# THE USE OF BIOSLURRY FOR FODDER PRODUCTION IN SUSTAINABLE CROP AND LIVESTOCK PRODUCTION SYSTEMS BY SMALLHOLDER FARMERS

**by**

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## PREFACE

The research contained in this dissertation was completed by the candidate while based in the Discipline of Crop Science, School of Agricultural, Earth and Environmental Sciences of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, PMB, South Africa. The research was financially supported by Water Research Commission (WRC) and National Research Foundation (NRF).

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

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## DECLARATION

I, Mthokozisi Kwazi Zuma, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

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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. 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. The use of fodder crops could provide an alternative and also reduce the pressure on the rangeland to allow a rest period and ensure long-term sustainable productivity. Sorghum (*Sorghum bicolor*) and cowpea (*Vigna unguiculata*) are potential crops that could be produced by farmers because they grow under drought conditions and they are nutrient rich crops which can be intercropped. 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). 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. Growth and yield were measured for both sorghum and cowpea species .Nutritive quality was also analysed for soil and plant samples. No significant differences were observed between MAP, bioslurry and control treatment with respect to growth characters, yield components and nutritive quality in both on farm trials. Sorghum yield in New Stand ranged between 3.75 to 5.47 kg $m^{-2}$ for the applied treatments (control, bioslurry and MAP), the highest yield was recorded for MAP. Cowpea yield ranged between 4.97 to 6.73 kg $m^{-2}$ for the applied treatments in New Stand. In Potshini, there were no significant differences on yield. Sorghum yield ranged from 1.8 kg $m^{-2}$ to 3.09 kg $m^{-2}$ and cowpea ranged from 3.7 kg $m^{-2}$ to 5.33 kg $m^{-2}$. An incubation study was 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. Ammonium-N concentration decreased for all the bioslurry application rates in all the soils (non-acidic, acidic unlimed and limed). There were no significant differences in ammonium-N concentration 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. Results showed that there were no significant differences in nitrate-N concentrations between bioslurry application rates during the incubation period for non-acidic soil. 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. 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. The study concluded that although there were no significant differences, bioslurry remain the potential source of organic fertilizer for fodder production in smallholder farming systems.

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My family especially my mother for the support she gave to me during the stressful times

*Ngibonga angiqedi kubo bonke abadlale indima kwizifundo zami ze- masters. Nkulunkulu anibusise. Amen*

# DEDICATION

*This work is highly dedicated to my late brother Dumsani H. Zuma and his wife M.C Zuma for their contribution and the role they played in my life.*

*Secondly it is dedicated to my lovely daughter Kwandokuhle Luthabo Zuma whom I believe one day will read this work and be proud*.

*To God almighty*

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# LIST OF ABBREVIATIONS

ADF- Acid Detergent Fibre

Al- Aluminium

Ca- Calcium

Cu- Copper

Fe- Iron

K- Potassium

MAP- Mono-Ammonium Phosphate

Mg- Magnesium

Mn- Manganese

N- Nitrogen

Na- Sodium

NDF- Neutral Detergent Fibre

P- Phosphorus

S- Sulphur

WRC- Water Research Commission

Zn- Zinc

# CHAPTER ONE: GENERAL INTRODUCTION

Livestock play a major role for smallholder farmers in the Upper Thukela region (Everson et al., 2012). Livestock, especially cattle, provide animal traction, income, meat and milk. In communal areas the natural rangeland is the main source of feed for cattle. In these areas livestock owners overstock and overgraze in the range which results in decline of quality grasses especially in winter season when grasses are dormant. In addition, current grazing regimes in communal areas results in poor veld condition and soil degradation caused by overstocking and cattle movement in the range. There is need to introduce alternative grazing systems that could reduce the pressure on natural rangelands during the winter season.

Provision of quality feed sources such as cowpea and sorghum can increase cattle production. The benefit of fodder provision in the homesteads includes resting of the range in winter when the nutritive value of grasses is dormant thus improving the soil cover. Secondly, cattle are fed sufficient quality feed in the homestead and thirdly, through this grazing system animal manure can be easily collected for feeding biogas digesters. The manure can be used in the production of biogas energy which could be used for cooking and lighting (Islam et al., 2010). The effluent which is bioslurry can then be used as organic fertilizer for fodder production (Warnars and Openoorth, 2014).

The potential of recycling nutrients from animal waste back to the soil could provide a basis for the development of simple and integrated systems/technologies that could lead to improved and sustainable livestock and crop production systems by smallholder farmers. Such systems could include the production of fodder crops as an alternative source for animal feed particularly during the winter season when forage quantities and quality are low in the natural grasslands. The animal waste from feeding on the fodder crops could be used for biogas production which could lead to savings on electricity. The bioslurry could then be incorporated into farm lands for the production of fodder and other crops.

Organic fertilizer sources such as bioslurry processed from animal excreta and plant and animal materials have been used in many farming communities as sources of plant nutrients (Tambone et al., 2010). Depending on the fodder species, approximately 70-80 percent of the nitrogen (N), 60-85 percent of the phosphorus (P) and 80-90 percent of the potassium (K) fed to animals is excreted in the manure (Sommerfeldt et al., 1988). Additional benefits could include enriching the soil organic matter and contributing to improved soil physical properties such as better water infiltration, soil water retention and aeration (Gurung, 1997). However the major limitation to the use of organic fertilizer sources including bioslurry could be the relatively low mineral nutrient concentrations compared to inorganic fertilizer (Ahmad et al., 2006). The low mineral nutrient concentrations could require labour-intensive handling because of the relatively high volumes needed to meet crop nutrient requirements. This can be very expensive especially if large volumes of animal manure have to be transported to distant farms (Al Seadi, 2008). The problem of transporting large amounts of organic fertilizers could be minimized if for example, bioslurry produced in homesteads is re-used for fodder production in the same farm/locality thus eliminating the need for transportation.

Bioslurry can be considered as a slow release fertilizer and the availability of nutrients for plant growth at critical stages of crop development would be greatly influenced by the rate of mineralization, soil microbial activity, pH and temperature (Chiyoka, 2011). The amount of nutrients contained in bioslurry and their eventual uptake by plants could vary considerably from farm to farm (Al Seadi, 2008). Nutrient content and availability could depend on: the composition of the feed ration; the amount of water added or lost from the feed; methods of manure collection and storage; methods and timing of application; and soil characteristics and the crop to which the manure is applied and environmental variables such as rainfall or dry weather conditions during the time of application (Lukehurst et al., 2010; Singh et al., 1996; Makadi et al., 2012).

Key to the success of using bioslurry for fodder production in integrated/crop livestock systems is knowledge and a clear understanding of the processes that influence nutrient content in the feed and bioslurry, the processes of decomposition, microbial activities and soil conditions including pH that influence the mineralization of N and P. In addition an understanding of the methods and timing of the application of bioslurry and how these impact fodder production and yield is critical to the development of integrated and sustainable crop and livestock production systems that incorporate fodder and biogas production.

## Aims and Objectives

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 Upper Thukela, South Africa.

The specific objectives were:

1. To determine the effect on bioslurry application on growth, biomass yield and nutrient content of cowpea and sorghum fodder at two rural homesteads in the Upper Thukela
2. To determine the N and P release from bioslurry in two contrasting soils (acidic and non-acidic) sampled from two farms in Upper Thukela
3. To assess the impact of using cowpea and sorghum fodder for supplementary feeding on the current carrying capacity (AU $ha^{-1}$).

## Hypotheses

1. Bioslurry will have impact on both cowpea and sorghum fodder growth, yield and nutrient content
2. The release patterns of N and P will increase with bioslurry application rate and time for all the contrasting soils
3. Supplementing with cowpea and sorghum fodder will reduce the pressure on natural rangelands

**Dissertation Structure**

Chapter 2 reviews the literature on the importance of fodder production in communal areas, the dependency on natural rangelands for grazing livestock and the potential benefits of utilizing bioslurry as an alternative fertilizer source for increasing the production of fodder.

Chapter 3 explores the effect of bioslurry on cowpea and sorghum fodder in two on-farm trials in Upper Thukela.

Chapter 4 describes the 70 days incubation study and the nutrient release patterns of bioslurry, with a special focus on N and P release and soil pH.

Chapter 5 presents a case study on the potential of cowpea and sorghum fodder (produced with and without bioslurry) to meet the forage demand at Potshini in KwaZulu-Natal. The results will be used to develop recommendations on the potential of bioslurry as a fertilizer on fodder production and enable farmers to select options that will benefit the grazing capacity of communal rangelands.

Chapter 6 is a general discussion of the potential use of bioslurry as an alternative fertilizer for fodder production. It also includes the recommendation for future work.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Introduction

Livestock and crop farming have great potential to contribute to the alleviation of household food insecurity and poverty in communal areas of South Africa (Valbuena et al., 2012). Farming systems that integrate both livestock and crop production could improve crop production through the provision of animal manure. Animal manure can be used as organic fertilizers and applied to maintain soil fertility in smallholder farms where the high costs of inorganic fertilizer limit agricultural productivity. Therefore, the role of animals in nutrient cycling is key to improved productivity and livelihoods especially in communal areas where farmers are tagged as "resource poor" (Steinfeld et al., 2006).

In most communal areas of South Africa livestock such as cattle, goats and sheep are overnight kraaled for security (Salomon, 2011). Benefits of overnight kraaling include easy collection of animal manure and floor polishing (*ukusinda* in Zulu). Additional benefits also include the use of dung for biogas production. In the study site four biogas digesters were installed and they are mainly fed cow dung mixed with water. Biogas is used as an energy source for cooking purposes. The by-product of biogas production is bioslurry, the digested nutrient rich effluent (Smith, 2011). The effluent may be used as organic fertilizer for food and fodder production. This chapter reviews the potential use of bioslurry as a plant nutrient source for fodder production in the context of sustainable crop-livestock production systems among smallholder farmers.

This review will cover the following topics:

Livestock grazing regimes in South African communal areas

Impact of continuous grazing and cattle movement on communal rangelands

Fodder provision as an alternative grazing system to continuous grazing system in communal areas

The use of fodder for integrated crop/livestock systems

## 2.2 Livestock grazing regime in South African communal areas

Livestock play a major role in the livelihoods of rural communities. Livestock are kept for various uses such as cash income, milk, capital, draft power, meat, manure and socio-cultural uses (Everson and Hatch, 1999; Everson et al., 2012). They supplement crop production activities through provision of manure for soil fertility maintenance and animal traction for cultivation (Powel et al., 2004). In addition, livestock play a major role in smallholder farming systems and provide livelihoods benefits" (Mutibvu et al., 2012). Besides being a source of nutrients manure is used for other different purposes mainly floor polishing and in some places it is used as fuel where fire wood is scarce.

In communal areas livestock holding may vary from a few to hundreds depending on the financial status of the farmer/household. Livestock species include cattle, sheep, goats, donkeys and horses (Nqeno et al., 2011). Of these, cattle are regarded as the most important due to the various roles that they play in local cultures. Agricultural productivity in communal areas is generally low productivity (Mapiye et al., 2009). This has been attributed to the fact that communal farmers may have different production aims compared to commercial farmers. (Mutibvu et al., 2012). In communal areas of South Africa, livestock production could be affected by climate change, livestock theft (Salomon, 2011), environment and feed shortages.

Nqeno et al. (2011) reported that to improve livestock productivity on communal rangelands, greater attention should be on the interaction between livestock and their management. Cattle productivity in communal areas may also be constrained by lack of knowledge on herd dynamics, cattle nutrition, seasonal variation and environment (Mapiye et al., 2009).

In South Africa, rangelands are broadly divided into three veld group in terms of grazing namely sourveld, sweetveld and mixed veld (Tainton, 1999). Sourveld is the veld that is palatable only in the growing season whereas sweetveld is palatable and nutritious all year. Mixed veld is an intermediate of sourveld and sweetveld (Smith, 2006).Sourveld generally occurs in areas that receive about 600 mm to 800 mm of rainfall per year and consist of perennial grasses which lose their nutritive value and palatability during winter. By contrast, sweet rangelands comprise annual grasses that are palatable all year long (Tainton, 1999) and receive less than 500 mm of rainfall per annum.

In communal areas where sourveld are the primary feed sources available for livestock; farmers struggle with shortage of quality forage during the winter season. In the Upper Thukela region of South Africa livestock are kept grazed on the range during the growing season and in winter after harvesting in the maize fields they are grazed closer to homesteads in the fields. They are grazed on maize stover as a way to supplement livestock feed during the winter season when rangeland when the palatability of grasses has decline (Everson et al., 2012) This practice does not only aid with feeding only but it also helps farmers to monitor their cattle and vaccinate if diseases and pest are spotted. In addition, this helps with dung collection and overnight kraaling.

Insufficient information on grazing management by communal farmers is one of the constraints that limit proper range management (Stroebel, 2011). In communal areas, farmers use their local indigenous/traditional knowledge to manage their livestock; and therefore there is a need to supplement local knowledge with new scientific knowledge and technology on rangelands management (Gura, 2008).

### 2.3 Impact of grazing regimes and cattle movement on communal rangelands

The current grazing regime in communal areas results in grass deterioration. Livestock are continuously grazed in the rangeland without resting. Continuous grazing on the range for a long time by cattle without changing the camp may cause decline in grasses and result in the degradation of soils (Chonco, 2009). Reasons for continuous grazing by communal farmers vary and include the lack of resources such as fencing for dividing camps. This then leaves local farmers with no option but to let livestock graze freely and continuously on the range. Stocking density can also cause soil compaction and destroy the soil structure. This may affect the infiltration rates and increase the risk of soil erosion and consequently nutrient losses which would negatively impact the long-term productivity and sustainability of the veld (Ratsele, 2013).

It is essential that proper grazing management is developed to ensure that the rangeland is rested to ensure that soil cover develops and grasses are able to recover (Chonco, 2009). However, due to land tenure right (Everson and Hatch, 1999), livestock owners have no right to put in fencing in the rangeland which then limit the options of implementing the rotational resting system in communal areas. Therefore another form of resting that livestock owners can adopt is to provide winter fodder to enable the grasses to rest.

### 2.4 Fitting fodder provision systems in the current grazing systems

Continuous grazing is not the only limiting factor to rangeland productivity. Cattle movement is also a major challenge experienced by farmers in communal grazing areas. Cattle are herded back in nearby fields to graze on the maize stovers left after harvesting and are kraaled overnight (Everson and Hatch, 1999). In the Upper Thukela animals are kraaled overnight due to theft reasons and moved back to the range in the morning (Salomon, 2011). The movement of cattle to and from the homesteads to the veld could negatively impact on the range and affect the quality and quantity of forage. This could occur as a result of trampling and creating pathways in the rangeland, destruction of the soil structure and loss of palatable and nutritious grass species. Therefore there is need for implementation of other grazing systems that would reduce impact of these factors in winter.

Provision of fodder is one system where animals are provided with fodder without them having to move to the rangeland during the winter season. This grazing system has been widely practised by both commercial and communal livestock production systems in the sub Saharan region (Gebreyohannes and Hailemariam, 2011). It also helps with easy the collection of dung for cooking or floor polishing and manure for crop production. This system relies on the quality and quantity of forage being produced (Gebreyohannes and Hailemariam, 2011). Sufficient fodder should be produced to meet feed requirement during the winter period. The current situation in Upper Thukela, farmers produce maize for their household consumption in their homestead fields and they are only giving stover to livestock (Chonco, 2009). Stover is not enough to feed animals for the whole winter season. Other winter crops can be introduced to meet the fodder requirements in these areas.

## 2.5 The role of fodder production in managing communal rangelands

Fodder production in communal areas should aim at closing the gaps in fodder flow by ensuring that enough feed is available the whole year. Fodder production could supplement the rangeland especially in winter when the productivity is low (Grunow et al., 1984). There are several benefits that may accrue when fodder production is incorporated in the management of communal rangelands. For example, animals fed on fodder in homesteads or fields would contribute to soil fertility because of the nutrient content in the faecal droppings. The collection of dung for fuels purposes would also be easy since animals are closer (Rahman et al., 2008). In homesteads with biogas digesters dung can be fed easily to the digester without travelling long distances and the bioslurry produced from the digester can be used to fertilise the crop fields (Al Seadi, 2008). Fodder crops can also act as cover crops and provide soil cover during the dry season when rainfall is scarce which could contribute to soil moisture conservation. Plant residues from the fodder crops could also be used to improve the soil organic matter.

Different crops such as oats, millet, cowpea, sorghum, maize, lucerne and rye grass can be used for fodder production and animal feeding (Islam et al., 2010) and animals will respond differently to these crops (Muregerera, 2008). Fodder can be fed as grains, leaves and pods to livestock. However the environment plays a major role in determining the crop productivity in a given area.

## 2.6 Cowpea and sorghum as potential supplemental fodder crops in communal rangelands

Cowpea is an important source of nutrients for both human and animals; it plays a major role in the livelihoods of millions of people in less developed countries of the tropics (Odindo, 2010). It is consumed in many different forms from young leaves, green pods like green beans, green seeds and dried seeds which are used in food preparation (Singh et al., 2003). Cowpea is also a major source of protein (20-25%) and vitamins.

The nutrient content of cowpea makes it a good supplement in many human and animal diets in Africa. Cowpea addition enhances the protein content of the diets (Singh et al., 2003; Odindo, 2010). Cowpea can also be used in as green manure and cover crop; it is also considered a good intercropping plant in fodder production (Jeranyama et al., 2000; Odindo, 2010). Furthermore this crop is important for farmers especially in communal areas with small portion of land to produce crops. Cowpea can be intercropped with other crops resulting into different crops planted rather than one. Therefore farmers can have two harvested crop while maintaining the soil cover. Cowpea is a legume which has the ability to fix nitrogen in the soils (Adeoye et al., 2011). The high protein content in cowpea would be valuable in sourveld areas where grass protein content is low during winter. The abilities of fixing nitrogen is an added advantage to the soils as this can improve soil fertility and add as an option to intercrop with the staple crop (maize) of Upper Thukela region.

Sorghum (*Sorghum bicolor L.*) is indigenous to Africa and it is cultivated for human and animal feeding in sub Saharan regions of Africa. The sorghum grain is also used for brewing beer. In southern Africa it is produced to feed livestock and intercropping (Brauteseth, 2009). Sorghum is an important hay crop which is well adapted to different regions (temperate and sub-tropical) in the world and it is water efficient. It can easily withstand the warm African climate and adapts to different soil types. Likewise it can grow well under rain fed condition where water is scarce (Almodares et al., 2009). As a result of its dual purpose, farmers in communal areas can produce this crop to feed their livestock and for grain consumption.

Sorghum is a nutritious and palatable fodder crop for livestock; it can be fed as green fodder in summer and as hay during winter. In the case where rangeland is under pressure during winter, sorghum fodder can be fed to livestock as a supplement to the rangeland. The crop parts can be divided and fed differently with the leaves and stem being fed to livestock while the grains can be fed to poultry birds (Khan et al., 2007). Sorghum fodder contains more than 50% digestible nutrients with about 8% protein and 2, 5% fat (Khan et al., 2007).

## 2.7 Constraints with cowpea and sorghum fodder production

### 2.7.1 Constraints to cowpea production

Cowpea fodder production can be limited by abiotic and biotic factors (Mashilo, 2013). Biotic factors include disease, insect pests and parasitic weeds. Abiotic factors are namely temperature, drought, and soil pH and storage techniques. Cowpea can be affected by numerous diseases caused by viruses, fungal and bacteria (Mashilo, 2013; Department of Agriculture Forestry and Fisheries (DAFF), 2011) given in Table 2.1

Table 2.1 Common cowpea disease (viruses, fungal and bacterial)

| Disease group | Diseases |
|---|---|
| Seed borne Virus | Blackeye cowpea mosaic potyvirus (BICMV) |
| | Cowpea aphid-borne mosaic potyvirus (CABMV) |
| | Cucumber mosaic cucumovirus (CMV) |
| | Cowpea mosaic (CPMV) |
| | Cowpea severe mosaic |
| | Southern bean mosaic sobemovirus (SBMV |
| | Cowpea mottle carmovirus (CPMoV) |
| Fungal disease | Anthracnose (*Colletotrichum lindemuthianum*) |
| | Ascochyta blight |
| | Black leaf spot or leaf smut |
| | Brown blotch |
| | Brown rust |
| | Powdery mildew |
| | Pythium soft stem rot |
| | Septoria leaf spot |
| | Sphaceloma scab |
| | Web blight fungus |
| Bacterial disease | Cowpea bacterial blight (CoBB) |
| | bacterial pustule |

Source: Mashilo, 2013; DAFF, 2011

Insects have become the most limiting factor for cowpea production (DAFF, 2011) and each growth phase attracts different insect types. The major insect pests in cowpea are Aphids (*Aphis craccivora, Aphis fabae* ), Maruca pod borer (*Maruca vitrata*), pod sucking bugs (*Clavigralla* spp., *Acanthomia* spp., *Riptortus* spp, blister beetle (*Mylabris spp.*) and storage weevil *Callosobruchus maculatus* (Mashilo, 2013; DAFF, 2011). Principal weeds that attack cowpea in the fields are namely *Striga gesnerioides* and *Alectra sp.* (Asiwe, 2009) and these weeds are a serious concern as they affect cowpea yields.

Cowpea grows best during summer in Limpopo, Kwazulu Natal, North West and Mpumalanga province of South Africa (DAFF, 2011) and it can be harvested in winter depending on the growth phase and the utilisation strategy by the farmer. It is sensitive to drought; therefore it reacts serious to water stress resulting into lower yields (Mashilo, 2013). This could be a challenge for smallholder farmers who plant in dry land areas when water stress challenges occur. Cowpea yield also depends on soil fertility and pH. It grows well in pH 5.6 to 6.0; therefore in acidic soil farmers will have a challenge of obtaining higher yields.

### 2.7.2 Constraints to sorghum production

Sorghum fodder production is highly affected by several constraints such as insect pests, weeds, grain mould, birds, monkeys, nutrient deficiency and water deficiency (Olupot, 2011). Insect pests such as stem borers and shoot flies are also the cause of reduced yields in sorghum (Olupot, 2011). Striga is also the major biotic constraint with sorghum production in the sub-Saharan Africa (Olupot, 2011; Ndung'u, 2009).Sorghum fodder production is highly dependent on soil fertility especially nitrogen and phosphorous. Therefore deficiency of these nutrient results into lower sorghum yields.

## 2.8 Integration of fodder supplementation and biogas digesters

As part of the Water Research Commission (WRC) four biogas digesters were installed for energy production in Upper Thukela communities (Potshini, New Stand, Okhombe and Obonjaneni). One of the selection criteria was that farmers with a minimum of four cattle could afford to feed a biogas digester with manure on a daily basis. These digesters are fed cow dung mixed with water in a 20 litre to 20 Kg ratio (Smith, 2011). Gas produced is used for cooking and boiling of water.

The relationship between overnight kraaling, fodder provision/semi zero grazing and biogas production is that when cattle are overnight kraaled, households can easily collect dung to feed their digesters. Hence when they are fed fodder in a nearby field, cow dung can also be easily collected and residues can be used to feed the digesters (Gebreyohannes and Hailemariam, 2011). The link between biogas production and the use of fodder crops for improved fodder flow in winter is presented in Figure 2.1. The biogas by product called bioslurry is then used in the gardens as an organic fertilizer.

Given the low income of communal households, bioslurry can be used as an alternative or with other fertilizer sources to produce fodder for cattle feeding. Communal farmers cannot afford to buy inorganic fertilizers for fodder production due to their costs and transportation. Therefore bioslurry provides an opportunity for livestock owner to produce fodder at a lower cost compared to inorganic fertilizers.

### 2.9 The potential use of bioslurry as an organic source of fertilizer

The use of organic manures and their recycling has been given considerations for ensuring sustainable land use and agricultural production (Oad et al. 2004). Organic amendments have the potential to improve soil fertility and can be used as an alternative for poor farmers who cannot afford expensive chemical fertilizers (Uzoma et al.2011). However, the challenge with these organic amendments is that they rapid decompose in the soils under high temperatures and aeration. Eghball, B., & Power, J. F. (1999) argued that the organic matter is usually mineralized in few planting seasons therefore repeated application is recommended per growing season to sustain soil productivity. Bioslurry has better nutrient composition than most organic manures and it more stable therefore it can be used as an alternative organic amendment in smallholder farming systems.

Bioslurry is an example of organic fertilizer that can be used as a source of fertilizer in fodder production especially in communal areas that have benefitted from biogas digesters (Gurung, 2007; Islam et al., 2010). Figure 2.1 below shows an integrated crop to livestock production with biogas technology.

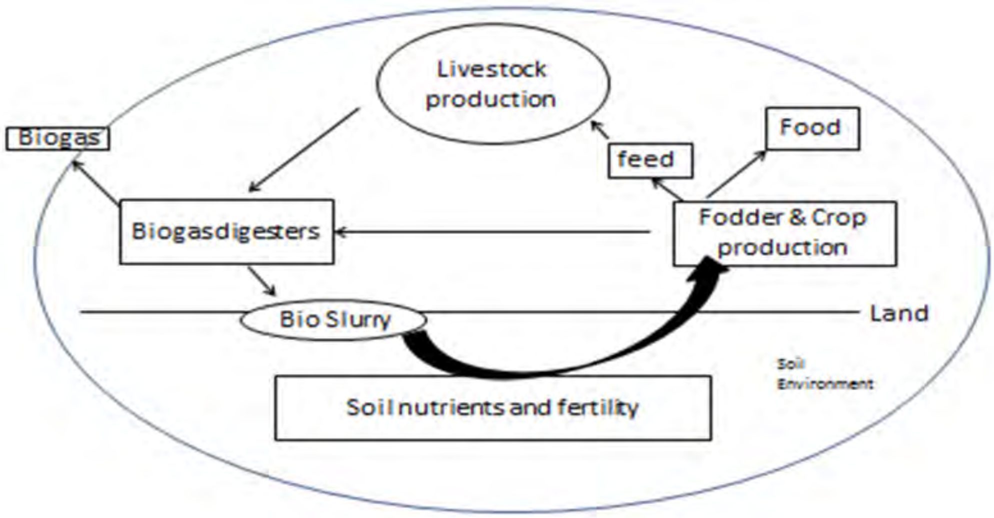


**Figure 2.1** Closed sustainable crop and livestock production system that is centralized by bioslurry (Al Seadi, 2008; Smith, 2011).

Bioslurry is the effluent that is produced in a biogas digester following the anaerobic digestion of animal dung and water for the production of methane gas which can be used for cooking (Islam, 2010). This effluent contains plant nutrients in the form of nitrogen, phosphorus and potassium (Table 2.2). This organic form of fertilizer can be used for crop production after it application on soils (Islam, 2010). Nutrient availability in bioslurry is reported to be much higher than other organic sources (Table 2.2)(Makadi et al., 2012). The digestion process improves nutrient content of bioslurry.

Table 2.2 Comparison of different organic manure macro nutrient content

| Manure | N % | $P_2O_5$ % | K % |
|---|---|---|---|
| **Fresh cattle dung** | 0.3-0.4 | 0.1-0.2 | 0.1-0.3 |
| **Farmyard manure** | 0.4-1.5 | 0.3-0.9 | 0.3-1.9 |
| **Compost** | 0.5-1.5 | 0.3-0.9 | 0.8-1.2 |
| **Poultry manure** | 1.0-1.8 | 1.4-1.8 | 0.8-0.9 |
| **Cattle urine** | 0.9-1.2 | trace | 0.5-1.0 |
| **Paddy straw** | 0.3-0.4 | 0.8-1.0 | 0.7-0.9 |
| **Wheat straw** | 0.5-0.6 | 0.1-0.2 | 1.1-1.3 |
| **Bioslurry** | 1.5-2.5 | 1.0-1.5 | 0.8-1.2 |

Source: Makadi et al. 2012

Bioslurry is a nutrient rich substrate compared to other organic manure sources (Chiyoka, 2011). The slightly higher N in the bioslurry is the consequence of the N concentration effect because of the carbon degradation to $CO_2$ and $CH_4$ and N preservation during the anaerobic digestion (Tambone et al., 2009). These levels of N, P and K in bioslurry can benefit both soil and plants when it is used as an organic source of fertilizer. It is generally known that bioslurry like other organic residues is a slow nutrient releaser (Chiyoka, 2011).

The nutrient availability in bioslurry as an organic fertilizer makes it a better choice for resource poor farmers in communal areas (Smith, 2011). Other benefits of using bioslurry in soil, is the improvement of soil organic matter, water holding capacity and stabilizing of humus content (Gurung, 1997). Furthermore, the soil improvement will have positive impacts on soil microorganisms in the soil and biological activities. Bioslurry, unlike other organic manures has less weed presence (Makadi et al., 2008). This is due to the digestion process in biodigesters.

Bioslurry can be used as a liquid or solid compound which is distinguished on the basis of its dry matter (DM) content. Liquid slurry contains less dry matter content (15 %) compared to solid or drier slurry with DM content above 15% and similar to those of composts or farm yard manures (Makadi et al., 2012). Applying it in liquid form allows slurry to move into the soils.

However the solid form might get stuck in the topsoil (Al Seadi, 2008). There is little information on factors that may influence the application of bioslurry to soils for and the effect on soils and fodder production.

Nitrogen mineralization and nitrification reflect the capacity of soil microbes to mineralize organic nitrogen to ammonia then oxidize it to nitrate (Abubaker et al., 2012). Nitrogen in the bioslurry is in the form of ammonia when applied to the soils (Al Seadi, 2008). However, the ammonia content depends on the feed sources fed to the biogas digester. Some digesters can produce bioslurry with high ammonia content while in others it is less (Makadi et al., 2012). In the soils, ammonia is converted to nitrate during the nitrification process.

Ammonia volatilization is a serious concern for farmers when applying bioslurry to the soil surface (Lukehurst et al., 2010). Volatilization rates differ with the source and application method of bioslurry (Sommer, 1997). Sommer (1997) also argued that storage of slurry is key in prevention of volatilization before it application into the soils. Volatilization reduces the amount of available inorganic nitrogen in the bioslurry.

As consequence, it is important to ensure that the soil surface is covered after application of bioslurry to reduce soil exposure to air. Application methods are important to achieve the desired bioslurry impact on the soils (Al Seadi, 2008). Studies have shown that regardless of volatilization issues, bioslurry can be used for production different types of crops (Shahabaz, 2011).

## 2.10 Bioslurry application on fodder production

Islam et al. (2010) conducted a study on the effectiveness of bioslurry as a nitrogen source for the production of maize fodder. Bioslurry was applied at 60, 70 and 82 kg per hectare. The results showed that the application of approximately 70 kg of bioslurry per hectare improved the biomass and nutrient content in maize fodder. Ding et al. (2011) studied the effects of bioslurry on table bean and soil fertility, their findings showed that the application of bioslurry had no significant impact on bean growth. Rahman et al. (2008) carried out a different experiment on the effect of undigested cattle slurry on maize fodder production. Maize fodder was produced using four cattle slurry levels (0, 10 , 12  and 14 ton $ha^{-1}$ ) in a randomized block design; and agronomic characteristics (plant height, circumference of stems, number of leaves, leaf area and dry matter yield of maize fodder) were determined. The authors found that the increase in the slurry levels had different effects on growth and yield. Bioslurry application increased the leaf area index, yield and root length density (Garg et al., 2005). In a study done by Jothi et al. (2003) found that plants amended with bioslurry had more vegetative growth and produced fruits than those under control treatment. Previous research has shown that bioslurry can be applied on fodder production. However, the information on the yield and growth impact is scarce (Gurung, 1997).

### 2.11 Summary and conclusions

Livestock production in communal areas is largely dependent on communal rangelands. Cattle graze continuously in these communal rangelands and this poses a threat to the productivity and long-term sustainability of these rangelands. There is need to consider alternative grazing systems that could allow a rest period and recovery in the rangelands and ensure long-term sustainability and improved productivity. Zero grazing systems where livestock are fed on fodder crops produced in the homesteads could provide appropriate alternative systems that could supplement fodder production and improve the fodder flow particularly during winter. Feeding livestock under this system in winter would allow a rest period for the veld. In this chapter the current challenges with regard to the management of communal rangelands in the Upper Thukela and the potential of using fodder crops for livestock feed in rural homesteads has been reviewed.

The review shows also that bioslurry can be used as an organic fertilizer for fodder production especially in households that own biogas digesters. Previous studies have shown that bioslurry contains nutrients (N, P and K) that can be used in both food and fodder production. However, there is limited information on bioslurry nutrient release patterns and the impact of bioslurry on sorghum and cowpea fodder production

# CHAPTER THREE: EFFECT OF BIOSLURRY ON GROWTH, YIELD AND NUTRIENT CONTENT OF COWPEA (*VIGNA UNGUICULATA* L. WALP) AND SORGHUM (S*ORGHUM BICOLOR*.L) FODDER AT TWO RURAL HOMESTEADS IN THE UPPER THUKELA


## Abstract

The aim of the study was to determine the effect of bioslurry on growth, biomass and nutritive quality of cowpea and sorghum fodder. 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) and fodder species (2 levels – cowpea and sorghum) replicated 3 times giving a total of 18 experimental units (plots measuring 5 x 5m). 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. Results from the on-farm trials at New Stand and Potshini showed that bioslurry and MAP fertilizer had no significant effect on cowpea and sorghum fodder yield. In New Stand, there were no significant differences ($P>0.05$) between the treatments applied with respect to sorghum yields. Sorghum yield 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 range 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, the effect of bioslurry, MAP and control on cowpea and sorghum yield did not differ significantly ($P >0.05$). 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 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.

### 3.1 Introduction

Livestock play a major role in the livelihoods of smallholder farmers in the rural areas of South Africa. Livestock can be utilized for different purposes such as source of income, food (meat), milk and manure. They can also be used for socio-cultural purposes such as dowry, traditional ceremonies and animal traction (Tau, 2005; Chonco, 2009). Maintaining animal health is therefore important for livestock owners. One of the key factors contributing to good animal health is sufficient high quality grazing. In rural areas the provision of grazing is mainly from communal rangelands (Tau, 2005; Chonco, 2009). Communal rangeland is generally owned and managed by the community as opposed to private or individual ownership" (Everson and Hatch, 1999). As these rangelands are managed by the whole community, every smallholder farmer has free access to graze his livestock on them. Livestock keepers depend on the range for grazing their cattle the whole year (Chonco, 2009). However, in sourveld areas the range has no nutritional value in winter as all nutrients are translocated to the plant base (Tainton, 1999). According to Tau (2005) poor grazing management (e.g. continuous grazing during the winter and summer season) leads to reduced forage quantity and quality of the rangeland. During the dry (winter) season, farmers have to feed their animals on maize stover which is left in the maize field after harvesting their maize (Everson et al., 2012).

Provision of alternative fodder is an option to assist and reduce the high dependence on the rangeland and address the problem of fodder shortage during winter. Ideal forage crops which grow quickly and produce high yields such as sorghum fodder would be good alternative fodder crops to feed during the winter period when the range has poor quality (Islam et al., 2010; Ayub et al., 1999). Alternative crops should supply the major nutrients to livestock such as carbohydrates and proteins. One such potential crop is sorghum (*Sorghum bicolor L.)* which can be fed to animals in different forms such as silage, green fodder and grain, and is therefore a good fodder plant to feed livestock when the grasses in the range are under pressure (Ayub et al., 1999). Furthermore sorghum is an annual grass that is drought tolerant and can therefore tolerate the extreme weather conditions that can occur in the study area. It adapts well in different soils and produces good yields even on low fertility soils. Another potential crop is cowpea (*Vigna unguiculata* L. Walp.) which is a source of protein and an important legume crop which could be utilized by both livestock and human beings (Odindo, 2010). Furthermore this crop is a nitrogen fixing legume which is widely grown because of its ability to grow in poor soil conditions (Singh et al., 2003; Farahvash et al., 2010). When grown in crop rotation and as an intercrop it provides nitrogen to cereal crops (such as maize, millet and sorghum).

Fodder crops are responsive to nitrogen (N) fertilizers, which contribute to the quantity and quality of forage production. However, there are limitations in the use of fertilizers (Islam et al., 2010). Improper use of inorganic fertilizers affects the soils and contaminates water bodies thus posing health concerns for human beings. Chemical fertilizers are expensive and unsustainable to the environment (Rahman et al., 2008). The majority of communal farmers lack financial resources to purchase sufficient or any inorganic fertilizers (Mutegi et al., 2012). Therefore cheap and sustainable N fertilizers are needed to reduce the negative factors involved in using inorganic fertilizers. One such option is the use of bioslurry, a by-product of the anaerobic digestion of manure and water which results in the production of biogas which is used for cooking; Bioslurry contains nitrogen, phosphorous and other macro and micro nutrients (Makadi et al., 2008). It improves the soil fertility and is a good organic fertilizer that ensures proper use of livestock waste for sustainable crop production (Smith, 2011).

There is limited data on the application and effect of bioslurry on fodder production in rural areas. Therefore the aim of the present study was to evaluate the effect of different fertilizers on the production of different fodder crops. The specific objective of the study was to carry out on-farm trials to determine the effect of bioslurry and fertilizer on growth, yield and nutrient content of sorghum fodder and cowpea in two biogas operating homesteads in the Upper Thukela region of KwaZulu-Natal.

## 3.2 Materials and Methods

### 3.2.1 On-farm trials

The on-farm trials were conducted at two homesteads in the villages of Potshini (S 28° 48' 46.8" E 29° 22' 35.76") and New Stand (S 28° 41' 37.07" E 29° 18' 41.39”) in the Upper Thukela region of KwaZulu-Natal, South Africa. The sites are situated at the base of the Drakensberg Mountains and receive rainfall during summer. The area receives 800 to 1265 mm of rainfall per annum (Smith, 2011). The rangeland in the study area is classified as sourveld which is palatable during the growing season (6 to 8 months of the year). The dominant grasses are *Hyparrhenia* *hirta*, *Eragrostis species* and *Sporobolus species*. (Everson et al., 2012; Tau, 2005). The area is dominated by Hutton soil forms (red soil) which are characterized by good drainage.

### 3.2.2 Experimental design

The trials were established using a randomized complete design (RCBD) laid as a 3 x 2 factorial combination 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 5m).

### 3.2.3 Treatments

Bioslurry was collected from the pilot biodigesters in the New Stand and Potshini homesteads, which were implemented as part of a Water Research Commission project (K5/1955). Bioslurry was 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 (Table 3.3). Mono-Ammonium Phosphate (MAP) fertilizer was used following the recommendations of the Department of Agriculture (DARD) based on the results of soil analysis. MAP fertilizer was applied once during planting at 100kg $ha^{-1}$.

### 3.2.4 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$^{th}$ December 2013(Potshini) and harvesting occurred in March/April 2013 at both sites.

### 3.2.5 Data collection

#### *3.2.5.1 Growth characters*

Five plants were randomly selected in each plot and the selected plants were tagged for repeated measurements. Growth data for cowpea were collected biweekly, starting from 4 weeks after planting (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 sorghum was measured from the plant base to the height growing tip 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.

#### *3.2.5.2 Biomass*

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 1cm above ground level. Biomass harvested was weighed in the field as fresh weight and oven dried at $60^0$Cuntil constant weight. Biomass samples were analyzed for nutrient content.

#### *3.2.5.3 Agronomic practices*

Prior to planting, soils samples were taken and analysed at the Cedara laboratory (Fertilizer Advisory Service). Nutrients analyzed 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 tests to compare differences prior to and after application of treatments. Routine weeding was done by hand. Bioslurry was analyzed for nutrient composition prior to planting by Talbot and Talbot laboratories in Pietermaritzburg.

#### *3.2.5.4 Statistical analysis*

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

## 3.3 Results

### 3.3.1 Cowpea growth

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. At 10 WAP, the maximum height occurred in the control treatment (42.2 cm) whereas bioslurry (32.87 cm) was the minimum (Figure 3.1).

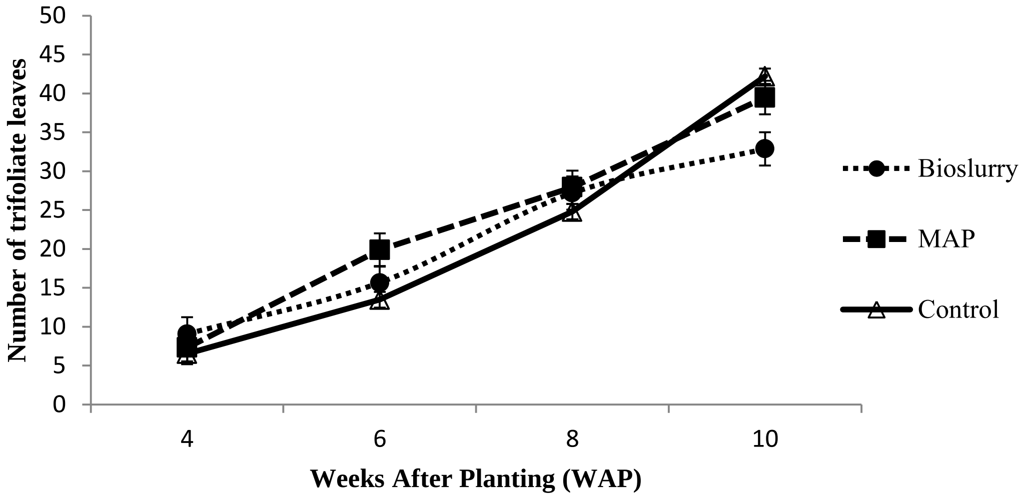


**Figure 3.1** Mean number of trifoliate leaves for cowpea in the New Stand trial during the growth period

Results of the Potshini on-farm trial showed significant effect ($P<0.05$) of the bioslurry on the mean number of cowpea trifoliate leaves when compared to the other treatments (Figure 3.2). 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.

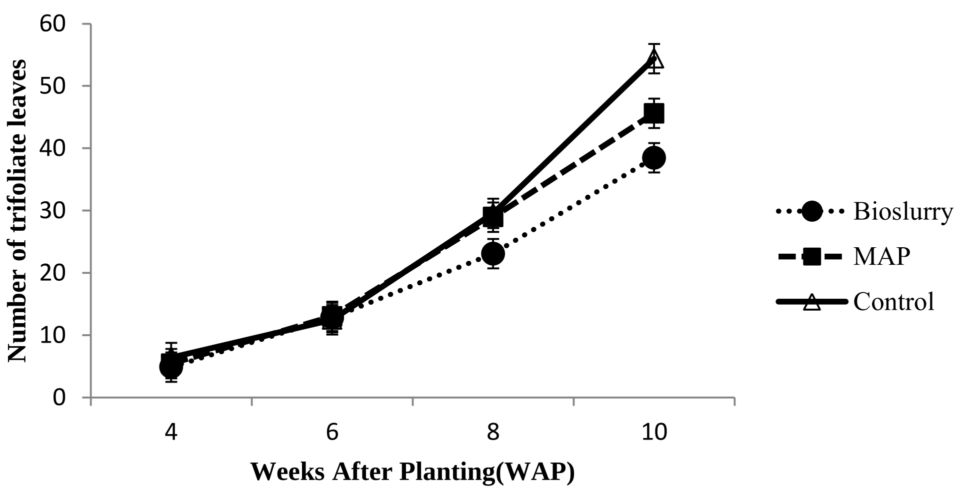


**Figure 3.2** Mean number of trifoliate leaves for cowpea in the Potshini trial during the growth period

### 3.3.2 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 3.3 a). At harvest (12 WAP), maximum height occurred with MAP (176.8 cm), followed by bioslurry (173.3 cm) and the control (165.3 cm).

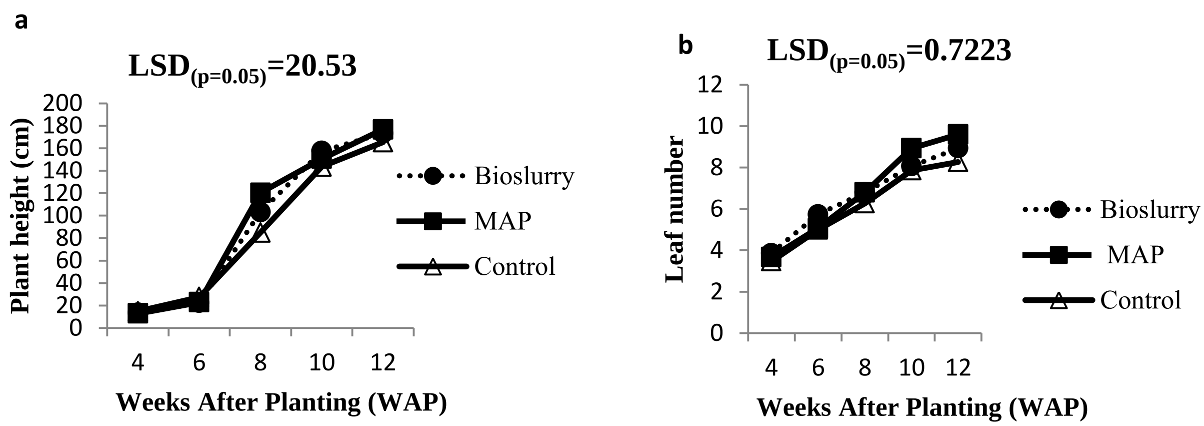


**Figure 3.3** Mean height (a) and leaf number (b) of sorghum fodder grown on the on-farm trial in New Stand

The mean number of leaves increased linearly during the growing season for all the treatments (Figure 3.3b). 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 3.3b), 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 was little increase in height until 8 WAP after which height increased exponentially until 12 WAP when plants were harvested (Figure 3.4a). , 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. 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 3.4a).

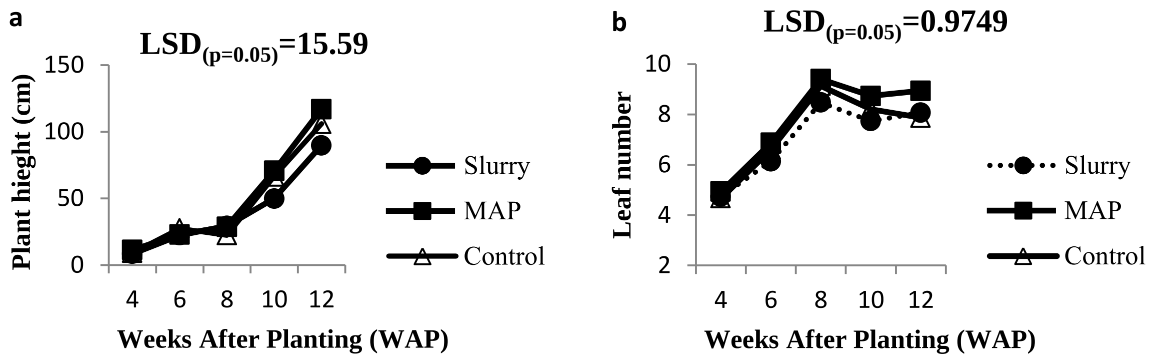


**Figure 3.4** Means of height (a) and (b) leaf number of sorghum fodder grown on the on-farm trial in Potshini

### 3.3.3 Yield

At New Stand the average cowpea yield for the MAP treatment was significantly higher (6.73 kg $m^{-2}$) than the control treatment which had the lowest yield of 4.97 kg $m^{-2}$ (Table 3.1). The bioslurry treatment (5.73 kg $m^{-2}$) 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 kg $m^{-2}$ (MAP) treatment (Table 3.1).

Table 3.1 Average biomass (kg.$m^{-2}$ ±se) for cowpea and sorghum fodder at the New Stand trial.

| Treatment | Cowpea ( kg $m^{-2}$) | Sorghum ( kg $m^{-2}$) |
|---|---|---|
| **Control** | $4.97\pm 0.328^{b}$ | $3.75\pm0.32^{a}$ |
| **MAP** | $6.73\pm0.88^{a}$ | $5.47\pm0.71^{a}$ |
| **Bioslurry** | $5.73\pm0.35^{ab}$ | $4.76\pm0.37^{a}$ |

*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 3.2). Cowpea biomass yields ranged from 3.7 to 5.33 kg $m^{-2}$ 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 kg $m^{-2}$, no significant differences were (Table 3.2).

Table 3.2 Average biomass (kg.$m^{-2}$ ±se) for cowpea and sorghum fodder at the Potshini trial.

| Treatment | Cowpea ( kg $m^{-2}$) | Sorghum( kg $m^{-2}$) |
|---|---|---|
| **Control** | $3.7 \pm 0.82^a$ | $1.8 \pm 0.95^a$ |
| **MAP** | $5.33 \pm 0.12^a$ | $3.09 \pm 0.37^a$ |
| **Bioslurry** | $4.93 \pm 0.63^a$ | $2.14 \pm 0.30^a$ |

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

### 3.3.4 Nutritive quality

***Bioslurry nutrients***

The bioslurry used for the experiment was liquid, comprising about 90% moisture (Table 3.3). 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 3.3 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 |

***Soil nutrients***

At New Stand there was an increase in the soil organic carbon in both the sorghum and cowpea experimental sites. Organic C increased from 1.1% prior to planting to a maximum of 4.67 % after (post) experiment (Table 3.4). 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 3.4).

Table 3.4 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 | 3.80 |
| 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 a decrease in organic C after the trial experiment in both crop plots (Table 3.5). 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 36.33 the lowest in the cowpea plot.

Table 3.5 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** | | | | | |
| **Sorghum** | **Bioslurry** | 0.32 | 51.50 | 722.00 | 1.83 |
| | **MAP** | 0.40 | 53.00 | 725.00 | 1.73 |
| | **Control** | 0.40 | 51.67 | 727.67 | 1.80 |
| **Cowpea** | **Bioslurry** | 0.28 | 36.67 | 796.00 | 1.90 |
| | **MAP** | 0.26 | 33.33 | 726.00 | 1.87 |
| | **Control** | 0.23 | 36.33 | 909.30 | 1.77 |

***Plant nutritive quality***

There were no significant differences (P>0.05) between treatments (MAP, bioslurry and control) for the sorghum nutrients content in the New Stand trial (Table 3.6a). With respect to cowpea nutrient content there was no significant different observed for the three treatments except for N (Table 3.6b).

Table 3.6a Plant nutrient content of sorghum in response to 3 treatments (bioslurry, MAP and control) in New Stand trial

| | Sorghum | | | |
|---|---|---|---|---|
| | Bioslurry | MAP | Control | LSD |
| N % | 2.10[a] | 1.95[a] | 1.93[a] | 0.36 |
| Ca % | 0.21[a] | 0.18[a] | 0.19[a] | 0.13 |
| Mg % | 0.25[a] | 0.24[a] | 0.23[a] | 0.06 |
| K % | 1.32[a] | 0.97[a] | 0.95[a] | 0.496 |
| Na mg/kg | 40.40[a] | 40.40[a] | 47.39[a] | 42.61 |
| Zn mg/kg | 37.04[a] | 31.64[a] | 32.48[a] | 9.14 |
| Cu mg/kg | 5.86[a] | 4.17[a] | 4.13[a] | 2.40 |
| Mn mg/kg | 80.16[a] | 78.77[a] | 88.65[a] | 31.55 |
| Fe mg/kg | 699.70[a] | 577.65[a] | 463.59[a] | 531.6 |
| P % | 0.30[a] | 0.31[a] | 0.31[a] | 0.06 |
| Al mg/kg | 824.94[a] | 635.07[a] | 996.97[a] | 352.2 |

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

Table 3.6b. Plant nutrient content of cowpea in response to 3 treatments (bioslurry, MAP and control) in New Stand trial

| | Cowpea | | | |
|---|---|---|---|---|
| | Bioslurry | MAP | Control | LSD |
| N % | 5.23[a] | 4.70[b] | 4.52[bc] | 0.375 |
| Ca % | 1.52[a] | 1.31[a] | 1.27[a] | 0.978 |
| Mg % | 0.51[a] | 0.53[a] | 0.50[a] | 0.111 |
| K % | 4.01[a] | 4.09[a] | 4.02[a] | 1.133 |
| Na mg/kg | 445.41[a] | 506.98[a] | 335.93[a] | 174.4 |
| Zn mg/kg | 73.36[a] | 58.34[a] | 54.89[a] | 14.57 |
| Cu mg/kg | 14.96[a] | 7.08[a] | 7.68[a] | 10.51 |
| Mn mg/kg | 230.15[a] | 190.92[a] | 184.40[a] | 148.4 |
| Fe mg/kg | 209.71[a] | 161.08[a] | 210.67[a] | 92.9 |
| P % | 0.57[a] | 0.62[a] | 0.57[a] | 0.143 |
| Al mg/kg | 137.73[a] | 111.09[a] | 122.81[a] | 44.51 |

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

No significant differences ((P>0.05) where observed with respect to the different treatments on N, Ca, Mg, Na, Zn, Cu, Fe and Al. However, significant differences were observed for P and K in sorghum at New Stand trial ( Table 3.7a) with respect to cowpea at Potshini there were no significant response (P>0.05) for all the element except for Zn (Table 3.7b).

Table 3.7a. Plant nutrient content of sorghum in response to 3 treatments (bioslurry, MAP and control) in Potshini trial

| | Sorghum | | | |
|---|---|---|---|---|
| | Bioslurry | MAP | Control | LSD |
| N % | 1.32[a] | 1.24[a] | 1.44[a] | 0.415 |
| Ca % | 0.21[a] | 0.23[a] | 0.26[a] | 0.168 |
| Mg % | 0.26[a] | 0.27[a] | 0.29[a] | 0.071 |
| K % | 0.76[b] | 0.66[b] | 1.00[a] | 0.528 |
| Na mg/kg | 33.95[a] | 27.14[a] | 47.88[a] | 41.14 |
| Zn mg/kg | 37.33[a] | 38.00[a] | 40.30[a] | 20.46 |
| Cu mg/kg | 4.14[a] | 3.66[a] | 4.44[a] | 1.886 |
| Mn mg/kg | 42.09[a] | 44.78[a] | 43.05[a] | 19.04 |
| Fe mg/kg | 689.44[a] | 658.10[a] | 549.22[a] | 196.2 |
| P % | 0.34[ac] | 0.32[bc] | 0.38[a] | 0.045 |
| Al mg/kg | 787.58[a] | 709.01[a] | 582.06[a] | 289.1 |

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

Table 3.7b. Plant nutrient content of cowpea in response to 3 treatments (bioslurry, MAP and control) in Potshini trial

| | Cowpea | | | |
|---|---|---|---|---|
| | Bioslurry | MAP | Control | LSD |
| N % | 5.17[a] | 5.16[a] | 5.40[a] | 0.586 |
| Ca % | 2.03[a] | 1.83[a] | 1.93[a] | 0.378 |
| Mg % | 0.53[a] | 0.54[a] | 0.52[a] | 0.093 |
| K % | 3.12[a] | 2.94[a] | 3.05[a] | 0.937 |
| Na mg/kg | 294.88[a] | 332.64[a] | 352.53[a] | 135.6 |
| Zn mg/kg | 48.01[a] | 40.18[bc] | 42.71[ac] | 6.97 |
| Cu mg/kg | 10.70[a] | 9.63[a] | 10.44[a] | 1.161 |
| Mn mg/kg | 192.11[a] | 138.26[a] | 138.99[a] | 83.5 |
| Fe mg/kg | 211.16[a] | 179.36[a] | 236.64[a] | 96.1 |
| P % | 0.47[a] | 0.47[a] | 0.45[a] | 0.118 |
| Al mg/kg | 157.07[a] | 116.27[a] | 205.44[a] | 149.3 |

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

### 3.4 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 significance 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 integrated effect of different N-fertilizer rates and bioslurry application on growth and N-use efficiency of okra. They found that the application of bioslurry increased plant growth (plant height, branches per plant and fruit yield) of okra when bioslurry was applied alongside chemical fertilizers. Islam et al (2010) also reported that bioslurry stimulated maize growth (plant height, stem circumference and leaf area) at the optimum rate of 70kg of slurry N $ha^{-1}$. This does not agree with Reddy et al. (1987) who reported that inorganic fertilizers application on crops increases maize plan height.

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. Fodder plants are always expected to respond to fertilizer application, either organic or inorganic and despite being legume or grain (Islam et al., 2010).

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 kg $m^{-2}$. These findings are similar to those of Islam et al. (2010) who observed that the application of bioslurry had positive effects on maize fodder yield. Their yields ranged from 34.67 to 54.12 tons ha $^{-1}$.They also reported that 70 kg N $ha^{-1}$ was the optimum levels to achieve maximum yield. By contrast, treatments did not have a significant effect on cowpea fodder yield in Potshini which ranged from 3.7 to 5.33 kg $m^{-2}$. 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 improved wheat 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).

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 significance 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 were not similar with observation of Islam et al. (2010) who observed that the application of bioslurry had 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. (2012) 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 Mutegi et al. (2012) 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 required nutrients.

Ammonia losses occurs at a higher rate when bioslurry is applied at the soil surface, previous studies have shown that when bioslurry is applied at the 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 apply 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 concluded that 70 kg of bioslurry N $ha^{-1}$ was an optimum level for maize fodder production after they investigated the effects of different bioslurry application rate of maize fodder. Shahbaz et al. (2013) 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 yield in dry land farming systems. The current study findings does not agree with the authors suggestions, bioslurry did not have significance effects on fodder yield when at the current study rate. This might 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.

### 3.5 Conclusion

In conclusion no significant effects of bioslurry and MAP on cowpea and sorghum crop yield and growth were observed in this study.

# CHAPTER FOUR: NITROGEN AND PHOSPHORUS RELEASE PATTERNS FROM BIOSLURRY IN SOILS COLLECTED FROM FARMERS FIELD AT TWO HOMESTEADS IN THE UPPER THUKELA


## Abstract

An incubation study was conducted to determine the N and P content and the release patterns from bioslurry in two contrasting soil types (acidic and non-acidic). The experiment was laid out as a 3 x 4 x 14 factorial treatment structure with the following factors: soils- (non-acidic, acidic unlimed and acidic limed – 3 levels); bioslurry application rate- (0, 2.1, 4.2, 10.5 g/kg bioslurry N- 4 levels; days (0, 1, 2, 4, 7, 14, 21, 28, 35, 42, 49, 56, 63 and 70)- 14 levels replicated 3 times in plastic tubs under CRD ( completely randomised design). Plastic tubs were drilled holes on 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 on each tub containing 1kg soil with the treatment and it was maintained at 70% water holding capacity. Ammonium-N concentration decreased for all the bioslurry application rates (2.1, 4.2 and 10.5 g/kg) 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 soils sampled from non-acidic soil increased with increasing bioslurry application rates. Phosphorus content at the end of the incubation on day 70 at after applying the rate of 10.5 g/kg was 49.89 mg $kg^{-1}$ in the non-acidic soil and 21.154 mg $kg^{-1}$ in the acidic soil. Similar findings were observed for the acidic limed soils, (20.193 mg $kg^{-1}$ at 10.5 g/kg bioslurry application rate after 70 days).

## 4.1 Introduction

Poor soils, characterized by low plant available nutrient and organic matter content and acidity limit agricultural productivity in most smallholder farms in Sub Saharan Africa (Gachengo et al., 1999). Furthermore nutrients removed from the soil due to crop harvesting are usually greater than the quantity returned by fertilizers (Gachengo et al., 1999) resulting in limited plant growth and decline in yields. Poor soil fertility is a major challenge in the Upper Thukela area; this is caused by low nitrogen and phosphorus in the soils. There are possibilities of using different amendments to recover the soil fertility (Essa and Nieuwoudt, 2001). Therefore there is urgent need to understand the nutrient release patterns of the amendment and the soils of the area.

Improved soil fertility and increased food production can be achieved through correct application of organic and inorganic fertilizers. However, the costs of inorganic fertilizers are very high which makes them inaccessible to smallholder farmers in developing countries (Warnars and Openooth, 2014). Although inorganic fertilizers nourish plants and improve soil fertility, they also have their disadvantages caused by over application and oversupply of these fertilizers to the soils (Chiyoka, 2011). Too much application of chemical fertilisers leads to imbalanced nutrients in the soil and may also lead to acidic and alkaline soils. Organic fertilizers such as livestock manure also nourish plants; they offer sufficient nutrients to sustain crop yields and soil fertility when they are applied at the recommended rate (Al Seadi, 2008; Edmeades, 2003).

Bioslurry is a fertilizer which promotes the use of livestock waste for sustainable crop production and conservation of the environment. Like other organic fertilisers bioslurry is a slow nutrient releaser leading to a more balanced contribution to the residual pool of organic nitrogen and phosphorus in the soils reducing N losses (Islam et al., 2010). According to Johansen et al. (2013) these manures have less nutrient content compared to bioslurry for example farmyard manure contains 0.3-0.4 compared to 1.5-2.5 N (%) for bioslurry. Therefore bioslurry has the potential contributes to soil fertility better than other farmyard manures. 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 it 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 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.

## 4.2 Materials and Methods

### 4.2.1 Soils and bioslurry samples

Soil samples were collected from two homesteads in the Upper Thukela namely New Stand (S 28° 41' 37.07" E 29° 18' 41.39”) and Okhombe (S 28° 42' 13.29" E 29° 58' 24.80”). For this study they are referred to as New Stand (non-acidic) and Okhombe (acidic) soils. Soil samples were taken for fertility analysis to the Soil Fertility and Analytical Services in Cedara (KwaZulu-Natal, Department of Agriculture and Environmental Affairs). Fertility outcomes that were used to calculate the bioslurry application rates were based on a selected target yield for sorghum fodder of 9 ton $ha^{-1}$.

Soils used for the lab incubation were air dried and sieved to pass through a 2 mm mesh before use. Bioslurry used for the incubation was collected from a cow dung-fed digester at the New Stand homestead. The bioslurry was taken for analysis at Talbot and Talbot laboratories (Pietermaritzburg) for mineral nutrient content (Table 4.1).

### 4.2.2 Experimental set up

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); 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 were drilled holes on the sides to allow for aerobic conditions. One kilogram of soil (passed through a 2 mm sieve) was weighed into each tub. Water holding capacity was calculated prior to the application of treatment. Deionized water was applied at 70% water holding capacity (determined by saturating a subsample of known mass of each soil and allowing it to drain for 24 hours and reweighing).

The treated soils were wetted to 70 % of their water holding capacity. After wetting, samples were incubated at a controlled room temperature of 25°C. Moisture corrections were done weekly to maintain the water holding capacity of the soils. These corrections were done after determining weight loss; samples were opened to avoid anaerobic conditions every 7 days after initial sampling. The incubation sampling was done on 0, 1, 2, 4, 7, 14, 21, 28, 35, 42, 49, 56, 63 and day 70, starting from 8 April to 17 June.

### 4.2.3 Extraction and analysis

Soil pH was analyzed using a Meter Lab (PHM 210 pH meter) with a standard glass electrode in both water and 1M KCl at a 1: 5 soil-solution ratio. Inorganic nitrogen was extracted using 2 M potassium chloride (KCl); 5g of soil was mixed with 50 ml of KCl solution. The solution was then shaken for 30 minute at 180 rpm; the samples were allowed to settle for 30 minutes after shaking following recommendation by Chiyoka (2011). Samples were then filtered through filter paper 42 into 250ml volumetric flasks and they were then transferred to 50ml containers. Sample extracts were kept in a deep freezer until completion of the incubation study and analyzed for inorganic nitrogen (ammonium-N: $NH_4$-N and nitrate-N: $NO_3$-N) using a discreet analyzer (Thermo Gallery: Thermo Scientific).

Phosphorus was extracted using 0.25 M sodium bicarbonate ($NH_4HCO_3$), EDTA disodium salt and 0.01 M ammonium fluoride (AMBIC) solution, and analyzed using the molybdenum blue method. 2.5 g of soil was mixed with 25ml of AMBIC solution in a centrifuge tube and shaken using a reciprocal shaker for 30 minutes at 180 rpm.

### 4.2.4 Statistical analysis

The statistical package Genstat version 14 (VSN International, UK) was used for analysis of variance (ANOVA) to determine whether there were significant differences between the treatments and interactions. Least significant difference (LSD) was used to separate means at 5% level of significance.

### 4.3 Results

The quantities of N applied to each soil were calculated based on the characteristics of bioslurry (Table 4.1) and the required nitrogen was calculated following the soil analytical results. The application rates were 0, 2.1, 4.2 and 10.5 g/kg of bioslurry as shown in Table 4.2

Table 4.1 Characteristics of the experimental bioslurry

| **Characteristics** | **Bioslurry** |
|---|---|
| Moisture (%) | 92.67 |
| pH | 8.62 |
| Total nitrogen (%) | 1.48 |
| Potassium mg/kg | 574 |
| Phosphorus (%) | 2.23 |
| Total organic carbon (%) | 20 |
| NDF (%) | 50.54 |
| ADF (%) | 42.81 |
| Total solids (%) | 8 |
| Volatile solids (%) | 80 |

Table 4.2 Application rates of bioslurry on non-acidic and acidic (unlimed and limed) soils for the incubation

| Soil | N (kg/ ha) | Amount bioslurry applied (g bioslurry / kg soil) | Lime (g/kg) |
|---|---|---|---|
| Non-acidic | 0 | 0 | 0 |
| Non-acidic | 75 | 2.1 | 0 |
| Non-acidic | 150 | 4.2 | 0 |
| Non-acidic | 375 | 10.5 | 0 |
| Acidic unlimed | 0 | 0 | 0 |
| Acidic unlimed | 75 | 2.1 | 0 |
| Acidic unlimed | 150 | 4.2 | 0 |
| Acidic unlimed | 375 | 10.5 | 0 |
| Acidic limed | 0 | 0 | 1.4 |
| Acidic limed | 75 | 2.1 | 1.4 |
| Acidic limed | 150 | 4.2 | 1.4 |
| Acidic limed | 375 | 10.5 | 1.4 |

Table 4.3 Characteristics of the experimental bioslurry

| | Acidic soil | non acidic |
|---|---|---|
| **P (mg/l)** | 7 | 7 |
| **K (mg/l)** | 76 | 161 |
| **Ca (mg/l)** | 616 | 1805 |
| **Mg (mg/l)** | 125 | 588 |
| **Exchangeable acidity (cmol/l)** | 1.29 | 0.46 |
| **Total (cations cmol/l)** | 5.59 | 14.72 |
| **Acid saturation (%)** | 23.4 | 3 |
| **pH (KCl)** | 4.01 | 4.14 |
| **Zn (mg/l)** | 0.8 | 5.4 |
| **Mn (mg/l)** | 4 | 29 |
| **Cu (mg/l)** | 0.13 | 6 |
| **Organic C (%)** | 1.4 | 2.4 |
| **N (%)** | 0.16 | 0.24 |
| **Clay (%)** | 28 | 30 |

### 4.3.1 Nitrogen release during the incubation

#### *4.3.1.1 Ammonium-N release during incubation*

During the incubation period, the application of different bioslurry rates had no significant differences ($P>0.05$) on the ammonium-N concentration in the non-acidic soil (Figure 4.1).There was a decrease in ammonium-N concentration with time in non- acidic soil for all the bioslurry application rates (Figure 4.1). The concentration of ammonium-N showed a decreasing pattern until day 14, from day 14 it increased to the maximum concentration (29.18 mg $kg^{-1}$) for 10.5g/kg bioslurry application rate in day 28. After day 28, the maximum ammonium-N level dropped until day 70 (Figure 4.1). In addition, the concentration levels of ammonium-N showed no stability during the incubation period for non- acidic soil. On day 70 the lowest ammonium-N concentration (5.4 mg $kg^{-1}$) was recorded for the 4.2 g/kg application rate of bioslurry.

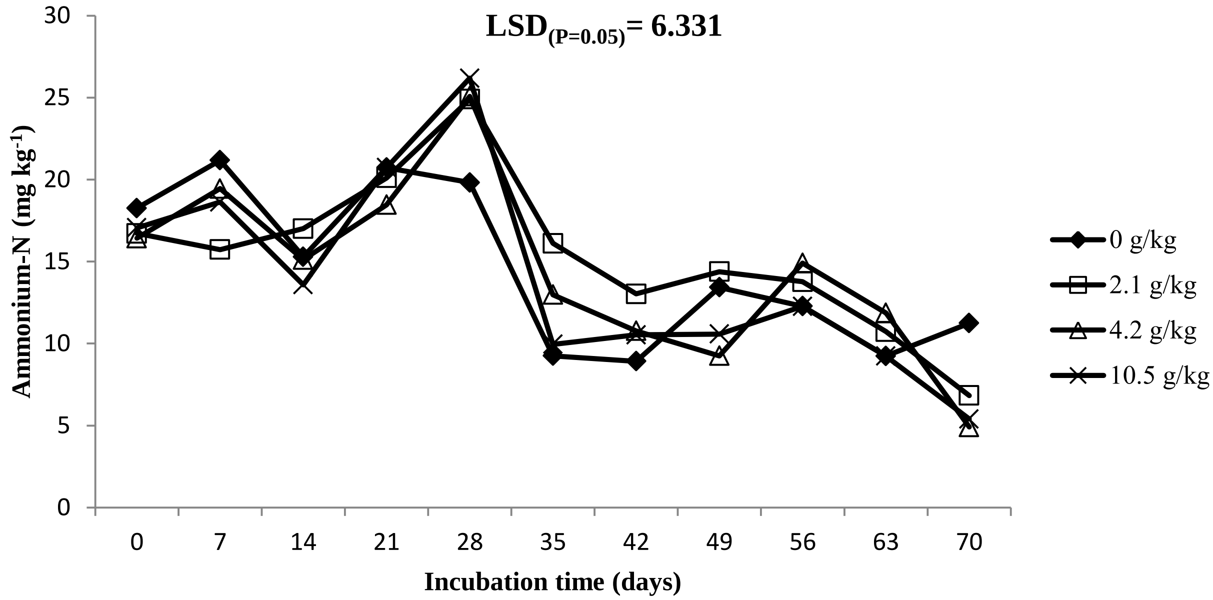


**Figure 4.1** Ammonium-N concentrations (mg $kg^{-1}$) during the incubation of non- acidic soil at different application rates of bioslurry

Similar to the non-acidic soil, application rates did not differ (P>0.05) with respect to ammonium-N concentration in the acidic unlimed soil (Figure 4.2a). However, treatments had highly significance differences (P< 0.001) on the ammonium-N concentration in the acidic limed soils during the incubation period (Figure 4.2b). Ammonium-N concentration decreased over time during the incubation study for both acidic (unlimed and limed) soils (Figure 4.2a and b). With respect to the acidic unlimed soil, ammonium-N increased after day 1 to a maximum of 24.89 mg $kg^{-1}$ with the 2.1 g/kg application rate and then declined to 10.87 mg $kg^{-1}$ on day 14. Thereafter there was a decline for all application rates. From day 14 to 70 the concentration levels of ammonium-N fluctuated between 8.55 and 24.89 mg $kg^{-1}$, none of the application rates was constant throughout the incubation (Figure 4.2a). Acidic limed soil had a similar pattern to the unlimed soil; however, the acidic limed soil had higher ammonium-N concentration levels compared to unlimed. The highest concentration level in acidic limed soil (Figure 4.2b) was on day 1 (30.83 mg $kg^{-1}$ with a bioslurry application rate of 10.5 g/kg). During the first seven days the concentration levels were higher (>20 mg $kg^{-1}$) than for days 14-70.

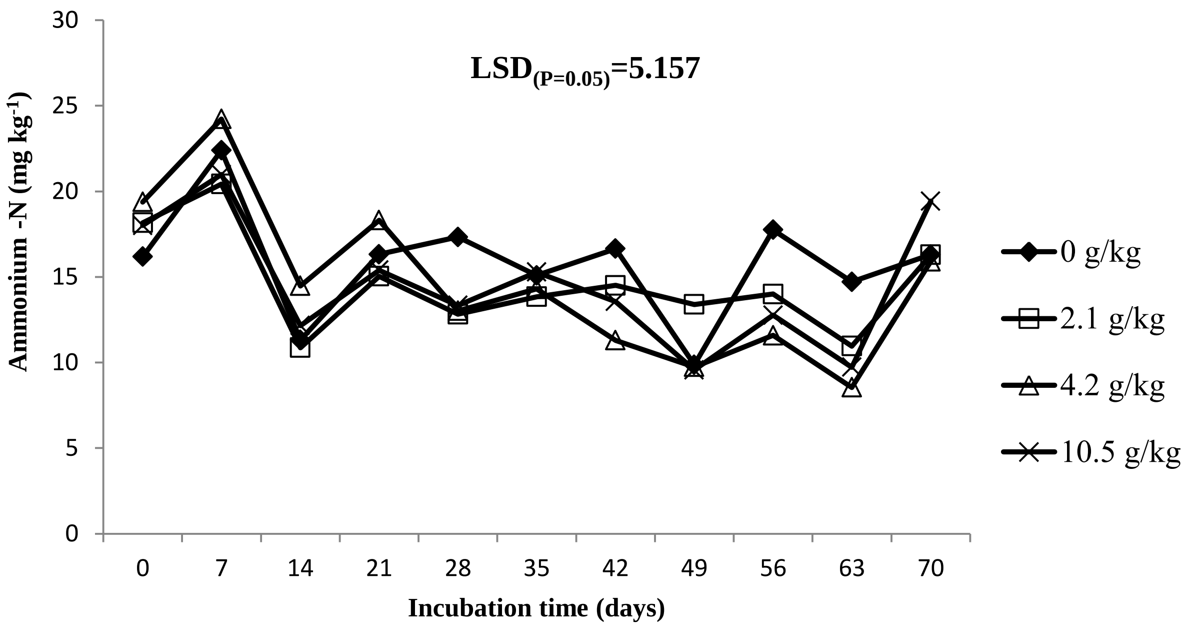


**Figure 4.2(a)** Ammonium-N concentration (mg $kg^{-1}$) during incubation of acidic unlimed soil at different bioslurry application rates

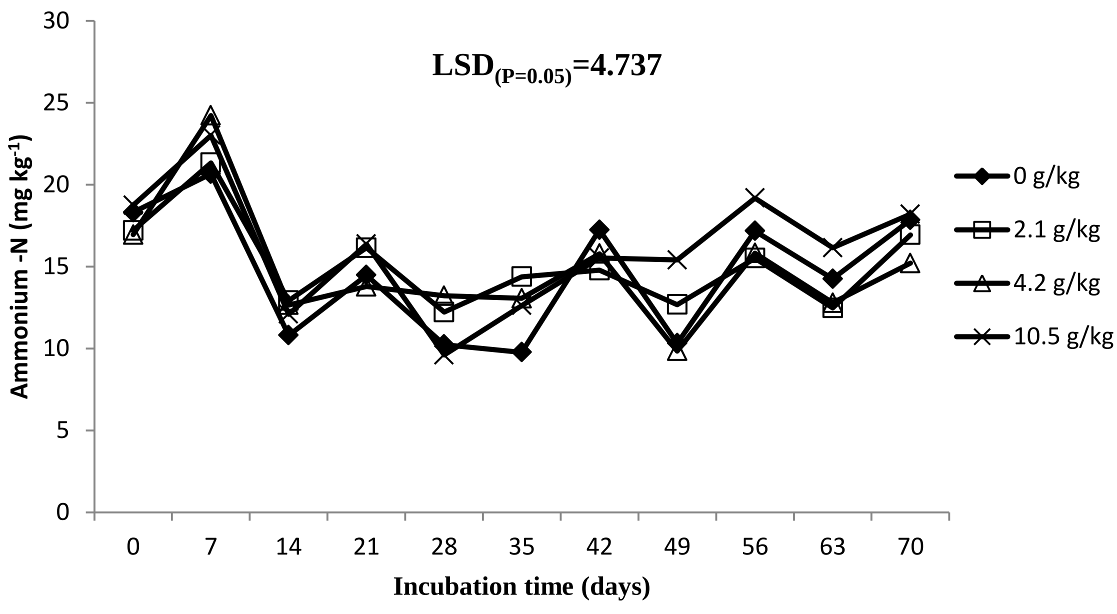


**Figure 4.2(b)** Ammonium-N concentration (mg $kg^{-1}$) during incubation of acidic limed soil at different bioslurry application rates.

#### *4.3.1.2 Nitrate release during incubation*

With respect to nitrate-N concentration in non- acidic soil, there were no significant differences (P>0.05) between application rates (Figure 4.3).The highest nitrate-N concentration recorded was 1.34 mg kg$^{-1}$ on day 2 for the control treatment (no bioslurry)(Figure 4.3). Following this, there was a rapid decline in nitrate-N concentration followed by fluctuating low concentrations (give range**)** from day 7 to 70 of the incubation period (Figure 4.3).

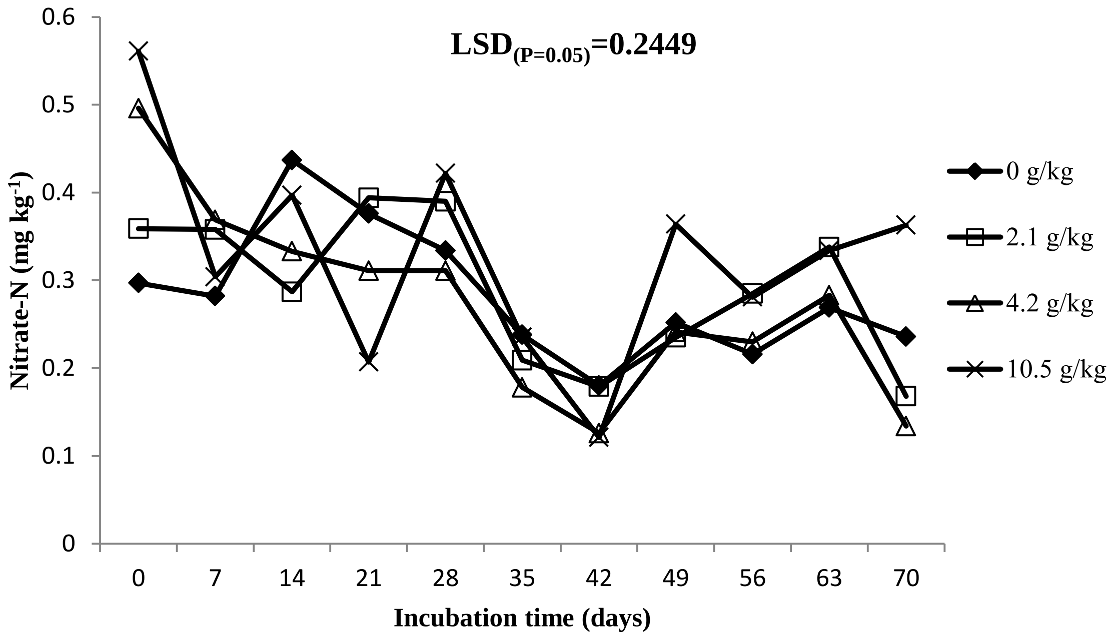


**Figure 4.3** Nitrate-N concentrations (mg kg$^{-1}$) in non-acidic soil during the incubation period at different bioslurry application rates

There were no significant differences (P>0.05) in the nitrate-N concentration following the application of different bioslurry rates on the acidic unlimed soil (Figure 4.4a). Inconsistency in the nitrate-N concentration was recorded in acidic unlimed soil during the incubation period. The trend also showed that at day 70 the concentration levels had decreased for all the application rates. Similar to the unlimed soil, the application of different bioslurry rates had no significant effect (P>0.05) on the nitrate-N concentration during the incubation period on acidic limed soil (Figure 4.4b).

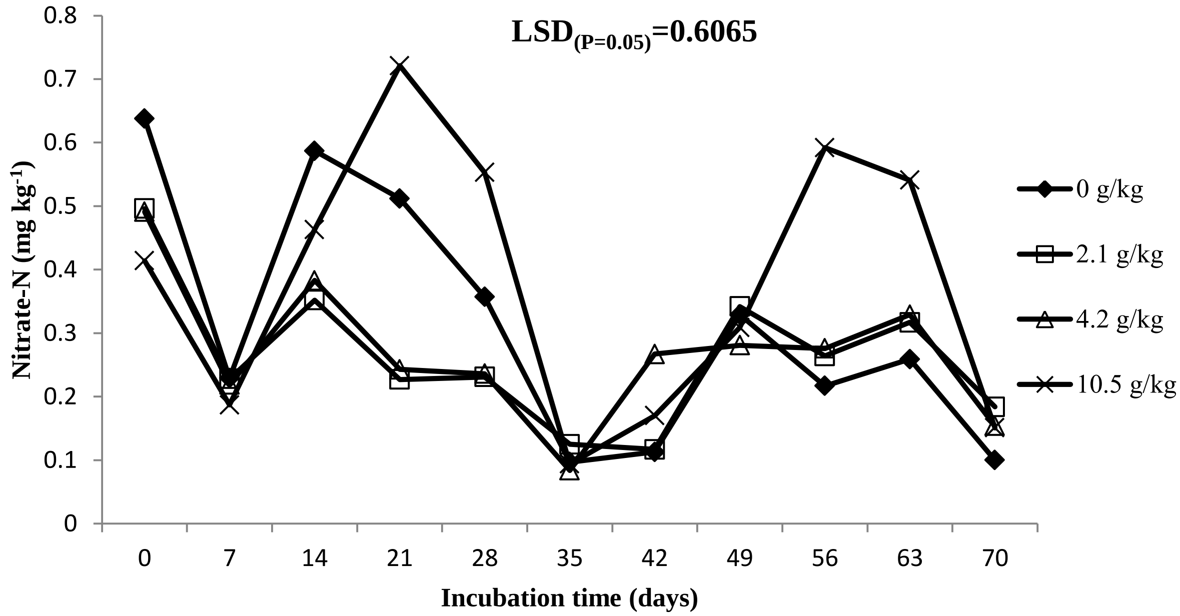


**Figure 4.4(a)** Nitrate-N concentrations (mg kg$^{-1}$) in acidic unlimed soils during the incubation period at different bioslurry application rates

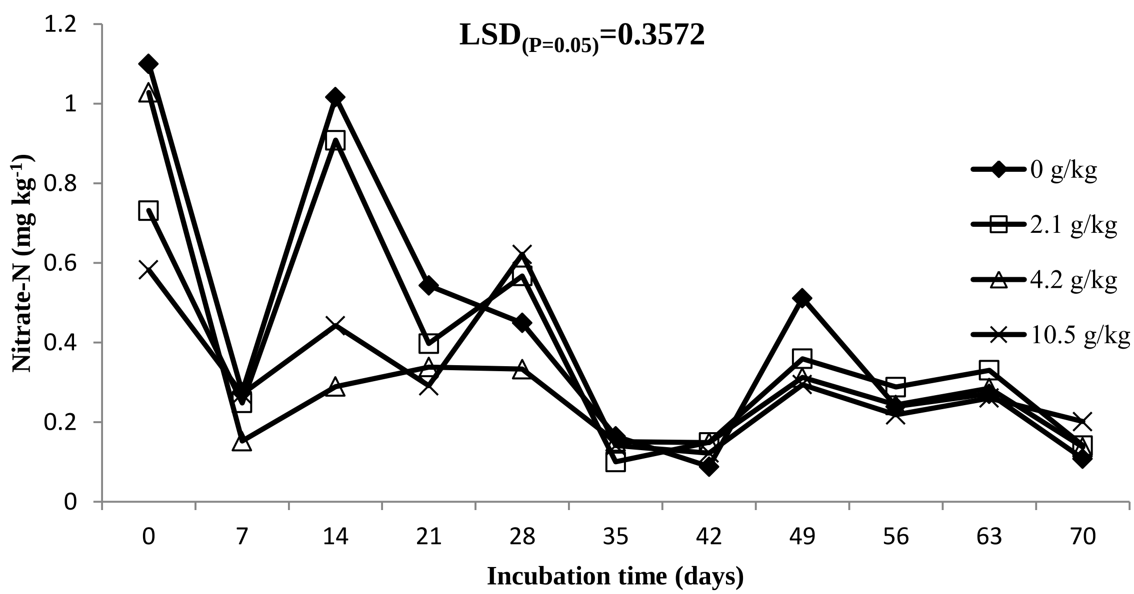


**Figure 4.4(b)** Nitrate-N concentrations (mg kg$^{-1}$) in acidic limed soil during the incubation period at different bioslurry application rates

### 4.3.2 Phosphorus release during the incubation

During the 70 day incubation, different bioslurry application rates resulted in highly significant differences in P concentration (P<0.001) in the non-acidic soil (Figure 4.5). Phosphorus increased with the increase in bioslurry application rate with the maximum P release being recorded on day 70 for all rates. At that stage the 10.5 g/kg rate had the highest concentration level of 49.89 mg $kg^{-1}$ of P. With the exception of day 7, the highest bioslurry application rate (10.5 g/kg) resulted in greater P release than the other treatment groups throughout the incubation period (Figure 4.5).

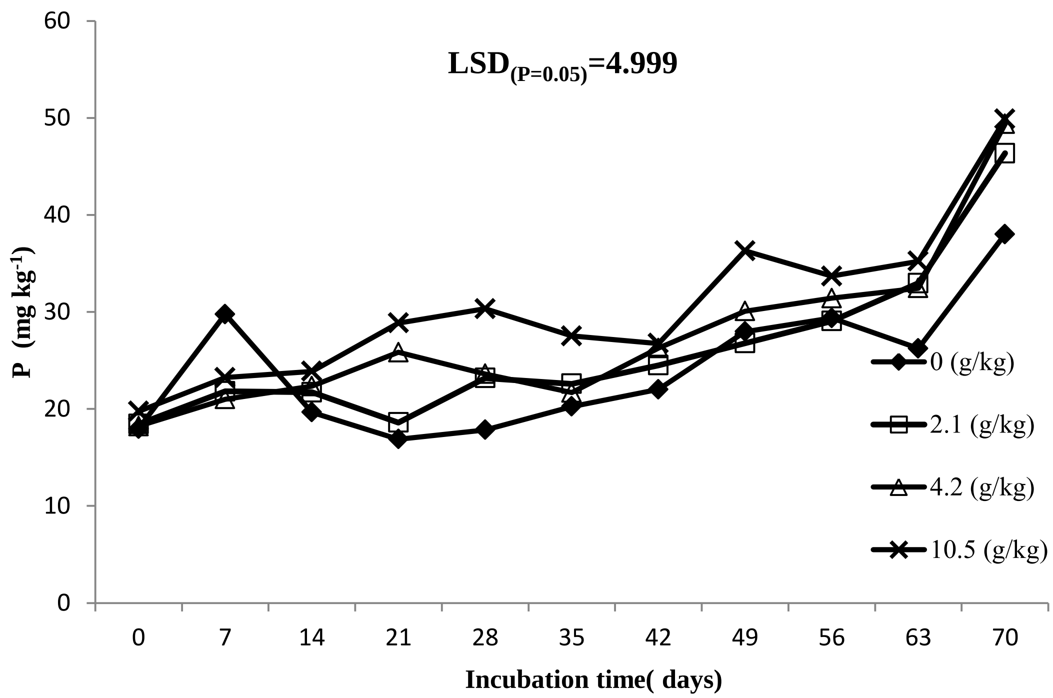


**Figure 4.5** Phosphorus concentration (mg $kg^{-1}$) in non-acidic soil following different bioslurry application rates during the incubation period of 70 days

With respect to phosphorus, there were no significant differences (P>0.05) between the different bioslurry application rates in acidic unlimed soil during the incubation period (Figure 4.6a). Phosphorus concentration in the unlimed soil increased from 13.96-14.09 mg $kg^{-1}$ on day 0 to from 19.64-21.154 mg $kg^{-1}$ on day 70 during the incubation period (Figure 4.6a). The highest P concentration was recorded on day 70.

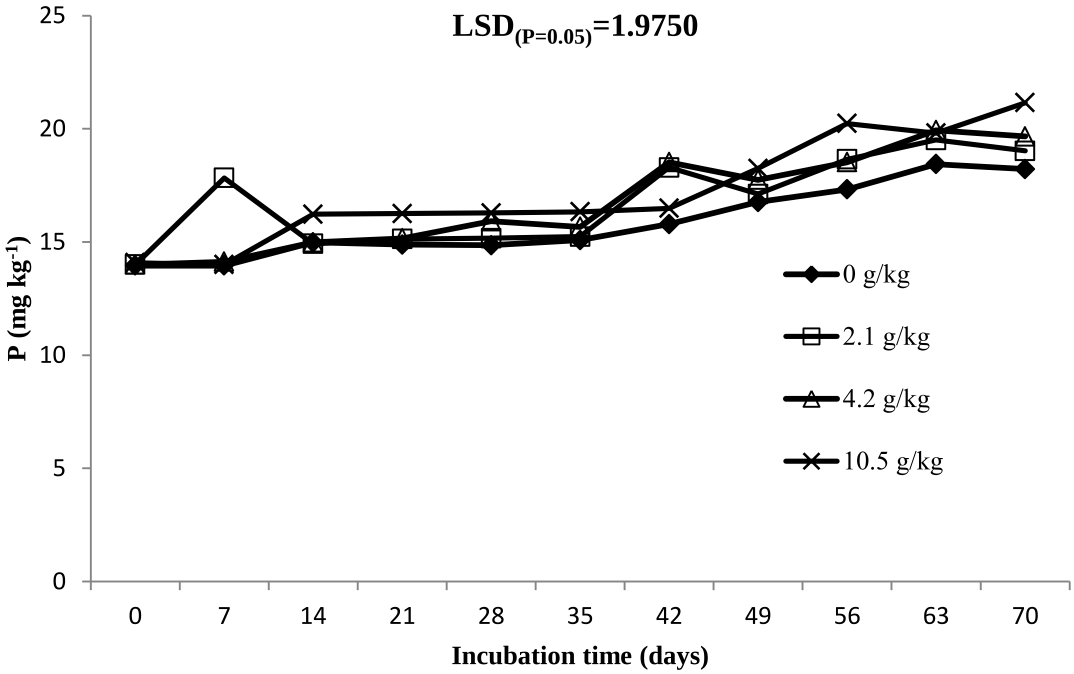


**Figure 4.6a** Phosphorus concentration (mg $kg^{-1}$) in acidic unlimed soil following different bioslurry application rates during the incubation period of 70 days.

In contrast to the acidic unlimed soil, in the limed soils there were significant differences observed in the phosphate concentration after application of different bioslurry rates during the incubation study (Figure 4.6b). From day 0 to 70 the highest bioslurry application rate (10.5 g/kg) in acidic limed soil resulted in greater P release compared to other treatments. The maximum P release levels were recorded on day 56 for the 10.5 g/kg application rate (Figure 4.6b). For the highest application rate the P concentration fluctuated during the incubation but remained greater than the other treatments.

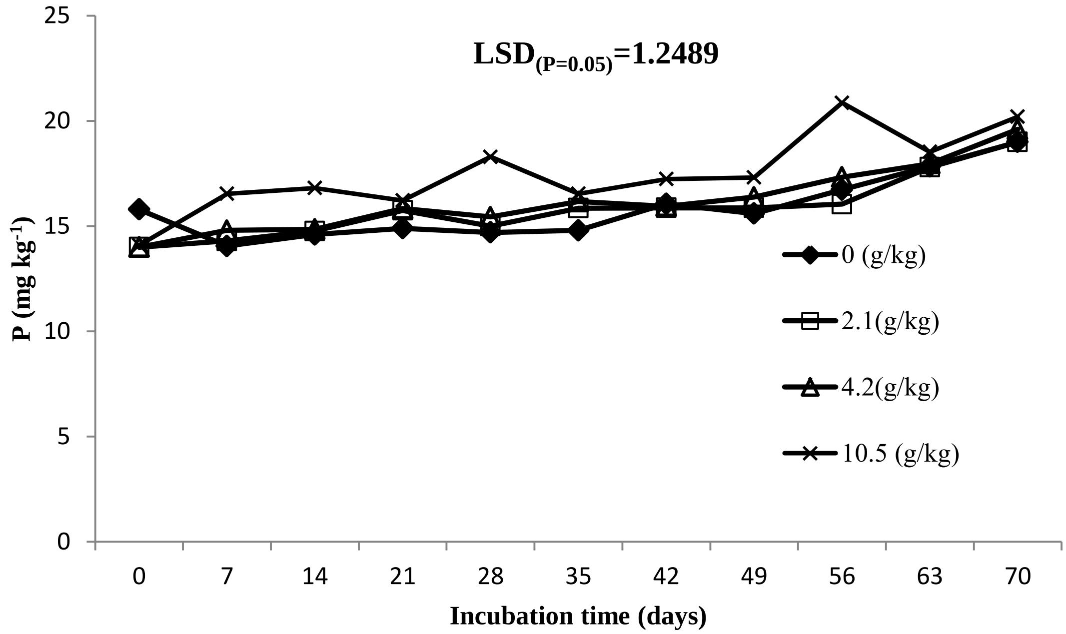


**Figure 4.6b** Phosphorus concentration (mg $kg^{-1}$) in acidic limed soil following different bioslurry application rates during the incubation period of 70 days

### 4.3.3 pH changes during the incubation period

During the incubation period, changes in pH were observed after the application of different bioslurry rates. With respect to non- acidic soil, highly significant differences ($P< 0.001$) were observed in pH ($H_20$) between the application rates during the incubation period (Appendix 1). pH was more or less constant until day 49 after which there was an increase in pH to reach the maximum level at day 70 (6.603 in 10.5 g/kg). Similarly, the pH (KCl) maximum was reached at day 70 (5.527 in 10.5 g/kg). There were significant differences ($P>0.05$) in pH (KCl) between the application rates during the incubation period. However the results show an increase in pH during the incubation period.

With respect to acidic unlimed, the pH ($H_20$) showed highly significant differences ($P<0.001$) between different bioslurry application rates during the incubation period (Appendix 2). The maximum soil pH (7.157) was recorded on day 70 for 10.5 g/kg application rate. Drop in pH was recorded in day 49 for all the application rates. With respect to pH (KCl), highly significant differences ($P<0.001$) were observed between the application rates during the incubation period.

Similar to pH ($H_20$) the maximum pH (KCl) (6.143) was recorded on day 70, however this was in the lowest application rate (2.1 g/kg).

Changes in pH were observed for acidic limed soil during the incubation period. For pH ($H_20$), significant differences ($P<0.05$) were observed between the applied bioslurry rates during the incubation (Appendix 3). During the incubation, the maximum pH (7.15) was recorded on day 70 for 10.5 g/kg while the minimum pH (5.76) was recorded for 4.2 g/kg on day 49 of the incubation period. With respect to pH (KCl), highly significant differences ($P<0.001$) were observed between the bioslurry application rates during the incubation period. The minimum pH (KCl) (4.28) was recorded on day 14 for 0 g $kg^{-1}$ and the maximum (6.30) was recoded on day 70 for 4.2 g/ kg.

### 4.4 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 for over the 70 day incubation period for the entire application rate in all the soils (non-acidic, acidic unlimed and limed) (Figures 4.1; 4.2a and b). 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 consistency release patterns and this was observed across all the soils used for the incubation study. 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 (Figure 4.2) followed a similar trend to nitrate-N (Figure 4.3) 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.

Phosphorus concentration was significantly higher in the non- acidic soil especially on the last day of the incubation (Figure 4.4). It is also important to note that the highest application rate of bioslurry (10.5 g $kg^{-1}$ of bioslurry) had the highest P release pattern for most of the days during the incubation compared to other treatments. No significant differences were recorded for the P release patterns of the soils with and without lime (acidic). For both soils there was no clear P release for all application rates of bioslurry. The release of P from bioslurry was constant throughout the incubation period for all the soils. Similar results have been found for other P sources (Nongqwenga, 2013). The availability of P in the soil is driven by both biological and chemical process and these processes are adsorption and microbial mineralization of P. The current findings show that P concentration increased with time (day 0 to 70) for all the soil 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.

For all the soils (non-acidic, acidic unlimed and limed) the maximum pH was recorded on day 70 in both KCl and $H_20$ methods. The increase in soil pH during the incubation period for all the soils correlates with the increase in P for all the soils. The P concentration at day 70 was the maximum recorded for all the soils and this was reflected in the pH where maximum levels were recorded on day 70. This supports Nongqwenga's (2013) findings that P was sensitive to soil pH changes during the incubation study. By contrast, no relationship was found in this incubation study between the ammonium-N and nitrate-N levels and soil pH. Similarly, Chiyoka, (2011) found that N was less affected by pH (compared to P, but that N was highly available for plants at the pH range 6.5 -7.0. For all the bioslurry application rates and soils the pH ($H_20$) was higher than pH (KCl). Since plant nutrients are optimally available at neutral pH levels, the current findings reflects that on day 70 when the pH ranges were ±7 optimum levels of P was recorded.

## 4.5 Conclusion

The finding showed that ammonium -N was released from the slurry during the incubation period and the levels declines with time. However, the nitrate concentration did not show a clear pattern for all the three soils. Phosphorus levels increased during the incubation in all the soils and this was also reflected by the soil pH in both KCl and H20. Phosphorus release in non-acidic soil was higher than for both acidic soils (limed and unlimed). Phosphorus release increased with the increase in the bioslurry application rate.

# CHAPTER FIVE: THE IMPACT OF SUPPLEMENTARY FEEDING (COWPEA AND SORGHUM FODDER) ON THE CURRENT CARRYING CAPACITY OF COMMUNAL RANGELANDS


## Abstract

The aim of the study was to assess the impact of using cowpea and sorghum fodder for supplementary feeding on the current grazing carrying capacity (AU $ha^{-1}$). 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 findings showed that the range 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. Cattle are continuously grazed on the natural rangeland and that has led to soil degradation, runoff and poor veld condition. The rangeland in the community can produce 260 tons of forage per year in 218 ha and this is not enough to feed all the 378 cattle owned by the community. The results of this study indicated that producing fodder for livestock in communal areas has potential to meet the fodder shortage. The current findings show that producing both fodder crops with fertilizers (MAP) resulted in higher yields (5.33±0.120, 3.09±0.374 ton $ha^{-1}$) compared to bioslurry (4.93±0.637, 2.14 ton $ha^{-1}$±0.303) for cowpea and sorghum respectively. The treatments applied to produce fodder had no significant differences on yield. However, the results also showed that yields when applying bioslurry into the soils were higher 4.93±0.637 ton $ha^{-1}$ (cowpea), 2.14±0.303 ton $ha^{-1}$ (sorghum) compared to nothing applied (control) 3.70±0.819, 1.80±0.957 ton $ha^{-1}$ for cowpea and sorghum respectively.

## 5.1 Introduction

In southern Africa, livestock are a vital part of the communal farming system. Livestock such as cattle are important animal species supplying meat, milk, manure, animal traction and social exchange activities such as lobola (Powell et al., 2004). Communal rangelands are the main feed source for livestock in communal areas. It is therefore important that the grazing area is able to support the livestock without deterioration to the overall ecosystem (Tainton, 1999). In these communal areas livestock are continuously grazed in the rangeland throughout the year, resulting in poor veld condition (Bennett and Barrett, 2007). One of the major challenges for cattle owners in sourveld areas is the shortage of quality fodder in winter. In winter the nutritive quality of the grasses declines in the rangeland as nutrients are translocated to the roots, making the grass less palatable for livestock consumption (Mwilawa et al., 2008). Currently all communal livestock owners allow their livestock to feed on maize stover after harvesting the maize crop. However this stover is also of low quality (Everson et al., 2012).

In the sourveld areas of the study site cattle graze on the rangeland for the entire growing (cropping) season. During this period the livestock are grazed in the higher areas of the rangeland and return to lower areas of the rangeland during the winter season. When the grass quality in the natural rangeland declines during winter period there is need for an alternative system which will reduce pressure on natural rangelands and provide quality fodder for livestock (Ngongoni et al., 2007).

Fodder provision for livestock helps to maintain animal condition and production. This could be achieved through purchasing of fodder in silage and hay forms or growing fodder and cutting and carrying it to feed kraaled animals (Magona and Musisi, 2002). However, the purchase of feeds is a limiting factor for resource-poor farmers. Shortage of land for fodder production could also be a limiting factor in fodder production for communal farmers. Therefore fodder production should be based on the productivity and nutritive quality of the fodder crop.

Different fodder crops can be used for fodder production. Sorghum (*Sorghum bicolor*) is known as an ideal forage crop because it can grow quickly, it produces high yields, it is rich in nutrients, it can be consumed as grains or leaves and it is responsive to nitrogen fertilizers (Ndung'u, 2009). Another potential fodder crop is Cowpea (*Vigna unguiculata*) which is a drought tolerant and warm climate crop with the ability to fix nitrogen like other legumes (Odindo, 2010). Cowpea is a protein rich legume which can be intercropped with different crops such as sorghum, maize and millet (DAFF, 2011). In the Upper Thukela there is a need to produce fodder with fertilizer because of the highly leached soils of the area. However, due to a lack of financial resources, communal farmers in the study area are generally unable to afford the purchase and transport costs of inorganic fertilizers. Therefore cheaper and sustainable nitrogen fertilizers are needed. One option is to use bioslurry as an organic fertilizer for fodder production.

Bioslurry is the fertile effluent that is obtained as a by-product of the anaerobic digestion of manure and water where biogas, a renewable energy is produced (Smith, 2011). Bioslurry, like other organic fertilizer sources, contains nutrients that could be used by plants (Rahman et al., 2008). In the study site where biogas technology has been installed and introduced, farmers have the opportunity to use the effluent for fodder production. The aim of this project was to determine the effect of fodder supplementation using different types of fertilizer on the carrying capacity of the rangeland. The objective of this study was to determine the potential impact of sorghum and cowpea fodder produced using bioslurry as an organic fertilizer and MAP as an inorganic fertilizer on the carrying capacity of the Potshini communal grazing system.

## 5.2 Materials and Methods

### 5.2.1 Description of study site

The study was conducted in the Upper uThukela region of Kwazulu-Natal. In this region, biogas digesters were implemented in four households in the villages of Potshini, New Stand, Obonjaneni and Okhombe as part of a WRC funded project (K5/1955). A case study in one of these villages, Potshini (S 28° 49' 14.20" E 29° 21' 56.40”), was carried out to develop guidelines for livestock management in communal rangelands.

### 5.2.2 Carrying capacity

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

- The amount of forage produced,

- The grazing area,
- The number of livestock in the area,
- The amount of forage needed per animal unit, and
- The veld condition of the rangeland.

Since these data were only available for one of the villages, Potshini, this village was selected for the calculations on fodder flow.

### 5.2.3 The amount of forage produced

To determine the potential of supplementary fodder on the current grazing capacity of Potshini, fodder yields were obtained from the on-farm field trial at Potshini as outlined in Chapter 3. Biomass of two crops, namely sorghum and cowpea, were used for this study. The crops were subjected to three treatments:

a. no bioslurry, no fertilizer (control),

b. bioslurry and

c. MAP fertilizer

### 5.2.4 Grazing area

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

***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.

***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.

***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:

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 of 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.

CGC = PGC * numerical rating for the site………………………………………….………. (1)

Where PGC = potential grazing capacity, and

Numerical rating = CF + BCF + TF + SEF……………………………………………………… (2)

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

BCF (basal cover factor) = -0.75 + 2 (BCS/BCB) – (BCS/BCB) 2……………………… (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 $ha^{-1}$

## 5.3 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 $ha^{-1}$*218ha $yr^{-1}$).

**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 and sorghum fodder under bioslurry production in Potshini

The yield values of cowpea and sorghum fodder were used to determine the potential impact of fodder production on the current carrying capacity of Potshini. Dry matter yields of fodder crops grown under different nutrient regimes (MAP fertilizer, bioslurry, control) were used to calculate the area required for producing sufficient fodder for a year at the current stocking density (Table 5.1) to meet forage demand.

Cowpea yield ranged from 3.70 to 5.33 ton $ha^{-1}$ for the three fertilizer treatments (control, bioslurry, and MAP). The corresponding area of land required to fill the fodder shortage was 121.6 (control), 84.4 (MAP) and 91 ha (bioslurry). 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 (Table 5.1), 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 5.1).

Table 5.1: Total dry matter yield (ton ha$^{-1}$±se) of cowpea and sorghum and corresponding area required to meet the fodder shortage in Potshini

| | **Cowpea** | | **Sorghum** | |
|---|---|---|---|---|
| | **Yield(ton ha$^{-1}$)** | **Area (ha)** | **Yield( ton ha$^{-1}$)** | **Area (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 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 negative impact on livestock production. Therefore it was 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.

Currently, cattle graze in the rangeland during the growing season and after the growing season they graze nearby homesteads and they get to feed on crop residues in the fields (Everson et al., 2012). The common residue animals feed on is maize stover; however maize nutrient composition is unbalanced (Everson et al., 2012). Possible immediate interventions would be to introduce different grazing systems in the sourveld of Potshini. Rotational grazing system is an opportunistic grazing management practice that could be implemented by smallholder farmers as an alternative grazing system to the current continuous grazing system. 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 the purchase of 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 (Everson et al., 2014). 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 to practise 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 challenge with the implementation of a zero grazing system in communal areas involves 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 day and at night they are fed near homesteads (Magona and Musisi, 2002).

Semi zero grazing system (where cattle are allowed to graze in the rangeland during the day and they are overnight kraaled) can be introduced as an alternative grazing system to the continuous grazing system 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 fodder is therefore important for communal smallholder farmers to meet the livestock forage demand (Simbaya, 2002). Supplementary feeding with quality fodder has the potential of reducing the critical fodder shortage in the natural rangeland in Potshini in winter. 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 $ha^{-1}$ compared to the current 1.195 tons $ha^{-1}$

and the required land to produce to produce sufficient sorghum fodder was 145-250 ha. These findings emphasise the importance of quality fodder production to supplement the natural rangeland especially during the winter season when the nutritive quality of the grasses have declined.

Mwilawa et al. (2008) found that as a strategy for forage conservation in communal areas of Tanzania communal farmers use traditional pastures as an alternative to rangeland. The authors found that the forage from the pastures were not enough to meet the animal feed and nutrient requirements because they were of low quality. Ngongoni et al. (2007) suggested the use of legumes as alternative forage to natural rangeland in smallholder farming systems. Legumes are a low cost alternative to nitrogen fertilisers due to their ability to fix nitrogen in the soil and they have a higher protein content than cereal grains (DAFF, 2011). In the current study the results from the on-farm trails (chapter 3) supported the findings and showed that cowpea had higher nitrogen levels than sorghum fodder.

Ngongoni et al. (2006) reported that majority of smallholder farmers in the communal areas of Zimbabwe grew fodder for their livestock and their main challenges were the shortage of land available for fodder production. These authors further reported that in these areas the farmers preferred Napier and Bana grass fodder compared to other fodder crops. In their study Napier was planted on 206 ha to feed cattle on a cut and carry feeding system. However, in the current study site implementing the cut and carrying feeding system on this area would be a challenge because of the land shortage for producing fodder. Nevertheless the implementation of a semi zero grazing system has potential and bioslurry can be utilised to produce fodder

Tavarimirwa et al. (2013) recommended the use of different high quality grasses and legumes as winter supplement in smallholder farming systems. Ngongoni et al. (2007) recommended a cereal-legume intercropping system for higher yields and balanced nutritive feed for livestock. These authors found that when sorghum and cowpea were intercropped they produced a balanced protein to energy ratio and they also obtained higher yields. In the current study cowpea was a legume which fixes nitrogen and sorghum was a cereal grain, therefore intercropping could have increased the yield of both crops. It is recommended that intercropping trials of these crops are carried out in the study area to determine their impact on fodder production in communal livestock systems.

## 5.5 Conclusion

In sourveld there is heavy dependence on the natural rangeland for grazing throughout the year. As a result of seasonally changes the nutritive quality of grasses declines during the winter season. Therefore there is a need for fodder supplementation during winter when the grasses in the rangeland are dormant and have low nutritive quality value. Zero grazing is a potential grazing system that could be implemented by farmers in the community to reduce the pressure on natural rangeland. However, due to cost and limited land available for fodder production zero grazing can be adapted to semi zero grazing through provision of fodder during overnight kraaling.

Fodder provision improves cattle production because of quality nutritive fodder supplied during winter when the rangeland cannot produce enough quality grasses. The current study showed that sorghum and cowpea can reduce the pressure on the natural rangeland through providing sufficient forage required for all the cattle owned in the community. This could be achieved through planting more hectares of land to meet the current forage requirement. For this purpose the production of cowpea requires less land than sorghum to meet the current forage requirement. Cowpea required about 91-121 ha of land to produce sufficient fodder while sorghum required about 145.6- 250 ha of land depending on the treatments, to meet the forage deficit. Considering the availability of land available to in the area, cowpea would be recommended for farmers to produce because of its nutritive quality, higher yields and it agronomic qualities such as drought tolerance and ability to fix nitrogen in the soil.

# CHAPTER SIX: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

## 6.1 General Discussion and Conclusion

There is need for alternative grazing system to support the natural rangeland in communal areas because of the current grazing regimes. This study sought 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 Upper Thukela, South Africa.

Firstly the study determined the effects of bioslurry on growth, yield and nutritive quality of cowpea and sorghum fodder production in two on farm trials at the homesteads in the study sites. Bioslurry had no positive effect on sorghum and cowpea growth, yield and nutrient content. This is contradictory to other work by Islam et al, 2010 who observed that bioslurry application had positive effects on maize fodder, especially at the optimum application rate of 70 kg bioslurry N $ha^{-1}$. The current findings were also contrary to Shahbaz et al. (2014) who observed that the application of different N fertilizers with bioslurry at different rate had positive effects on the growth and yield of okra. The study findings were similar to those of Lehmann et al. (2003) who observed no significant differences between inorganic fertilizers and manure application on the plant production. As a slow nutrient releaser bioslurry was expected to yield low than MAP fertilizer, however they non-significant differences between MAP and bioslurry may be caused by different factors in the study site. Since the experiment was an on farm trail the environmental conditions could not be controlled, therefore these might have had an impact on the results. Factors that could lead to no positive effects of fertilizer applied on fodder growth and yield could be linked with the application method/technique, environment conditions, and nutrient release patterns of fertilizer applied, volatilization and leaching. Due to no significant differences in the on farm trails a laboratory incubation study was designed to determine the nutrient release patterns in bioslurry after application to contrasting soils.

The laboratory incubation study determined the N and P release from bioslurry in two contrasting soils (acidic and non- acidic) sampled from two farms in Upper Thukela. Results from the laboratory incubation showed that ammonium-N was released for all the soils (non-acidic, acidic lime and acidic unlimed) while nitrate-N was not released in the soils. Phosphorus was released for all the soils during the incubation study and the rate of release increased with the increase in bioslurry application rate. In the non-acidic the release was higher than in acidic soils. The current findings were similar to those of Daudu et al., (2012) who observed the increase in ammonium-N after applying organic residues in the soil. Chiyoka (2011) also observed no increase in nitrate-N during the laboratory incubation study. In general during the mineralization process ammonium-N decreases as nitrate-N increases and for the current study this could not be clearly justified due to scarce information on the bioslurry release patterns. However, Chiyoka (2011) suggested that immobilization of nitrate-N could be the cause of no nitrate release during the incubation study. With regards to phosphorus, the study findings were similar to the observation of Nongqwenga (2013) who observed that when the pH increases the P release also increases. Phosphorus was sensitive to pH during the incubation study.

Lastly the study assessed the potential impact of cowpea and sorghum fodder for supplementary feeding on current grazing carrying capacity. Fodder produced in the on farm trials was used to assess the impact of fodder production for supplementary feeding during winter season when the range is under pressure. The findings showed than currently farmers are overstocking the range and they graze cattle all year long. In addition the veld is in poor condition (Smith et al., 2005) therefore there was need to introduce alternative grazing systems that will reduce pressure on the natural rangeland. The current study showed that sorghum and cowpea can reduce the pressure on the natural rangeland through providing sufficient forage required for all the cattle owned in the community. This could be achieved through planting more hectares of land to meet the current forage requirement. For this purpose the production of cowpea requires less land than sorghum to meet the current forage requirement. Cowpea required about 91-121 ha of land to produce sufficient fodder while sorghum required about 145.6- 250 ha of land depending on the treatments, to meet the forage deficit. When farmers produce their fodder using bioslurry they would not save themselves costs but they also ensure the sustainable crop-livestock production system because they recycling manure and producing feed for their livestock. Producing fodder with the application of fertilizer would reduce the pressure on the natural rangeland during winter season and it could also reduce the fodder deficit in the area.

## 6.2 Recommendation

The current findings show that bioslurry like other organic sources can be used for fodder production in sustainable crop-livestock systems for smallholder farmers of South Africa. However, there are major gaps that still need to be researched. Long term studies on the effect of bioslurry on fodder production under controlled environment should be carried in order to gather insight on long term effects of bioslurry and the behaviour of bioslurry under controlled environment conditions where issues of such as volatilization would be reduced. It is also recommended that further studies must focus on long term effects of bioslurry on soils under different field conditions in order to make proper conclusions on the behaviour of bioslurry on soils. Considering the availability of land available to in the area, cowpea would be recommended for farmers to produce because of its nutritive quality, higher yields and it agronomic qualities such as drought tolerance and ability to fix nitrogen in the soil

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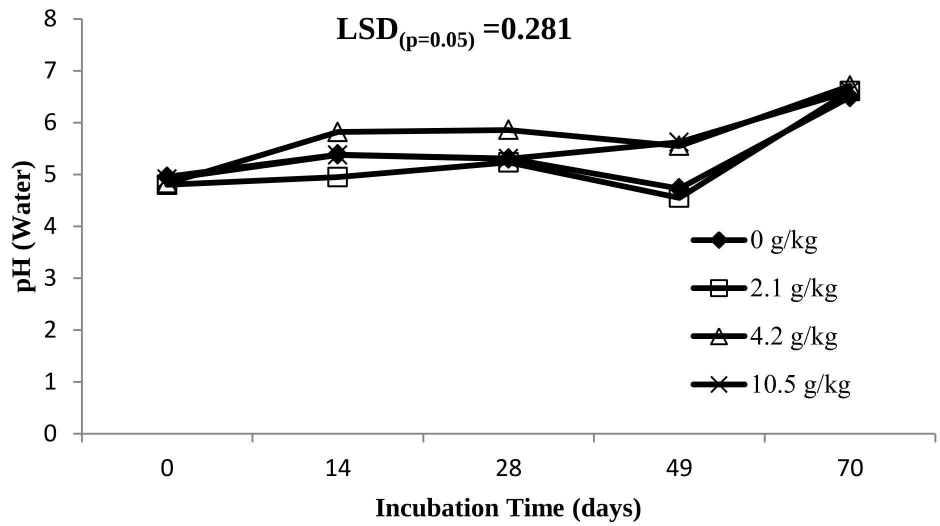
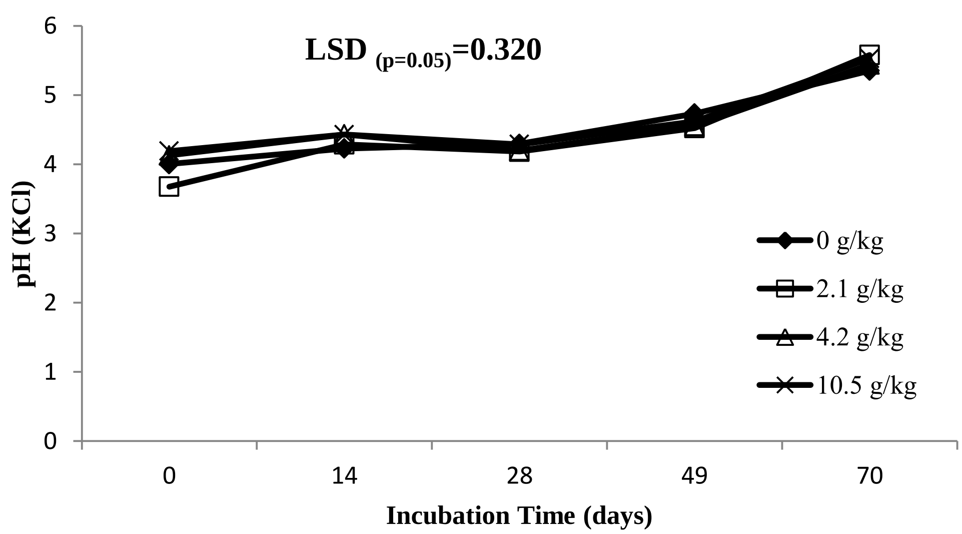
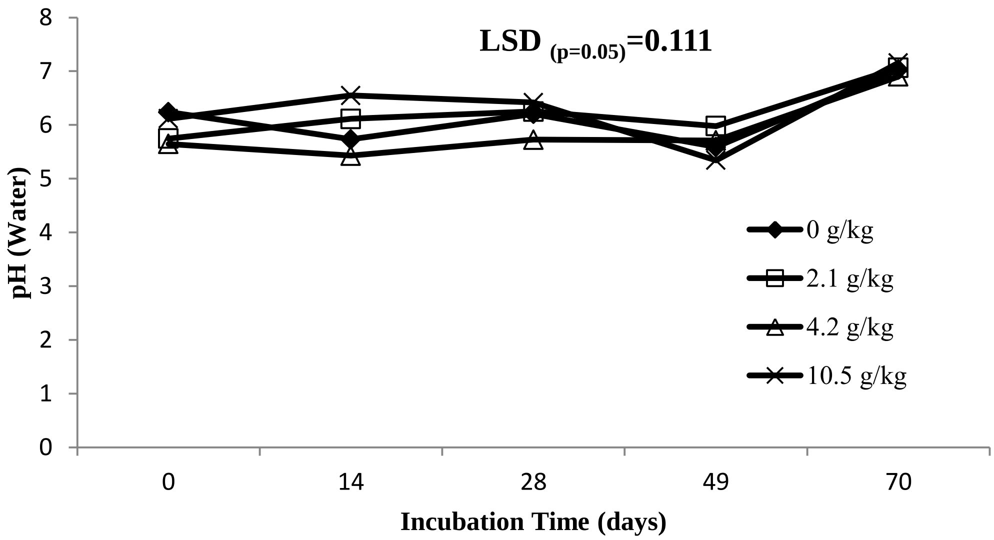
**APPENDICES:**

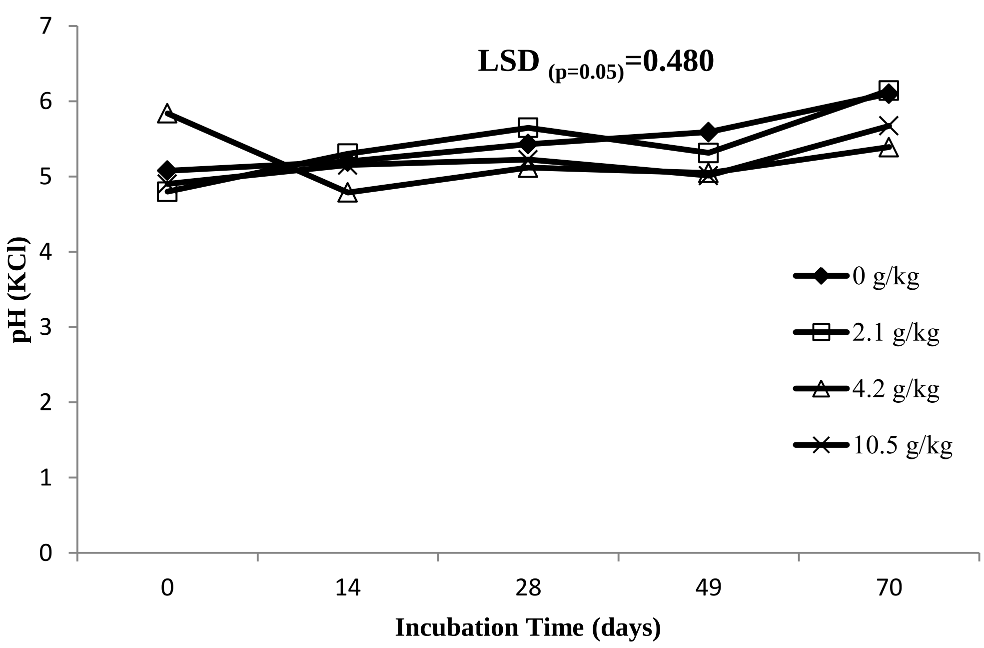
**Appendix 1**. **Soil pH changes during the incubation period with response to different bioslurry application rate in Water (a) and KCl (b) for New Stand soil**



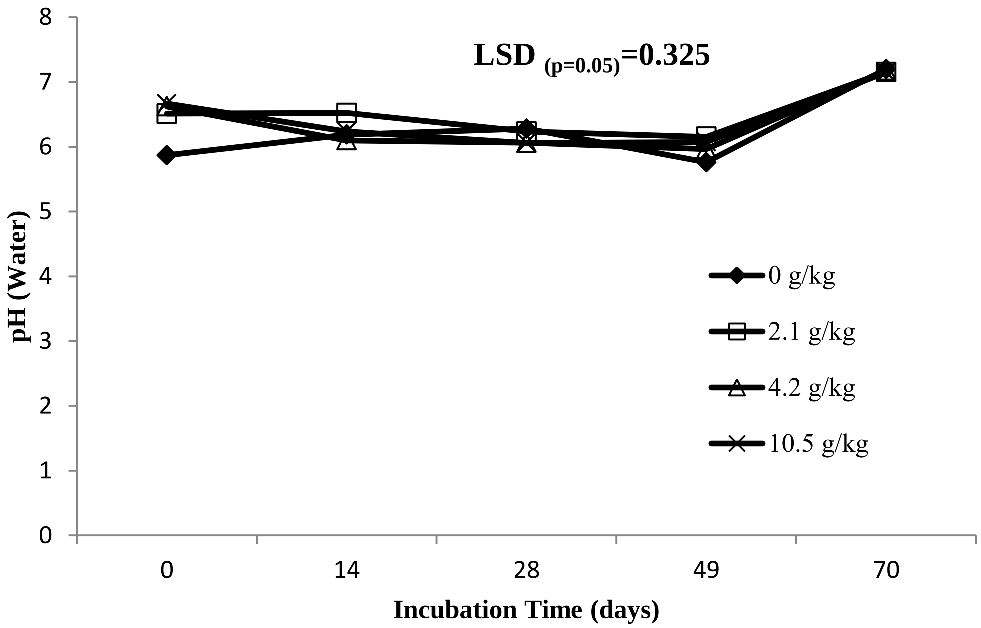



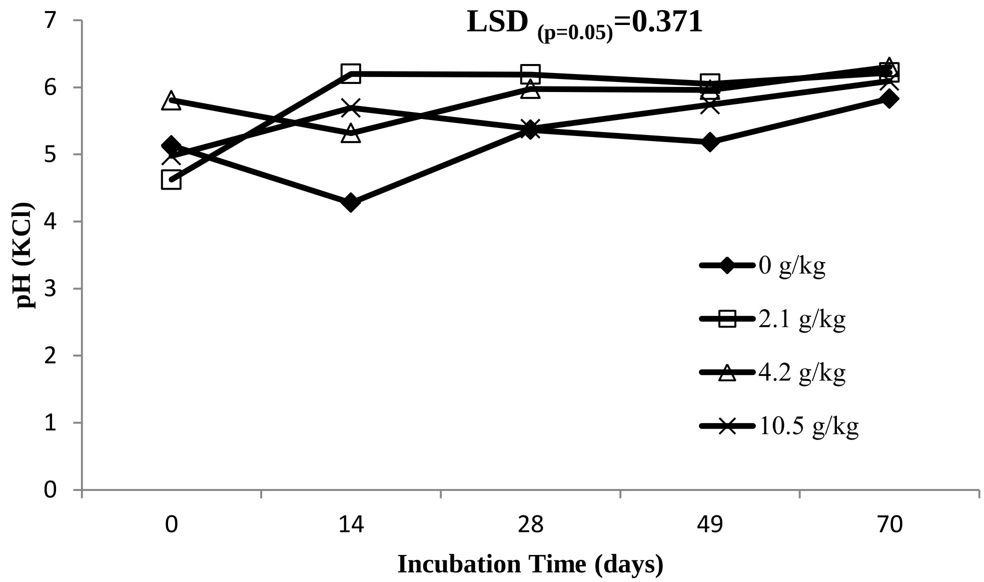
**Appendix 2: Soil pH changes during the incubation period with response to different bioslurry application rate in Water (a) and KCl (b) for Okhombe unlimed soil**



**Appendix 3: Soil pH changes during the incubation period with response to different bioslurry application rate in Water (a) and KCl (b) for Okhombe limed soil**






**Appendix 4: analysis of variance for (a) ammonium-N, (b) nitrate-N and (c) P for the acidic unlimed soil**

## (a) Analysis of variance

Variate: Amm_mg_kg

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Day | 13 | 2049.32 | 157.64 | 15.52 | <.001 |
| Treatment | 3 | 11.77 | 3.92 | 0.39 | 0.763 |
| Day.Treatment | 39 | 620.35 | 15.91 | 1.57 | 0.036 |
| Residual | 112 | 1137.95 | 10.16 | | |
| Total | 167 | 3819.39 | | | |

## (b) Analysis of variance

Variate: Nit_mg_kg

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Day | 13 | 10.4705 | 0.8054 | 5.73 | <.001 |
| Treatment | 3 | 0.9283 | 0.3094 | 2.20 | 0.092 |
| Day.Treatment | 39 | 7.3220 | 0.1877 | 1.34 | 0.122 |
| Residual | 112 | 15.7406 | 0.1405 | | |
| Total | 167 | 34.4614 | | | |

## (c) Analysis of variance

Variate: KAP_mg_kg

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Day | 13 | 580.926 | 44.687 | 29.98 | <.001 |
| Treatment | 3 | 36.511 | 12.170 | 8.17 | <.001 |
| Day.Treatment | 39 | 69.596 | 1.785 | 1.20 | 0.231 |
| Residual | 112 | 166.922 | 1.490 | | |
| Total | 167 | 853.955 | | | |

**Appendix 5: analysis of variance for (a) ammonium-N, (b) nitrate-N and (c) P for the acidic limed soil**

## (a) Analysis of variance

Variate: Amm_mg_kg

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Days | 13 | 3034.278 | 233.406 | 27.23 | <.001 |
| Treatment | 3 | 35.257 | 11.752 | 1.37 | 0.255 |
| Days.Treatment | 39 | 806.600 | 20.682 | 2.41 | <.001 |
| Residual | 112 | 960.094 | 8.572 | | |
| Total | 167 | 4836.229 | | | |

## (b) Analysis of variance

Variate: Nitr_mg_kg

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Days | 13 | 8.33759 | 0.64135 | 13.16 | <.001 |
| Treatment | 3 | 0.45565 | 0.15188 | 3.12 | 0.029 |
| Days.Treatment | 39 | 2.64182 | 0.06774 | 1.39 | 0.093 |
| Residual | 112 | 5.45908 | 0.04874 | | |
| Total | 167 | 16.89414 | | | |

## (c) Analysis of variance

Variate: KBP_mg_kg

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Day | 13 | 349.0982 | 26.8537 | 45.06 | <.001 |
| Treatment | 3 | 71.9745 | 23.9915 | 40.26 | <.001 |
| Day.Treatment | 39 | 58.8658 | 1.5094 | 2.53 | <.001 |
| Residual | 112 | 66.7435 | 0.5959 | | |
| Total | 167 | 546.6820 | | | |

**Appendix 6**: analysis of variance for (a) ammonium-N, (b) nitrate-N and (c) P for the non-acidic unlimed soil

## (a) Analysis of variance

Variate: Amm_mg_kg

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Day | 13 | 4401.62 | 338.59 | 22.11 | <.001 |
| Treatment | 3 | 55.53 | 18.51 | 1.21 | 0.310 |
| Day.Treatment | 39 | 804.14 | 20.62 | 1.35 | 0.116 |
| Residual | 112 | 1715.45 | 15.32 | | |
| Total | 167 | 6976.74 | | | |

## (b) Analysis of variance

Variate: Nitr_Mg_kg

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Day | 13 | 10.89418 | 0.83801 | 36.56 | <.001 |
| Treatment | 3 | 0.10078 | 0.03359 | 1.47 | 0.228 |
| Day.Treatment | 39 | 1.11836 | 0.02868 | 1.25 | 0.183 |
| Residual | 112 | 2.56748 | 0.02292 | | |
| Total | 167 | 14.68080 | | | |

## (c) Analysis of variance

Variate: P_mg_kg

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Day | 13 | 8226.829 | 632.833 | 66.28 | <.001 |
| Treatment | 3 | 640.225 | 213.408 | 22.35 | <.001 |
| Day.Treatment | 39 | 823.555 | 21.117 | 2.21 | <.001 |
| Residual | 112 | 1069.311 | 9.547 | | |
| Total | 167 | 10759.919 | | | |

## Appendix 6: Bioslurry characterization

**Table 3.3 Composition of nutrient in biogas slurry collected from trail sites**

| Sites | Moisture (%) | pH (%) | Total N (%) | K(mg/kg) | Total organic C (%) | NDF (%) | ADF (%) | Total Solids (%) | Volatile Solids (%) |
|---|---|---|---|---|---|---|---|---|---|
| **Newstand** | 92.67 | 8.62 | 1.48 | 574 | 20 | 50.54 | 42.51 | 8 | 80 |
| **Potshini** | 92.16 | 7.86 | 1.39 | 443 | 22 | 50.48 | 41.76 | 6 | 78 |

**Appendix 7: Characteristics of soils at two different sites ( Potshini and New Stand)**

# FERTILIZER ADVISORY SERVICE

KZN Department of Agriculture and Environmental Affairs; Soil Fertility and Analytical Services; Private Bag X9059, Pietermaritzburg 3200. Tel : 033-3559455. Fax : 033-3559454. Enquiries:Les Thurtell

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## SUMMARY OF ANALYTICAL RESULTS

(These results may not be used in litigation)

Batch : 898 Year : 2012 Printed : 2012/11/01

| Your sample ID | Lab number | Sample density g/mL | P mg/L | K mg/L | Ca mg/L | Mg mg/L | Exch. acidity cmol/L | Total cations cmol/L | Acid sat. % | pH (KCl) | Zn mg/L | Mn mg/L | Cu mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-New Stand | F19193 | 0.99 | 60 | 1707 | 973 | 472 | 0.06 | 13.17 | 0 | 5.27 | 10.0 | 12 | 3.5 |
| 2-Potshini | F19194 | 1.12 | 26 | 237 | 377 | 141 | 1.15 | 4.80 | 24 | 3.83 | 4.0 | 9 | 3.7 |

| Your sample ID | Lab number | Mid-Infrared Estimates Org. C % | N % | Clay % |
|---|---|---|---|---|
| 1-New Stand | F19193 | 3.8 | 0.34 | 30 |
| 2-Potshini | F19194 | 1.1 | 0.13 | 29 |

Comments:

(1) Recommended rates of fertilizer and lime for the relevant crops are reported on the following pages. No recommendation will be given for crops not entered on the submission form.
(2) Recommendations are not provided for subsoil samples.
(3) It is assumed that samples submitted for crops and for the establishment of pastures were taken from the top 15 cm of soil. For the maintenance of established pastures, a sampling depth not exceeding 10 cm is assumed.
(4) It is assumed that the lime to be used has a neutralising value equal to 75% of that of pure calcium carbonate. Dolomitic lime is recommended if soil Mg levels are low, and calcitic lime, if soil Mg exceeds 0.6 x soil Ca. Where Mg is sufficient, but not excessive, either type of lime may be used. If lime is not necessary, but the soil Mg level is suboptimal for the intended crop, this is indicated under the "Lime type" heading with the comment "low Mg". Consult your advisor for the most cost-effective method of improving Mg status.
(5) Phosphorus recommendations are based on a water-soluble P source.
(6) The recommendations are based on the assumption that the soil sample is trully representative of the land and that other growth factors are not limiting.
(7) Organic carbon, total nitrogen and clay percentage, estimated by mid-infrared (MIR) spectroscopy, is given for most samples. MIR measurements should be viewed as reasonably reliable estimates. Actual C, N and clay percentages (as well as S concentrations) can be determined (at extra cost) on request.