000 kg/ha with eight to ten percent crude protein depending on factors such as soil fertility and fertilizers, age of regrowth and season of the year (Perez, 1995). Mineral in forages are dependent upon the interaction of a number of factors including soil, plant species, stage of maturity, yield, pasture management and climate (Poland et al., 2001). Minerals derived from feedstuffs are sometimes insufficient to meet animal requirements, these later exhibiting subclinical symptoms as a result (Serra et al., 1996). The objective of study was to determine the growth performance, chemical and mineral composition *Panicum maximum* fodder irrigated with biodigester slurry.

7.2.2 Materials and methods

7.2.2.1 Site description

The *Panicum maximum* fodder was grown at Maila (22.933°S and 30.467°E) in Elim, 35 km south of Louis Trichardt in the Limpopo province in South Africa. Daily average temperature in summer at both sites ranges between 20 and 22.5ºC in summer 10°C and 15°C in winter. Maximum daily temperatures can reach as high as 35ºC at Maila. Annual average rainfall at Maila is 401 and 600 mm respectively. Rainfall is highly seasonal and 95% of it falls between October and March (Mmarete, 2003). Mid-season dry spell are often during early and intermediate stages of growth (FAO, 2009).

7.2.2.2 Experimental design and procedures

Two treatments of irrigation with slurry and no slurry were used in a complete randomised block design. Six plots of 5 x 4 m were demarcated; two plots per block were replicated three times. Soil samples were taken randomly in each plot using a 20 inch soil auger for mineral analyses. The *Panicum maximum* grass was banded in rows spaced at 75 cm apart and then after germination were thinned to 75 cm within the row. Before irrigation, poultry slurry samples were collected in 50 ml containers for mineral analyses. The irrigation was done weekly using 10 litre watering cans at a rate of 5 litres per row in both treatments.

7.2.2.3 Characteristics of the experimental soil and slurries

The soil was characterised by moderate acidity. Among the macro-nutrients, Calcium level was the highest element in the soil (Ca>Fe>K>Mg>B). Nitrogen was the most abundant mineral in poultry biodigester slurry. The order of mineral content in poultry biodigester slurry was N>K>Mg>P>Cu>P. Micro-nutrients were low (<30 ppm) in both soils and poultry biodigester slurry. However, Fe was the most dominant micronutrient in all cases.

7.2.2.4 Measurements of growth performance

During the experimental period, growth was measured by recording number of tillers per plant, number of leaves per plant, the height of the grass and the longest leaves length (in cm) every two weeks up to 16 weeks when the grasses were harvested.

7.2.2.5 Determination of mineral composition

The Napier fodder leaves samples harvested at the different stages of maturity were dried in an oven at 105°C for 48 hours following procedures by (AOAC, 2000). The minerals in the leaves and extracts from soil and slurry (P, K, Ca, Mg, B, Cu, Fe Mn and Mo) were determined using Inductively Coupled Plasm Optical Emission Spectrometry (ICP-OES) (SOP, 2005) and they were recorded in parts per million.

7.2.2.6 Determination of chemical composition

The *Panicum maximum* leaves samples harvested at different stages of maturity were oven dried to determine moisture and dry matter (DM). The dried leaves samples were then analysed for crude protein (CP). Ash content was then also determined from the dried leaves samples by burning the samples in a muffle furnace at 550°C overnight following procedures by (AOAC, 2000). The organic matter (OM) was obtained by subtracting ash weight from the dried sample. Neutral detergent samples following Goering and Van Soest (1970) procedures.

7.2.2.7 Statistical analysis

1: Statistical Model for growth parameters of *Panicum maximum* fodder at different stages of maturity was as follows:

$Y_{ij} = \mu + T_i + \varepsilon_{ij}$

Where Y^{ij} is the j^{th} sample of the i^{th} treatment

Y_{ij} = Observation, e.g. Tiller number per plant, number of leaves per plant, the height of the grass and the longest leaves length (in cm)

μ = Overall mean

T_i = Effect of the i^{th} treatment (with or without poultry biodigester slurry)

ε_{ij} = Random error

2: Statistical Model for chemical and mineral composition of *Panicum maximum* forages at different stages of maturity was as follows:

$Y_{ijk} = \mu + T_i + S_j + (T \times S)_{ij} + \varepsilon_{ijk}$

Where Yijk is the kth sample of the i^{th} treatment in the j^{th} stage of maturity

Yijk = Observation, e.g. Chemical composition (g/kgDM) and minerals (ppm)

μ = Overall mean

T_i = Effect of the i^{th} treatment (with or without poultry biodigester slurry)

S_j = Effect of the j^{th} stage of maturity

$(T \times S)_{ij}$ = Interaction between treatment and stage of maturity

ε_{ijk} = Random error

7.2.3 Results and discussion

7.2.3.1 Growth performance of Panicum maximum

In this study, results showed that the application of poultry biodigester slurry improved growth of fodder when compared to the no biodigester slurry but statistical it was not significant (P>0.05). Mean plant height, tiller count, number of leaves and longest leaf length of *Panicum maximum* as affected by treatment are shown in Figure 7-9 to Figure 7-12. Effect of the treatment was observed on growth parameters but the differences were not significant (P>0.05). This can be attributed to the fact that poultry biodigester slurry supplied other nutrients, such as calcium and potassium, all of which had an influence on the growth of fodder grass (Chadwick et al., 2000). In addition to supplying nutrients, biodigester slurry affect plant growth indirectly by improving the physical, chemical and biological properties of soil, aeration, pH, cation exchange capacity and microbial activity and diversity (Harris et al., 1997; Cooperband, 2002).

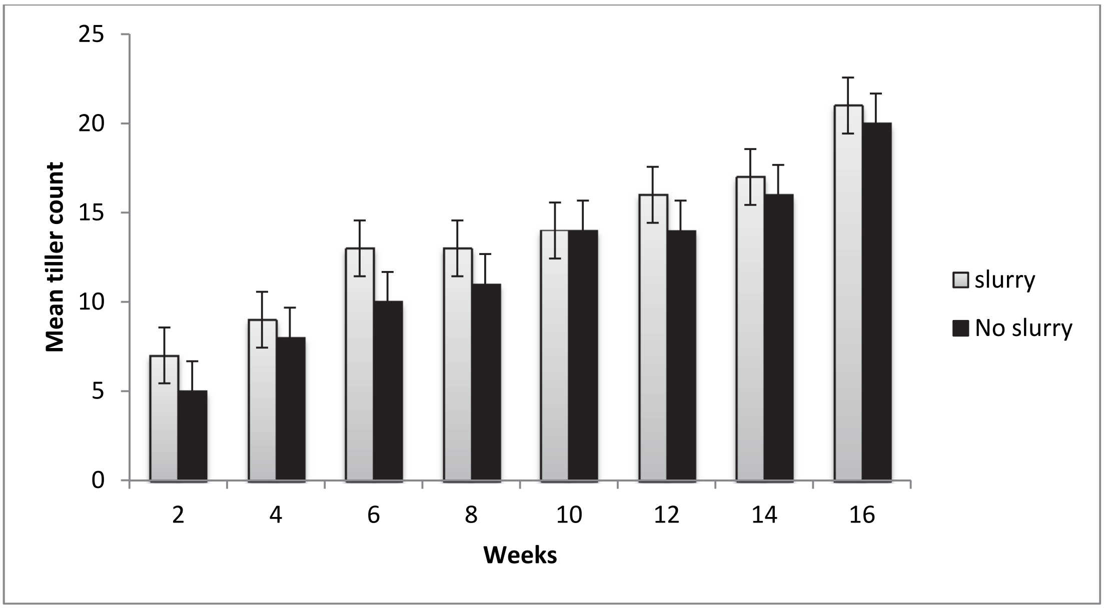


Figure 7-9: Mean tillers of *Panicum maximum* grass under the treatments of poultry biodigester slurry and no biodigester slurry for a period of 16 weeks.

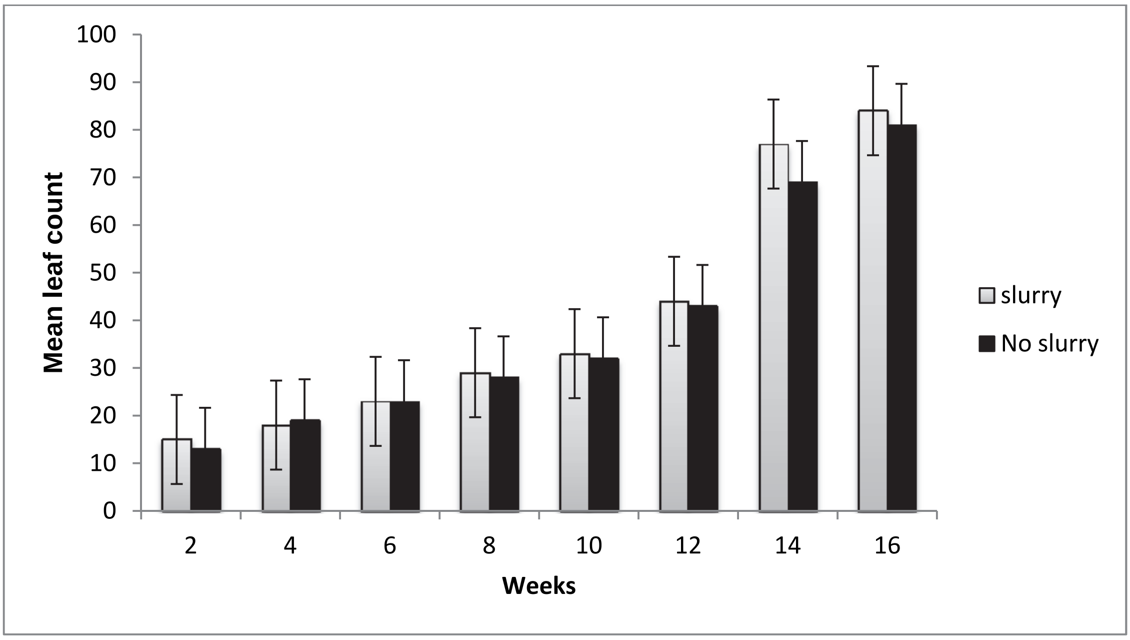


Figure 7-10: Mean number of leaves per plant of *Panicum maximum* grass under the treatments of poultry biodigester slurry and no biodigester slurry for a period of 16 weeks.

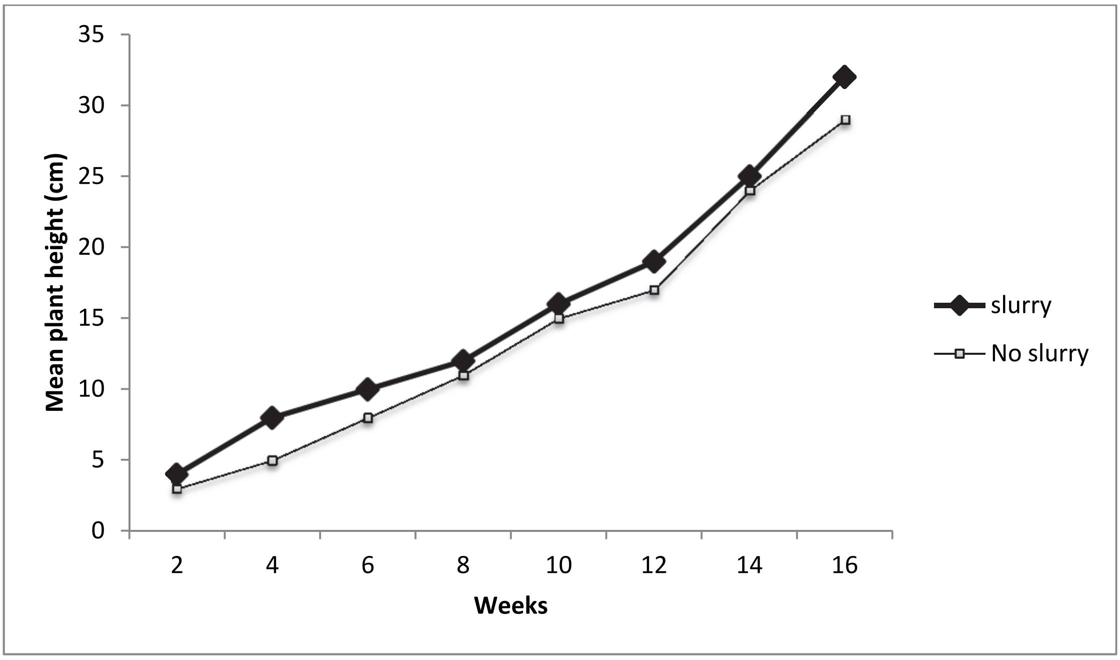


Figure 7-11: Mean plant height of *Panicum maximum* grass under the treatments of poultry biodigester slurry and no biodigester slurry for a period of 16 weeks.

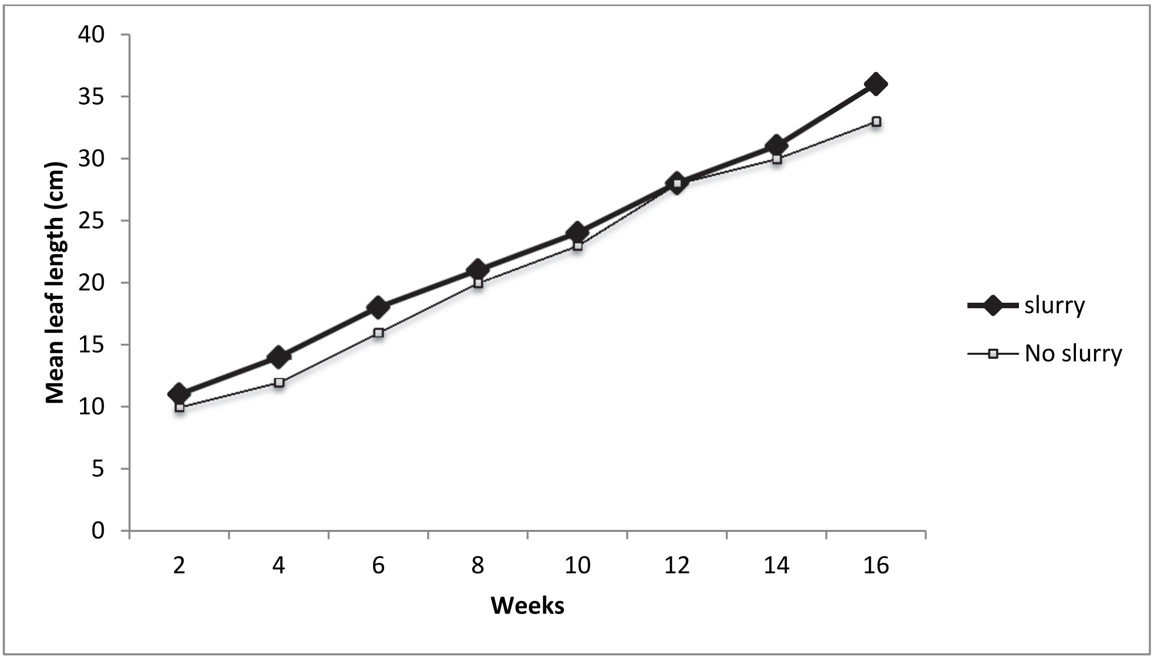


Figure 7-12: Mean leaf length of *Panicum maximum* grass under the treatments of poultry biodigester slurry and no biodigester slurry for a period of 16 weeks.

7.2.3.2 Chemical and mineral composition of Panicum maximum fodder

The plant height and nutritive value of the plant was observed in the study as reported by Shinoda et al. (1999). The chemical and mineral composition of the *panicum maximum* affected by the biodigester slurry is shown by Table 7-6 and Table 7-7. DM increased with maturity until late stages of growth. CP decreased (P>0.05) with maturity. Ash, ADF and NDF increases with maturity though they were not statistically significant (P>0.05). This shows that plant maturity is inversely related to CP content of the forage. Bilal (2009) attests to this by stating that with plant growth, there is a decrease in leaf to stem ratio as well as accelerated rate of accumulation of structural material.

Table 7-6: Chemical composition (g kg^{-1}DM) of *Panicum maximum* grass irrigated with or without poultry biodigester slurry at different growth stages.

Stage of maturity	Treatment	DM (g kg^{-1})	Ash	CP	NDF	ADF
Early stage	Biodigester slurry	290^{b}	110	170^{a}	740	430
	No biodigester slurry	250^{b}	110	170^{a}	740	410
Intermediate stage	Biodigester slurry	290^{b}	110	130^{b}	750	450
	No biodigester slurry	330^{b}	110	120^{b}	770	430
Late stage	Biodigester slurry	550^{a}	100	1004^{c}	790	490
	No biodigester slurry	420^{a}	110	90^{c}	790	420

		Treatment means				
	Biodigester slurry	380	1010	130	760	460
	No biodigester slurry	340	110	130	770	420
	SE	0.04	1.0	1.3	1.4	1.2
		Stage of maturity means				
Early stage		270[b]	110	170[a]	740	420
Intermediate stage		310[b]	110	130[b]	760	440
Late stage		490[a]	100	100[c]	790	460
SE		0.03	1.1	1.1	1.3	1.5
Significance						
Treatment (T)		ns	ns	ns	ns	ns
Stage of maturity (S)		*	ns	***	ns	ns
T x S		ns	ns	ns	ns	ns

*[a b c] Mean values with different superscript letters in the same column differ significantly (P<0.05) SE = Standard error; SM = Stage of maturity; DM = Dry matter; NDF = Neutral detergent fibre; ADF = Acid detergent fibre; CP = Crude protein; ns = Not significant; * = Significant; *** = Strongly significant*

Table 7-7: Mineral composition of *Panicum maximum* grass irrigated with or without poultry biodigester slurry at different growth stages.

Stage of maturity	Treatment	Ca	Mg	P	K	Zn	Cu	Mn	Fe
				%			mg/kg or ppm		
Early stage	Biodigester slurry	0.4	0.2	0.3	2.3	26	6	60[a]	170[a]
	No biodigester slurry	0.4	0.2	0.3	2.5	25	7	66[a]	174[a]
Intermediate stage	Biodigester slurry	0.5	0.3	0.2	2.3	23.7	7.7	65[a]	180.0[a]
	No biodigester slurry	0.4	0.3	0.2	2.2	25.3	5.3	53[a]	168.7[a]
Late stage	Biodigester slurry	0.3	0.4	0.2	2.1	46	5	17[b]	121[b]
	No biodigester slurry	0.3	0.3	0.2	3.1	22	5	19[b]	91[b]

		Treatment means							
	Biodigester slurry	0.4	0.3	0.23	2.2	31.9	6.2	47.3	157
	No biodigester slurry	0.4	0.3	0.23	2.6	24.1	5.8	46	144
	SE	1.3	0.4	0.1	1.1	0.003	0.2	0.3	0.4
		Stage of maturity means							
Early stage		0.4	0.2	0.3	2.4	25.5	6.5	63^{b}	172^{a}
Intermediate stage		0.4	0.3	0.2	2.3	24.5	4.3	59^{b}	116.3^{a}
Late stage		0.3	0.35	0.2	2.6	34	5	18^{b}	106^{b}
SE		1.2	0.3	0.2	1.2	0.03	0.4	0.4	0.5
Significance									
Treatment (T)		ns	ns	ns	ns	ns	ns	ns	ns
Stage of maturity (S)		ns	ns	ns	ns	ns	ns	*	*
T x S		ns	ns	ns	ns	ns	ns	ns	ns

*[a b] Mean values with different superscript letters in the same column differ significantly ($P<0.05$), SE = Standard error, ns = Non significant ($P>0.05$), * = Significant; Phosphorus (P), potassium (K), calcium (Ca), Magnesium (Mg), Sulphur (S), Boron (B), Copper (Cu), Iron (Fe), Manganese (Mn) and Molybdenum (Mo).*

Miles and Manson (2000) also reported that the level of P, K, Ca and Mg in the plant depends upon the availability of these minerals in the soil. Macro-nutrients and micro-nutrients content showed no significant difference for K, B, Cu, Mn and Mo in all the stage of harvest. P, Mg, Ca and Fe showed significant differences between treatments at an early stage. The mineral concentrations were compared to the critical level recommended by McDowell (1985) to cover the requirements of ruminants. Values for Ca, P, K and Mg were on average exceeding the critical level. This is in agreement with Norton (1994) who reported that calcium is rarely limiting in forage diets and with Minson (1990) who stated that it is unlikely for magnesium to be critically low in tropical forages. Though the value of calcium and potassium did not exceed critical value they were low and the season was favourable because of the rain availability. The lower Ca and K content during wet season may be due to the natural dilution process by which dry matter production surpasses mineral uptake (Fleming, 1973 and Masters et al., 1993), while the low P content in the dry season may be due to the low soil P during the season.

7.2.4 Conclusion

Forage chemical composition and mineral concentration varies with stages of maturity. It has been concluded that growth performance of the *Panicum maximum* fodder irrigated with or without poultry biodigester slurry did not differ significantly. The nutritional composition of the fodder at different stages of maturity was not affected by using poultry biodigester slurry as a fertilizer in all the other chemical and mineral composition.

7.3 EFFECT OF ADDITIVES ON SILAGE QUALITY OF BIODIGESTER SLURRY IRRIGATED NAPIER GRASS (*Pennisetum purpureum)*

7.3.1 Introduction

Silage making helps in preserving the nutritional value of fodder and is available for animals even during the dry period when there is a shortage of natural veld supply. Silage has several advantages over hay for the conservation of fodder. However, silage requires a good microbial fermentation process to produce good quality silage. In tropical grass species, desirable anaerobic fermentation is difficult to achieve to ensure a high level of lactic acid production with a low pH as well as low acetic acid and ammonia nitrogen (NH3-N) concentrations (Imura et al., 2001).

There is a possibility of preserving excess green Napier grass in form of silage (Wanyama, 2006). The harvested material can be ensiled at its most nutritious stage (Anonymous, 2004). Harvesting of the forage for ensilage making will ensure high quality regrowth and maximum utilisation of area under production (De Figueiredo, 2000). The silage could supply quality roughages during late dry and early spring periods when the pasture is low in nutritive value, but high in dry matter (DM) concentration (Rethman, 1983; Tainton, 2000).

Conservation of forage would ensure availability of affordable feed for livestock in the smallholder farmers. Therefore, a study was designed to determine the effect of selected carbohydrate additives (sugar, molasses and maize meal) on the fermentative characteristics and chemical composition of Napier grass (*Pennisetum purpureum*) silage ensiled for a period of six weeks.

7.3.2 Materials and methods

7.3.2.1 Site description

The study was carried out at Nthabalala (23.26’S and 29.97’E in Elim, 35 km south of Louis Trichardt in the Makhado Municipality of the Limpopo province in South Africa. Daily average temperature ranges between 20-22.5ºC and 10-15°C in summer and winter respectively. Annual average rainfall is 401 and 600 mm and is highly seasonal with 95% of it falling between October and March (Mmarete, 2003). Mid-season dry spell are often during critical periods of growth (FAO, 2009).

7.3.2.2 Napier grass sampling

Already established Napier grass that was obtained from plots treated with biodigester slurry and no biodigester slurry in the Nthabalala Agricultural cooperative were used in the experiment. The Napier fodder was harvested manually at about 15 cm above the ground using a pruning scissors and the height of the grass ranged between 1.2 to 1.5 meters.

7.3.2.3 Preparation for ensiling

The harvested grass was chopped to about 1.2 to 1.27 cm length (Aganga et al., 2005) using pruning scissors. Four carbohydrate additives namely molasses, brown sugar, maize meal and no additive (control) were added in four replicates. The additives were added at ten percent of the total weight of the chopped material. About 600 g of the chopped grass materials that were mixed thoroughly with the additives was ensiled in 1 l bottle jars with tight fitting lids to prevent oxygen entry. The chopped grass material was weighed before being ensiled then compressed to squeeze to create an anaerobic condition and stored under room conditions.

7.3.2.4 Chemical, mineral and pH analysis

The dry matter (DM) was analysed by drying samples at 105°C in an oven for 48 hours, crude protein (CP) using Kjeldahl method (McDonald et al., 2002); ash by combustion at 550°C overnight and fibre (NDF and ADF) was measured by using a Fibretec hot extractor. The elements (Ca, Mg, Na, K, P, Fe, Cu, Zn, Mn) were determined by Inductively Coupled Plasm Optical Emission Spectrometry (ICP-OES) (SOP, 2005). Samples of 40 g from each Napier grass treatment were soaked in 200 ml of cool distilled water for 12 hours. The mixture was then filtered and the supernatant was used for the determination of the pH and non-structural carbohydrates (NSC) (Mtengeti et al., 2006).

7.3.2.5 Sensory evaluation of the silage

After six weeks sensory evaluations were carried out on the silage (mouldiness, odour, colour and moisture) using the silage physical characteristics rating scale (Table 7-8) as described by Ukanwoko and Igwe (2012) by different evaluators.

Table 7-8: Silage physical characteristics rating scale.

Scale	Mouldiness	Odour	Colour	Moisture
1	Without mouldy	Pleasant	Light greenish brown	No moisture
2	Slightly mouldy	Fairly pleasant	Greenish brown	Slightly moist
3	Average mouldy	Averagely pleasant	Dark greenish brown	Average moist
4	Highly mouldy	Slightly pungent	Brown	Heavily Moist
5	Black spores	Pungent	Dark brown	Completely moist

Source: Ukanwoko and Igwe (2012)

7.3.2.6 Statistical analysis

Statistical Model for quality of Napier silage is as follows:

$Y_{ijk} = \mu + T_i + A_j + (T \times A)_{ij} + \varepsilon_{ijk}$

Where Yijk is the kth sample of the ith treatment in the jth additive in the silage

Yijk = Observation

μ = Overall mean

Ti = Effect of the ith treatment (cattle biodigester slurry and no biodigester slurry)

Aj = Effect of the jth additive

(T x A)ij = Interaction between treatment and additive

Ɛijk = Random error

Tukey's procedure (SAS, 2013) was used to compare treatment means of Napier fodder silage quality irrigated with cattle biodigester slurry.

7.3.3 Results

Table 7-8 shows that there were no significant differences (P>0.05) in DM, Ash, NDF, ADF and pH values between the biodigester slurry and no biodigester slurry freshly Napier ensiled material. Table 7-9 shows no significant difference (P>0.05) for Mg, K, Na, P, Zn, Cu, Mn Fe and Ca between cattle biodigester slurry and no biodigester slurry. The mineral composition of freshly ensiled Napier grass is shown in Table 7-10.

Table 7-11 shows that there were no significant differences (P>0.05) in the physical properties of the silages among different additives. All the silages were without mould except for brown sugar no biodigester slurry Napier grass and maize meal for both with and without biodigester slurry which was slightly mouldy followed by molasses without biodigester slurry which was average mouldy. All the silages had a fairly pleasant odour but maize meal without biodigester slurry had an averagely pleasant odour. The silages were greenish in colour except control with and without biodigester slurry. The silages all of them were slightly moist with maize meal without biodigester slurry scoring the highest.

Table 7-9: The chemical composition (g kg^{-1}DM) of freshly ensiled Napier grass.

Treatment	DM (g kg^{-1})	ASH	CP	ADF	NDF	pH
Biodigester slurry	400	110	110	420	730	6.2
No biodigester slurry	330	110	111	430	740	6.2

DM = Dry matter; NDF = Neutral detergent fibre; ADF = Acid detergent fibre and CP = crude protein.

Table 7-10: The mineral composition of freshly ensiled Napier grass.

Treatment	Ca	Mg	K	Na	P	Zn	Cu	Mn	Fe
			%				mg/kg or ppm		

Biodigester slurry	0.3	0.3	3.1	0.03	0.2	24.0	5.6	17.7	93.3
No biodigester slurry	0.3	0.3	2.9	0.02	0.2	28.7	5.3	26.3	99.7

Phosphorus (P), potassium Mg = Magnesium, (K), Na = Sodium, calcium (Ca), Copper (Cu), Iron (Fe), Manganese (Mn), Zn = Zinc and Molybdenum (Mo).

Table 7-11: The physical characteristics of the Napier silages with different carbohydrate additives.

Properties	Treatment	Additives			
		Control	Sugar	Molasses	Maize
Mouldiness	Biodigester slurry	1.7 ± 1.7	1.7± 0.6	1.7 ± 0.6	2.3 ± 1.2
	No biodigester slurry	1.7 ± 0.6	2.3 ± 0.6	3.3 ± 1.5	2.3 ± 2.3
Odour	Biodigester slurry		1.7 ± 0.6	1.3 ± 0.6	2.0 ± 1.0
	No biodigester slurry		2.0 ± 1.0	2.7 ± 2.1	3.0 ± 1.7
Colour	Biodigester slurry	3.3 ± 0.6	1.0	1.0	1.3
	No biodigester slurry	3.0	1.7 ± 1.2	1.7 ± 1.2	3.0 ± 2.0
Moisture	Biodigester slurry	1.0	1.0 ± 0.6	1.0 ± 0,6	2.0
	No biodigester slurry	1.0	1.3 ± 0.6	1.7 ± 0.6	2.7 ± 1.5

Table 7-12 shows that there were significant differences (P<0.05) in the moisture, DM contents, NH_3 and NSC of the silages for both biodigester slurry and no biodigester slurry. There were no significant differences (P>0.05) in the ash content for both biodigester slurry and no biodigester slurry. There were no significant differences (P>0.05) in ADF; however. There were no significant differences (P>0.05) in NDF of the silages. There were significant differences (P<0.05) in Lactic acid for no biodigester slurry and the order in silage was maize> sugar> molasses = control based on their significant differences.

A significant difference (P<0.05) was observed in the pH values of the different silages. Silage pH decreased (P<0.05) in response to addition of additives to the forage at ensiling, with the lowest (P<0.05) value observed for silage containing brown sugar from the biodigester slurry irrigated Napier grass. Sugar from biodigester slurry irrigated Napier grass, had significantly different (P<0.05) lower pH values compared to the other additives.

Table 7-12: The chemical composition and fermentative quality of the Napier grass silages with different carbohydrate additives.

Additives	Treatment	DM(g kg^{-1})	ASH	CP	NDF	ADF	NH$_3$	LA	NSC	pH
				g kg^{-1}DM			% of silage DM			
Control	Biodigester slurry	250	120	100	690	450	0.5	0.5^{c}	1.9	6.2^{a}
	No biodigester slurry	240	140	110	710	460	0.6	1.0^{c}	0.8	6.2^{a}
Sugar	Biodigester slurry	280	100	90	610	360	0.4	1.8^{b}	6.6	3.5^{c}
	No biodigester slurry	260	110	100	620	390	0.4	2.2^{b}	2.7	4.4^{b}
Molasses	Biodigester slurry	300	100	110	570	360	0.5	1.0^{c}	3.3	4.3^{b}
	No biodigester slurry	310	90	90	460	310	0.5	0.4^{c}	0.5	3.8^{b}
Maize	Biodigester slurry	280	160	110	540	330	0.6	3.5^{a}	2.1	3.9^{b}
	No biodigester slurry	300	140	120	550	330	0.6	4.4^{a}	2.2	4.5^{b}
			Treatment means							
	Biodigester slurry	278	120	103	602	375	0.5	19	3	4.5
	No biodigester slurry	278	120	105	585	373	0.5	20	4	4.7
	SE	1.3	0.4	0.2	1.5	1.1	0.04	0.3	0.7	0.01
			Additive means							
	No additive	245	130	105	70	450	0.5	0.5^{b}	0.5	6.2^{a}
	Brown sugar	270	105	95	615	375	0.4	2^{b}	0.5	4.0^{b}
	Molasses	305	95	100	515	335	0.5	0.7^{c}	0.4	4.1^{b}
	Maize meal	290	150	115	545	330	0.6	4^{a}	0.2	4.2^{b}
	SE	1.4	0.5	0.2	1.6	1.2	0.04	0.3	0.7	0.02
Significance										
Treatment (T)		ns	ns	ns	ns	ns	ns	ns	ns	*
Additive (A)		ns	ns	ns	ns	ns	ns	*	ns	**
T x A		ns	ns	ns	ns	ns	ns	ns	ns	*

*[a b c] Mean values with different superscript letters in the same column differ significantly (P<0.05) SE = Standard error; DM = Dry matter; NDF = Neutral detergent fibre; ADF = Acid detergent fibre; CP = crude protein; NH$_3$ = Ammonia, LA = Lactic Acid, NSC = Non Structural Carbohydrates, ns = not significant; * = Significant; ** = Highly significant, T = treatment*

Table 7-13 shows that silages with maize meal as an additive differed significantly (P<0.05) for Na, Fe and Mn from the other additives. The other nutrients P, K, Mg, Ca, Cu and Zn did not differ significantly (P>0.05).

Table 7-13: The mineral composition of the Napier grass silages with different carbohydrate additives.

Additives	Treatment	P	K	Mg	Ca	Na	Cu	Fe	Mn	Zn
		%					Mg/kg or ppm			
Control	Biodigester slurry	0.2	3.2	0.3	0.3	0.03[b]	5.7	81.3[b]	19.7[b]	41.0
	No biodigester slurry	0.3	3.7	0.3	0.3	0.04[b]	6.0	96.0[b]	23.7[b]	49.6
Sugar	Biodigester slurry	0.2	3.0	0.2	0.2	0.03[b]	4.3	63.0[b]	14.3[b]	18.3
	No biodigester slurry	0.2	2.8	0.2	0.3	0.03[b]	4.7	73.6[b]	17.3[b]	25.6
Molasses	Biodigester slurry	0.2	2.7	0.5	0.3	0.03[b]	5.3	81.3[b]	20.3[b]	24.3
	No biodigester slurry	0.2	2.4	0.2	0.3	0.04[b]	4.7	80.6[b]	18.7[b]	32.6
Maize	Biodigester slurry	0.2	5.0	0.5	0.6	0.09[a]	5.8	127.0[a]	44.5[a]	28.0
	No biodigester slurry	0.2	4.1	0.5	0.6	0.1[a]	5.5	123.5[a]	43.5[a]	33.0
		Treatment means								
	Biodigester slurry	0.2	3.5	0.3	0.4	0.05	5.3	88.2	24.7	28.0
	No biodigester slurry	0.2	3.3	0.3	0.4	0.05	5.2	93.4	25.8	35.2
	SE	0.02	0.3	0.05	0.01	0.003	0.3	4.6	1.3	3.5
		Additive means								
	No additive	0.3	3.5	0.3	0.3	0.035[b]	5.9	88.7[b]	21.7[b]	45.3
	Brown sugar	0.2	2.9	0.2	0.3	0.03[b]	4.5	68.3[b]	15.8[b]	22.0
	Molasses	0.2	2.6	0.4	0.3	0.035[b]	5.0	81.0[b]	19.5[b]	28.5
	Maize meal	0.2	4.6	0.5	0.6	0.095[a]	5.7	125.3[a]	44[a]	30.5
	SE	0.02	0.3	0.06	0.02	0.003	0.4	5.0	1.6	3.8
Significance										
Treatment (T)		ns	ns	ns	ns	ns	ns	ns	ns	ns
Additive (A)		ns	ns	ns	ns	*	ns	*	*	ns
T x A		ns	ns	ns	ns	ns	ns	ns	ns	ns

*[a b] Mean values with different superscript letters in the same column differ significantly (P<0.05), SE = Standard error, ns = Non significant (P>0.05), * = Significant; Phosphorus (P), potassium Mg = Magnesium, (K), Na = Sodium, calcium (Ca), Copper (Cu), Iron (Fe), Manganese (Mn), Zn = Zinc and Molybdenum (Mo)*

7.3.4 Discussion

7.3.4.1 The chemical composition of freshly ensiled Napier grass

In this study, DM was 40 g kg^{-1}DM (biodigester slurry) and 330 g kg^{-1}DM (no biodigester slurry). The grass was harvested at the height of 1.2 to 1.5 meters. Dry matter increase, ADF and NDF increased with maturity. Dry matter content may vary according to variety, stage of fodder maturity, soil topography, season, temperature and climatic conditions. Fodder DM content is also an indicator of its quality (Islam et al*.,* 2009). Significantly, higher DM content of forage crop with application of fermented biodigester slurry was reported by Mikled et al*.,* (1994).

The CP content of Napier grass in this study ranged from 110 g kg^{-1}DM (both biodigester slurry and no biodigester slurry). This range was higher than 90 g kg^{-1}DM CP reported by Mbuthia and Gachuiri (2003) and lower than 120 g kg^{-1}DM CP reported by Bilal (2009) at the same age. The CP contents of 6.36% obtained by Dlamini (2010b) and 6.3% obtained by Kariuki et al*.,* (1999) are lower than that obtained from this study. The variation in CP content in the different studies could be attributed to the fact that the CP content of Napier grass is highly dependent on soil fertility (Kariuki, 1998 as cited by Mbuthia and Gachuiri, 2003).

NDF was 730 g kg^{-1}DM (no biodigester slurry) and 740 g kg^{-1}DM (no biodigester slurry). The digestibility of the forage in the rumen is related to the crude fibre content and the extent to which it is lignified (Van Soest, 1994). ADF obtainable from this study was 420 g kg^{-1}DM (biodigester slurry) and 430 g kg^{-1}DM (no biodigester slurry).

The ash content from this study was 110 g kg^{-1}DM and these value is similar to the value of 110 g kg^{-1}DM from Yang et al*.,* (2004) and one of 110 g kg^{-1}DM obtained by Bilal (2009), and lower than that of 210 g kg^{-1}DM obtained from the study of Kariuki (1999). The pH value of the ensiled material ranged 6.2 (both biodigester slurry and no biodigester slurry).

7.3.4.2 The mineral composition of freshly ensiled Napier grass

According to biphasic model of crop growth response to salinity stress (Munns, 1993), salinity limits plant growth due to osmotic effect at early stage, while at the intermediate stage of maturity it is due to accumulation of toxic ions (ion toxicity). No significant difference for Mg, K, Na, P, Zn, Cu, Mn, Fe and Ca was observed between biodigester slurry and no biodigester slurry Napier grass harvested for ensiling.

7.3.4.3 The physical characteristics of the silages with different carbohydrate additives

There were no significant differences ($P>0.05$) in the physical properties of the silages. All the silages were without mould except for sugar (no biodigester slurry) and maize (for both with and without biodigester slurry) which was slightly mouldy followed by molasses without biodigester slurry which had moderate moulds. The reason for the occurrence of mould in the silages is poor compaction of the forages during ensiling (Mdziniso, 2012). The oxidation of plant sugars by respiratory processes as stated by Jennings (2011), also negatively affects fermentation characteristics in the silo. Jennings et al*.,* (2011) stated that excessive or prolonged respiration can limit the availability of this primary substrate necessary for production of lactic acid, thereby decreasing the potential for a good fermentation. The mouldiness according to Seglar et al., (2003) does not conclude poor fermentation because mould activity begins when the environment exceeds pH of 4.5 and that homofermenters are viable at a pH below 5. Maize (without biodigester slurry) had a slightly pungent odour and was heavily moist, this may be due to the presence of undesirable bacteria called clostridia which grow when the moisture content of the forages is high (Bolsen et.al., 1996).

All the silages had a fairly pleasant odour but silage with maize additive (without biodigester slurry) had a moderate pleasant odour. Jatkauskas and Vrotniakiene (2011) recommend that grasses and legumes should be cut early in the vegetative stage for ensiling. However, the relatively high moisture content at this stage, adversely affects the fermentation quality of the silage (Titterton and Bareeba, 1999).

The silages were greenish in colour except the control (with and without biodigester slurry). A light colour in silage generally indicates good fermentation while a dark colour indicates spoilage (Olorunnisomo and Fayoni, 2012). All silages were slightly moist with maize additive (without biodigester slurry) scoring the highest. The colour of silage is of good quality, since the pH of these silages show that there was adequate fermentation except that of the control which was with a pH of 6.2. Yang et al., (2004) stated that a rapid decrease in pH inhibits Clostridial fermentation and hydrolysis of plant proteins. This is why the other silages with lower pH values had an averagely pleasant odour.

7.3.4.4 Chemical and fermentative quality of Napier grass silage with different additives (carbohydrates sources)

There were no significant differences observed in the DM contents, NH_3 and NSC of the silages (both biodigester slurry and no biodigester slurry) after ensiling the Napier grass for 42 days. The highest DM content was in molasses additive (biodigester slurry) 300 g kg^{-1} which was the same as the DM of 300 g kg^{-1} reported by Tong (2011) while the lowest DM content was in control (biodigester slurry) 240 g kg^{-1} which is lower than the DM of 260 g kg^{-1} reported by Odedire and Babayemi (2008). According to McDonald et al., (1991) as cited by Mtengeti et al., (2006), ensiling forage material with high moisture content can adversely affect fermentation quality of the silage and also lead to high effluent production which drain away silage nutrients. In this study, the DM contents of the silages were lower than those reported earlier on (Tables 4.5 and 4.6) at intermediate growth stage and late growth stage where ensiling was higher (ranging from 330 to 390 g kg^{-1}) in biodigester slurry and no biodigester slurry Napier grass.

There were no significant differences ($P>0.05$) in the CP content of all the silages (both biodigester slurry and no biodigester slurry). However, maize additive silage (no biodigester slurry) was recorded the highest in all the silages with 120 g kg^{-1}DM and molasses additive silage with the lowest 90 g kg^{-1}DM. The CP contents of the silage produced from control, sugar, molasses and maize additives (both biodigester slurry and no biodigester slurry) were above the critical CP level of 80 g kg^{-1}DM (Norton, 1994) acceptable for ruminant performance. The CP content of all the silages in this study fell below that reported by Ojebiyi et al., (2006) (200 g kg^{-1}DM) and Aderinola et al., (2008) (210 g kg^{-1}DM) for fresh *C. Pubescens*. The results of this study were below the CP contents of 250 g kg^{-1}DM and the CP of 230 g kg^{-1}DM reported by Ugwu and Chukwuma (2001). The variation in CP content in the different studies could be attributed to the fact that the CP content of Napier grass is highly dependent on soil fertility (Kariuki, 1998 as cited by Mbuthia and Gachuiri, 2003). The height at which the Napier grass was harvested was 1.2 to 1.5 metres tall and this could have led to the reduced CP content of the Napier grass as the early results proved that stages of maturity have an effect on CP content of the Napier grass. Although biodigester slurry was used to fertilize the soil it did not have an impact at that early growth stage. This study also proved that when a plant continues to grow, the CP content decreases while the crude fibre (NDF and ADF) content increases (Table 7-12). The relationship between plant height and nutritive value of the plant is well observed in the study by Shinoda et al*.,* (1999). Shinoda et al*.,* (1999) found that the CP content in 1 m Napier grass was 120 g kg^{-1}DM.

There were no significant differences (P>0.05) in the ash content of all the silages (both biodigester slurry and no biodigester slurry). However, maize additive silage (biodigester slurry) was significantly different in all the silages with a 160 g kg^{-1}DM and the lowest was observed from sugar with 100 g kg^{-1}DM. The ash contents of the silages (no biodigester slurry) with maize additive of 140 g kg^{-1}DM was the highest and low in molasses additive silage with 90 g kg^{-1}DM. The ash content of the molasses additive (biodigester slurry) and maize additive (no biodigester slurry) is higher than the 120 g kg^{-1}DM reported by Omole et al*.,* (2011). Sugar and molasses additive DM was higher than 50 g kg^{-1}DM reported by Valarini and Possenti (2006) although it is reported as the lowest in this study.

The NDF content reported in this study is lower than the NDF content of 750 g kg^{-1}DM reported by Ansah et al*.,* (2010) for fresh *P. purpureum* but is higher than the NDF content of 650 g kg^{-1}DM reported by Fajemilehin et al*.,* (2008) for fresh *P. maximum*. There were no significant differences (P>0.05) in ADF content. However, the control (biodigester slurry) contained 450 g kg^{-1}DM while sugar (biodigester slurry) had 330 g kg^{-1}DM and for control (no biodigester slurry) contained 460 g kg^{-1}DM as highest and sugar (no biodigester slurry) 31 g kg^{-1}DM had the lowest. Neutral detergent fibre content was significantly different (P<0.05). However, the control (no biodigester slurry) contained significantly higher amounts compared to other silages with 710 g kg^{-1}DM and molasses (no biodigester slurry) contained the lowest with 460 g kg^{-1}DM.

DM below 25% promotes Clostridial activity and DM losses as reported by McDonald et al*.,* (2002). This may cause effluent to occur. On the other hand, if the forage is wilted prior to ensiling, organic acids are lost in the wilting process and this reduces the buffering capacity of the plants which improves the ensiling process. Non-structural carbohydrates (SWC + Starch) are easily lost due to high moisture content. The silages recorded the highest value of 80 g kg^{-1}DM and the lowest is 20 g kg^{-1}DM therefore carbohydrate additives play a crucial role in contributing to successful ensiling and that is when silage material has high water content and low WSC content. This is in agreement with McDonald et al*.,* (2002) who suggested for more WSC in silage material for good fermentation.

Silage NH_3 content is another indication of silage quality. McDonald et al*.,* (2002) reported that well-preserved silage is considered to be good with less than 100 g NH_3-N/kg total nitrogen. In this study, NH_3 content was high for control and maize with 0.6% of silage DM (biodigester slurry) and all the additive treatments were averaged between 0.4 and 0.6% of silage DM. This can be explained by the fact that increasing additive reduced pH in silage product rapidly, resulting in decreasing NH_3 production. NH_3 content and NH_3-N/total nitrogen ratio increased with longer storage time, as occurred in the treatment with additives because of continued deamination. These results are similar to the one's report by Malavanh et al., (2006) on taro silage.

There were significant differences ($P<0.05$) in lactic acid content in silages (no biodigester slurry) and the order was maize>sugar>molasses = control. However, maize additive silage (biodigester slurry) was significantly different from other silages ($P<0.05$).The lactic acid production was significantly affected by the additives (Table 7-12). A higher concentration of lactic acid (in a range of 60 - 100 g kg^{-1}DM) is desirable for good quality silage as this retains more DM and energy and preserves the silage well for a long period of time (Schroeder, 2004; Bethard, 2006). The reduction in lactic acid could be partly due to the degradation of lactic acid to butyric acid, CO_2 and water by the action of *Clostridium tyrobutyricum* and/or yeasts (Oude elferink et al., 2000). However, in this study, lactic acid from control (biodigester slurry and no biodigester slurry) due to 6.2 pH value remained low following the pH level.

The pH for the fresh Napier grass irrigated with biodigester slurry and without biodigester slurry ranged between 6.1 and 6.3. According to (Heinritz, 2011), the pH for fresh forages ranges between 6.5 and 6.0. When fermentation precedes successfully, the pH decreases to 3.8 to 5.0. The decline in pH promotes increased populations of efficient homo-fermentative lactic-acid bacteria. These bacteria reduce silage pH faster and more efficiently by producing predominantly lactic acid (Seglar, 2003). According to Bilal (2009), the optimum pH for high quality silage is between 3.8 and 4.5 where the activity of proteolytic enzymes stops. However, Yunus et al., (2000) states that quality silage has a pH of 4.2 or below. The freshly ensiled samples for both the biodigester slurry and no biodigester slurry irrigated Napier grass pH was 6.2 ($P>0.05$). The pH value of the silages (biodigester slurry) that contained additives ranged between 3.5 and 4.5, (sugar = 3.5, molasses = 4.3 and maize = 3.9) and for the silage (no biodigester slurry) ranged between 3.8 and 4.5 (sugar = 4.4, molasses = 3.8 and maize = 4.5). When sugar, molasses and maize additives are applied at a rate of ten percent, they play a crucial role in reducing pH of ensiled Napier grass silage. The pH value of the control (biodigester slurry and no biodigester slurry) did not change compared to the freshly ensiled Napier grass and was recorded at 6.2. Van Hiep et al., (2008) reported that molasses additive has a clear effect on reducing silage pH values and this is the main factor that contributes to the successful ensiling of foliage. This means sugar, molasses and maize also has the main factor that contributes to the successful ensiling of fodder.

The control did not have any additive and had the pH = 6.2 and Napier grass had a low content of water soluble carbohydrates (Yokota et al., 1991). Therefore, the amount of sugars in the control treatment was low and the fermentation quality of the silage was also low. As additives were added at ten percent of the sample weight, the fermentative quality of the silage improved for both treatments (biodigester slurry and no biodigester slurry) irrigated Napier grass and all the additives had an effect during fermentation in a period of six weeks. The silages with additives recorded high quality silages as stated by Bilal (2009) that high quality silage is between 3.8 and 4.5. However, sugar (biodigester slurry) had a pH of 3.5 it has proven to be excellent than the expected pH values based on the early findings recorded by Bilal (2009).

7.3.4.5 The mineral composition of the Napier grass silages with different carbohydrate additives

The mineral composition of the silages showed no significant difference for K, B, Cu, Fe and Mo. Maize meal differed significantly for Na, Fe and Mn among the other additives. The calcium content of all the silages in this study were (both biodigester slurry and no biodigester slurry) higher than 0.15% reported by Ajayi et al*.,* (2007). Maize differed significantly in mineral Na (both biodigester slurry and no biodigester slurry) content. Maize differed significantly in Mn (no biodigester slurry) and Fe (biodigester slurry) However, Mn biodigester slurry differed significantly in silage (control = molasses)>(sugar = maize).

7.3.5 Conclusions and recommendations

Addition of feed additives to the silage (both biodigester slurry and no biodigester slurry) decreased the pH after 42 days of ensiling. Additives serve as the primary substrates for the lactic acid-producing bacteria that should dominate silage fermentation. The fermentative and nutritional quality of Napier grass silage using additives was excellent. Therefore it was concluded that molasses, brown sugar and maize meal had a positive effect in the fermentation quality and nutritive value of Napier grass silage. Therefore high production in fodder yield silage making by the use of additives must be considered as a key factor for long-term preservation of the fodder grass.

CHAPTER 8: FINANCIAL FEASIBILITY

by Smith M.

8.1 INTRODUCTION

The sustainability of development and conservation initiatives is largely dependent on the degree to which they are deemed financially feasible. This project investigated the potential for a system – including rainwater harvesting and small-scale anaerobic digesters for rural households – to have positive impacts on the livelihoods of rural people and the sustainability of the natural resources surrounding them. This section presents the results of a financial and economic feasibility study.

8.2 SCOPE OF STUDY AND REPORT

This study included three broad research sites in the Eastern Cape, KwaZulu-Natal (KZN) and Limpopo. This report relates predominantly to a comprehensive financial and economic assessment conducted in the Okhombe community, Ward number 7 of the Okhahlamba Local Municipality – one of the areas included in the broad KZN study site. The application of the research to a single community is intentional to gain a comprehensive and accurate representation of the costs and benefits for a community in which a statistically significant sample group can be investigated. In this case the sample group comprised 120 households, representing 10.2 per cent of the total estimated population to be interviewed through a survey process. This sample size (greater than 10 per cent of the study population) ensured an accurate estimate of the survey results for the economic assessment of a specific area. In reality, forms of energy use and energy use profiles tend to differ greatly from one area to the next and therefore it is necessary to conduct area specific sampling in order to gain a representative and accurate assessment.

This report presents the findings of this area specific research, and then considers the potential for extrapolation of the research to the wider areas surrounding the three provincial study sites (see Chapter 9).

8.3 METHODOLOGY

8.3.1 Economic assessment method

Cost-benefit analysis (CBA) was used as an economic assessment tool to identify the financial and economic feasibility of biogas generation and related impacts. CBA is a project appraisal procedure that includes the identification, assessment and valuation of the various costs and benefits involved in a project. CBA is an established and versatile technique, and in terms of sustainable development, it holds great merit as it offers the capacity for all-encompassing feasibility assessment, especially where social and environmental impacts need to be assessed simultaneously. CBA is supported by a substantial body of theoretical and empirical work. The details of CBA and the methods applied in this research can be found in Chapter 4 of Smith (2011).

8.3.2 Survey and survey process

The application of CBA required that a survey be conducted in the study area. The questionnaire was designed to gain information relating to the energy use and energy use patterns of the households, as well as information relating to their water usage and farming practices. Questions were specifically designed to be used, as far as possible, with quantitative economic methods.

The questionnaire was used within individual households and administered as a one-on-one interview. The interviewer was instructed to administer questionnaires to a representative sample of households throughout the defined boundaries of the study area. Selecting differing households is a subjective process and required the interviewer to use intuition in selecting households with varying socio-economic characteristics. The results displayed a representative sample group with the exception of interviewees being predominantly female, a result that was not considered to be of major concern[6].

One hundred and thirty five individuals, each representing different households in the Okhombe area were interviewed. Fifteen interviews were removed from the sample on the basis of unreliable and contradictory data, leaving a sample group of 120 individuals which represented 120 separate households and a collective number of 647 people living in those households (see Figure 8-1 for the location of 119 of these households[7]). The sample group thus represents 10.2% of the estimated population of the study area[8].

8.3.3 Methods of economic valuation

The monetary valuation of individual impacts for cost-benefit analysis is a critical and challenging part of the economic assessment process. Various methods were used in assessing the monetary value of different impacts and the basic method and assumptions are included in APPENDIX V. The details of these methodologies are available in Chapter 4 of Smith (2011).

[6] It is proposed that the bias of female to male interviewees poses no threat to the accuracy of data as the females of rural populations tend to have more experience with the daily chores that require energy use in rural households (Matsika et al, 2011: 11).
[7] Only 119 locations, out of the original 135 households, were recorded due to technical errors.
[8] Okhombe population was estimated at 6 343 people (see *section 2.1.3*).

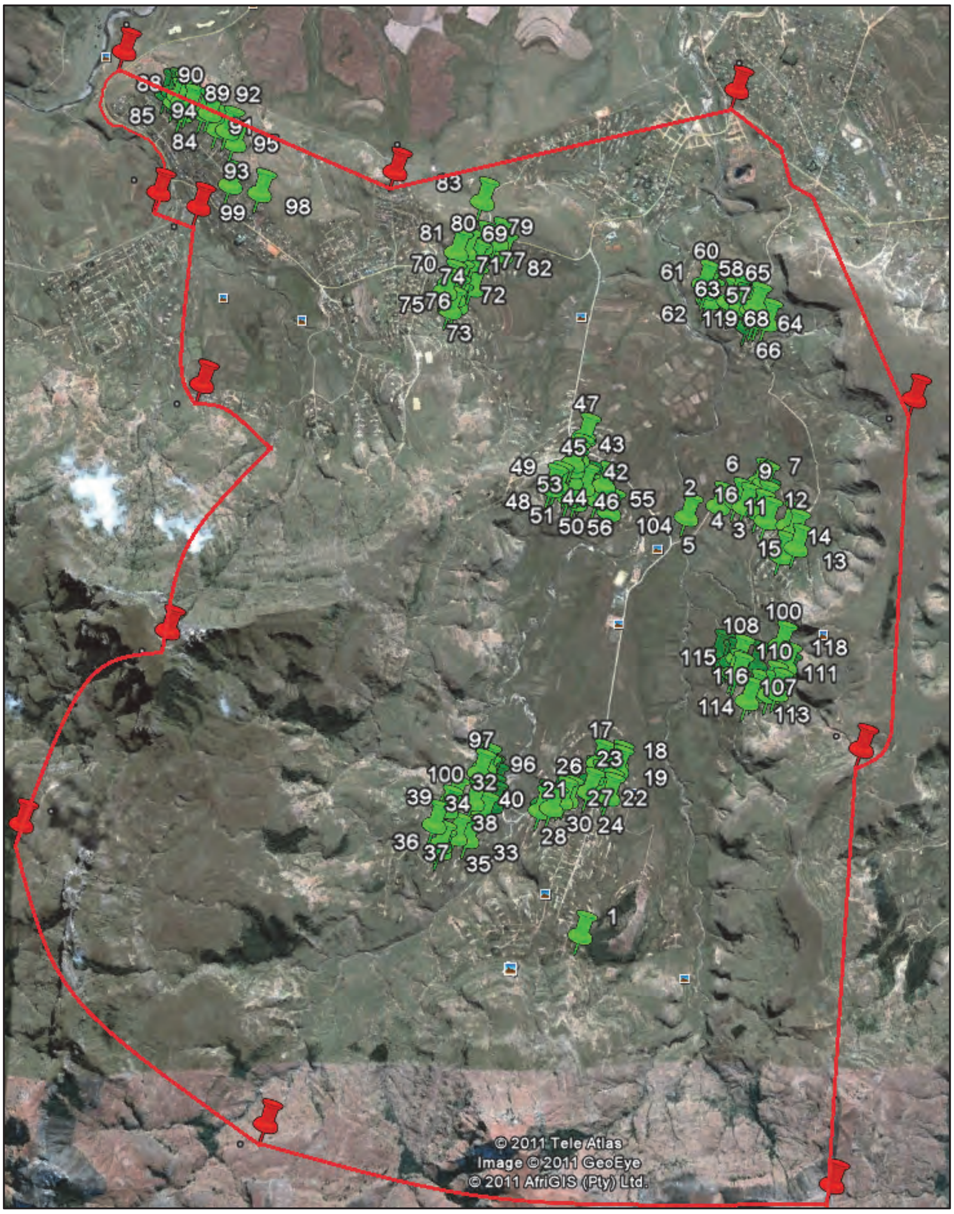


Figure 8-1: Google Earth map representing the study area and sample distribution (Smith, 2011 - adapted from Google Earth imagery dated 08-08-2010, Google©).

8.4 RESULTS

The costs and benefits of a rural household biodigester are presented in this section and rely on the analysis of information sourced from the survey conducted in the study area, existing studies and relevant literature (see baseline survey results in Section 4.2).

8.4.1 Cost Appraisal: Financial Costs

8.4.1.1 Biodigester and installation cost

The cost of a BiogasPro is set at R19 950.00 excluding VAT and economies of scale did not appear possible (at the proposed level of investment) for the reduction of this price. The installation costs of a BiogasPro in the Okhombe area are presented Table 8-1. The price of a single digester installation is 45.1% higher than the unit price of installation when nine biodigesters are installed in the period of one week. The cost factors that drive the price down significantly are the service provider's transport and the assumption that services required to backfill a biodigester hole can be spread across two digesters installed in the course of one day.

The total cost of installing a single biodigester is R15 916.78 and the cost of installing a biodigester where nine biodigesters are installed in the same area within the period of one week is R10 971.56. Although 10 digesters could be installed by the same team within one week, digesters are transported in quantities of nine and thus it is pragmatic to calculate installation costs across nine digesters.

Table 8-1: Rural biodigester installation costs.

INSTALLATION COSTS						
Item	**Quantity**	**Unit**	**Rate**	**Price per digester (single installation) (ZAR)**	**% of single installation price (9 installations)**	**Price per digester (9 installations within one week) (ZAR)**
Civil Construction (Rural area)				**10088.78**		**6425.63**
Hole excavation	116.67	hours	7.04	821.36	100%	821.36
Backfill	1	each	6053.97	6053.97	56%	3363.32
Plumbing (18m from household)	1	each	1869.39	1869.39	100%	1869.39
Transport	262	km	5.13	1344.06	11%	149.34
Accommodation	4	night	500.00	0.00		222.22
Gas installation				**5828.00**		**4545.93**
Ground preparation	1	each	696.54	696.54	56%	386.97
Plumbing (18m from household)	1	each	3787.40	3787.40	100%	3787.40
Transport	262	km	5.13	1344.06	11%	149.34
Accommodation	4	km	500.00	0.00		222.22
Total				**R15 916.78**		**R10 971.56**

Note: It should be noted that the rounded-off figures found in tables do not necessarily sum to the presented totals as figures are not rounded off in the calculation process.

8.4.1.2 Biogas utilising equipment

Based on information from the product supplier, the final cost of a single plate biogas specific burner is R150.00 inclusive of VAT and transport to the site.

8.4.1.3 Cost of transporting biodigester tanks

The cross-subsidised transport model used by the biodigester suppliers allows for transport from Cape Town to any major centre in South Africa at a cost of R2 000.00 excluding VAT, assuming that nine biodigesters are transported on the same truck. Pietermaritzburg is the nearest 'major centre' to Okhombe and therefore the transport of digesters to Okhombe is separated into two sections, from Cape Town to Pietermaritzburg and from Pietermaritzburg to Okhombe. The cost of transporting nine digesters to Pietermaritzburg is R20 520.00 including VAT. The cost of transporting nine biodigesters on a truck to Okhombe is R7 809.00. The total financial cost of transport is thus R28 329.00 (R3 147.67 per digester, assuming nine digesters are transported on a single truck). The supplier's quotation for transport was R3 591.00 cheaper than the next best of two quotations sourced.

In the case of only one digester being installed in the Okhombe area, the cost of transport is assumed to be the cost of transporting one digester on a standard pick-up truck at a cost of R5.13 per km (i.e. the standard cost of travel R4.5 plus VAT). The cost amounts to R16 159.50[9].

8.4.1.4 Cost of training and technical assistance

Based on the service provider's recommended four days of training within the period of one year from installation date, the cost of R3 420.00 per day and the assumption that 9 user households[10] may participate – the cost of training for one installation is R1 520.00. If a single biodigester was installed in the area, the cost of training would be R13 680.00 plus the transport costs of the training consultant, on the assumption that having a locally trained consultant would not be feasible.

8.4.1.5 Total financial cost of a biodigester system

The total financial cost of installing a biodigester system in Okhombe is R38 532.23 and is detailed in Table 8-2. The difference between a single installation and multiple installations (installations in multiples of nine – referred to as multiple installations)[11] is demonstrated. The costs in Table 8-2 are not subject to discounting as they are all experienced in the first year of appraisal.

[9] The distance from Cape Town to Okhombe, and return, is approximately 3 150 km.

[10] Although it was stated by the service provider that 10 users may participate in training, installations are proposed to occur in multiples of 9 due to the transport and installation implications on total cost. Cost is equal to the cost of training for a year (ZAR13 680.00) divided by nine.

[11] Factors of nine biodigesters are required to assure that economies of scale for transportation are realised to the full potential.

Table 8-2: Financial costs of a biodigester installation in Okhombe.

TOTAL FINANCIAL COST		
Item	**Cost (single installation) ZAR**	**Cost (multiple installations) ZAR**
BiogasPro biodigester	22 743.00	22 743.00
Installation cost	15 916.78	10 971.56
Biogas utilising equipment	150.00	150.00
Transport	16 159.50	3 147.67
Maintenance	0.00	0.00
Training	13 680.00	1 520.00
Total*	**R68 649.28**	**R38 532.23**

**No rainwater tank costs are included in this assessment as these are entirely dependent on the chosen site and are not required were sufficient water or waste water is accessible.*

In the CBA, the cost of a biodigester will be considered as a multiple installation option. The cost of a single installation is not cost effective and it will be assumed that all installations referred to in this project are those described as a multiple installation (nine biodigesters transported on one truck and installed in the study area over the period of one working week).

8.4.2 Cost Appraisal: Economic Costs

8.4.2.1 The social cost of transport

The social cost of transport is based on the average fuel economy of a heavy duty vehicle (HDV – as prescribed for transporting nine biodigesters) and the stated CO_2 emissions of various reviewed sources (as presented in appendix IV of Smith (2011: 213)). The standard rate at which CO_2 emissions were valued (the social cost of carbon - SCC), was discussed and chosen on the basis of literature review as presented in appendix IV of Smith (2011: 213). The total travel distance for the transport of goods includes the return trip of transport vehicles and was equal to 3 558 km[12]. Using the methods prescribed in the methodology (section 4.6.2.1, Smith (2011: 97)) and a social cost of carbon (SCC) of R180.81, the total cost of one truck load (nine digesters) is R550.60.

On the assumption that nine biodigesters are transported on the same vehicle, the social cost of transport per biodigester is R61.18.

12 Cape Town (where the BiogasPro is produced) to Pietermaritzburg and return (approx. 3 150 km), Pietermaritzburg to Okhombe and return (approx. 408 km).

8.4.2.2 The economic cost of time taken in feeding a biodigester

The total time spent feeding a biodigester is a composite of time spent collecting 20 litres of water, collecting 20 kg of cow dung and mixing the two before pouring the mix into a biodigester. The respective times are indicated in Table 8-3.

Table 8-3: The total time taken to feed a biodigester per day.

BIODIGESTER FEEDING TIME		
Total time for biodigester feeding	**Minutes/day**	**Hours/day**
Time per 20 l bucket of water	8.11	0.14
Time per 20 kg dung	6.19	0.10
Time to mix and pour into biodigester	10.00	0.17
Total time	**24.30**	**0.40**

The weighted opportunity cost value of time, as calculated in appendix IIX of Smith (2011: 223), is R5.44 per hour. In total, the amount of time spent feeding a biodigester per month is 12.32 hours and amounts to an economic value of R67.04 per month. It should be noted again that the figures displayed in tables do not always correlate with stated totals (in the tables and/or text) as rounding-off is not done until the final result.

8.4.3 Benefit Appraisal: Financial Benefits

8.4.3.1 Avoided fuel costs

The avoided fuel costs are a composite of the purchase of paraffin, purchased firewood, LPG and electricity for cooking activities. The methods of calculation for each energy form are presented in section 4.7.1.1 (Smith, 2011: 100) and calculated in appendix VIII (Smith, 2011: 220). Table 8-4 displays the results of these calculated values.

Purchased firewood was the greatest cost to households (39.3% of total avoided fuel cost), which was not surprising considering that 47.5% of households used firewood as their primary cooking energy. LPG (29.4%) was second and paraffin third (19.5%) in average household expenditure on energy for cooking. Electricity (11.9%) was the lowest contributor to average cooking energy expenditure. The total avoided fuel cost from switching to biogas is R180.57 per month per average household.

Table 8-4: Break down of average household total avoided fuel costs.

TOTAL AVOIDED FUEL COSTS		
Energy form	**Percentage of total cooking energy expenditure**	**Monthly expenditure (ZAR)**
Purchased firewood	39.27%	70.92
Paraffin	19.45%	35.12
LPG	29.42%	53.12
Electricity	11.86%	21.42
Total	**100.00%**	**R180.57**

8.4.3.2 Avoided fertiliser costs

Section 4.2.3 showed that 84.2% of households used fertiliser in their standard farming practice and that 80.0% of households purchased fertilisers. Table 8-5 illustrates that total saving as a result of replacing purchased fertiliser with bioslurry is R30.82 per month for the average sample group household.

Table 8-5: Avoided fertiliser costs.

AVOIDED FERTILISER COST				
	Percentage of households	**Quantity used (kg)**	**Cost per year (ZAR)**	**Cost per month (ZAR)**
Average (for fertiliser buyers)	100.00%	105.05	462.29	38.52
Average (for all households)	80.00%	84.04	R369.84	R30.82

8.4.3.3 Financial benefit of improved health

8.4.3.3.1 Financial value of avoided medical expenditure

The method for calculating avoided medical expenditure, discussed in section 4.7.1.3.1 (Smith, 2011: 107) and presented in appendix IX (Smith, 2011: 225), proved to be unreliable and thus the estimates from existing studies were extrapolated for this report. The average avoided medical expenditure, for a household using biogas, is R167.54 per household per year (calculated using information from Pandey et al., 2007: 74; Renwick et al., 2007: 32). The value proposed by Pandey et al. (2007) was converted to Rand (R) using PPP-adjusted exchange rates and annual average inflation figures (CIC, 2011b; Stats SA, 2011a).

8.4.3.3.2 Financial value of saved lives

The method of calculating avoided deaths is discussed in section 4.7.1.3.3 (Smith, 2011: 110) and applied in appendix IX (Smith, 2011: 225). The average number of avoided deaths in Okhombe was calculated to be 1.3 per annum as a result of reduced IAP from using biogas for cooking (see appendix IX of Smith (2011: 225)). The financial value of a saved life is considered to be R4358.50, which is the equivalent of one third of mean annual income. The potential financial saving for a biogas using household is aggregated at R4.95 per annum per household.

8.4.4 Benefit appraisal: Economic Benefits

8.4.4.1 Economic value of time saving due to using biogas in place of traditional cooking fuels and methods

The total time saving due to cooking with biogas is a composite of time saved on wood collection activities, cooking with traditional solid fuels and cleaning cooking utensils. The methods of calculation for each item of time saving are presented in section 4.7.2.1 (Smith, 2011: 111) and applied in appendix IIX (Smith, 2011: 224). Table 8-6 displays the results of these calculations.

Table 8-6: Total time saving due to biogas use in place of traditional cooking fuels and methods (per household).

TOTAL TIME SAVING		
Time saving activity	**Percentage of total time saved**	**Monthly saving (ZAR)**
Wood collection time (65% reduced)	41.48%	132.21
Cooking activities	42.24%	134.63
Cleaning cooking utensils	16.28%	51.89
TOTAL	100.00%	R318.72

Table 8-6 shows that the monthly time saving of wood collection was 41.5% and cooking activities was 42.2% of the total time saved. The total economic value of time saving, due to using a biodigester system in place of traditional cooking fuels and collection of firewood, is calculated as R318.72 per month.

8.4.4.2 Economic benefit of improved health

8.4.4.2.1 The economic value of health-related productivity gains

Using information from a variety of sources and methods described in section 4.7.2.2.1 of Smith (2011: 114), the total incapacity time attributed to IAP was calculated at 46 867.31 hours per year for the Okhombe community (see appendix IX (Smith, 2011: 225)). On the assumption that using biogas reduces 65% of IAP and using a calculated value of time of R4.75 per hour (see section 4.7.2.2.1 and appendix IIX

(Smith, 2011: 114, 223)), the total health-related productivity gains per biodigester using household was calculated as R123.02 per annum.

8.4.4.2.2 Economic value of saved lives

The value of a statistical life (VOSL) is taken as the value of US$ 2 million[13] used by Renwick et al. (2007:34). The VOSL value is converted into Rand using a calculated PPP-adjusted exchange rate which correlated closely with the PPP-adjusted exchange rate proposed by the Center for International Comparisons of Production, Income and Prices (CIC) in the Penn World Table (appendix IX of Smith, 2011: 225; CIC, 2011b). The economic value of saved lives per biodigester using household is R16 331.21 per year.

8.4.5 Cost-Benefit Analysis (Base Case Results)

Table 8-7 presents the base case scenario results for a biodigester installed in the Okhombe community and evaluated over a period of 15 years. The results represent the valuation of a single biodigester for one user household. The impact appraisal was calculated using community aggregation and thus the results are representative of a biodigester installed in an average household in the Okhombe community. The financial net present value (FNPV) is negative R651.85 and the economic net present value (ENPV) is positive R178 783.29 per household, using a discount rate of six per cent in the CBA. The financial and economic internal rates of return (FIRR and EIRR) are -0.25% and 57.68% respectively. The financial and economic benefit-cost ratios (FBCR and EBCR) are 0.98 and 4.83 respectively. The negative financial indicators (FNPV and FIRR) and FBCR value below unity indicates that a biodigester is not a financially feasible investment in Okhombe. The economic indicators, however, indicate that a biodigester is an economically feasible investment in Okhombe. The details of this analysis and implications are discussed in Section 8.5.

[13] Converted to 2011 ZAR using the calculated PPP-adjusted exchange rate (World Bank, 2011; IMF, 2011b) and annual inflation figures (Stats SA, 2011a).

Table 8-7: Base case cost-benefit analysis for household biodigesters in Okhombe (all data is per household and in 2011 Rand unless otherwise stated).

COST-BENEFIT ANALYSIS at 6% discount rate, 2011 Rand values															
		Year													
Item	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
FINANCIAL COSTS															
BIOGASPRO	22743														
INSTALLATION															
Hole preparation	821.4														
Backfill	3363.3														
Plumbing	1869.4														
Transport	149.3														
Accommodation	222.2														
Ground prep (gas)	387.0														
Plumbing (gas)	3787.4														
Transport (gas)	149.3														
Accommodation (gas)	222.2														
BIOGAS EQUIPMENT	150.0														
DIGESTER TRANSPORT	3147.7														
MAINTENANCE	0.0														
TRAINING	1520.0														
TOTAL	**38532.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

ECONOMIC COST															
SOCIAL COST TRANSPORT	61.2														
BIODIGESTER FEEDING															
Water collection	268.8	252.7	237.5	223.3	209.9	197.3	185.4	174.3	163.9	154.0	144.8	136.1	127.9	120.3	113.0
Dung Collection	204.9	192.6	181.1	170.2	160.0	150.4	141.4	132.9	124.9	117.4	110.4	103.8	97.5	91.7	86.2
Water/dung mix	331.1	311.2	292.5	275.0	258.5	243.0	228.4	214.7	201.8	189.7	178.3	167.6	157.6	148.1	139.2
TOTAL	**866.0**	**756.5**	**711.1**	**668.4**	**628.3**	**590.6**	**555.2**	**521.9**	**490.6**	**461.1**	**433.5**	**407.5**	**383.0**	**360.0**	**338.4**
FINANCIAL BENEFIT															
AVOIDED FUEL COST															
Purchased firewood	780.1	800.0	752.0	706.8	664.4	624.6	587.1	551.9	518.8	487.6	458.4	430.9	405.0	380.7	357.9
Paraffin	386.3	433.0	445.0	457.2	469.8	482.8	496.1	509.8	523.8	538.3	553.1	568.4	584.0	600.1	616.7
Liquefied petroleum gas	584.3	655.0	673.0	691.6	710.6	730.2	750.4	771.0	792.3	814.1	836.6	859.6	883.3	907.7	932.7
Electricity	390.7	409.8	394.1	378.9	364.3	350.3	336.9	323.9	311.5	299.5	288.0	276.9	266.3	256.1	246.2
AVOIDED FERTILISER COST	335.5	344.0	323.4	304.0	285.7	268.6	252.5	237.3	223.1	209.7	197.1	185.3	174.2	163.7	153.9
AVOIDED MEDICAL EXP.	0.0	157.5	148.0	139.2	130.8	123.0	115.6	108.6	102.1	96.0	90.2	84.8	79.7	74.9	70.5
SAVED LIVES	0.0	4.6	4.4	4.1	3.9	3.6	3.4	3.2	3.0	2.8	2.7	2.5	2.4	2.2	2.1
TOTAL	**2476.8**	**2803.9**	**2739.8**	**2681.8**	**2629.7**	**2583.1**	**2541.9**	**2505.8**	**2474.6**	**2448.1**	**2426.1**	**2408.4**	**2394.9**	**2385.5**	**2379.9**
ECONOMIC BENEFIT															
TIME SAVING															
Reduced wood collection	1454.3	1491.3	1401.8	1317.7	1238.6	1164.3	1094.5	1028.8	967.1	909.0	854.5	803.2	755.0	709.7	667.2
Reduced cooking time	2051.7	2103.9	1977.7	1859.0	1747.5	1642.6	1544.1	1451.4	1364.3	1282.5	1205.5	1133.2	1065.2	1001.3	941.2
HEALTH PROD. GAINS	0.0	115.6	108.7	102.2	96.0	90.3	84.9	79.8	75.0	70.5	66.3	62.3	58.5	55.0	51.7

SAVED LIVES	0.0	15351.3	14430.3	13564.4	12750.6	11985.5	11266.4	10590.4	9955.0	9357.7	8796.2	8268.5	7772.4	7306.0	6867.7
TOTAL	**3505.9**	**19062.2**	**17918.4**	**16843.3**	**15832.7**	**14882.8**	**13989.8**	**13150.4**	**12361.4**	**11619.7**	**10922.5**	**10267.2**	**9651.1**	**9072.1**	**8527.7**
GOVERNMENT SUBSIDY															
Capital investment subsidy	0.0														
COST-BENEFIT ANALYSIS															

TOTAL FINANCIAL COST	**R38 532.23**	**TOTAL ECONOMIC COST**	**R46 704.43**
TOTAL FINANCIAL BENEFIT	**R37 880.37**	**TOTAL ECONOMIC BENEFIT**	**R225 487.72**
FINANCIAL NPV	**-R651.85**	**ECONOMIC NPV**	**R178 783.29**
FINANCIAL IRR	**-0.25%**	**ECONOMIC IRR**	**57.68%**
FINANCIAL B/C RATIO	**0.98**	**ECONOMIC B/C RATIO**	**4.83**

8.4.6 Sensitivity Analysis Results

The results of 14 separate sensitivity analyses are presented in Appendix X of Smith (2011: 228). In addition to the separate sensitivity analyses, all conservative, base and optimistic assumptions were combined in sensitivity analyses to gauge the collective result of the varied assumptions. The results of the combined analyses are presented in Table 8-8. The combination of these assumptions was highly amplified and the subsequent result believed to be excessive. The excessive result was also likely to be partially due to deterministically dependent variables resulting in double counting (Florio et al., 2008: 61). It was thus decided that a separate combined sensitivity analysis would be conducted where all *final* variables were increased or decreased by a margin of 20.0%. The conservative sensitivity analysis was conducted by decreasing benefits by 20.0% and increasing costs by 20.0%, and vice versa for the optimistic sensitivity analysis. The results of this 20.0% variation sensitivity analysis are presented in Table 8-8 and Table 8-9.

Table 8-8: Combined sensitivity analysis.

COMBINED SENSITIVITY ANALYSIS (Financial)			
	FNPV	FBCR	FIRR
CONSERVATIVE	-R36 069	0.28	-16.98%
BASE	-R652	0.98	-0.25%
OPTIMISTIC	R58 262.61	3.15	18.83%

COMBINED SENSITIVITY ANALYSIS (Economic)			
	ENPV	EBCR	EIRR
CONSERVATIVE	-R27 507	0.51	-11.81%
BASE	R178 783	4.83	57.68%
OPTIMISTIC	R1 099 821.77	32.37	489.07%

Table 8-9: Combined sensitivity analysis with 20.0% variation.

COMBINED SENSITIVITY ANALYSIS (20.0% VARIATION) (Financial)			
	FNPV	FBCR	FIRR
CONSERVATIVE	-R16 955.05	0.63	-6.19%
BASE	-R652	0.98	-0.25%
OPTIMISTIC	R14 630.67	1.47	6.42%

COMBINED SENSITIVITY ANALYSIS (20.0% VARIATION) (Economic)			
	ENPV	EBCR	EIRR
CONSERVATIVE	R112 378.84	3.03	32.07%
BASE	R178 783	4.83	57.68%
OPTIMISTIC	R233 221.72	7.24	99.84%

The results of the CBA reveal that a biodigester is not a financially feasible investment in Okhombe. The positive ENPV and EIRR as well as an EBCR above unity indicate that a biodigester is a feasible investment on economic grounds. The results of the research study in Okhombe have been presented factually and without analysis, further discussion continues below.

8.5 DISCUSSION

This section of the report includes an analysis of the results found in Smith's (2011) study and an assessment of financial and economic factors for implementation.

8.5.1 Financial and Economic Feasibility as per Smith (2011)

The base case scenario CBA shows that a BiogasPro installed for a single user household in the Okhombe community is not financially feasible. Where a BiogasPro biodigester and a discount rate of six per cent are used in the base case scenario, the financial NPV per household is negative R651.85, the FBCR is 0.98 and the FIRR is negative 0.25%. Table 8-7 illustrates a breakdown of the costs and benefits.

In contrast, the economic results presented a significantly feasible result. Under the same base case assumptions; the economic NPV is R178 783.29, the EBCR is 4.83 and the EIRR is 57.68%. The results of the economic analysis (Table 8-7) displayed a significantly feasible outcome in contrast to a non-feasible financial analysis result.

Smith (2011) concluded that a household biodigester, installed in the Okhombe community, is not a financially feasible investment. For financial feasibility to be achieved, significant capital cost reductions would be required. While the results indicate non-feasibility with respect to financial outcomes, it was resoundingly clear that a household biodigester, installed in the Okhombe community, would be an economically beneficial investment. The significant economic benefit provided a convincing argument for the social value of biodigester systems in rural households. The final remark was made that, "considering a governmental imperative to uplift the social wellbeing of its people, the economic result is compelling evidence for government support to make financial desirability of biodigester systems a reality".

8.5.1.1 Meeting the Energy Demands of Rural Households

8.5.1.1.1 Assumption of the study

Experts and literature were consulted prior to conducting the Okhombe study and it was concluded that a BiogasPro would produce between 1.2 and 1.9 hours of burn time on a large single-plate gas burner, which was sufficient energy to cook three meals for a five to six person household per day (AGAMA Energy, 2010; Guidotti, 2002: 12). Consultation of literature and assumptions were required as the study biodigesters had not been active for a sufficient period of time and information was therefore unavailable.

8.5.1.1.2 Empirical findings

The project team has been met with mixed findings and information relating to the study biodigesters' abilities to meet household's needs.

On the 6th of March 2012 a group of 14 met at Mrs. Khumalo's house in Obonjaneni (one of the study site households in the KZN province). The project team, led by Dr Monique Salomon conducted a training workshop where pressure cookers and a wonder bag[14] were used to prepare a meal for the entire team (14 members) using only the biogas from the biodigester. Even though Mrs. Khumalo reported using the gas during that morning, there was sufficient gas to prepare the meal as well as the preparation of coffee at an earlier stage during the site visit. Discussions with community members and other sources of information have supported the theory that rural people in KZN tend to prepare only two cooked meals on an average day. This evidence supports the finding that there is sufficient gas produced to meet the cooking demands of the average rural household (approximately five to six people in the Okhombe community) when efficient cooking methods, as used on this site visit, are practised.

This said, it was also noted that pilot households stated they did not have sufficient gas for their cooking needs and were often required to use alternatives simultaneously (see 4.5 QUALITATIVE SURVEYS AT PILOT HOUSEHOLDS).

The Okhombe study (Smith, 2011) made consideration of the fact that only 65% of fuelwood usage would be reduced, based on the consultation of literature and the observed importance of wood fires in rural households. Although this assumption does not appear to be unrealistic, and the use of wood could be reduced even further with suitable education, evidence from the study households in KZN has pointed to the fact that household members continue to use fuelwood fires, regardless of the quantity of gas available to them. Study participants have noted that the single plate gas burner (as used in the project) is a limitation to their cooking needs and this is one of the reasons they continue to use a fire.

One of the other concerns is the significantly reduced production of gas during cold periods (see Figure 8-2 as an example from one of the KZN study households).

[14] http://nb-wonderbag.com/.

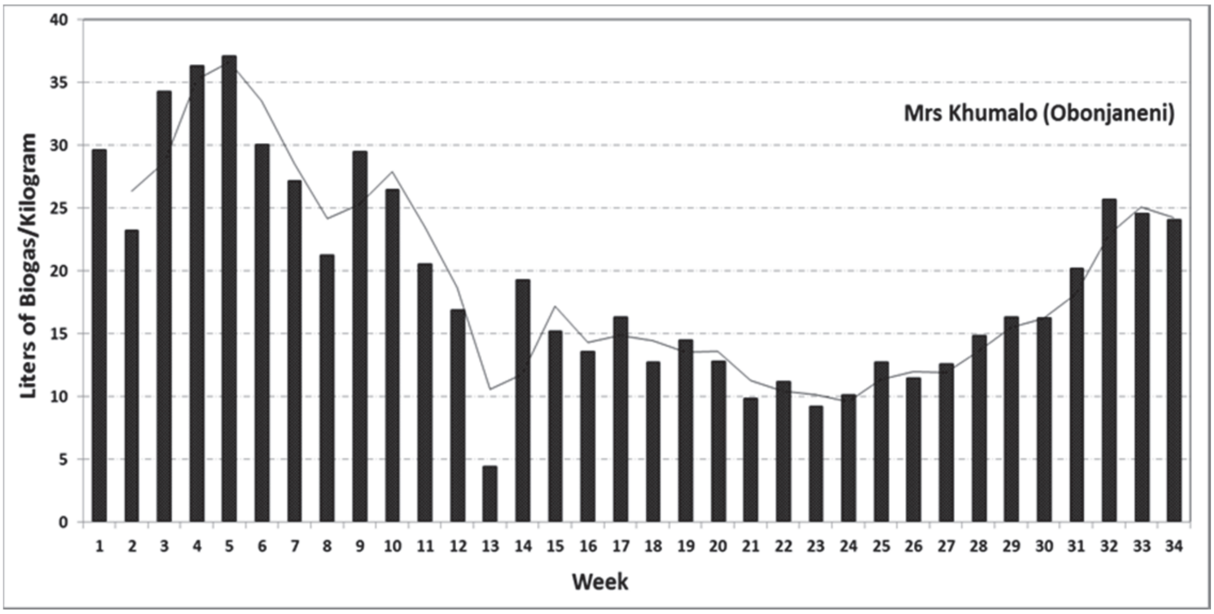


Figure 8-2: Graph showing biogas produced per kilogram of feedstock at Obonjaneni (KZN) study site. The decline in gas noted from week 10 to 31 coincides with colder winter months.

Excluding the recent findings of lower biogas production in winter months, this report's findings supports the theory that a well-run[15] biodigester should provide sufficient biogas for the cooking requirements of an average rural household when used in conjunction with efficient cooking methods[16]. The project team will, however, endeavour to interrogate this finding at a later period when households have used the biodigesters for as sufficient period of time.

8.5.2 Further Considerations for Financial and Economic Assessment

8.5.2.1 The use of alternative technologies

Although there are certain reliability benefits related to the use of the BiogasPro6 biodigester, it is clearly an expensive option. When comparing existing studies to that of the financial analysis conducted in this study it became apparent that the most notable difference in these project appraisals is in the capital cost of the biodigester and its installation. The cost of a 6 m^3 biogas plant in Austin and Blignaut's (2008: 27) study was R8 050.00 (2008 value) and the average capital cost for the Ethiopian area, the highest FIRR in Renwick et al. (2007: 47) study, is R5 402.18 (2007 value). These costs are extremely low in contrast to a biodigester cost of R22 743.00 and a total financial cost of R38 532.20 in the current study, which predictably produce a negative FIRR of -0.25%. If the biodigester and installation costs in the current study were assumed to be (R9405. 92[17]) with all other costs remaining the same, the FIRR would be 17.93%.

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15 A biodigester that is consistently fed 20 kg of fresh cow manure and 20 litres of water on a daily basis and not subjected to any chemicals which are damaging to anaerobic digestion microbials.
16 The use of a pressure cooker and/or wonder bag and/or other methods of efficient cooking.
17 The cost of a biogas plant used in the Austin and Blignaut (2008) study, adjusted for annual inflation (Stats SA, 2011a). Transport and accommodation of service providers are kept unchanged, as is the cost of gas plumbing.

This result displays the significance of capital costs and raises the need to identify other reliable technologies available in South Africa. To date, only the "Little Green Monster" has been identified as a potential alternative, but the project team has unfortunately not had the time or resources to install and investigate this technology (see Section 2.2.6).

The BiogasPro6 used in this feasibility analysis is a complete, prefabricated tank. The WRC Project team also installed Agama Smart Top biodigesters (an Agama BiogasPro6 top section, with a brick and mortar constructed bottom section) and another prefabricated biodigester made by an Indian manufacture (which has proved to produce insufficient levels of biogas, see Figure 8-3). The benefit of the Smart Top system, and other on-site constructed digesters is that they require manual labour. Although these digesters tend not to be as reliable, or have the longevity of a prefabricated tank (BiogasPro), they generate employment in the construction phase – a significant point of consideration in South Africa, where unemployment poses a major problem.

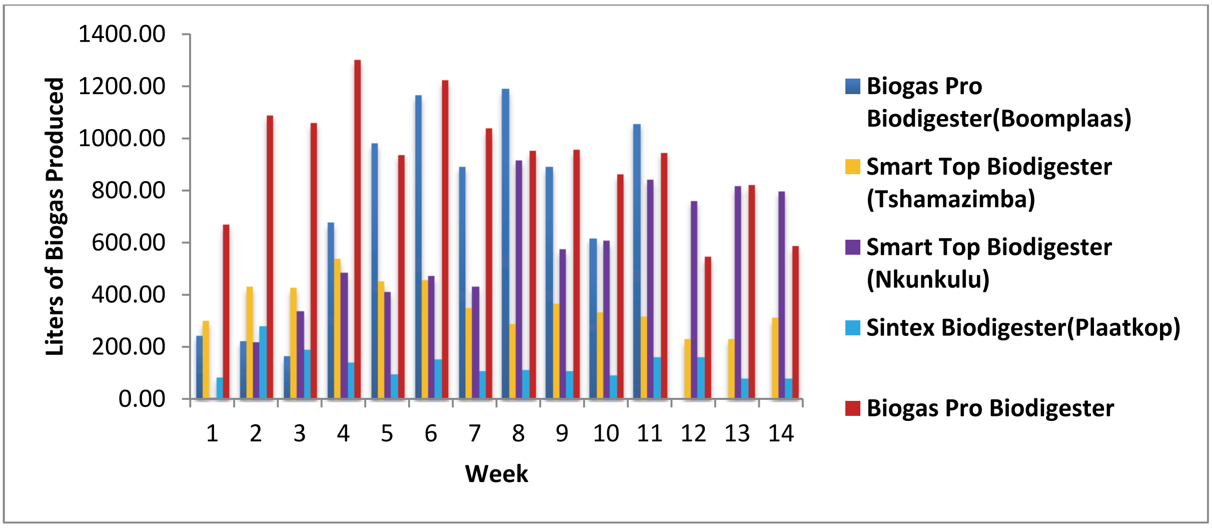


Figure 8-3: Biogas production (usage)[18] by digester at EC study sites.

8.5.2.2 Inclusion of environmental benefits

Environmental benefits were excluded from the financial and economic study. Although all these impacts were noted, it proved difficult and unreliable, given the availability of data at the time, to accurately quantify the environmental benefits relating to a biodigester system.

Some of the potential environmental benefits include a reduction of greenhouse gas emissions, reduced deforestation and reduced erosion as a result of fodder production and changed cattle keeping practices. The environmental benefits stated here are distinctly site specific and would therefore need to be

[18] Only usage data could be captured, as gas metering could only be done on a usage metering system.

assessed in each respective area. In addition, the assessment of reduced deforestation and its environmental benefits, for example, is an extremely challenging task. In this example, it is noted that wood collected in the Okhombe area is largely from alien species and few indigenous trees. The removal of alien trees (i.e. deforestation) could actually be considered a benefit in terms of water resource use, while the removal of both alien and indigenous trees would have negative impacts on carbon sequestration. Further to the challenges of quantifying these impacts, assigning a monetary value to their occurrence is also a technical and subjective process.

Regardless of these concerns, it is suggested that environmental impacts be considered when conducting economic assessments for large-scale biodigester rollouts.

8.6 CONCLUSION

A financial and economic feasibility study was conducted for the Okhombe community in the greater KwaZulu-Natal study site. The results of this study were presented with consideration of current challenges and extrapolations being deliberated. The findings of this reported are summarised as:

- The Okhombe study (Smith, 2011) identified that a BiogasPro biodigester installed at households in the Okhombe community was not a financially feasible investment; however, significant economic feasibility was identified.
- The high level of economic benefit identified in the Okhombe study revealed the significant social (welfare) benefits relating to biodigesters, and it was suggested that government subsidisation should be considered in an effort to create financial incentive for households to invest in the technology, thereby securing the economic benefits for their households and society as a whole.
- Scaling-up and extrapolating findings from the Okhombe study was concluded as being difficult and impractical. Benefits and costs were noted as being highly site specific, and therefore it was only possible to give rough examples of scaled-up rollout scenarios. Data from the study sites, and national feasibility literature suggested that there were thousands of households who were technically suitable for biodigester use, and it was therefore identified that a large-scale biodigester rollout programme would have definite potential in South Africa.
- It was noted that the project team needed to extend the investigation of whether the biodigester systems were meeting the energy demands of the study households. Findings have, thus far, pointed to the belief that there is sufficient biogas for the average household's cooking requirements, if the gas is used in conjunction with efficient cooking methods. It was noted that recent information has shown a decline of gas production during winter, an element that requires further investigation and one that would rebut the finding of sufficient biogas for cooking.
- A number of challenges to an effective large-scale biodigester rollout programme were identified. Most notably, the importance of the training and education required for effective use of the technology, and the need for technical assistance in the event of failing technologies.
- Finally, the use of alternative technologies, inclusion of environmental benefits, and a systems approach to feasibility assessment were discussed and noted as potentially adding to the financial and economic benefit of a biodigester system.

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS FOR UPSCALING TO A GREEN VILLAGE

by Smith M, Everson T.

The 'Food-Energy-Water Nexus' has become a central theme in sustainable development as the interconnections between these three vital commodities is increasingly recognised (WWF, 2014). In the past, research on the production of these three goods and services has largely been in isolation. The recognition of the fact that food, energy and water production and consumption are strongly interlinked has given rise to a growing need for integrated natural resource management. Integrated natural resource management has been defined by Campbell et al. (2001) as a "process of incorporating the multiple aspects of natural resource use (be they bio-physical, socio-political or economic) into a system of sustainable management to meet the production goals of farmers and other direct users (food security, profitability, risk aversion) as well as the goals of the wider community (poverty alleviation, welfare of future generations, environmental conservation".

The WRC has formally incorporated integrated natural resource management into its strategic plan through the initiation of its Green Village (GV) concept, one of the five lighthouse programs aimed at integrating and implementing knowledge in relatively complex pilot studies. A GV is a village in which a healthy ecological infrastructure is maintained which supports sustainable and productive agriculture, utilizes renewable energy and where communities are largely self-sufficient with the ability to improve their livelihoods. The goal of the GV program is to demonstrate that integrated research programs are better able to improve the livelihoods of poor rural communities. The current pilot study examined various "green" options for sustainable development at the household scale to determine the potential for implementation at a GV scale.

This chapter presents some of the findings, relative to the GV concept, that were identified through the research of this report.

9.1 BIOGAS AWARENESS

In each of the three provinces, KwaZulu-Natal (KZN), Eastern Cape (EC) and Limpopo, the project team sought to identify individuals and groups with an interest in the four main components of the project (water, food, fodder and energy). These stakeholders then engaged in the implementation and research aspects of the project. A key factor in the success of this process was the existing community links which the project team (University of KwaZulu-Natal, University of Rhodes and University of Venda) had established prior to the commencement of the project.

Surveys were conducted in the three provinces to identify the level of awareness and acceptability of biodigesters and biogas use for personal households. From the surveys it was apparent that biogas technology was perceived to be a potential solution to energy provision. Households claimed that the ever increasing price of electricity was prohibitive to its use. Although firewood energy was still widely used, there was a need for biogas as it was a clean energy which saved time and money.

9.2 HOUSEHOLD INVESTMENT AND GOVERNMENT SUBSIDISATION

Based on the findings of the CBA presented in Chapter 8: a biodigester is not a financially feasible investment for a rural household. Further to this, the direct financial benefits accruing to user households are exaggerated in the finding of a financial IRR of -0.25% as avoided medical costs are considered a benefit to society (a reduction in government health care costs) and not a financial benefit to the household itself. If these benefits are removed from the analysis of household financial benefits, the FIRR is -0.84%.

Although a substantial economic IRR represents a desirable investment in terms of social welfare benefits, it is unlikely that a rural household would invest in a biodigester and suffer a potential financial loss. It is also not likely, even considering the potential health-benefit and time saving implications of a biodigester, that a household would make this investment. Based on a loan at South African prime interest rate of 9.0% (as of December 2011), a zero per cent deposit and various payback periods expressed in Table 9-1, it is clear that even over a 15 year repayment period the monthly instalments would be well in excess of an average household's potential monthly savings of R211.39[19] in 2011 (saving on avoided fuel and fertiliser costs[20]).

Table 9-1: Monthly repayments in Rand.

MONTHLY REPAYMENTS IN RAND		
Capital investment	**R38 532.23**	**Interest rate 9.0%**
Terms in months	**Monthly repayment**	**Total repayment**
60	R799.87	R47 991.94
120	R488.11	R58 573.20
180	R390.82	R70 347.52

As proposed, the case for a government subsidy is compelling given the significant economic and societal welfare benefit shown by the economic results. It is suggested that government subsidisation, at least to a point where financial desirability becomes evident, would be worthy of consideration. Financial desirability would be at a point where the financial IRR of household benefits (as discussed above) is in excess of the rate of interest of a loan.

[19] The value of life is also omitted from this discussion for logical reasons. It is expected that the value of life as a probability of death and expenditure on funeral costs would be difficult to explain to rural households.
[20] This value is an undiscounted value and represents average household expenditure on cooking energy.

Calculations reveal that a capital subsidy of R16 953.79 would be required in order to produce a household specific financial IRR of 9.00%. This amount would thus, under the base case scenario, be the minimum capital subsidy required to make a biodigester financially feasible for the average household in Okhombe. Table 9-2 displays the effect of various subsidy levels on the FIRR and monthly repayment.

Table 9-2: Effects of various levels of government subsidy on monthly repayment and FIRR.

EFFECTS OF VARIOUS GOVERNMENT SUBSIDIES ON MONTHLY REPAYMENT AND FIRR						
Capital investment	**R38 532.23**		**Interest rate**	**9.0%**		
Terms in months	**R10 000 Subsidy**		**R16 593.79 Subsidy**		**R20 000 Subsidy**	
	FIRR	**Monthly Repayment**	**FIRR**	**Monthly Repayment**	**FIRR**	**Monthly Repayment**
180	3.79%	R289.39	9.00%	R218.86	12.35%	R187.97

Based on the information provided in Table 9-2, the recommendation for a subsidy of R20 000.00 is made. A subsidy of this amount would result in an FIRR of 12.35% and would provide a financial incentive for the average household to invest in a biodigester system repaid over a period of 15 years (180 months). A household's investment in a biodigester system would consequently secure the societal welfare gains inherent in the substantial economic benefit. At an interest rate of 9%, the repayment of this investment would be R187.97 per month, which is less than the monthly monetary saving in avoided fuel and fertiliser costs, and would thus be a desirable investment.

9.3 SCALING-UP: HYPOTHETICAL EXAMPLES OF BIODIGESTER ROLLOUTS

There is compelling evidence for a biodigester to be a valuable asset to the progress of sustainable development in rural areas. Biodigesters have the ability to contribute to the energy needs of rural people as well as the potential to aid in food security development and natural resource management. If a wide scale rollout of biodigesters to suitable households became a reality, it is probable that the cumulative impacts would result in worthy benefit to society and the environment.

Modelling a scaled-up scenario, where biodigesters are rolled-out to a village and/or entire rural community in a local municipality is, however, a challenging task from a financial and economic perspective. As has been seen in the discussion of the Okhombe study results, the financial returns on investment are negative and marginal in the case of a government subsidy. In addition to this, it is clear that the energy use practices and therefore financial/economic impacts are highly site specific. It is therefore not feasible, at the current level of research, to present an accurate feasibility study for the rollout of biodigesters at larger scales of implementation. It is, however, possible to present some hypothetical models, displaying the potential for rollout scenarios based on stated assumptions.

One such model considers the rollout of biodigesters to the Okhombe community which consists of an estimated 1 160 households and 6 343 people. In this rural development project model, it is hypothesised that biodigesters are to be installed in all suitable households in Okhombe (411 suitable households – see section 4.2.4) and to all suitable households in the local municipality region (Okhahlamba Local Municipality). In this model, the assumption is made that sufficient installations in the area are possible to reduce biodigester and installation costs dramatically; however, it should be noted that the model is generated with respect to the Okhombe community specifically[21].

Table 9-3: Model of a hypothesised rollout of biodigester installations to all suitable households in Okhombe.

MODEL OF HYPOTHESISED ROLLOUT					
Number of installations	**411**	**Government subsidy**	**R5000**	**Interest rate**	**9.00%**
Cost of single installation	R23 119.34				
FINANCIAL NPV	R8 121 786.24	ECONOMIC NPV	R81 869 629.40		
FINANCIAL IRR	13.93%	ECONOMIC IRR	156.87%		
FINANCIAL BCR	2.09	ECONOMIC BCR	8.58		
	Monthly terms of repayment	**Monthly repayment**			
	180	R183.78			

In the CBA model presented in Table 9-3, the unproven assumption is made that *all* financial costs are reduced by 40% due to economies of scale present in a large scale rollout of biodigester installation in a localised area. It is assumed that there is a capital subsidy of R5000.00, the interest rate on the investment repayment is 9.00% per annum, and the repayment period is 15 years (180 months).

Under these assumptions, the financial and economic NPVs of the project are approximately R8.1 million and R81.9 million respectively. The economic and financial IRRs are 13.93% and 156.87%, and the BCRs are 2.09 and 8.58 respectively. The calculation of these results does not include any environmental benefits and it is believed that these would contribute significantly to the calculated economic returns.

The presented model is one based on assumption and extrapolation from the findings in the study of the Okhombe population. Under these methods, it is clear that there is great potential for a rural development project of this magnitude to contribute to the sustainable development needs of rural areas like that of Okhombe. Further research into the potential for large scale biodigester projects is required to clarify the potential of economies of scale to reduce financial costs and the potential for biodigesters to have a quantifiable impact on the environment.

21 The Okhombe community is not expected to be large enough to result in economies of scale alone, and therefore the assumption goes further – that this rollout includes more biodigesters in other neighbouring villages.

9.3.1 Scaling-up to a local municipality level

Again, using the KZN study area as a hypothetical case study, the technical potential for scaling-up the rollout of biodigester technology for application in the Okhahlamba Local Municipality (OLM) is feasible. Although a detailed financial and economic feasibility assessment has not been conducted for this scenario, the socio-economic profile of the OLM is similar to that of the Okhombe community, and therefore presents a likely case for a greater number of suitable households for biodigester installation and use.

Based on Census 2011 data and 5.4 people per household (as found in Smith, 2011: 127), the population of the OLM is 132 100 people and therefore approximately 24 400 households (Stats SA, 2012). Considering that the OLM is only "predominantly rural", including a number of small urban settlements, as opposed to Okhombe which is exclusively rural, it would be fair to assume that there would be less households (in percentage terms) in the greater area that met the strict suitability requirements for a biodigester as used in Smith (2011: 20). Considering that 35% of the sample population in Okhombe met the suitability requirements, it could be conservatively assumed that as much as 10% of the OLM households might meet these criteria and would thus be suitable for the installation and use of a biodigester. Under these assumptions, 2 440 biodigesters could be installed at households in the OLM alone, and would potentially make significant contributions to the welfare of rural people in the area. It could be presupposed further that the use of biogas in place of electricity and/or wood for cooking could result in slightly reduced pressure on the local electrical grid and reduction of deforestation in the area respectively. In addition to this, the complete system including the biodigester, rainwater harvesting, and fodder and food production could result in reduced pressures on the grasslands in the area.

9.3.2 National-scale rollout

The research included in this project, and specifically the research conducted at Okhombe, does not lend itself easily to national-scale extrapolation. Austin and Blignaut (2008) did, however, conduct a feasibility study for a national rollout of biodigesters and this information provides interesting insight to the potential that exists.

Based on similar assumptions and suitability (or technical viability) criteria as used in Smith (2011), Austin and Blignaut (2008) identified that 310 000 South African rural households were technically viable for installation of a biodigester. The study also identified significant financial and economic benefits and suggested a five-year installation programme for initial investment in rural areas.

The five-year programme proposed the installation of biodigesters at 12 000 households in the Eastern Cape and KZN, with a model requiring households to pay 10% of their monthly income for five years and 10% of the upfront capital cost. The proposed programme was expected to cost approximately US$ 17.5 million over the five year period.

The potential for the success of this project is not interrogated in this report, however, it is noted that this programme is yet to be initiated – possibly due to the absence of suitable investors, lack of government support and/or the difficulty of large scale implementation.

9.4 POTENTIAL CHALLENGES TO RURAL BIODIGESTER ROLLOUT

The realisation of financial and economic benefits relating to a biodigester, and therefore the actual success of a biodigester at a rural household is dependent on a large number of factors. The financial and economic feasibility will only be sustainable if it takes into consideration the incentives (of at least secure land use rights) and management of the resource (dependent on individual and group responsibilities) (Backeberg, 2009). In natural resource management, it is particularly important at the community level, to have appropriate incentives, as natural resources are linked to local community's livelihoods (Emerton, 1999). In particular, there is a need to develop guidelines for determining incentives that are specifically suitable for communal land owners, or rural communities. Schultz (1979) stated that investments that include improvements in human skills are a key factor in improving the well-being of poor people. Intangible incentives (e.g. environmental education, skills transfer, human development and empowerment) form a critical part of biogas implementation. These include knowledge dissemination through farmer's days, workshops, presentations, cooking demonstrations and cross visits to existing biogas digesters. Tangible incentives are generally associated with material gain (Hares and Royle, 1994). In this project the production of biogas as an energy source and the production of bioslurry as a fertilizer are key tangible incentives. The implementation of biogas will only be sustainable if there is a combination of tangible and intangible incentives.

A large scale rollout of biodigesters to suitable rural households poses many challenges for implementing parties. This report has identified a number of key challenges to the success of a large scale rollout, and although these challenges are not insurmountable, they should be monitored closely when considering single and multiple biodigester installations.

9.4.1 Capital cost/financing mechanisms:

The greatest barrier to entry for rural biogas is the capital cost of a system. As has been noted under Section 9.1, a biodigester requires subsidisation under current costs to make financial sense for a rural household. In furthering the research for rural biodigesters, avenues of financial support need to be investigated and/or the cost of construction and installation needs to be reduced. Alternatively, if a model exists in which gas can be sold to people for an equivalent price of other energies, then this could provide a solution. The complexities of this system and cost of technology are currently prohibiting the ability to achieve this.

9.4.2 Education

Education and training has proven to be a critical factor in the success of a biodigester plant at a rural household. Even though the project team had close supervision of the households, there were still many aspects of biodigester running and biogas utilisation that needed to be reiterated to the households. Clear empirical evidence of this statement is found in fact that after months of operation, the project team identified that one of the study households was not using their gas so as to save it for later use. The biodigester systems used in this project, like most small scale rural digesters, have limited gas storage capacity and thrive on an environment where the gas is constantly used. Not using biogas ultimately results in it being vented into the atmosphere and lost.

The correct management of a biodigester is absolutely crucial to its optimal running and the realisation of financial benefits. It is important that a BiogasPro digester be fed each day with water and organic matter. Not feeding the digester for an extended period of time could result in the system hydraulics being interrupted, blockages and ultimately ceased gas production.

The optimal use of the biodigester outputs and therefore the realisation of their benefit is also something that requires specific training and education. As noted previously there is a limited amount of biogas available for cooking and therefore it is necessary that efficient cooking methods be used. Training rural people to change their traditional cooking behaviour is naturally a difficult process as it is something that has often been carried down from prior generations. Cooking with pressure cookers and Wonderbags[22], for example, are very foreign concepts to most people and can even be daunting to some. These new techniques require training in order for the system to work effectively.

In addition to the biogas, the bioslurry digestate provides a potentially significant financial benefit to households. The project has identified that "using the biogas method" (as one study participant named it) is also a foreign concept and therefore requires close monitoring and training.

The training and education of households is an expensive and time consuming process. It is, however, one that is critical to the success of a biodigester rollout. The rollout of digesters to a community provides an opportunity for local people to be trained and employed to monitor digester use and education.

9.4.3 Failing technology, support and maintenance

Considering the marginal level of financial returns, under a subsidised financial model, it is clear that failing technology would have a significant impact on the feasibility of a household's biodigester. In a scenario where rural households are expected to pay back the investment cost of their biodigester on a monthly basis, failing biogas production would result in great discontent from households and most probably failure of payment.

Experience from this study has shown that a biodigester system does require intermittent, albeit minor, support and maintenance (see example Plate 9.1). In some cases, a blocked valve or pipe will cease usable operation of a system. It is critical that a roll out programme be followed by accessible support and maintenance; (i) to ensure that systems are being used optimally, (ii) to assist with any technical issues, and (iii) to provide intermittent maintenance, and replacement of aging parts. Capacity building of community members to carry out the maintenance has potential for job creation.

[22] A simple polystyrene and cloth bag insulator that allows heated food, in a pot, to be kept hot and continue cooking for an extended period of time (http://wonderbagworld.com/international).

Plate 9.1: Minor repair required after household damaged a subsurface gas line with a new fence post.

9.4.4 Social acceptability of biogas for cooking

Findings from project investigations (namely Deliverables 10, 14 and Smith, 2011) have identified that the interviewed populations in the Eastern Cape, Limpopo and KZN have generally been willing to use biogas for cooking and are not scared to do so. There were, however, a small number of respondents who were either not interested in changing their current practices, or were scared that the gas (or digester itself) posed some danger to them or their families.

Although this sentiment does not appear to be of great concern, a lack of social acceptance would pose a serious threat to a large scale biodigester rollout and thus, the project's continued monitoring of changing biogas awareness levels, in areas where the project is active, provides important information to guide future progress.

9.4.5 Availability of cattle and other biodigester inputs

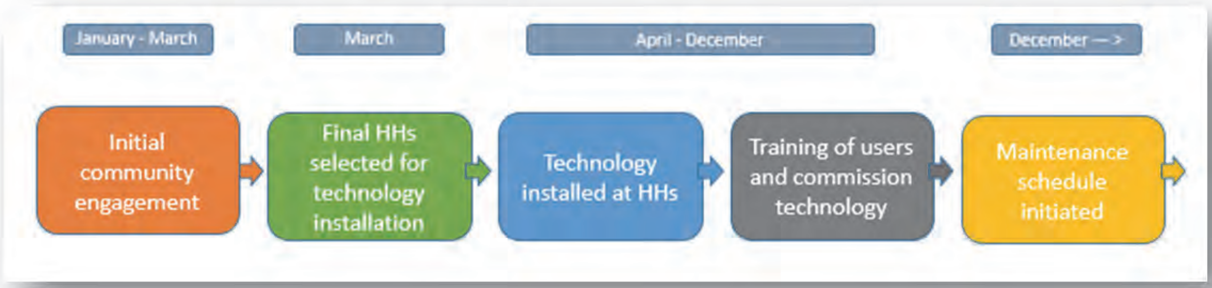
The design of the biodigester system investigated in this project is one that required at least four cattle kraaled at the homestead overnight. This requirement is an obvious limiting factor as many rural families do not own cattle. The survey process identified that many households still collected cow manure on a daily basis, even if they did not own cattle. It also became apparent that many households owned far greater than four cattle. Considering these findings, it is possible that a household need not own cattle to run a digester, especially considering that other organic matter (including food waste) can supplement the digester feedstock. The degree to which this scenario is possible remains unfounded, but should be considered and explored further in the planning of a biodigester rollout programme.

The connection of latrine systems to a biodigester, in order to make use of human waste is common practice for biodigesters in other African countries (Renwick et al., 2007). Consultation with an expert anaerobic digestion microbiologist (Prof Stefan Schmidt of UKZN: pers. comm., May 2013) confirmed concerns about the presence of harmful pathogens in the digestate (bioslurry). Prof Schmidt strongly advised against the use of human waste[23] if any plans existed to use the digestate for food crops, or even if the digestate was to be applied by hand to fodder crops. Prof Schmidt's comments, amidst concerns of the social acceptability of cooking on biogas generated by human waste, confirmed the project team's apprehension that the use of human waste would not be suitable for biodigesters in South Africa – especially where a key focus is to use the digestate for crop cultivation.

9.5 PROJECT IMPLEMENTATION STRATEGY

Findings from this study have identified that while biogas is a good and effective provider of cooking energy, it is not an answer to all of the energy requirements at rural household level. Interaction with households and technology specialists alike has led to the understanding that a "composite solution" of various technologies is required to meet household needs and remove reliance on grid and/or fossil fuel derived energies. While it was originally hoped that this project would lead to a conclusive answer on how to implement a biodigester roll out as an energy solution for rural areas, it has become apparent that further research needs to be conducted to (i) understand household needs better, (ii) develop a suite of energy and water options that can meet those varying needs.

With respect to the implementation of a standalone biodigester roll out, the following implementation process is advised (as per Section 3.3. of the Guidelines Report Volume 2).



Step 1: Community engagement

Community engagement is a pivotal part of any rural development process. In order for new technologies and processes to be accepted, it is important that all tiers of a community, from local and tribal authority to community members, are offered participation in the process. The Guidelines report outlines the process followed in the project and the suggestion for a larger roll out.

23 Prof. Schmidt advised against the use of human waste in rural biodigesters unless additional technologies were put in place to destroy pathogens in the digestate.

Step 2: Household (HH) selection process

The household selection process forms an integral part of community engagement, especially where subsidised or free technology is being offered to households. It is important that the community plays a part in choosing which households receive technology. This process should not be neglected even when technology is being implemented at full retail price, as it is important the community have a shared vision of the process and a clear understanding of all the processes involved.

Step 3: Technology installation

This part of the process is, quite simply, the implementation portion – which should be administered and overseen by experienced personnel. As far as possible, local community members should be employed as part of the project team – and employment opportunities can be used as a compensation mechanism for households who do not receive free/subsidised biodigesters.

Step 4: User training and technology commissioning

As noted under Section 9.4.2 education and training is a pivotal part of achieving the benefits from a biodigester system. This education should be designed for the receiving audience, and topical analogies should be used where possible. In the KZN rural context, it became evident that the fermentation of compost, and the heat that was generated in this process, was a suitable example of the description of the natural and self-perpetuating reaction that takes place in a biodigester. It is important that these explanations be made by someone who can not only speak the appropriate language, but has a sound understanding of the culture to deliver the message clearly.

While it is inconceivable to educate users on the intricacies and details of all chemical reactions that take place in a digester, it is important that they understand the nature of a biodigester being a 'living system' and can then be directed to care for it appropriately.

It is advised that the following topics be covered in this initial education process:

- The natural process within a biodigester (keep it simple)
- What anaerobic bacteria can and cannot digest (or eat)
- The importance of feeding/operational consistency for the bacteria within a digester
- A basic explanation of how the system is susceptible to varying conditions (e.g. temperature changes)
- What is biogas and bioslurry
- How safe is biogas and how should it be treated.

Step 5: Implementation of support and maintenance programme

It is highly recommended that the initial training of households be followed up with subsequent monitoring / training visits. It became apparent in the course of the project that biodigester users could easily develop misconceptions about the system, leading to suboptimal operation.

The training schedule to be implemented can be dynamic to changing circumstances and the abilities of the users. Training should, however, not be compromised – as it is a critical component of biodigester use and subsequent realisation of output benefits. An inappropriately managed or used biodigester is not only a useless entity, but a detriment to the delivery of services via renewable energy and potentially damaging to the way in which alternative options may be perceived. It is, therefore, critical that the training component of a biodigester (or other renewable energy) project be carefully planned and budgeted for.

The Guidelines Report (Volume 2) provides further detail on the proposed training programme.

9.6 FINANCIAL IMPLICATIONS AND SUSTAINABILITY

The financial implications of a biodigester have been detailed in Section CHAPTER 8: of this report. In brief, it is clear that a biodigester does not provide a feasible financial investment for a household – where averted fuel and fertiliser costs would provide the repayment of capital. This said, it has been noted that a biodigester provides significant economic benefit, and therefore implementation by governmental directive could provide significant welfare contributions to rural areas.

If large scale roll outs of biodigesters were be implemented, the question of financial implications and sustainability would need to be directed toward the need for maintenance.

The running of a support and maintenance programme requires significant resources, whether a few or a few hundred biodigesters have been installed. From experiences in the project, however, it appears possible that a skilled and equipped technician would likely be able to visit two digesters per day, if they were in the same area. This would mean that an equipped and mobile technician could potentially visit and address any problems at 50 biodigester sites, in proximity to a specific community or area, in a given month.

The question applicable to this discussion is, "Who should be responsible for the funding of a support and maintenance programme"? While it is not the directive of this project to answer this, possible options are:

1: The local government should support and maintain the biodigesters in an area.

- This proposition is built on the notion that a local government is typically responsible for the support and maintenance of service provision, including electricity and water supply. The delivery of services from a biodigester, albeit off-grid, is still a service which could be provided by the government as an alternative to grid provided services. If this were the case, it follows that the provider of this 'service' would be responsible for its maintenance, and the ability of the system to continue providing a service.

2: The biodigester using households should pay a monthly fee for the maintenance and support of their biodigester.

- If a project were to be funded by a non-governmental organisation, or even if households were to purchase their biodigesters in their private capacity, it would appear sensible that some form of funded maintenance programme be initiated and sustained. In this scenario, it would seem appropriate that, like any service, a household be responsible for some payment of that service. The suggestion herein is quite simply that the household should be paying for a 'service contract', to ensure that their installation continues to be operational into the future. Orchestrating a system of this nature, the actual transferal of funds, and educating a population about its relevance or need, is likely to pose many challenges – gas from a biodigester system cannot simply be shut off, when a household refuses to pay a maintenance bill.

9.6.1 Sustainability

With respect to sustainability, experience at the KZN project sites has shown that if users operate their biodigesters appropriately, there is some, albeit minor, maintenance required over a four year period. The key item here is the need for a system to be operated appropriately. Project experience has shown that inconsistent feeding and use of biodigesters, as well as the feeding of incorrect substrates, leads to poorly performing systems and even blockages in extreme cases (see Plate 9.2).

Plate 9.2: Blocked digester, requiring emptying and re-commissioning.

It appears that a support and maintenance programme would be required to (i) ensure that digesters are continuously operated appropriately, (ii) provide assistance with unforeseen damage and technical faults, and (iii) assist with the replacement of equipment when required (e.g. a biogas burner, like other gas devices, has a limited life expectancy and requires replacement after approximately 4 years). If this support could be provide on an ongoing basis, it is confidently assumed that a household Agama BiogasPro biodigester would last for at least 15 years, and most likely longer.

9.7 RECOMMENDATIONS

The research and implementation conducted in this study has allowed the team to develop a better understanding of the possibilities and plausibility for large-scale rollout of biogas technology. The following summarises some of the key elements, relative to the Green Village concept, which influence the recommendations made.

Biodigester technology:

The project has proven that biodigesters can make a significant difference to rural people's lives, through the provision of convenient clean energy. Biodigester technology is not complicated, nor technically advanced, but the project has shown that technical faults can occur and require experienced service providers, with appropriate resources, to rectify these.

Support and maintenance:

In continuation of the above, it became clear that support and maintenance were necessary and would be required into the future. Support should be provided to ensure that biodigesters are being used appropriately and optimally, and maintenance, albeit minor, is necessary and important in ensuring the delivery of a biogas system. Minor faults, either from human error or technical failures, have been seen to cease biogas accessibility and therefore render the system useless.

Education:

Education and training is a critical requirement for a biodigester implementation project, and is something that needs to be continued over a period of time. The project showed that initial training was not sufficient to ensure optimal and correct administration of a biodigester.

Energy provision:

The project has shown that biogas is not a complete solution for a household's energy requirements. Biogas cannot efficiently provide lighting and heating, and is unable to deliver the electrical requirements of a household – which have become apparent as important energy needs. In addition to this, it became apparent that while biogas is a convenient and efficient energy for cooking, pilot households noted that there was insufficient gas for all cooking requirements and for specific foods. Although efficient cooking techniques would make a significant difference to this situation, it seems that alternative cooking mechanisms would still need to be available for intermittent use and to prevent use of solid fuels and generation of indoor air pollution (i.e. open wood fires).

Small-scale application:

While the application of three to four biodigesters in each study area has provided valuable research opportunities, implementation at this scale is not sufficient to draw representative conclusions on a greater rollout scenario. Although hypothetical scenarios can, and have, been developed, a small-scale pilot project is not sufficient to test the intricacies that would be involved in a larger project, where implementation would take place in varied circumstances and across a range of households (note: that this project used carefully selected pilot households).

The recommendations following these key points have been included in the next section.

CHAPTER 10: FURTHER RESEARCH AND RECOMMENDATIONS

- The input from "greywater" from normal household activities such as washing and showering needs to be quantified and accounted for as it provides an additional source of water. Quantifying these factors should form part of a planned monitoring process.
- There is an urgent need to determine ways of storing bioslurry so that households can store it for the cropping season. Dried bioslurry can be more easily stored and transported than liquid bioslurry. Furthermore, there are income-generating opportunities as excess bioslurry can be sold as a fertilizer.
- Continued need to identify alternative biodigester options, as they become available to the market. Of key consideration here is the need to reduce capital cost of implementation, while not compromising the need for effective and reliable technologies.
- The need to continue remote monitoring through a full seasonal cycle. This will allow the team to better understand the impact that cold temperatures (through winter) has on the production of biogas.
- Research and development of system enhancing technology. The team has already been made aware of the possibility of using solar collectors to heat a biodigester and thereby improve its efficiency, and reduce the assumed impact of cold temperatures. This research would require assistance from technically proficient service providers, and capital funding for the pilot systems to be developed.
- With reference to these key points noted under 9.7, the project team recommends the need for:
    i. An investigation into various alternative energy options, provided in a composite solution to meet a household's needs

    ii. A larger-scale rollout project to representatively and conclusively test biodigesters and other composite solutions. It is apparent that only through larger scale rollout could representative and conclusive assessment be made of the potential for biodigesters and other green technologies. It is recommended that a rollout of 50-100 households be implemented with an integrated research programme that investigates ecological, economic and social factors associated with a full suite of green technologies for up-scaling to a green village.

CHAPTER 11: REFERENCES

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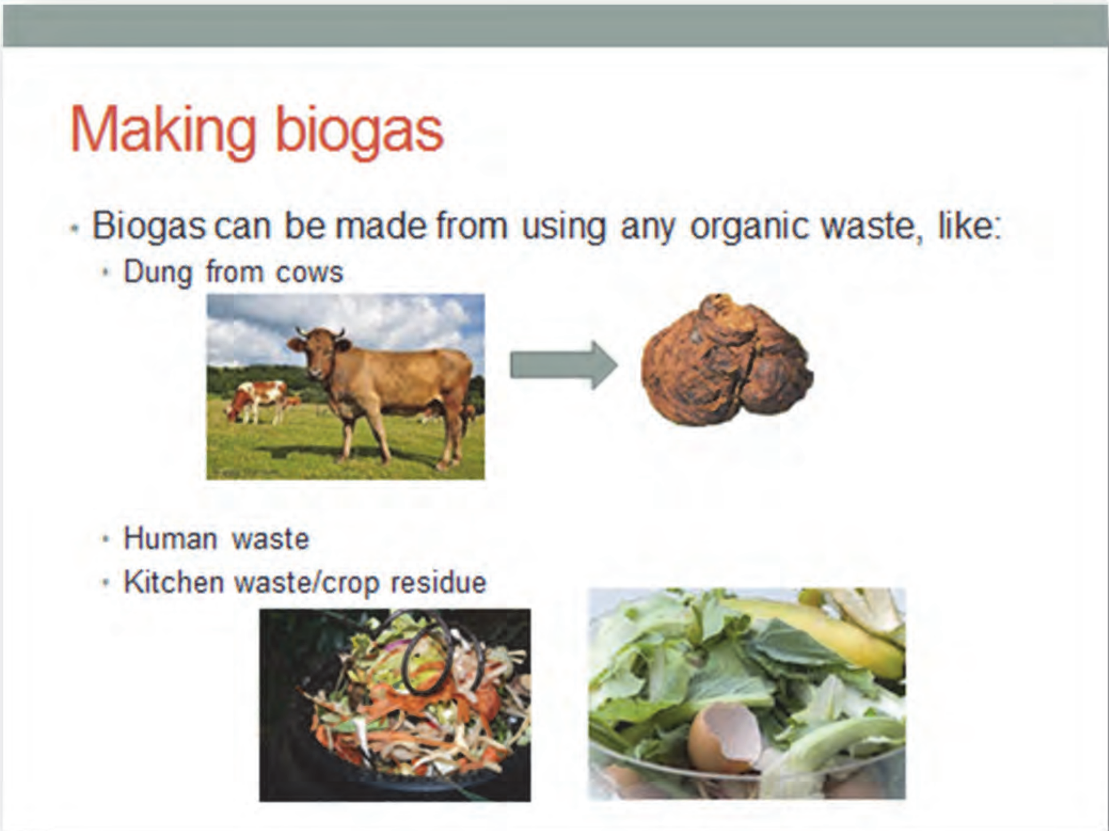
CHAPTER 12: APPENDICES

List of appendices:

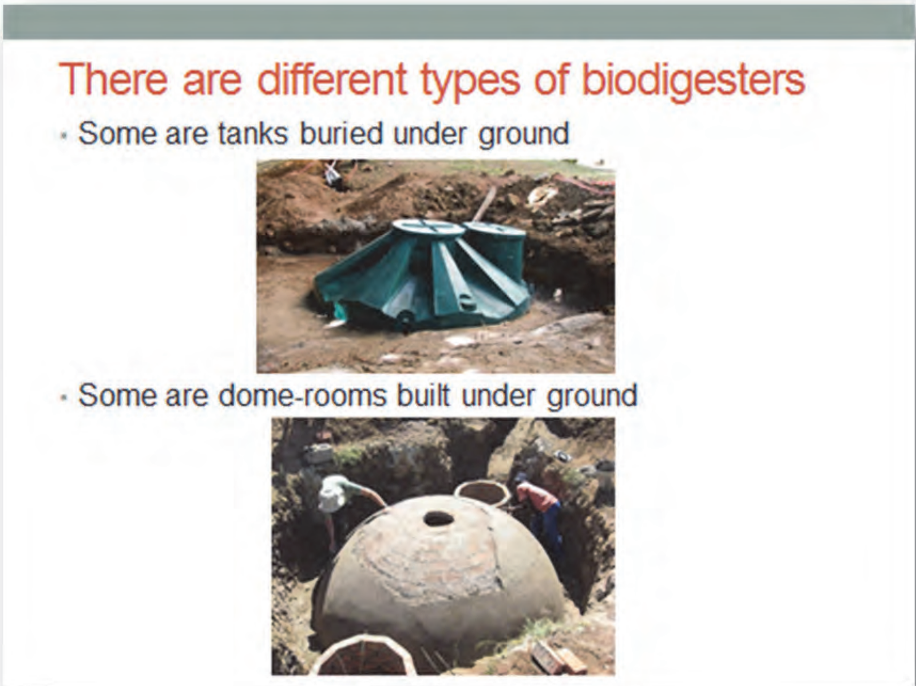
APPENDIX I.
Biodigester Explanation for Household Questionnaire Respondents

To be read after H3:

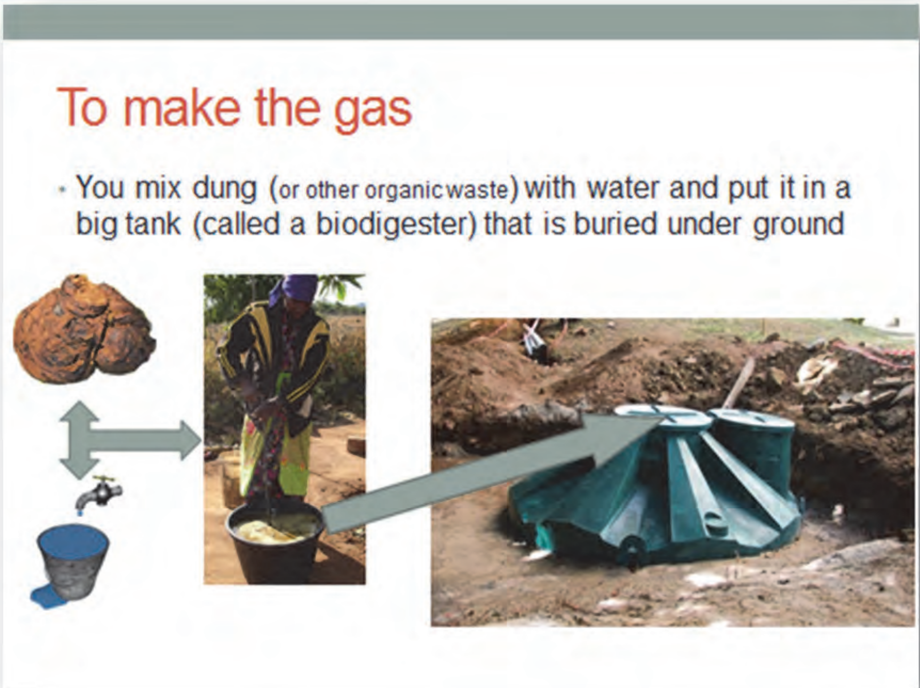
Biogas can be produced from any organic waste, like dung (from all kinds of animals), human waste, and kitchen waste (remainders of vegetables).

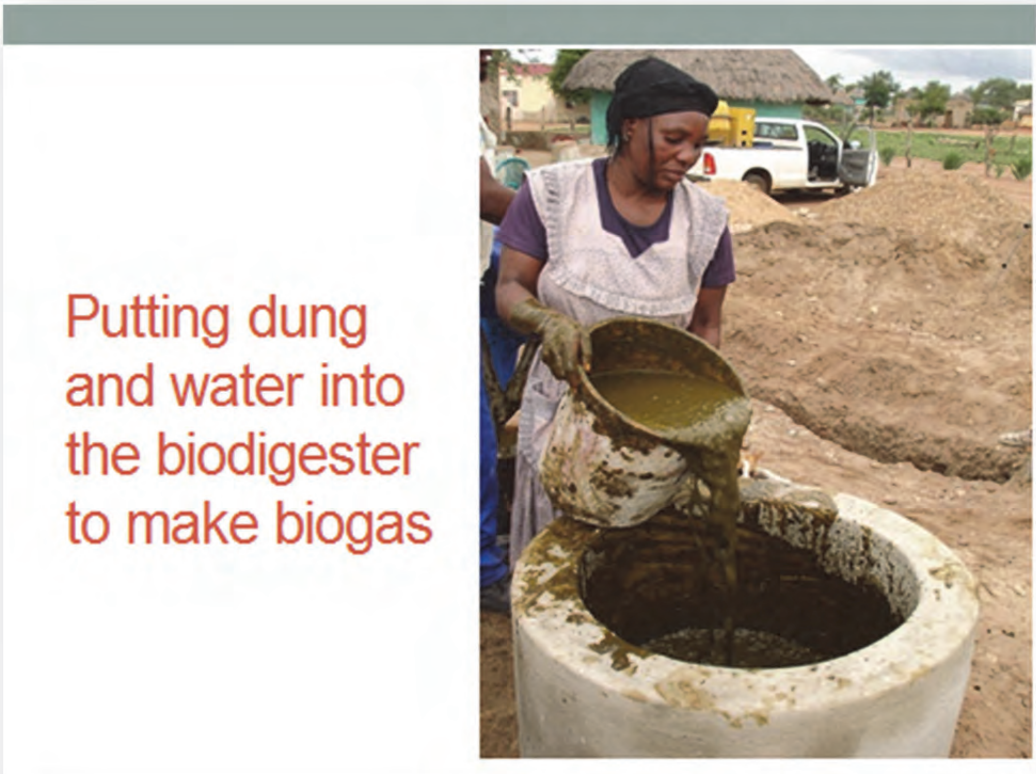


To generate the gas, a biodigester is used. A biodigester is a big container that is buried in the ground (**show pictures*).



The waste is mixed with water and enters the digester where bacteria generate the gas (**can be analogised to compost getting hot*).


To make the gas
• You mix dung (or other organic waste) with water and put it in a big tank (called a biodigester) that is buried under ground


Putting dung and water into the biodigester to make biogas

The gas is piped from the top of the digester and can be used for cooking (**show pictures*).

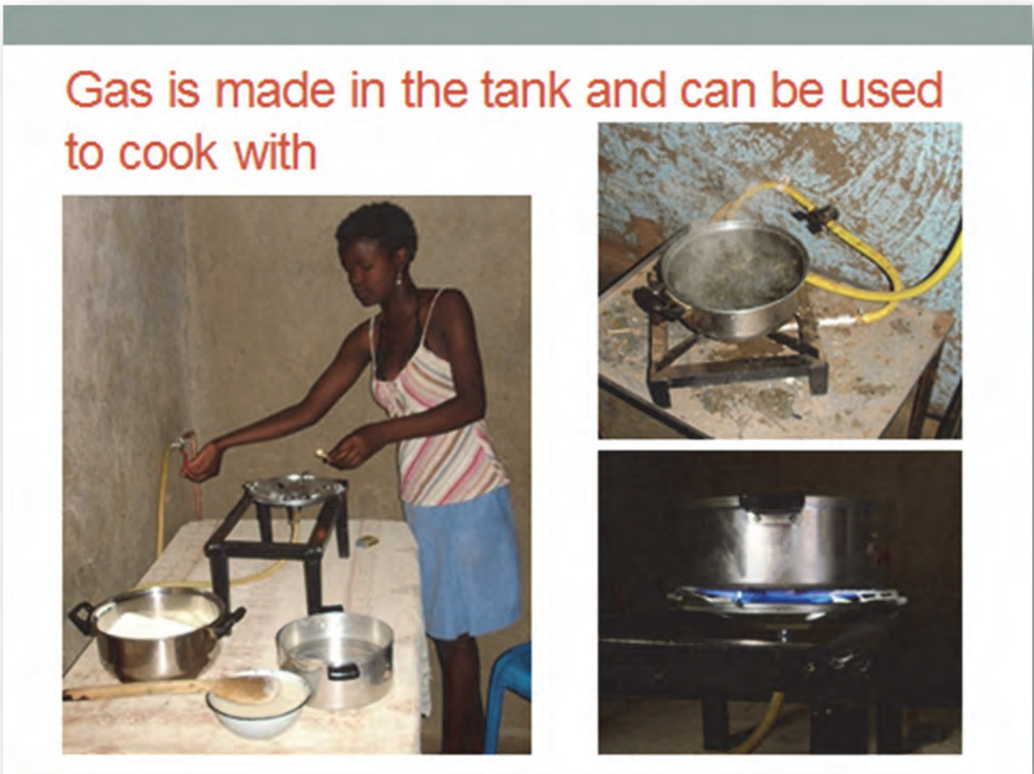
At the one side of the digester the waste goes into the digester, and at the other side the residue (bioslurry) comes out. This bio-slurry can be used as a fertiliser to grow food for yourself and your animals. Many people around the world and in Africa are already using biogas for cooking and the bioslurry for fertiliser.

REQUIREMENTS TO RUN A BIODIGESTER:

If you have a biogas digester at your home, you will have to **fill the digester each day** with 20 kg of dung (**show bucket*), and/or other organic waste, and 20 l of water (**show bucket*).

The dung might be collected from a kraal where the cattle (or any other livestock) sleep at night.

If you have access to this gas, you will not have to use any other sources of energy for your cooking needs. If you have sufficient animal dung and install a **biogas digester, then you will not have to search for firewood, buy paraffin or gas for cooking**.



ADVANTAGES OF BIOGAS

1: It will give you energy for cooking.

2: Biogas will save you time that you spend collecting firewood. This time can be used for any other activity, such as agriculture and/or leisure.

3: When you cook on biogas, you help to protect the environment because you will cut fewer trees for wood.

4: Cooking with biogas is also good for your health because you do not have to inhale the smoke if you cooked on an open fire.

5: You will get fertiliser, for free.

Building the digester may create a small number of jobs.

APPENDIX II.
Questionnaire for pastoralists

QUESTIONNAIRE TO PASTORALISTS

Date…………………… **Start Time……………** **Finish time……………**

Village…………………

Section1: Personal details

1.1 Gender of respondent

1. Male		2. Female	

1.2 Age of respondent

<25 yrs		26-35 yrs		36-45 yrs		46-55 yrs		56-65 yrs		>65 yrs	

1.3 Marital status

1. Single		2. Married		3. Separated	
4. Divorced		5. Widowed		6. Other (specify)	

1.4 Highest education level

1. No formal education		2. High School	
3. Primary school		4. Degree	
5. Diploma		6. Masters	
7. Honours		8. Other (specify)	

1.5 Primary means of livelihood

Section 2: Knowledge, Attitudes and Practices: Rangelands and Livestock

2.1 What condition is the rangeland currently in? (*Tick answer*)

1. Excellent		2. Good	
3. Fair		4. Poor	
5. Very-Poor			

2.2 Please state the reasons for the current rangeland condition

____

____

2.3 How do you assess rangeland condition? (*Tick answers and **rank** in terms of importance*)

1. Grass cover		2. Plant species richness		3. Abundance of trees	
4. Incidence of fruit & flowers		5. Abundance of palatable shrubs		6. Abundance of palatable grasses	
7. Livestock condition		8. Soil texture		9. Other (specify below)	

____

____

2.4 How could the condition of the rangeland be improved? (Tick and ***rank*** *answers except* *Don't know*)

1. Don't know		2. Increase availability of feed resources	
3. Resting of grazing lands		4. Reduce number of livestock	
5. Set rules on the use of rangelands		6. Rotational grazing (dry & wet season)	
7. Use of irrigation		8. Other (specify below)	

____

____

2.5 What condition was the rangeland in five years ago? (*Tick answer*)

1. Excellent		2. Good	
3. Fair		4. Poor	
5. Very poor			

2.6 Why do you believe this was the case?

____

____

____

2.7 What condition do you think the rangeland will be in five years from now? (*Tick answer*)

1. Excellent		2. Good	
3. Fair		4. Poor	
5. Very poor			

2.8 Why do you think this will be the case?

____

____

____

2.9 What type of livestock do you have?

Type of animal	Tick	Number
1. Cattle		
2. Small stock (goat and/or sheep)		
3. Donkey		
4. Horse		
5. Other (specify below)		

____

____

2.10 What is the importance of keeping livestock? (*Tick answers and* ***rank*** *in terms of importance*)

Reason	Tick	Rank
1. Milk		
2. Income from sales		
3. Meat		
4. Ploughing		
5. Breeding		
6. Prestige		
7. Other (specify below)		

2.11 Do you believe that there is a limit to the amount of livestock the rangeland can carry?

Yes		No	

2.12 Why?

____

____

____

2.13 What condition was your livestock population in five years ago?

1. Excellent		4. Poor	
2. Good		5. Very poor	
3. Fair			

2.14 What was the reason for this?

____

____

____

2.15 What condition do you think your livestock population will be in five years from now?

1. Excellent		4. Poor	
2. Good		5. Very poor	
3. Fair			

2.16 Why do you think this will be the case?

____

2.17 What are the ecological benefits of rangelands?

Benefit	Relative Importance			
	Not at all	Somewhat	Important	Very Important
1. Habitat for wildlife				
2. Habitat for native plants				
3. Livestock forage				
4. Crop production				
5. Provision of biological diversity				
6. Other (specify below)				

____

____

____

2.18 What are the social benefits of rangelands? *(Tick relative importance)*

Benefit	Relative Importance			
	Not at all	Somewhat	Important	Very Important
1. Aesthetic value				
2. Promote social interactions				
3. Promote outdoor exercise				
4. Provide learning opportunities				
5. Offer cultural, religious & spiritual fulfilment				
6. Other (specify below)				

____

____

Section 3: Knowledge, Attitudes and Practices: Fodder Production

3.1 (a) Do you know any fodder species that can be grown in your area?

Yes		No	

(b) If yes, list the species below:

____
____
____
____
____
____
____
____

(c) Do you grow any fodder species?

Yes		No	

(d) Give reasons for your answer

____
____
____
____
____

(d) If you grow fodder species, list these below:

Species grown	Month planted	Type of fertilizer applied	Amount applied

(e) Fodder management practices:

Species grown	Weeding (when and frequency)	Harvesting practices	Irrigation/watering (times per week)	How fed to livestock (graze or cut and carry)

3.2 What are the benefits of growing fodder?

____

____

____

____

3.3 What are the challenges in growing fodder?

____

____

____

____

3.4 Do you know of anyone in your village who grows fodder plants?

Yes		No	

(b) If yes, list the species they grow below:

Thank you for your time

END OF QUESTIONNAIRE

APPENDIX III.
Baseline questionnaire

Questionnaire on energy sources, use and views on household biogas

BIOMASS ENERGY AUDIT QUESTIONAIRE

Date: __________ Interviewer: ____________________ Translator: _____________________

Town/area _____________________ Street: _______________ Household number: ________

Sub-ward __________________

Sample no.: _____ GPS Co-ordinates: ____

SECTION A: ENERGY USE PROFILE

A1. Which of the following energy forms does this household use? (*write the rank 1-3 of the most to least used energy forms, where a combination is used in the household*).

Energy	Use			Energy	Use		
	a) Lighting	b) Cooking	c) Heating		a) Lighting	b) Cooking	c) Heating
Electricity	1	1	1	Fire wood	7	7	7
Paraffin	2	2	2	Coal	8	8	8
Gas	3	3	3	Charcoal	9	9	9
Candles	4	4	4	Dung	10	10	10
Dry cell batteries	5	5	5	Crop residues	11	11	11
12 V car batteries	6	6	6	Generator	12	12	12

A2. Which of the above energy forms are most important for your household?

Lighting	1	Cooking	2	Heating	3

SECTION B: USE OF FIREWOOD

B1. Does your household ever use firewood? Yes [*1*] No [*2*]

*(*If No, continue to Section E)*

B2. If yes, for what purposes? (*write the rank 1-3 of the most to least important use, where firewood is used for a variety of needs in the household*).

Cooking	1	Heating inside the home	2	Heating when outside	3
Other (please specify):					

B3. If you use an inside fire, do you make an open fire, or burn the wood in a stove?

Open [*1*] Stove [*2*]

B4. If you cook on an open fire, where do you make the fire?

- a) In summer:	In the house	1	In an external cooking shelter	2	Outdoors	3
- b) In winter:	In the house	1	In an external cooking shelter	2	Outdoors	3

B5. Can you please show me how much wood you use in a day (**weigh the bundle*)

_____________________ kg

SECTION C: COLLECTION OF FIREWOOD

(only complete this section if answer to Q B1 is yes)

C1. a) How do you usually obtain the firewood that you use?

Buy only	1	Collect only	2	Buy and Collect	3

b) If you 'buy and collect', do you?

Buy More	*1*
Equal	*2*
Collect More	*3*

C2. If you hardly ever collect firewood, why is that so?

Not enough	1	Don't have time	2	We prefer to buy it	3	Too far away	4

available							

C3. Who in the household collects the firewood?

a) Who is the main person?

Men	1	Women	2	Boy child	3	Girl child	4

b) Who helps?

Men	1	Women	2	Boy child	3	Girl child	4

C4. From where do they collect the firewood?

a) ____________________

b) Distance? ______________*km*

C5. How long does each trip to collect firewood take you? _____________________*hours, minutes*

C6. How often do you/they go to collect wood?

a) In summer ______________*trips per week*

b) In winter ______________*trips per week*

C7. What tree species do you use for firewood?

(for a) *write the rank 1-3 of the most to least used tree species, where a combination is used in the household*).

Tree Species	a) Used for firewood	b) Used for firewood most often	c) Most preferred as a firewood
Sazimane	1	1	1
Wattle	2	2	2
Pine Tree	3	3	3
Gum Tree	4	4	4
Uqayi	5	5	5
Isiqalaba (*Protea caffra*)	6	6	6
uSondeza (*Scutia myrtina*)	7	7	7
uSiphahluka (*Hippobromus paucifino*)	8	8	8

uKhamba (*Acacia sieberana*)	9	9	9
Other (please specify)			

SECTION D: BUYING FIREWOOD

(only complete if answer to *Question C1* is yes to buy)

D1. How often do you buy firewood

a) In summer ________________________*times per month*

b) In winter __________________________*times per month*

D2. How much do you generally buy each time? (* *remember to record unit- ask to be shown the bundle and weigh it*) _________________*kg*

D3. What is the cost? (**remember to record the unit*) ____________________ *per bundle/kg?*

D4. How long does that amount usually last? ______________________*days*

SECTION E: USE OF GAS/BUYING OF GAS

E1. Does your household ever use gas?

Yes [*1*] No [*2*]

*(*if No, go to Section F)*

E2. If yes, for what purposes (**rank 1-3 from most to least used, where gas is used for more than one purpose*)?

Cooking	1	Heating water (for tea)	2	Heating inside the home	3	Heating outside the home	4

Other (please specify):

E3. How many days a week do you use gas?

a) In summer: _____________________ *per week*

b) In winter: ______________________ *per week*

E4. What gas appliances do you have? (**rank 1-3 from most used to least used appliance, where more than one item are used in the household)*

Small LPG gas burner	1	Gas Stove	2	Heater	3	Lamp	4
Other							

E5. Can you please tell me how much gas you use in a month? (**record unit)* ______________*kg*

SECTION F: USE OF DUNG/COLLECTION OF DUNG

F1. Does your household ever use cow dung?

Yes [*1*] No [*2*]

*(*if No, go to Question F4)*

F2. How much cow dung do you use per month for? *(*use the 20 l bucket to estimate kg, if they say how much they use per YEAR, divide by 12)*

a) Cooking	b) Construction	c) Heating inside the home	d) Heating when outside	e) Fertilizer for crops
kg	kg	kg	kg	kg

F3. How do you usually obtain the dung that you use?

Collect from our own livestock	1	Collect from the livestock of others	2	Buy it	3

F4. How many livestock do you own?

a) Cattle		b) Goats		c) Pigs		d) Donkeys	
e) Horses		f) Sheep		g) Chickens		h) Duck/Goose	

F5. Do you keep your cattle in a kraal overnight?

Yes [*1*] No [*2*]

F6. Where is the dung collected from?

a) ________________________

b) Distance? _______________ *km*

F7. How long does it take to collect the dung? _________________*hours, minutes*

F8. How often do you/they go to collect dung:

a) In summer ____________ *trips per week*

b) In winter ____________ *trips per week*

SECTION G: WATER and FOOD SUPPLY

G1. Where do you get your water from? (**rank 1-3 from most to least used source, where water is obtained from more than one source*)

River/Stream	1	Municipal tap inside house	2	Municipal tap directly outside house	3
Borehole	4	Rainwater Tank	5	Community stand/municipal tap	6
Tap from runoff water (captured from mountain)	7	Other (Please specify)			

G2. How far from the household is your water source, distance? _____________________ *km*

G3. How much time do you spend a day collecting water? _________________ *hours, minutes*

G4. How much water do you use per day? ____________________ *litres (*show 20 l bucket)*

G5. Who in the household collects the water?

a) Main person

Men	1	Women	2	Boy child	3	Girl child	4

b) Helpers (if any)

Men	1	Women	2	Boy child	3	Girl child	4

G6. Do you grow your own vegetables?

Yes [*1*] No [*2*]

G7. Do you grow fodder for your cattle?

a) Yes [*1*] No [*2*]

b) If yes, what fodder do you grow?

Kikuyu	Eragrostis hay (bought)	Lucerne hay (bought)	Home grown legumes
1	2	3	4
Other			

c) If no, why don't you grow fodder for your cattle?

Don't have cattle	Don't have time	Don't have enough land	They can survive without it	Too much effort	It doesn't grow well	Can't afford to
1	2	3	4	5	6	7

G8. Do you use fertiliser for your crops/gardens/any growing you do (* *make certain that fertiliser is not just considered to be bought 'fertilisers'*?

Yes [*1*] No [*2*]

*(*If NO, continue to Section H)*

G9. Do you buy fertiliser?

a) Yes [*1*] No [*2*]

If YES				
b) What fertiliser do you buy?	232 (22) NPK	232 (25) NPK	DAP	Other (please specify)
	1	2	3	
c) How much do you buy per year?	*kg per year*			
d) How much does it cost you per year?	*per year*			
If NO				
e) What do you use for fertiliser?				

SECTION H: PERCEPTIONS OF BIOGAS

H1. Have you heard of biogas

Yes [*1*] No [*2*]

H2. If yes, could you please tell me what you have heard about biogas? ______________________

____

H3. What experiences have you had with biogas as a fuel? *(*ask only if the response of H1 is Yes)*

Advantages/good aspects	b) Disadvantages/problems

(* If insufficient space in table continue writing on back of page)

*(*A detailed explanation must be given about biogas at this point – see supplementary information and pictures.)*

H4. Assuming equal prices, which energy source would you rather buy to satisfy your household cooking needs?

Firewood	1	Dung	2	Gas	3	Biogas	4	Paraffin	5
Other (please specify)									

H5. Would you be happy to use biogas for cooking?

Yes [*1*] No [*2*]

H6. If a biogas system is installed at your house how much would you be willing to pay for the gas (and fertiliser) if sufficient gas is provided to replace ALL your cooking needs and you get fertiliser from the digester to use on your food garden and fodder crops? (**this is hypothetical, make sure they know that this will not influence how much they may be charged if a biodigester is given to them in the future*)

R __________________ *per month*

SECTION I: PERCEPTION OF HOUSEHOLD BIODIGESTERS AND SUITABILITY REQUIREMENTS

It is possible to have a biodigester for each household. The household needs to feed the biodigester with 20 kg of dung and 20 l of water every day. They will be able to use the biogas (for cooking/heating) and the fertiliser from the biodigester (for growing vegetables and fodder to feed livestock). If you use gas for cooking, you would not have to buy it and travel to collect it. If you use firewood, you would not have to collect it and make fires for cooking.

I1. If your household could run a biodigester that can give you biogas for cooking and fertiliser, would you want to have one?

Yes [*1*] No [*2*]

*To run a biodigester and get biogas, it is required that you feed it with 20 kg (two 20 l buckets [*show bucket]) of dung and 20 l of water every day.*

I2. Would your household be willing to do this?

Yes [*1*] No [*2*]

I3. Where would you get the 20 kg of dung from?

Collect from our own livestock	1	Collect from the livestock of others	2	Buy it	3

I4. Who will collect this dung?

a) Main person

Men	1	Women	2	Boy child	3	Girl child	4

b) Helpers (if any)

Men	1	Women	2	Boy child	3	Girl child	4

I5. From where will they collect this dung?

a)______________________

b) Distance? _____________ *km*

I6. How long will it take to collect this dung? ______________________________ *hours, minutes*

I7. Will your household be able to get 20 l of water for the biodigester every day?

Yes [*1*]   No [*2*]

I8. Who will collect this water?

a) Main person

Men	1	Women	2	Boy child	3	Girl child	4

b) Helpers (if any)

Men	1	Women	2	Boy child	3	Girl child	4

I9. Do you have a space in your garden to dig a 6m X 6m hole for a biodigester?

Yes [*1*]   No [*2*]

SECTION J: POTENTIAL TIME SAVING

*The running of a biodigester will take you some time, but it will also save you time. To run it, you will have to feed it 20 kg of dung (two 20 l buckets [*show bucket]) and one 20 l bucket of water every day. Depending on what fuel you use for cooking, it could save you from having to collect firewood, gas for cooking and any time involved in preparing fires.*

J1. Who is responsible in your household for preparing meals and the way you cook them?

a) Main person

Men	1	Women	2	Boy child	3	Girl child	4

b) Helpers (if any)

Men	1	Women	2	Boy child	3	Girl child	4

J2. Who would be responsible for running the biodigester if your household had one?

a) Main person

Men	1	Women	2	Boy child	3	Girl child	4

b) Helpers (if any)

Men	1	Women	2	Boy child	3	Girl child	4

J3. If they could save time by using a biodigester and not having to collect fuel for cooking, what would they do with this extra time?

Nothing	Find employment	Work in home and garden	Other: (please specify)
1	2	3	

<u>SECTION K: HOUSEHOLD PROFILE</u>

K1. How many people live/sleep in your household? ______________ *people*

K2. How many people eat at your household? ______________ *people*

K3. What is the total combined monthly income of your household? R____________________

K4. Is the head of your household:

Male	Female	Girl Child (below 18)	Boy Child (below 18)
1	2	3	4

K5. Is your house electrified? Yes [*1*] No [*2*]

*(*If Yes, continue… If No, continue to L1)*

K6. If yes, when was it connected? __________________*dd/mm/yyyy*

K7. Does your household own an electric stove/oven/hot plate?

Yes [*1*] No [*2*]

K8. How much do you spend per month on electricity?

a) We don't use the electricity as it is too expensive:

Yes [*1*] No [*2*]

b) In winter? R_____________

c) In summer? R_____________

SECTION L: DEMOGRAPHIC OF INTERVIEWEE AND Interview DETAIL

L1. Gender of the interviewee?

Male	Female
1	2

L2. Age of the interviewee? _______________ *years old*

L3. Race of the interviewee?

Black	White	Indian	Coloured	Asian
1	2	3	4	5

L4. Home language of interviewee?

isiZulu	isiXhosa	English	Afrikaans	Other (please specify)
1	2	3	4	

L5. Time taken to complete interview? _____________________ *hours, minutes*

APPENDIX IV.
Follow-up questionnaire

Questionnaire on energy sources, use and views on household biogas

BIOMASS ENERGY AUDIT QUESTIONAIRE

Date: __________ Interviewer: ____________________ Sample no.: _____

Household number: ______________ Sub-ward __________________

GPS Co-ordinates: ____

SECTION G: WATER and FOOD SUPPLY

G1. Where do you get your water from? (**rank 1-3 from most to least used source, where water is obtained from more than one source*)

River/Stream	1	Municipal tap inside house	2	Municipal tap directly outside house	3
Borehole	4	Rainwater Tank	5	Community stand/municipal tap	6
Tap from runoff water (captured from mountain)	7	Other (Please specify)			

G2. How far from the household is your water source, distance? ______________________ *km*

G3. How much time do you spend a day collecting water? (**inform interviewee that this is time taken for ALL collection, not the time taken for one trip*)

__________________ *hours, minutes*

G4. How much water do you use per day? _____________________ *litres (*show 20 l bucket)*

G5. Who is the main person in the household who collects the water?

Men	1	Women	2	Boy child	3	Girl child	4

G6. Do you grow your own vegetables?

Yes [*1*]   No [*2*]

G7. Do you grow fodder for your cattle?

a) Yes [*1*]   No [*2*]

b) ***If yes***, what fodder do you grow?

Kikuyu	Eragrostis hay (bought)	Lucerne hay (bought)	Home grown legumes
1	2	3	4
Other			

G8.

a) Do you use manure for your crops or vegetables?

Yes [*1*]   No [*2*]

b) Do you use fertiliser for your crops or vegetables?

Yes [*1*]   No [*2*]

*(*If NO, continue to Section H)*

G9. Do you buy fertiliser?

a) Yes [*1*] No [*2*]

If answer to G9. a) is YES, ask following questions:					
b) What fertiliser do you buy?	232 (22) NPK	DAP	231 NPK	Lime	Other
	1	2	3	4	
c) How much do you buy **per year**?	kg	kg	kg	kg	kg
d) How much does it cost you **per year**?	R	R	R	R	R

SECTION H: PERCEPTIONS OF BIOGAS

H1. Have you heard of biogas or a biodigester?

Yes [*1*] No [*2*]

H3. What are the good things that you have heard about biogas and what are the bad things that you have heard about biogas? *(*ask only if the response of H1 is Yes)*

a) Advantages/good aspects	b) Disadvantages/bad/problems

(* If insufficient space in table continue writing on back of page)

*(*A detailed explanation must be given about biogas at this point – see supplementary information and pictures.)*

H4. If all the cooking energies cost exactly the same amount of money, what source of energy would you choose for your household cooking needs?

Firewood	1	Dung	2	Gas (LPG)	3	Biogas	4	Paraffin	5	Electricity	6
Other (please specify)											

H4 REASON.

____

____

H5. Would you be happy to use biogas for cooking?

Yes [*1*] No [*2*]

H6. If a biogas system is installed at your house how much would you be willing to pay per month if it makes enough gas for ALL your cooking needs and you get fertiliser from the digester to use on your food garden and fodder crops? (**this is hypothetical, make sure they know that this will not influence how much they may be charged if a biodigester is given to them in the future*)

R _________________ *per month*

SECTION I: PERCEPTION OF HOUSEHOLD BIODIGESTERS AND SUITABILITY REQUIREMENTS

I1. If your household could run a biodigester that can give you biogas for cooking and fertiliser, would you want to have one?

Yes [*1*] No [*2*]

*To run a biodigester and get biogas, it is required that you feed it with 20 kg (two 20 l buckets [*show bucket]) of dung and 20 l of water every day.*

I2. Would your household be willing to do this?

Yes [*1*] No [*2*]

I3. Does your household own cattle?

Yes [*1*] No [*2*]

How many cattle?	

APPENDIX V.
Summary of methodology applied in Okhombe study (Smith et al., 2013)

FINANCIAL COSTS		
Item	Estimation method	Key assumptions
1. BiogasPro digester	Price obtained directly from supplier	Biodigester model used for the study is BiogasPro.
		Constant costs (no economies of scale in production).
2. Biodigester transportation Cape Town – Pietermaritzburg – Okhombe	Provided by supplier (validated by three higher quotations from transport companies)	Nine biodigesters at a time transported on an 18 m heavy duty vehicle (HDV), i.e. multiple (9) installations on site.
3. Installation cost		
3.1 Civil construction		
Hole excavation	Cost of labour: shadow wage rate [Minimum wage for farm workers x estimated time based on previous installations.]	Community members dig and prepare own holes.
Backfill	Cost estimates provided by RenEn, the only accredited installer in KZN	Nine installations over one week; two digesters filled per day.
Plumbing		Biodigester installed 18 m from house.
Transport (service providers)	Travel cost from Pietermaritzburg to Okhombe return	Nine installations over one week; technical staff on site.
Accommodation	Average cost of nearby accommodation	Four nights' accommodation for technical staff.
3.2 Gas installation		
Ground preparation	Cost estimates provided by RenEn, the only accredited installer in KZN	Biodigester installed 18m from house.
Plumbing		
Transport (service providers)	Travel cost from Pietermaritzburg to Okhombe return	Nine installations over one week; technical staff on site.
Accommodation	Average cost of nearby accommodation	Four nights' accommodation for technical staff.

4. Cost of biodigester-utilizing gas burner	Price obtained directly from supplier	Includes transport and taxes.
5. Repair and maintenance costs	Obtained directly from supplier who expects these costs to be zero	Users abide by general guidelines of use as per training.
6. Training and technical assistance	Estimated by supplier, who provides training	Local resident will provide training to representatives of user households at installation, 3 months, 6 months and 12 months (one day each); multiple (9) installations.

FINANCIAL BENEFITS		
Item	Estimation method	Key assumptions
1. Avoided fuel costs	Market prices of estimated fuel savings. [Fuel expenditure breakdown obtained from household survey; cooking fuel savings per firewood, LPG, paraffin, electricity calculated as proportion of each fuel type used for cooking x market price.	Biogas will replace all other *cooking* fuels in households where a biodigester is installed.
2. Avoided fertilizer costs	Market price of fertilizer. [Fertiliser use and costs obtained from household survey.]	Bioslurry will replace all purchased fertilizer in households where a biodigester is installed.
3. Avoided medical expenditure	Health-related expenditure savings due to reduced indoor air pollution as a result of switching to biogas drawn from Ugandan study (Pandey et al., 2007; Renwick et al., 2007)	Biogas will reduce indoor air pollution by 65%, on the basis that biogas use reduces firewood consumption by 65%.
4. Financial value of saved lives	Avoided funeral costs	65% reduction in IAP related deaths as a result of replacing

		solid fuels with biogas.
	[Indoor air pollution (IAP) related deaths in the study area extrapolated from WHO data → reduction proportionate to reduced solid fuel use → valued using local data for average cost of funeral.]	Funeral cost: one third of the average, annual household income for the study area (UN-ECA, 2011:18).

ECONOMIC COSTS		
Item	Estimation method	Key assumptions
1. Social costs of biodigester transport Cape Town – Okhombe	Social cost of carbon emissions. [Applied to estimated carbon emissions based on expected fuel use of delivery vehicle.]	Limited to external cost of CO_2 emissions.
		Nine biodigesters transported on an 18m HDV.
		Round trip Cape Town – Pietermaritzburg – Okhombe 3 534 km
		Average HDV CO_2 emission 2 651 g/litre of fuel.
		Social cost of carbon (R180.81/tonne of CO_2)
2. Time spent feeding biodigeste	Value of time: weighted min wage. [Time required to collect and mix necessary water and dung estimated from household survey, and experienced rural biogas practitioner → time valued as explained in Section 4.7.2.1 (Smith, 2011: 111) as average min wage for unskilled labour in SA, weighted according to likely time use as derived from household survey.]	Value of time by activity: *Productive economic activity* valued at 100% of unskilled labour wage rate (w_e) *Household activity* valued at 50% of unskilled labour wage rate (w_h) *Other activity* (including leisure and socialising) valued at 25% of unskilled labour wage rate(w_o)

ECONOMIC BENEFITS		
Item	Estimation method	Key assumptions
1. Time saving from cooking with biogas instead of traditional fuels		
Reduced firewood collection time	Value of time: weighted min wage. [Expected reduction in reported wood collection time (from survey) → valued according to principles as per Section 4.7.2.1 (Smith, 2011: 111)]	Affects only households using traditional fuels (firewood, cow dung) before switching to biogas. Wood for cooking accounts for 65% of wood collected Value of time – see above.
Reduced cooking and utensil-cleaning time	Value of time: weighted min wage. [Expected time savings drawn from other comparable studies (Renwick et al., 2007) and valued as above.]	Daily average saving of 134 mins due to switch to biogas. Value of time – see above.
2. Improved health		
Health-related productivity gains	Value of time: weighted min wage. [Incidence of acute lower respiratory infections (ALRI) (data for Sub-Saharan Africa, WHO, 2004) → proportion due to IAP from solid fuel (Prüss-Üstün and Corvalán, 2006) → number affected in study population → x average number of days incapacitation due to ALRI → proportionate reduction in incidence and days lost due to switch to biogas → time valued as explained above.]	Focus on ALRI (the most prevalent IAP-related disease). Incidence of IAP-related ALRI and resultant incapacitation in Okhombe is comparable to that in source studies used. Switch to biogas reduces both solid fuel use and IAP-induced incapacitation by 65%. Time valued as above.
Saved lives	Value of a statistical / economic life. [IAP related deaths in study area extrapolated from WHO data → reduction proportionate to reduced solid fuel use → valued as a statistical life as explained in Section 4.7.2.2. (Smith, 2011:	65% reduction in IAP related deaths as a result of replacing solid fuels with biogas. Value of a statistical life (VOSL) adjusted to study context: $2 million (adjusted to, 2011 ZAR).

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3. Local environmental benefits:	Not quantified	
Preservation of indigenous trees		
Reduction of erosion		
4. Greenhouse gas and CO2 reduction	Not quantified	

APPENDIX VI. CAPACITY BUILDING AND TECHNOLOGY TRANSFER REPORT

Appendix

CAPACITY BUILDING AND TECHNOLOGY TRANSFER REPORT

TABLE OF CONTENTS

CAPACITY BUILDING AND TECHNOLOGY TRANSFER

The capacity building and technology transfer activities included the scientific training of students for postgraduate qualifications, training of community members to operate and monitor biogas digesters, several workshops on the development of a business case plan for the Green Village proposal, scientific papers delivered at regional and overseas conferences and numerous informal study group sessions by local and international visitors to the trial.

The following presentations were made by project team members or students:

- December 2012: Presentation by Mr M Smith on "Water Research Commission Project K5/1955 Rural biodigesters in KZN" at the KwaZulu-Natal Sustainable Energy Forum (KSEF) in Pietermaritzburg
- 28 November 2012: Presentation by Dr Terry Everson on "Energy, water harvesting and food security "at the planning workshop on the Green Village Project held by The Water Research Commission (WRC), the Department of Environmental Affairs (DEA), the Department of Water Affairs (DWA) and the Department of Rural Development and Land Reform (DRDLF).
- 24-26 April 2013: Prof. C Everson and Mr M Smith attended the "Training Seminar on Energy from Biomass and Waste in Africa" (hosted by IWWG [International Waste Working Group]). Prof. Cristina Trois of UKZN presented the potential for energy from organic solid waste in South Africa, with an inclusion of WRC K5/1955 project activities as provided by the K5/1955 team.
- 12 June 2013: Mr M Smith attended "Mitigation toolkit workshop" and engagement with UCT Energy Research Centre on the experiences of WRC K5/1955.
- 27 September 2013: Presentation on "Sustainable management of energy, water, food and fodder for small-holder farmers" by Terry Everson, Mike Smith & Colin Everson at the WRC Symposium 2013.
- October 2013: Mr M Smith Mike Smith attended and represented UKZN and the WRC Project K5/1955 at this feasibility presentation, workshop, discussion and others associated to the UMDM feasibility project – "uMgungundlovu District Municipality (UMDM) Anaerobic digestion feasibility study".

- 30-31 October 2013: Mr M Smith attended and Dr D Tinarwo hosted a poster and stand at the South African Biogas National Conference 2013 in Midrand, JHB.
- 21 November 2013: Presentation on "Past and on-going research as examples for potential GV pilot sites, situation needs analysis and research gaps" by Dr. Terry Everson at the Golder Hatfield Second and Follow up Workshop on Green Village Research Needs for now and the future.
- 16 January 2014: The WRC K5/1955 team assisted in putting together a Green Village project proposal document for the WRC / CSIR short-project led by Dr Nebo Jovanovic for the Economic Development Department For infrastructure Support.
- 24-25 March 2014: A research study site visit and meeting to complete DTI application documents to Okhahlamba, KZN. Attended by Mr Bonani Madikizela, Dr Nebo Jovanovic, Dr Terry Everson, Prof. Colin Everson, Mr Mike Smith
- October 2014: A presentation on "Green Village pilot site: Okhombe (uThukela district)" by Dr Terry Everson at the WISA green village workshop.
- 16 April 2014: Green Village implementation: Business Case. Presentation and discussion presented to a group of WRC managers at Pretoria by Nebo Jovanovic and Mike Smith
- 17 April 2014: Green Village implementation: Business case. Presentation to the Department of Trade and Industry by Dr Nebo Jovanovic and Mr Mike Smith (accompanied by Mr Bonani Madikizela and Dr Stanley Liphadzi). 45 page document

The building of research capacity was achieved through the registration of students at the University of Venda, Rhodes University and the University of KwaZulu-Natal. The following table indicates the students who have completed their qualifications as well as those who are in the process of completing them:

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Table 0-1. Candidates for postgraduate qualification.

STUDENT NAME AND SURNAME	GENDER	RACE	DEGREE	UNIVERSITY	COUNTRY OF ORIGIN	COMPLETED/TARGET DATE
Kyle Langley	Male	White	MSc	Rhodes Univ.	South Africa	Target date: 2015
Michael Smith	Male	White	MCom	UKZN	South Africa	Completed: 2011
Landiwe Zondi	Female	Black	BSc Hons	Rhodes Univ.	South Africa	Completed: 2012
Nobuntu Mapeyi	Female	Black	MSc	Rhodes Univ.	South Africa	Target date: 2016
Michael Smith	Male	White	PhD	UKZN	South Africa	Target date: 2016
Welcome Lubusi Mfanuzile	Male	Black	MSc	Univ. of Venda	South Africa	Completed 2014
Mashudu Daniel Rambau	Male	Black	B. Sc. Agriculture	Univ. of Venda	South Africa	Completed 2014
Lavani C Mabunda	Male	Black	BSc Hons	Univ. of Venda	South African	Completed 2014
Londiwe Magagula	Female	Black	BSc Hons	UKZN	South Africa	Completed: 2013
Nelile Ngobo	Female	Black	MSc	UKZN	South Africa	Target date: 2015
Mthokozisi Kwazi Zuma (submitted)	Male	Black	MSc	UKZN	South Africa	Completed: 2015
Londiwe Magagula	Female	Black	MSc	UKZN	South Africa	Target date 2015
Clare Sonto Mabilani	Female	Black	BCom Hons	Univ. of Venda	South Africa	Completed 2014
Phatuwani Magatshava	Male	Black	BSc Hons	Univ. of Venda	South Africa	Completed 2014
Tirabelo Mahandana	Male	Black	BSc Hons	Univ. of Venda	South Africa	Target date 2015

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In the following section the thesis titles and abstracts and publications are listed.

PEER REVIEWED SCIENTIFIC PUBLICATIONS

EFFECTS OF BIO-DIGESTER SLURRY ON THE MINERAL COMPOSITION OF NAPIER (*PENNISETUM PURPUREUM*) IN THE LIMPOPO PROVINCE

Mfanuzile W Lubisi *, Joseph J Baloyi, Jestinos Mzezewa

University of Venda, Department of Animal Science, Bag X5050, Thohoyandou, 0950, Republic of South Africa

Tel: 015 962 8206; Cell: 072 749 040; Email: hucfgyg@gmail.com

ABSTRACT

Slurry from either poultry or cattle manure has become a potential source of soil nutrients and renewable energy for rural farmers in efforts to manage waste and environment. An experiment was carried out to examine the effect of using bio-digester slurry on the mineral quality of cultivated pasture grasses at Maila and Nthabalala. Minerals were determined on twelve soil and twenty-four bio-digester slurry samples from Maila and Nthabalala by ICP-OES (Thermo Jarrell Ash IRIS Advantage Inductively Coupled Plasma Optical Emission Spectrometry). The Napier fodder was cultivated in six 5 x 4 m plots per block replicated three times in a completely randomised block design and irrigated with either bio-digester slurry or only rain harvested water. Samples of Napier leaves were harvested at three different stages of harvested and evaluated for mineral composition. The soils at Maila were characterised by moderate acidity whilst soils at Nthabalala had neutral pH 7.1. The level of micronutrients were significantly ($P<0.05$) low (<30 ppm) in both soils and slurry's at Maila and Nthabalala. Significantly ($P<0.05$) different was observed for ash at an early stage of maturity in both slurry and no slurry. K, Fe, Mn and Mo were not significantly different ($P>0.05$) in all the stages of maturity. Napier fodder irrigated with slurry at both sites contained significantly different P, Mg and Ca levels in all stages of maturity. The slurry's were characterised by minerals deficiencies, even though the biogas slurry contained an amount of P, K, and Ca.

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Smith MT, Schroenn Goebel J, Blignaut JN. The financial and economic feasibility of rural household biodigesters for poor communities in South Africa. *Waste Management*. 34 (1): 352-362.

Waste Management 34 (2014) 352–362

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

The financial and economic feasibility of rural household biodigesters for poor communities in South Africa

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ABSTRACT

Given the persistence of systemic poverty in, most notably, the rural parts of South Africa, the question is whether the use of biodigesters as a source of energy offers potential solutions to some of the difficulties and development needs faced by people in these areas. At the core, this translates into whether this technology would be financially and economically feasible for installation and use by rural households. Here we conduct both a financial and an economic cost-benefit analysis in one such community based on survey data from 120 households. Analysis of these data and supporting literature reveals that a biodigester is not a financially feasible investment for a rural household. Substantial economic benefits are, however, found to make a biodigester a worthwhile investment from a broader societal perspective. This is a compelling argument for further study and the consideration of government support in the light of broader economy-wide benefits.

INTERNATIONAL CONFERENCES

Proceedings Venice 2012, Fourth International Symposium on Energy from Biomass and Waste, Venice, Italy; 12 - 15 November 2012

THE FINANCIAL AND ECONOMIC FEASIBILITY OF RURAL HOUSEHOLD BIODIGESTERS FOR POOR COMMUNITIES IN SOUTH AFRICA AND THEIR POTENTIAL TO MEET SUSTAINABLE DEVELOPMENT NEEDS.

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In South Africa, sustainable development is set in the context of two separate economies. The second of these economies consists of the rural population and is characterised by poverty and stagnant development. Sustainable development is an increasingly topical concept which highlights the need for development to proceed in a manner that does not deplete natural resources. In addition to narrowing the gaps between the various classes (layers) in an economy, the key 'ingredients' of sustainable economic development include "natural resource management, food, water, and energy access, provision and security" (Blignaut, 2009: cited in Blignaut and van der Elst, 2009: 14)[1].

A biodigester is a potential solution to some of the difficulties faced by remote rural populations. Biodigester systems are submerged tanks capable of producing a nutrient rich fertiliser and combustible gas when consistently fed with organic matter and water. A biodigester may be one simple answer to the key ingredient needs of sustainable development – reducing the depletion of natural resources, providing clean burning energy for cooking and fertiliser for growing food.

The potential is clear for biodigesters to aid in the process of sustainable development. The question to be analysed is whether this technology would be financially and economically feasible for installation and use in rural households.

This paper presents the methodology and results of research conducted in a typically remote and rural community in KwaZulu-Natal, South Africa. The appraisal takes the form of a Cost Benefit Analysis (CBA) and aims to establish whether or not this technology is financially feasible for individual rural households and/or economically beneficial to society.

[1] Blignaut J, van der Elst L. 2009. South Africa and Sustainable development: a reflection. Perspectives: Political analysis and commentary from Southern Africa. 3: 13-18.

NATIONAL CONFERENCES

Alternative fodder sources to save natural grasslands: Increasing Napier grass (*Pennisetum purpureum*) production with bioslurry

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ABSTRACT

Livestock production in small-holder systems is often limited by both the unavailability and low quality of feed. In the current study, the communal rangeland produces an average of 260 ton ha^{-1} of forage annually compared to 945 tons needed to meet the current livestock forage demand. Therefore, there is need to increase fodder production. In this study, the aim was to determine the effect of bioslurry as a fertilizer on Napier grass (*Pennisetum purpureum*) production to address the fodder shortage and rangeland degradation induced by overgrazing. Two experiments were carried out: (1) on-farm field trials (2) a greenhouse potted plant trial. Plant growth parameters (leaf length, number of tillers and plant height), biomass and soil chemistry were quantified and analysed, and these were all not significantly affected by bioslurry in the field experiment. By contrast, in the greenhouse trial, plant height, leaf length and biomass were significantly higher in the bioslurry treatment than in the control, producing about 75% more herbage. This suggests that supplementary feeding with Napier fodder has potential to relieve the pressure on the rangeland consequently promoting sustainable grazing. We concluded that bioslurry can be used to improve Napier grass production, thereby optimizing land area use enabling farmers to produce higher biomass to feed more cows on marginal land.

Key words: *Biomass, Carrying capacity, Communal rangeland, Growth rate, Soil nutrients.*

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BUSINESS MANAGEMENT CONFERENCE 2011

COMPREHENSIVE AND TARGETED COST-BENEFIT ANALYSIS (CBA) FOR RURAL DEVELOPMENT PROJECTS IN AFRICA

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ABSTRACT

CBA is an established and versatile procedure that involves the identification and assessment of the costs and benefits relating to a particular project. In terms of sustainable development, it holds great merit as it offers the capacity for all-encompassing feasibility assessment, especially where social and environmental impacts need to be assessed simultaneously. CBA is supported by a substantial body of theoretical and empirical work. This paper is intended to build on and contribute to this knowledge by reviewing the purpose, procedures and outcomes of CBA for rural development projects in an African context. With reference to a newly initiated project piloting the introduction of biogas technology in a rural area of KwaZulu-Natal, this paper considers three main aims of CBA: to evaluate a project as comprehensively as possible and deliver a critical feasibility assessment; to present the analysis in a manner that convincingly proves the worthiness of a project to the stakeholders, government or funding parties; and – possibly of greatest importance in relation to rural development – to conduct the analysis and present the outcomes in a way that encourages 'buy-in' from the relevant communities themselves.

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Presentation by Michael Smith at the Energy Post Graduate Conference in Somerset West on 14th August 2013: Exploring a systems approach for the economic assessment of small-scale anaerobic biodigesters for rural areas.

Presentation by Prof. Cristina Trois of UKZN at "The first international seminar on Energy from biomass and waste in Africa" (hosted by the International Waste Working Group [IWWG]). WRC Project K5/1955 information was provided for the presentation and introduced as a current activity in South Africa.

Presenation by Mike Smith "Alternative options for water, energy and food: a Green village concept" at the Water Research Commission's Ecosystem research and innovation symposium. Hartebeespoort, 17-18 February 2015

THESIS ABSTRACTS

The following section comprises the abstracts and summaries from the theses of the PhD and MSc candidates:

Londiwe Magagula	**BSc Honours**
Magatshavha Fhatuwani Meshack	**BSc Honours**
Landiwe Thandeka Zondi	**MSc**
Mthokozisi kwazi zuma	**MSc**
Michael T Smith	**MCom**

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The effect of bioslurry on Napier grass (*Pennisetum purpureum*) production

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In the School of Life Sciences
College of Agriculture, Science and Engineering
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Pietermaritzburg
2013

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ABSTRACT

Increasing fodder production has become essential in the context of diminishing natural grazing veld for livestock in rangeland systems. In the current study an area of 218 ha produces an average 260 ton of forage yr^{-1} compared to 945 tons yr^{-1} needed to meet the current livestock forage demand. Therefore, the main aim of this study was to determine the effect of bioslurry as a fertilizer on Napier grass (*Pennisetum purpureum*) production to serve as an alternative fodder source to address fodder shortage and rangeland degradation induced by overgrazing. Two experiments were carried out: (1) an on-farm field experiments at three rural homesteads in the Upper Thukela region and (2) a greenhouse experiment at the University of KwaZulu-Natal. Plant growth parameters (length of longest leaf, number of tillers and plant height), biomass and soil chemistry were quantified and analysed using Generalised Estimating Equation model (GEE), Randomised block Analysis of variance (RANOVA) and a one sample independent t-test, respectively. All plant growth parameters including biomass and soil chemistry in the field experiment were not significantly different ($p > 0.05$). Contrary, plant height ($p = 0.002$) and leaf length ($p = 0.004$) were significantly different to the control in the greenhouse experiment. Furthermore, biomass was significantly different to the control ($t_{0.5,\ 24} = 2.688$ and $p = 0.015$), producing about 75% more herbage. Using current grazing capacity method by Tainton (1999), if Napier grass is grown with bioslurry adjacent to the communal grazing area of 218 ha, approximately 37 ha will be sufficient to meet current forage demand and take the grazing pressure off the rangelands compared to 79 ha if the grass is grown without bioslurry. The results show that bioslurry can be used as a fertilizer to improve Napier grass production in Upper Thukela communal rangelands.

Key words: *Biomass, Bioslurry, Carrying capacity, Communal rangeland, Growth rate, Tillers.*

AN ASSESSMENT OF RURAL HOUSEHOLD BIOGAS POTENTIAL AND NEED IN SOUTH AFRICA:

A CASE STUDY IN MAKHADO LOCAL MUNICIPALITY OF LIMPOPO

By

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A project report submitted in partial fulfillment of the requirements for the degree of Bachelor of Science Honours in Physics

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ABSTRACT

Limpopo Province is the poorest province of the country, manifesting highest percentage of its population living below all the three poverty lines used in StatsSA 2012, that is, the food poverty line, the lower-bound poverty line and finally the upper-bound poverty line. Although the government has tried to improve electric grid coverage throughout the country including the province of Limpopo, the modern energy is still unreachable for many. Electricity is mainly used for lighting and powering radios and televisions resorting mostly to firewood for the cooking and heating energy needs. However, most places in Limpopo and Makhado in particular have vast options of renewable energy sources. By virtue of its relatively good agricultural climatic conditions, many households can benefit from exploiting the existing potential of cheap and multi-beneficial biogas technology to replace the dirty, time consuming and in some instances also expensive firewood. So considering the present energy scenario in the province it is of interest to developmental agents from both national government, provincial down to municipal and non – government to get an assessment of the potential, that is, theoretical, economical, realizable and technical of such a promising technology. Also important is to assess whether it is necessary to consider the option of biogas in Makhado, in other words is there any need for the biogas technology in the community households.The present study project is derived from the tasks of the bigger Water Research Commission (WRC Project K5/1955) funded project with the title, "Improving the livestock carrying capacity with rainwater harvesting and conservation on grasslands for extensive and/or intensive livestock production and biogas generation from manure in rural areas of South Africa" implemented in three provinces of Limpopo, Eastern Cape and Kwa Zulu Natal through a collaboration of the Universities of Venda, Kwa Zulu Natal, and Rhodes. The overall aim of the study would then be to assess the biogas potential and to establish the need of using biogas in rural areas of Vhembe district, in particular Makhado Municipality ward 19 as a case study. It is very important to then document the biogas potential on these communities as this would sensitize the municipality of Makhado about the importance of biogas technology in reducing poverty. A baseline survey to determine the level of awareness and acceptability of biogas as source of energy for domestic purposes and financial and economic feasibility of biodigester use and biogas production for rural households in communities of ward 19 in Makhado was done. From the survey it has been established that although suitable conditions exist for the implementation of biogas technology, there are some challenges especially in the more urban households. The livestock population is low in these places. However for those areas in the outer periphery of the communities where people are still living with their livestock and practise some farming at the backyard, the technology can be a real solution. As for the need of the biogas, the surveyed communities showed great need of substitute of the dirty firewood energy and as they claim the ever increasing price electricity.

GROWTH PERFORMANCE, CHEMICAL COMPOSITION AND SILAGE QUALITY OF NAPIER (*PENNISETUM PURPUREUM*) AND GUINEA (*PANICUM MAXIMUM*) FODDER IRRIGATED WITH BIO-DIGESTER SLURRY

BY

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A dissertation submitted in fulfillment of the requirements for the degree of

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2014

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ABSTRACT

The objectives of study were to determine the growth performance, chemical composition and silage quality of Napier (*pennisetum purpureum*) and Guinea (*panicum maximum*) fodder irrigated with bio-digester slurry. Poultry and cattle bio-digester slurry and borehole water were used to irrigate the fodder at Maila and Nthabalala respectively. Two treatments of irrigation with or without bio-digester slurry were used in a complete randomised block design. Napier cuttings with three nodes were planted, two nodes in the ground and one above ground level at an angle of about 30 - 45°. Sterilized Guinea grass seeds were sown at the rate of 3 kg/h at a depth of 1 cm. The Panicum grass was banded in rows spaced at 75 cm apart and then after germination were thinned to 75 cm within the row. Turkey's procedure was used to compare treatment means. The slurries were characterised by mineral B, Cu, Mn and Mo mineral deficiencies. Mineral content in poultry and cattle slurry was N>K>Mg>P>Ca. Micronutrients were significantly ($P < 0.05$) low (< 30 ppm) in bio-digester slurry. Irrigating the fodder with bio-digester slurry or borehole water only did not affect ($P > 0.05$) number of tillers, leaves per plant, the height of the grass and the longest leaves length (in cm) and yield of the Napier and Panicum fodder. The stage of maturity at harvesting affected ($P < 0.05$) the quality of the Napier fodder. Napier fodder ash, nitrogen detergent fiber (NDF) and acid detergent fiber (ADF) increased ($P < 0.05$) with maturity. Napier fodder dry mater (DM) increased while CP decreased ($P > 0.05$) with increase in the stage of maturity. Panicum fodder DM and ash increased with maturity until late stage of maturity while Crude protein (CP) decreased ($P > 0.05$). Ash, NDF and ADF increases with maturity though they were not statistically significant ($P > 0.05$). Panicum fodder was not ensiled because it failed to establish well at Nthabalala and at Maila because both Napier and Panicum were grazed by cattle from the surrounding village. Ensiled Napier fodder from Nthabalala with four additives replicated four times did not differ significantly ($P > 0.05$) in their physical properties. The DM, CP, NDF, ADF and ash contents did not differ significantly ($P > 0.05$) of all the silages. All the silages were of good quality except the control with a pH value of 6.2 which is a reflection of low quality silage. The minerals were not significantly different except for Mn in maize that was significantly higher of all the silages. After six weeks of ensiling, the pH was 3.5 - 4.5. It was concluded that application of

bio-digester slurry as nitrogen fertilizer had positive effect on CP of the Napier fodder at late stages of maturity. The additives (molasses, sugar and maize) were added at 10% of the total weight of the chopped material and had a positive effect in the fermentation quality of silage.

Key words: Napier. Panicum. bio-digester slurry. fodder. irrigation. silage

AGES OF MATURITY ON THE PRODUCTIVITY AND CHEMICAL COMPOSITION OF NAPIER GRASS (*PENNISETUM PURPUREUM*) UNDER FLOOD IRRIGATION

BY

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A MINI-DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN AGRICULTURE (ANIMAL SCIENCE)

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2014

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ABSTRACT

The production and chemical composition of Napier grass (*Pennisetum purpureum*) under irrigation harvested at different stages of maturity was studied. Napier grass was planted by early March at the school of agriculture experimental farm (22°58'32"s, 30°26'45"e; 596 m above sea level), University of Venda, in 6 plots of 5 x 4m. Napier cuttings with 3 nodes were planted, two nodes into the ground and one up. Irrigation using water was done once on a weekly basis. Growth measurements were done once in every two weeks and were used to analyze the mean differences for the fodder growth stages. All parameters were subjected to General Linear Model procedure of statistical analysis system (SAS) software MINITAB version 16. The stages of maturity had significantly difference (at $p < 0.01$) in terms of longest leaf length per plant and plant height while no significant difference were observed on number leaves per plant and number of tillers.

The interval of cutting the grass was 4 weeks whereby it was firstly cut on the 22nd of May (early growing stage), secondly on the 23rd June and lastly on the 22th July (late stage), and then harvested to determine biomass. Samples taken at different stage were analyzed for chemical composition. The dry matter, CF, and ADF content showed an increase with increase in harvest day. The stages of analysis had significantly difference (at $p < 0.01$) in terms of DM, moisture, CF and ADF while for ash no significant difference was observed at all different stages of maturity as well for OM

KEYWORDS: stage of maturity, dry matter, crude fiber, acid detergent fiber, ash

Challenges in Fodder Production in Machubeni, Eastern Cape, South Africa

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Abstract

Livestock production is an essential component of the agricultural sector, directly supporting the livelihoods of millions of small-holder farmers and providing a range of social and economic benefits. Livestock production in small-holder systems is often limited by both the unavailability and low quality of feed. There is a need to improve the availability of forage for livestock which plays such a key role in people's livelihoods. The aim of this study was to determine what proportion of households grew fodder in Machubeni, Eastern Cape and to investigate the challenges faced by small-holder farmers in growing fodder. Data were collected through two sets of questionnaires issued at the household level. Key results showed that only 23.6% of the farmers sampled grew fodder. Overall the farmers had a positive attitude towards the growing of fodder. The biggest challenge identified by fodder growers was that they were often limited by the affordability of inputs such as tractors and seeds. Other challenges included; unreliable rainfall, lack of fencing and insufficient knowledge about fodder species. There is a need for extension officers to provide information and to support these farmers to help address these challenges and help improve a valuable part of their livelihood.

Keywords: Animal nutrition, Avena sativa, livestock production, small-holder farmers.

THE USE OF BIOSLURRY FOR FODDER PRODUCTION IN SUSTAINABLE CROP AND LIVESTOCK PRODUCTION SYSTEMS BY SMALLHOLDER FARMERS

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Submitted in fulfilment of the academic requirements for the degree of

MASTER OF SCIENCE (CROP SCIENCE)

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ABSTRACT

Livestock play a major role in the livelihoods of smallholder farmers in the rural areas of South Africa. In these areas livestock are continuously grazed in the natural rangelands (veld) for most of the year. This exerts a high grazing intensity on the veld and can result in compaction, soil degradation, increased run-off, loss of palatable grass species, poor veld condition and affect long-term sustainable productivity.

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In the sour veld areas of the Upper Thukela grazing livestock in the veld in winter is a major problem because the nutritive quality of the grasses is low. This means that there is a need to find alternative feed sources in order to ensure and maintain animal performance. The use of fodder crops could provide such alternatives and also reduce the pressure on the rangeland to allow a rest period and ensure long-term sustainable productivity. One option is to implement a semi zero grazing system whereby livestock are provided fodder during overnight kraaling and when the rangeland is under pressure.

For example, sorghum (*Sorghum bicolor*) is an ideal forage crop because it grows quickly and has a high yield potential. The species is rich in nutrients and is consumed as grain. Another potential fodder crop is cowpea (*Vigna unguiculata*) which is a nitrogen-fixing legume crop which is drought tolerant and adapted to warm climatic conditions. Cowpea can be intercropped with crops such as sorghum, maize and millet. These fodder crops can be fed to livestock in winter and the animal-excreta can be used to produce biogas. Liquid effluent from the anaerobic digestion of the manure and water in the biodigester can be used as organic fertilizer to provide important plant nutrients such as nitrogen (N) and phosphorus (P). This has potential to address the problem of infertile soils which limits yield in the Upper Thukela. The biogas slurry (organic fertilizer) can be applied on fields used for fodder production thus developing an integrated crop/livestock system for smallholder farmers in the Upper Thukela and similar production systems in South Africa.

There is little information on the use of bioslurry for fodder production in South Africa and the effect on soil chemical properties. The aim of the study was to establish whether bioslurry could be used as a nutrient source for fodder production and secondly, to determine whether this could contribute to sustainable livestock-crop production systems among smallholder farmers in the Upper Thukela, South Africa. The specific objectives were (1) to conduct on-farm trials to determine the effect of bioslurry on growth, biomass and nutritive quality of cowpea and sorghum fodder; (2) to determine the N and P release patterns from bioslurry in two contrasting soils (acidic and non-acidic) sampled from two farms in the Upper Thukela and (3) to assess the impact of using cowpea and sorghum fodder for supplementary feeding on the current grazing carrying capacity (AU ha^{-1}).

On-farm trials were conducted at two rural homesteads (New Stand and Potshini) in the Upper Thukela. The trials were established at each homestead using a randomized complete block design (RCBD) as a 3 x 2 factorial experiment with the following factors: fertilizer (3 levels – mono-ammonium phosphate (MAP), bioslurry and control (no fertilizer); fodder species (2 levels – cowpea and sorghum) replicated 3 times giving a total of 18 experimental units (plots measuring 5 x 5m). Bioslurry was applied at a rate of 20 litres bi-weekly per 5 x 5 m plot. MAP was applied at 100 kg ha^{-1} following the soil fertility and crop nutrient recommendations from the soil nutrient analysis. For the cowpea fodder species, data were collected on the number of trifoliate leaves and for sorghum fodder, crop leaf number and plant height were measured. Biomass was determined for both fodder species and dried samples were analyzed for plant nutrient concentration. The statistical package Genstat version 14 was used for the analysis of variance (ANOVA) to determine whether there were significant differences and interactions between treatments. Treatment means were compared using the LSD at the 5% level of significance.

The results from the on-farm trials at New Stand and Potshini showed that bioslurry, MAP fertilizer and control had no significant effect ($P>0.05$) on cowpea and sorghum fodder yield. Sorghum yield in New Stand ranged between 3.75-5.47 kg m^{-2} for the applied treatments (control, bioslurry and MAP), the highest yield was recorded for MAP. Cowpea yield was higher ranging between 4.97-6.73 kg m^{-2} for the applied treatments in New Stand with the highest yield also recorded for MAP treatment. In Potshini, cowpea and sorghum yield were lower than at New Stand. The highest sorghum yield was recorded in the MAP treatment (3.09 kg m^{-2}) compared to the bioslurry (2.14 kg m^{-2}) and control (1.8 kg m^{-2}) treatments. For cowpea in Potshini, MAP had the highest yield (5.33 kg m^{-2}) compared to the bioslurry (4.93 kg m^{-2}) and control (3.7 kg m^{-2}) treatments. The fertilizers did not have a significant effect ($P>0.05$) on the number of cowpea trifoliate leaves in New Stand. Similar findings were observed in the Potshini trial. The treatments (MAP, bioslurry and control (no fertilizer) had no significant effect ($P>0.05$) on sorghum height at New Stand and Potshini. Except for nitrogen no significant differences ($P>0.05$) were observed between the treatments with respect to sorghum nutritive quality. Sorghum nitrogen ranged from 1.93-2.10 % for all the treatments in the New Stand trial. Similar findings were observed for cowpea nutritive quality in both trials. Cowpea nitrogen ranged 4.52-5.23 % for all the treatments in Newstand trail. Soil N increased in the Newstand trial after harvesting for all the treatments in sorghum and cowpea plots. In Potshini, soil N decreased in cowpea plots and increased in sorghum plots for all the treatment applied.

One factor that may influence the uptake of nutrients from bioslurry is their accessibility to the plant. However, the information on the nutrient release patterns in relation to application rates of bioslurry is scarce. An incubation study was therefore conducted to determine the N and P content and the release patterns from bioslurry in two contrasting soil types (acidic and non-acidic) which represent the soils of the study area. The experiment was laid out in a completely randomised design as a 3 x 4 x 14 factorial treatment structure with the following factors: soils (3 levels - non-acidic, acidic unlimed and acidic limed); bioslurry application rate (4 levels – 0.0, 2.1, 4.2, 10.5 g kg^{-1}); incubation period (14 levels - 0, 1, 2, 4, 7, 14, 21, 28, 35, 42, 49, 56, 63 and 70 days) replicated 3 times.

Plastic tubs had holes drilled in the sides to allow for aerobic conditions. One kilogram of soil (passed through a 2 mm sieve) was weighed into each tub. Water was added to each tub containing 1kg soil with the treatment and it was maintained at 70% water holding capacity. Moisture corrections were made weekly after calculating weight loss to maintain the water content throughout the experiment. The incubation temperature was maintained at 25^{0}C. Inorganic nitrogen (ammonium-N and nitrate-N), phosphorus (P) and pH were analyzed during the incubation period. Inorganic nitrogen was analyzed using a discreet analyzer (Thermo Gallery, Thermo Scientific) after extracting with 2M KCl. Phosphorus was analyzed using the molybdenum blue method after extracting with AMBIC solution. Soil pH was extracted using 1M KCl and water using a 1:5 soil: KCl/water ratio. pH was analyzed using a PHM 210 pH meter.

Ammonium-N concentration decreased for all the bioslurry application rates (2.1, 4.2 and 10.5 g kg^{-1}) in all the soils (non-acidic, acidic unlimed and limed). There were no significant differences in ammonium-N concentration ($P>0.05$) between the different bioslurry rates applied on the non-acidic soil samples during the 70 day incubation period. Similar results were observed for ammonium-N in the unlimed and limed acidic soils. Nitrate-N did not increase during the incubation period in all the three soils (non-acidic, acidic unlimed and limed). The results showed that there were no significant differences in nitrate-N concentrations ($P>0.05$) between bioslurry application rates during the incubation period for non-acidic soil. Phosphorus increased with time during the incubation study in all the three soils and P release in non-acidic soils increased with increasing bioslurry application rates. Phosphorus content at the end of the incubation on day 70 after applying the rate of 10.5 g kg^{-1} was 49.89 mg kg^{-1} in the non-acidic soil and 21.15 mg kg^{-1} in the acidic soil. Similar findings were observed for the acidic limed soils, (20.19 mg kg^{-1} at 10.5 g kg^{-1} bioslurry application rate after 70 days).

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The major findings of this study show that phosphorus increased with the increased application rate of bioslurry. Phosphorus increased with the increase in pH indicating that phosphorus release to the soil is pH dependent. Ammonium-N decreased during the incubation study for all the bioslurry application rates. However, the nitrate-N concentration did not increase which suggests that ammonium-N was not converted to nitrate-N. This suggests that immobilization of nitrates impacted the nitrate-N levels during the incubation study. Other factors that may affect accessibility of nutrients to plants are environmental factors such as rainfall which may lead to volatilization and leaching of nutrients. Furthermore, the application methods of bioslurry, the amount applied and the time of application are important factors that may affect nutrient uptake and require further research.

The yield results from the on-farm trial at Potshini were used to present a case study on the potential of supplementary fodder to address the problem of fodder shortage for livestock in communal rangelands and assess its impact on the carrying capacity. The communal rangeland at Potshini is 1.7 times overstocked and the grazing regimes in Potshini have resulted in poor veld condition (41.4%) and low forage production which has negative impacts on the ecosystem services in the area. The dry matter production of the communal rangeland in this area (218 ha) is 260 tons of forage per year which does not fulfil the fodder requirement of the 378 cattle owned by the community (710 tons). The results of this study indicated that producing fodder for livestock in communal areas has potential to meet the fodder shortage. The current findings showed that cowpea produced higher yields (3.70-5.33 ton ha^{-1}) when compared to sorghum (1.8-3.09 ton ha^{-1}) and the natural rangeland (1.195 tons ha^{-1}). This indicates that cowpea requires about 91-121 ha of land to produce sufficient fodder while sorghum requires about 146-250 ha of land depending on the fertilizer treatments, to meet the forage deficit. Considering the limited availability of land in the area, cowpea would be recommended for farmers because of its nutritive quality, higher yields and its agronomic qualities such as drought tolerance and ability to fix nitrogen in the soil.

In conclusion, the results of the on-farm trial demonstrated no significant differences between the bioslurry, MAP fertilizer and control in both sorghum and cowpea growth and yield. No positive impact of MAP fertilizer could be associated with fertilizer application levels in the soil. The laboratory incubation study indicated that bioslurry released mineral-N in the form of ammonia in the soil; however, this ammonium-N was not converted to nitrate-N during the incubation. Since bioslurry may have a slower nutrient release pattern than the 70 day incubation study, long-term field experiments are recommended to determine the mineralisation potential of bioslurry over several seasons of application. Phosphorus was also released during the incubation study and increased with the increase in bioslurry application rate and pH for all the soils. This implies that bioslurry can supply phosphorus to the soils and this can be accessible to plants. The case study showed that sorghum and cowpea have potential for the implementation of a semi-zero grazing systems since the higher production of these crops can supplement the low production of the natural rangeland and reduce the grazing pressure on the natural rangeland.

UNIVERSITY OF KWAZULU-NATAL

THE FINANCIAL AND ECONOMIC FEASIBILITY OF BIODIGESTER USE AND BIOGAS PRODUCTION FOR RURAL HOUSEHOLDS

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Submitted in partial fulfilment of the requirements for the degree of
Master of Commerce

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ABSTRACT

In South Africa, sustainable development is set in the context of two separate economies. The second of these economies consists of the rural population and is characterised by poverty and stagnant development. Sustainable development is an increasingly topical concept which highlights the need for development to proceed in a manner that does not deplete natural resources. In addition to narrowing the gaps between the various classes (layers) in an economy, the key 'ingredients' of sustainable economic development include "natural resource management, food, water, and energy access, provision and security" (Blignaut, 2009: cited in Blignaut and van der Elst, 2009: 14).

A biodigester is a potential solution to some of the difficulties faced by remote rural populations. Biodigester systems are submerged tanks capable of producing a nutrient rich fertiliser and combustible gas when consistently fed with organic matter and water. A biodigester may be one simple answer to the key ingredient needs of sustainable development – reducing the depletion of natural resources, providing clean burning energy for cooking and fertiliser for growing food.

The potential is clear for biodigesters to aid in the process of sustainable development. The question to be analysed is whether this technology would be financially and economically feasible for installation and use in rural households.

This thesis focuses on a typically remote and rural community in KwaZulu-Natal, South Africa, in order to assess the potential feasibility of a biodigester system. The appraisal takes the form of a Cost Benefit Analysis (CBA) and aims to establish whether or not this technology is financially feasible for individual rural households and/or economically beneficial to society.

Data storage

All processed data have been stored at:

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