The effect of bioslurry, grass clippings and pumpkin live mulch on soil water content and maize production

by

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PREFACE

The research contained in this thesis 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, Pietermaritzburg Campus, South Africa. The research was financially supported by the Water Research Commission (WRC) of South Africa through WRC Project No. K5/1955 'Improving rural livelihoods through biogas generation using livestock manure and rainwater harvesting'.

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.

Signed: Dr Terry M. Everson

Signed: Dr Alfred O. Odindo

Date: 27 June, 2016

DECLARATION

I, Nelile Ngubo, 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;

(iv) this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

(vii) this dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

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Signed: Nelile Ngubo

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EXTENDED ABSTRACT

Poor soils, shortage of land and water scarcity are major challenges that limit agricultural production by small-scale farmers. Strategies aimed at improving soils and soil water content are therefore needed. In communal areas of South Africa, farmers can improve soil fertility by using crop residues to feed animals during winter and the resulting animal excreta used to fertilize soils. Farmers who have biogas digesters for energy production also use bioslurry, the effluent produced from the mixture of cow manure and water, as a fertilizer. The bioslurry can potentially be used as a soil amendment to address the problems of low soil fertility. In this study, it was hypothesized that bioslurry can act both as a nutrient source (as it is produced from the anaerobic digestion of cattle manure) and as a mulch (as it forms a hard cap on the soil surface which may reduce evaporation, thus improving soil water content). Therefore, the aim of the study was to evaluate the effect of bioslurry mulch compared to other selected mulches on soil moisture conservation in relation to maize yield. The study comprised a on-farm experiment conducted at Okhombe in the Upper Thukela, an on-station experiment conducted at the University of KwaZulu-Natal, Pietermaritzburg and a pot experiment carried out under controlled conditions in a growth chamber. The experiment conducted in the Upper Thukela region of KwaZulu-Natal on a communal farmer's crop land compared the effect of bioslurry, grass clippings and pumpkin live mulch on maize yield and on soil water content under rainfed conditions. The experiment was conducted as a single factor in a randomized complete block design (RCBD) and the treatments were replicated four times giving a total of 16 experimental units (5 m x 5 m plots). Measured variables were soil water content, maize growth and development (leaf area and number, plant height, stem girth), thousand seed weight, stover yield and maize yield. The results of the soil water content measured using a HydroSense II Probe system (HS_2P; CS659P; Campbell Scientific, Africa) showed that soil water content was significantly higher (21.55%; $P < 0.01$) in the bioslurry treatment compared to the control (18.39%). However, the effect of bioslurry on soil water did not differ significantly (21.55%; $P > 0.05$) from the grass clippings mulch (19.88%) and pumpkin live mulch treatments (21.30%). The largest leaf area (154.9 cm^2) was recorded from the plots mulched with bioslurry compared to other mulches. The different mulching materials used in this study significantly improved yield (1332-3498 kg ha^{-1}; $P < 0.05$) compared to the farmer's practice of no mulch (1017 kg ha^{-1}). The highest maize yield was recorded from bioslurry (3498 kg ha^{-1}) and grass clippings (3420 kg ha^{-1}) compared to

the control and pumpkin live mulch. The high grain yield obtained from the bioslurry treatment could be attributed to an increase in leaf area in plots mulched with bioslurry resulting in increased light interception and thus high photosynthetic activity and increased yield. It is also possible that the hard cap formation as a result of bioslurry application could have minimised soil water evaporation and thus conserved soil water.

A separate experiment was carried out in a growth chamber at the Controlled Environmental Facilities (CEF), University of KwaZulu-Natal to determine the effect of hard cap formed after bioslurry application on soil water conservation under different temperature regimes. The experiment was arranged as a complete randomised design. The results showed that at high temperatures (35°C), the application of bioslurry mulch had no benefits in soil water conservation. However, at 25°C and 30°C bioslurry mulch conserved more soil water than the control, which may be attributed to formation of the hard cap that may have reduced soil evaporation.

An on-station field experiment in which maize was planted and bioslurry used as mulch compared to a control (no mulch) was conducted at the University of KwaZulu-Natal. In this experiment, the effect of the hard cap formed by bioslurry on soil water content, soil infiltration rate and maize growth was evaluated. The experiment was laid out in a split-plot arranged in a completely randomized design with irrigation (irrigated and non-irrigated) as main plot and mulching treatments (bioslurry mulch and control of no bioslurry mulch) as sub-plot. Treatments were replicated three times, giving 12 experimental units (2 m x 2 m plots). Growth variables (leaf area and number, plant height, stem girth), stover yield, soil water content and water infiltration rate were determined. No significant differences ($P > 0.05$) were observed between the soil water content in the bioslurry and control treatments in the non-irrigated plots, whereas in the irrigated plots the bioslurry treatment was significantly higher (20.32%; $P < 0.05$) than the control (17.04%) with respect to soil water content. Bioslurry mulch under non-irrigated conditions had no effect on maize growth. Irrigated plants with bioslurry mulch were 0.49 m tall which differed significantly ($P < 0.05$) from the irrigated plants with no bioslurry (0.40 m). Bioslurry mulch under irrigation significantly ($P < 0.05$) increased the average leaf area (105 cm^2) in maize plants compared to the control (90.2 cm^2). The stover yield in maize harvested from plots mulched with bioslurry was 1967 kg ha^{-1} which differed significantly ($P < 0.05$) from the control (1068 kg ha^{-1}). Increased maize growth and high stover yield in the plots treated with bioslurry under irrigated conditions could have benefited from the higher water content recorded from these plots as well as the additional nitrogen supplied by the bioslurry. Low water infiltration rate was observed in plots mulched with bioslurry compared to the control plots in both irrigated and non-irrigated conditions. This indicated that the hard cap formed by the bioslurry could have sealed the soil pores, resulting in a low infiltration rate. In addition, under irrigated conditions bioslurry mulch further reduced the water infiltration rate (4.5 mm min^{-1}) compared to the control (7.7mm min^{-1}). This could be attributed to the high moisture content contained in the bioslurry which could have filled up the soil pores thus reducing soil water intake. Although the results showed that the bioslurry mulch lowered the water infiltration rate, this did not have a negative impact on maize growth, indicating that the hard cap could increase soil water content by reducing evaporation from the soil surface. In conclusion, bioslurry mulch can significantly improve maize growth under irrigated or rainfed conditions and should be recommended to rural farmers to improve maize production. Although there were no significant differences in soil water content between bioslurry mulch, grass clippings mulch and pumpkin live mulch, there are clear advantages with regard to the use of bioslurry as a mulch to conserve soil water. For those households that have biogas digesters bioslurry is more accessible as a mulch, when compared to grass clippings mulch and pumpkin live mulch. These mulches are difficult to obtain as they are also used as a source of fodder. Pumpkin live mulch may also contribute to increased water losses through evapotranspiration during hot and dry weather conditions. In conclusion, the findings of this study indicated that the use of organic mulches increased soil water content more than the control of no mulch and should be highly recommended to farmers operating rainfed agriculture in this region.

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CHAPTER 1

GENERAL INTRODUCTION

1.1 Background and introduction

Low soil fertility, shortage of land and water scarcity are major challenges to food security in sub-Saharan Africa (SSA), because they limit agricultural production by small-scale farmers (Mwangi, 1996). Land scarcity is a problem in many parts of Africa and this indicates that food insecurity will remain high in SSA due to the small area of land that produces inadequate food (Mwangi, 1996). Food insecurity remains high in SSA and has a negative effect on food availability, accessibility, stability and utilization (FAO, 2013). Furthermore, importing food into these countries is problematic due to poor infrastructure (roads, ports and unavailability of food storage facilities) and non-viable economic factors (Druilhe and Barreiro-Hurlé, 2012) and can be expensive.

The use of chemical commercial fertilizers can improve soil fertility and thus increase yield and consequently food production by small-scale farmers. This could contribute to producing enough food to feed the ever increasing population (Mwangi, 1996). However, chemical commercial fertilizer use in SSA is low and was estimated at 7 kg of nitrogen, phosphorus and potassium (NPK) per ha in 2008 which is about 3% of global fertilizer consumption (Mwangi, 1996; Druilhe and Barreiro-Hurlé, 2012). Low fertilizer use by small-scale farmers in SSA can also further aggravate soil degradation because nutrients removed via crops harvested in the previous seasons are not returned to the soils (Mwangi, 1996).

Low fertilizer use could be associated with the lack of knowledge on the value of using the fertilizer in addition to the high cost of chemical fertilizers. About 35% of the country’s population (mostly rural areas) is thought to be vulnerable to household food insecurity (De Klerk et al., 2004). Approximately 12% of the land surface in South Africa is suitable for growing rainfed crops and only 3% of the land is considered truly fertile (Goga and Pegram, 2014). This is attributed to poor soil types and unsuitable climate.

Initiatives or strategies aimed at improving soil fertility should consider alternatives to chemical fertilizers. Ideally, these alternatives could come from locally sourced materials either in the form of crop residues, or animal excreta that could be used as an organic fertilizer. The most common strategy to improve soil fertility in communal areas is the use of crop residues to feed animals during winter and the resulting animal excreta is used to fertilize the soil. According to No (2012), organic fertilizers such as cow dung and poultry manure can play a significant role in improving soil fertility and crop yield. Another viable strategy to farmers who have biogas digesters for energy production is the use of bioslurry, the effluent that is produced from the inputs of animal manure and water to produce biogas.

Smart (2013), defined bioslurry as the by-product of biogas production involving the mixing of biowaste such as animal manure or human excreta or plant material with water. In a biogas digester, the mixture goes through an anaerobic digestion process during which they converted by bacteria into biogas and a digestate or effluent called bioslurry. The bioslurry has the following advantages over raw manure such as cow dung or poultry manure. It is odourless and it does not attract flies. Manure attracts termites while bioslurry repels them. Therefore, fertilizing crops with manure increases the risk of crops being attacked by the termites (Karki and Expert, 2006). In addition, bioslurry could be considered as an alternative to chemical fertilizers because it is relatively cheap and safe and easily prepared from local material. Cow dung and poultry manure are reported to have higher fertilizer value when converted into bioslurry after undergoing the fermentation process, leading to the production of biogas (Bonten et al., 2014). Bioslurry could also potentially supplement commercial fertilizer, thus, reducing the amount of chemical fertilizer required by the farmer, hence, reducing production costs. One of the reports demonstrates the positive effects of the use of bioslurry on increased crop yield, improved crop quality and reduced dependence on chemical fertilizer use (Karki and Expert, 2006).

Water scarcity is also a major constraint to food production among rural households in South Africa (Hubbart, 1995). South Africa is classified as a water stressed country since water available per capita per annum is estimated to be 1 000 m^3 (Goga and Pegram, 2014). Based on international standards, South Africa receives low rainfall which is less than 60% of the world's average (Goga and Pegram, 2014) on one hand. On the other hand South Africa has high mean annual run-off as a result only 9% of rainfall enters the rivers compared to a global average of 31% (Goga and Pegram, 2014). In addition, agricultural productivity in small-scale farmers is often constrained due to uneven rainfall distribution. These farmers also experience mid-summer droughts (Goga and Pegram, 2014). Maize yields obtained by many small-scale farmers in SA under rainfed conditions average one ton per hectare (Barron and Okwach, 2005), which is far below the potential yield of three tons per hectare (Machethe et al., 2004). Strategies to improve soil moisture may include mulching, whereby a layer of inorganic or organic material is applied on bare soil around the plants to prevent excessive soil evaporation. Organic mulches enrich the soil (as they release the soil nutrients after decomposition) in addition to inhibiting weed growth thus conserving moisture (Ramakrishna et al., 2006; Mupangwa et al., 2007).

Inorganic mulches refer to non-living mulches such as rocks and plastic such as black polyethylene (Haapala et al., 2014). Organic mulches are mulching materials made from materials such as grass clippings, compost or animal manure, crop residues from previous crops, live mulch, paper or woody material such as bark and sawdust (Merfield, 2002). Small-scale farmers cannot afford to purchase inorganic mulching materials and some organic mulching materials due to high costs (Haapala et al., 2014). A potential solution to expensive mulching materials could be the use of a permanent organic soil cover such as a crop residue from a previous crop or grass and live mulch. Organic mulches are generally relatively cheap and locally sourced. Organic mulches are environmentally friendly because they do not release toxic chemicals which pollute the environment. They can be fully decomposed in the soil, eventually improving soil organic matter. However, the use of organic mulches such as crop residues can also pose challenges with regard to pest and disease infestation (Erenstein, 2002). For example, a disease affecting the previous crop can persist on the mulch and get a chance to establish and become a problem to the current crop.

Using such organic permanent soil covers reduces soil evaporation and erosion and suppresses weed growth, thus conserving soil moisture (Giller et al., 2009). The implementation of a permanent cover of the soil through mulching is beneficial to crop production because this forms a component of conservation agriculture which leads to sustainable and profitable agriculture while conserving the environment. In addition, the use of inexpensive locally sourced organic mulches could also provide a potential solution to low soil fertility since they decompose fully in the soil thus adding nutrients and organic matter (Haapala et al., 2014).

Another example of mulching that is common in developing countries is the use of growing plants as live mulch. Live mulches are also known as cover crops and are defined as crops planted as an intercrop which have an ability to suppress weeds thus conserving soil moisture by reducing competition for water between the crop and weeds (Romaneckas et al., 2012). One example of live mulch is intercropping maize with pumpkin. Pumpkin covers the soil surface, and hence, conserves moisture by suppressing evapotranspiration by the weeds and evaporation through the soil surface (Mupangwa et al., 2007). However, moisture can still be lost as a result of evapotranspiration through the pumpkin leaves (Mashingaidze, 2004). Pumpkin planted as an intercrop may contribute to food security during times of food scarcity since it also supplies edible parts before the other crop is harvested. Pumpkin grown for food plays an important role in food security in rural communities of KwaZulu-Natal. Pumpkin is largely grown for its fruit which is boiled and eaten as a dessert as well as for its leaves which serve as a source of vegetables (Mashingaidze, 2004).

The use of bioslurry as an organic mulch could potentially provide cheaper and alternative sources to the use of expensive mulching materials. Bioslurry is reported to have some characteristics of mulching, which include suppressing weed growth and improving soil water holding capacity (No, 2012). Bioslurry contains organic matter and fibre, and it also improves soil organic matter; all these features contribute to its ability to hold soil moisture (Karki and Expert, 2006). Possibly, the use of bioslurry during dry spells could allow soil to hold enough water for crop use and eventually improve crop yield. So far, the information on using bioslurry as a mulch is not well-documented.

1.2 Scope of the study

The use of animal excreta such as bioslurry in mixed crop-livestock production systems has potential to reduce heavy reliance on chemical fertilizers which have a negative impact on the environment (Karki and Expert, 2006). Bioslurry is an organic fertilizer that replenishes nutrients removed by plants or livestock eating fodder crops in the field, thus improving soil fertility. It is also environmentally friendly since it does not have toxic metals compared to chemical fertilizers (No, 2012). Furthermore, in mixed crop-livestock production systems, crop residues and fodder crops could be used as a supplementary feed in winter when the quality of natural veld is poor. Crop residues produced through bioslurry application could be used as a source of animal feed while bioslurry may enhance agricultural productivity by replenishing soil nutrients.

There is a need to study the impact of bioslurry and other mulching materials on water conservation for small-scale farmers who rely on rainfed maize production but often experience dry spells or drought during the growing season. In this regard it is, therefore, important to determine if bioslurry could be used as a mulch and as a nutrient source to promote sustainable crop production in rural areas.

1.3 Aim and objectives

The aim of the study was to evaluate the effect of bioslurry mulch compared to other mulches on soil moisture conservation in relation to maize yield.

Specific objectives:

- To carry out an on-farm field experiment to compare the effect of bioslurry, grass clippings and pumpkin live mulch on maize growth, yield performance and on soil water content under rainfed conditions.
- To carry out a pot experiment in a growth chamber to determine the effect of bioslurry mulch on soil water conservation under different temperature regimes.
- To experimentally evaluate the effect of bioslurry mulch on soil water content, soil infiltration rate and maize growth performance in a controlled on-station experiment.

1.4 Research hypotheses

- It was hypothesized that bioslurry would conserve more water than pumpkin live mulch and grass clippings mulch by forming a hard cap when applied onto the soil surface which would decrease soil water loss through evaporation, thereby conserving moisture and increasing maize yield. Bioslurry mulch would increase maize yield more than other mulches because bioslurry also supplies essential nutrients needed for plant growth in addition to conserving moisture.

- In this study, it was hypothesized that bioslurry mulch would decrease soil water loss under high temperatures because of the high organic content.

- It was hypothesized that the hard cap formed after bioslurry application would not reduce the soil infiltration rate because the cap is made from organic material, which is not water resistant.

1.5 Outline of the thesis

1. Chapter 1: General introduction
2. Chapter 2: A literature review on the different factors that affect the use of bioslurry for crop production
3. Chapter 3: Effect of bioslurry, grass clippings and pumpkin live mulch on maize yield and on soil water content under rainfed conditions
4. Chapter 4: Effect of bioslurry application on soil water infiltration and maize growth under irrigated and non-irrigated conditions
5. Chapter 5: Conclusions and recommendations for further research

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Bioslurry is a by-product of the anaerobic digestion of cattle, pig, or poultry manure in a biogas digester (Islam, 2006) and is rich in plant macro and micro-nutrients. The effluent has been reported to improve soil physical and chemical properties by adding organic matter to the soil (No, 2012). High organic matter content in the soil improves soil structure, soil water holding capacity and cation exchange capacity (CEC). The improved CEC, enables soil nutrients to become more available to plants since they are retained in the soil rather than being lost through leaching (No, 2012). This means that bioslurry can be used as an organic fertilizer to reduce soil fertility problems that might impact negatively the crop productivity.

The use of chemical fertilizers to enhance crop productivity is not sustainable in the long-term because of negative effects on the environment (No, 2012). They degrade soil by increasing soil acidity. They result in eutrophication, which may lead to polluting the ground water (Shahabz, 2011). Hence, the use of bioslurry could provide a solution to chemical fertilizers which are expensive in addition to the problems mentioned above. However, the nutrient content of digested bioslurry with respect to nitrogen (N), phosphorus (P) and potassium (K) is low compared to chemical fertilizers (No, 2012). This means that it may be necessary to apply large quantities of bioslurry to meet the same level of these nutrients compared to chemical fertilizers. Nonetheless, bioslurry is a good source of humus compared to chemical fertilizers (No, 2012). The beneficial effects of humus include enhancing the CEC, increasing soil water holding capacity, improving soils aggregation and preventing the leaching of nutrients. Therefore, bioslurry not only has the potential to supply plant nutrients but it also keeps them in the soil by preventing them from leaching.

Since the application rates and quality of bioslurry are poorly documented, the review was undertaken to assess the current understanding regarding the application of bioslurry for crop production and factors affecting the use of bioslurry for crop production. In addition, other factors affecting the bioslurry properties were examined including the feeding materials used to produce the different forms of bioslurry. Finally, the chapter concludes by attempting to identify knowledge gaps on the current information regarding the use of bioslurry for crop production.

2.2 Factors affecting the properties of bioslurry

The properties of bioslurry depend on many factors such as the material used to produce it or feeding substances (Islam, 2006). The forms of bioslurry, the methods used to store the bioslurry (Gurung, 1997), the application rate and application methods also affect the effectiveness of bioslurry (Bonten et al., 2014). These factors are discussed as follows;

2.2.1 Types of feeding material used for bioslurry production

Bioslurry is produced from the integrated system which is comprised of a biodigester, rain water, kraaled cattle, and the production of food and fodder. The biodigester will produce biogas and bioslurry by anaerobically digesting a mixture of water and cattle manure. The liquid bioslurry effluent is then used to fertilize the food and fodder crops. An example of bioslurry production system is shown in Fig. 2.1.

The nutrient content of the feeding substances can also have an effect on soil properties and crop yield, due to the resulting content in macro and micro- nutrients. These feeding substances could be kitchen garbage effluent and animal excreta such as poultry, sheep, cow dung, pig and human waste. Kitchen garbage effluent is rich in N and K, but lower in other nutrients (Warnars and Oppenoorth, 2014). Thus, the use of bioslurry derived from kitchen garbage effluent may not supply sufficient nutrients other than N and K to a crop. No (2012) reported that bioslurry made from chicken droppings had the highest total N and P followed by fresh pig manure on a wet basis. Chicken droppings also had a higher organic matter compared to other feedstock, followed by pig dung (Table 2.1). Islam (2006) reported that onion yield obtained from poultry litter bioslurry was superior to cow dung bioslurry and concluded that poultry litter bioslurry had a higher and balanced nutrient content than cow dung bioslurry. Sarker (2012) observed that bioslurry derived from human excreta contained a higher proportion of N compared to any other form of the organic manure mentioned above.

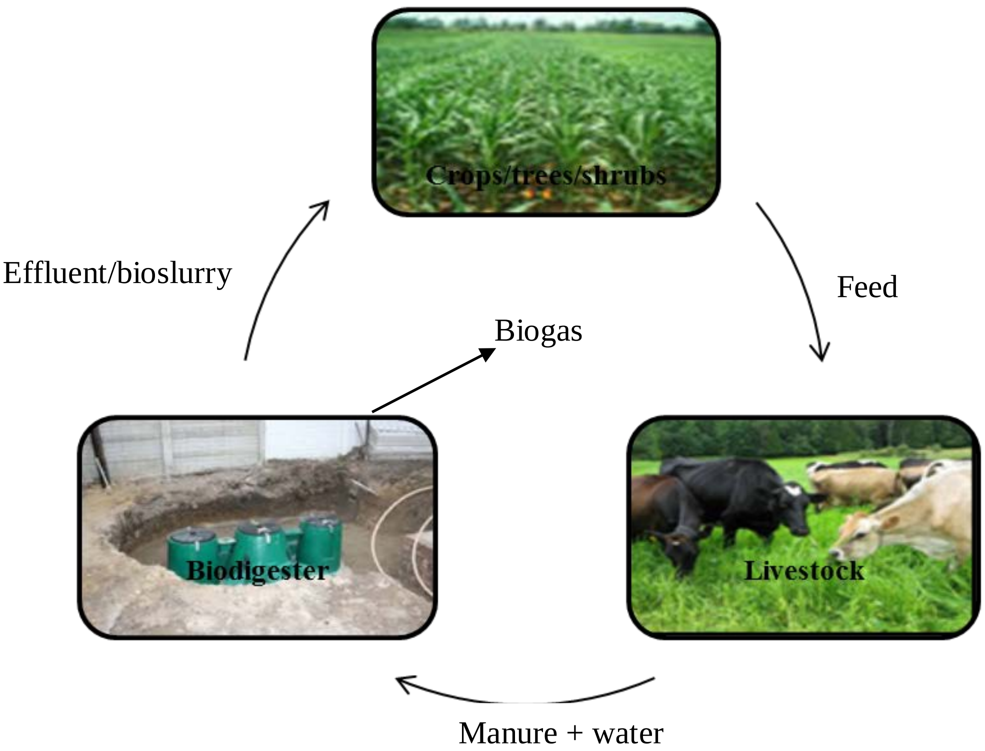

Figure 2. 1 A Flow chart of bioslurry production

Table 2. 1 The nutrient contents of different fresh feedstock in Nepal on a wet basis.

Feedstock (manure)	pH	Organic matter	Nitrogen (%)	P_2O_5 (%)	K_2O (%)
Cattle and Buffalo	8.11	14.88	0.26	0.77	0.39
Chicken	7.35	43.34	2.5	1.07	1
Pig	7.3	15.64	0.59	0.89	1.11

Source: (After ATC, 1997, cited by No, 2012)

2.2.2 The different forms of bioslurry and the effect on nutrient availability

There are three forms of bioslurry namely; liquid, dried and composted bioslurry (No, 2012). Liquid bioslurry is also known as fresh bioslurry. The challenge of using the liquid bioslurry is that it can spill when being transported to the field and the N content is low (Table 2.2). The exposure of liquid bioslurry to the atmosphere can result in ammonia-N losses through the process of volatilization (Karki and Expert, 2006). However, Bonten et al. (2014)

reported that there are studies which show that liquid bioslurry has a higher N content than composted and dried bioslurry which is contrary to the results presented in Table 2.2. The results in Table 2.2 showed that N content was low in liquid bioslurry on a dry and wet basis compared to composted and dried bioslurry. It should be noted that the feeding substances used can have an effect on the N content in liquid bioslurry. In addition, a major challenge of using liquid bioslurry is its tendency to separate into liquid and solid forms during application which results in non-uniform distribution (Karki and Expert, 2006; Warnars and Oppenoorth, 2014).

Dried bioslurry is produced by sun-drying the liquid bioslurry. This form of bioslurry can be transported easily. Theoretically, dried bioslurry is expected to have low N content due to the fact that ammonia escapes into the air when exposed to the sun. A report from Bonten et al. (2014) showed that N was lost from cow dung bioslurry and poultry bioslurry during the drying process. Therefore, drying the bioslurry with an intention of easy transportation or storage may reduce the N content of bioslurry and affect crop production negatively due to inadequate supply of N (Bonten et al., 2014; Warnars and Oppenoorth, 2014). However, Gurung (1997) showed that sun-dried bioslurry had a higher N content than composted bioslurry on a wet basis (Table 2.2). Dried bioslurry is expected to have lower N contents because of potential N- losses from the bioslurry in the form of gaseous ammonia (NH_3). The contradiction could arise from the comparison made from composted and dried bioslurry taken from different sources/animal manure.

There are reports in the literature which show that sun-dried bioslurry contains lower P and K compared to fresh bioslurry (Karki and Expert, 2006). The reasons for the decrease in P and K are not clear since none of these elements are volatile. Possibly, it can be speculated that these differences arise because the comparisons are made between fresh and dried bioslurry from different sources. The effect of drying on bioslurry quality and fertilizer value is under-researched. Studies that have been conducted do not give clear information in this regard. The studies lack detailed information on the animal dung and the methods used to produce the bioslurry as well as the method used to analyze the nutrient content within the bioslurry.

Composted bioslurry is made from the mixture of bioslurry with some vegetable or agricultural residue (Karki and Expert, 2006; Warnars and Oppenoorth, 2014). The composted form of bioslurry is considered to be the best over liquid and the dried form, since it is easier to transport than liquid bioslurry, and has less nutrients lost than dried bioslurry (Groot and Bogdanski, 2013; Bonten et al., 2014). However, Bonten et al. (2014) reported that approximately 15 to 25% of N is lost through volatilization of gaseous NH_3 during the bioslurry composting process. Karki and Expert (2006) observed a reduction in NH_3 concentrations after composting the bioslurry and concluded that this may be due to volatilization of ammonia or N immobilization on the added organic material. By contrast, Karki and Expert (2006) reported an increase in nutrient contents within cow dung and poultry bioslurries after composting. This may be attributed to high organic matter or N concentrations within the organic material added during the composting of bioslurry.

Table 2. 2 The NPK value of fresh, sun-dried and composted form of bioslurry.

Type of bioslurry manure	Nitrogen (%)	Phosphorus (%)	Potash (%)	Remarks
Liquid bioslurry	0.06 0.87	0.07 0.58	0.06 0.87	Wet basis Dry basis
Sun-dried bioslurry	1.73 2.92	0.69 1.17	0.68 1.15	Wet basis Dry basis
Composted bioslurry	1.31 3.75	1.18 3.37	0.88 2.25	Wet basis Dry basis

Source: (After ATC, 1997, cited in Gurung, 1997).

Different forms of bioslurry contain different levels of N, P and K, on account of difference in the contents of these nutrients in the material used. This means that crop responses might differ due to the type of bioslurry used. Nevertheless, most of the information on bioslurry nutrient content is not clear. Many researchers presented different results on the nutrient contents of bioslurry without mentioning the type of substrate used to produce a particular bioslurry that contained a certain amount of N, P and K (No, 2012). Therefore, studies that will give detailed information concerning bioslurry nutrients content are needed.

2.3 Nitrogen and phosphorus mineralization from the bioslurry

Nitrogen mineralization is known as the process whereby organic N is converted to inorganic forms (NH_4^+ and NO_3^-), thereby making it accessible to the plants (Crohn, 2004). Nitrogen mineralization can be used to estimate the amount of N available to the plants (Guntinas et al., 2012). Gurung (1997) reported that mineralization of organic N was superior in liquid bioslurry compared to dried bioslurry. Lower N mineralization in dried bioslurry could be due to poor diffusion of colloidal material resulting in an increase in resistance following microbial decomposition (Gurung, 1997).

Phosphorus mineralization is known as the microbial conversion of organic P to dihydrogen phosphate ion ($H_2PO_4^-$) or Hydrogen phosphate ion (HPO_4^{2-}) forms of plant available P known as orthophosphates. Phosphorus mineralization process is under-researched, the reason for that might be the constraint imposed by non-availability of analytical techniques (Randhawa et al., 2005). Overall information on N and P release from bioslurry in the literature is scanty. Therefore, studies that look at N and P mineralization from the bioslurry are needed.

2.3.1 Mineralization rates of N and P

All processes involved in N and P mineralization are all accomplished by various groups and types of microorganisms found in the soil. Mineralization rate of N and P is therefore affected by the factors that influence the functioning of microorganisms involved in the breaking down of organic matter. These factors include temperature, moisture, soil texture and manure characteristics (Griffin et al., 2002).

Nitrogen mineralization from pig bioslurry was observed to decrease with increasing temperature (Benitez et al., 1998). Marschner and Bredow (2002) reported that in cattle bioslurry, N mineralization increased with increasing temperature. This indicates that mineralization is highly influenced by manure characteristics and is probably related to the types of microbia involved in organic matter decomposition of that particular manure. Furthermore, the increased of N mineralization rate with increase in soil temperature could be associated with the increased microbial activities and associated increased decomposition of organic matter which enhances N mineralization.

Soil moisture is an important factor that is expected to affect microbial activity and hence mineralization rate. However, soil moisture was reported to have no effect on N mineralization from cattle bioslurry (Marschner and Bredow, 2002). On the contrary, a soil moisture content of 18% increased N mineralization in pig bioslurry (Benitez et al., 1998). This could be attributed to the fact that water availability increases microbial growth and nutrition and the ability of microorganisms to reach the substrate ammonium (Killham et al., 1993). The increase population of microorganisms around substrate ammonium increases N mineralization.

The mineralization of N and its availability to plants in bioslurry is also determined by the digestion process (aerobic or anaerobic), carbon to N (C:N) ratio, inorganic N content, pH, time of application, the method of application, soil type and soil properties (Warman and Termeer, 2005; Islam et al., 2010). High inorganic N content (ammonium and nitrate) increases N mineralization and availability to plants. Anaerobic digestion reduces N in the bioslurry into an ammonium form which is ready for uptake by some plants (Karki and Expert, 2006). Generally, fifty percent of N from bioslurry is inorganic form (ammonium) and the other fifty percent is organic form (Bonten et al., 2014). Aeration and soil type affect the availability of N to the plants. Griffin et al. (2002) observed that N mineralization rate of swine bioslurry was high in soils with high sand content compared to the soils with high silt and clay content. This was ascribed to rapid drainage in sandy soils which increased the aeration compared to silt and clay soils. Low C:N ratio in the bioslurry reduces N mineralization rate (Gurung, 1997; Shahabz, 2011), while promoting N immobilization (Bonten et al., 2014). If bioslurry contains high percentage of ammonia or carbon compounds that are easily decomposable, N immobilization increases. This is because, high decomposable compounds stimulate microbial activity which further decreases the N mineralization (Gurung, 1997; Shahabz, 2011). However, if the C:N ratio is high then the N is easily accessible. This means that N mineralization proceeds quickly (Gurung, 1997). The information on the factors affecting N availability from the bioslurry to the plants is scant therefore, further research in this regards is required.

Soil moisture, temperature and pH are factors that can affect the rate of P mineralization. A study conducted by Whalen et al. (2001) showed that P mineralization was favored when the soil was incubated at 20 °C and 75% field capacity. Grierson et al. (1999) reported that increasing the incubation temperature from 15 to 38 °C increased the KCl- extractable inorganic P from 13 to 53%. Phosphorus released from swine bioslurry was not affected by soil water content and temperature regimes (Eghball et al., 2005).

Availability of P to the crop is also influenced by soil alumunium (Al), iron (Fe) and calcium (Ca) content (Warman and Termeer, 2005). Phosphorus reacts with Al, Fe and Ca or magnesium (Mg) in soils with pH less than 5.5 or greater than 7.5 and becomes unavailable to the crops (Ebeling et al., 2003; Warman and Termeer, 2005). Mineralization of P from bioslurry and factors affecting P mineralization rate are not well-documented.

2.4 Factors affecting the effectiveness of bioslurry in crop production

2.4.1 Application rates

The quantity of bioslurry applied to meet crop nutrient requirements will depend on the nutrient contents of the feeding substance as well as the form of bioslurry (whether it is liquid, dried or composted) (Warnars and Oppenoorth, 2014). Different forms of bioslurry can be applied using different rates because they have dissimilar nutrient contents. This will ensure that the crop gets the required nutrients (Galli and Pulchok, 2001). Incorrect application rates (under and over-application) can have a negative effect on crop production. Under-application of fertilizer can decrease crop yields due to an inadequate nutrient supply. Over-application with bioslurry as a N or P source can lead to atmospheric pollution through gaseous ammonia emissions (Kukal and Sarkar, 2010) and eutrophication due to excessive P accumulation in surface water bodies (Adekalu et al., 2007). Over-application leads to fertilizer wastage since it does not increase crop yield (Kukal and Sarkar, 2010). The optimal application rate also depends on the conditions of the area (irrigated or non-irrigated).

2.4.2 Application time

The timing of bioslurry application is one of the factors that could affect the fertilizer value of bioslurry on crop production. The application time of bioslurry is highly affected by the temperature and rainfall. This may be because N in the bioslurry can only last for a maximum of six weeks under warm and moist conditions (Karki and Expert, 2006; No, 2012). Exposure of bioslurry to sun reduces N contents, hence application of bioslurry during hot and sunny days should be avoided. For these reasons, application conditions must be taken into consideration so that plants can access and utilize the N contained by bioslurry while it is available (No, 2012). This would probably increase the crop production and reduce N loss due to incorrect timing. Application of bioslurry when it rains can reduce the effectiveness of bioslurry because the NPK will be washed by the rain through leaching (Karki and Expert, 2006). Therefore, application time and the environmental factors such as temperature and rainfall should be considered during the application of bioslurry. This would increase the value of bioslurry as a fertilizer. Bioslurry can be applied before or after planting or at planting (Islam, 2006) and it can be applied after ploughing at 2-3 weeks before planting

(Galli and Pulchok, 2001). This suggests that bioslurry can be applied at different times and remains effective provided that the correct application method is used.

2.4.3 Application methods

Proper application method can also increase crop uptake rates, and consequently crop yield. Bioslurry application methods may differ according to the physical form of bioslurry used. Liquid bioslurry can be applied directly on the crops using foliar spraying method (Warnars and Oppenoorth, 2014) or it can also be applied on the soil with the aid of a bucket or using irrigation canals as a basal or top dressing (Karki and Expert, 2006). Liquid bioslurry must be diluted with water before it can be used as foliar fertilizer to avoid leaf burn due to high concentrations of P and N in the bioslurry (Warnars and Oppenoorth, 2014). Leaf burn can contribute to a reduction in crop yield because burnt leaves would negatively impact the photosynthetic process. Solid bioslurry (dried or bioslurry compost) can either be applied as basal or top dressing.

There are two ways by which bioslurry can be applied into the soil. The material can be spread over the soil surface without incorporating it into the soil or it can be incorporated into the soil. Bioslurry can be spread in the field during the slack season and incorporated during land preparation (Karki and Expert, 2006). This practice may lead to N losses due to volatilization which reduces the fertilizer value of bioslurry on crop production. However, some farmers incorporate bioslurry immediately after transporting it into the field. This is considered to be the best way because the quality of bioslurry deteriorates when exposed to the sun. Also the important plant nutrients can be washed away by rain if the bioslurry is not incorporated into the soil (Karki and Expert, 2006). Therefore, incorporating any form of bioslurry into the soil is most beneficial as it reduces N loss through volatilization (Al-Turki et al., 2004). Solid forms of bioslurry should be applied under irrigated conditions as this will increase the nutrient availability to growing plants (Warnars and Oppenoorth, 2014). Moisture helps microbes to reach the substrate (decomposable compounds) thus, increasing the rate of mineralization of nutrients contained by bioslurry.

2.4.5 Storage

Systems that are set up to produce bioslurry may work continuously, but the product may only be used during the growing season. In this case, it is therefore, crucial to store the bioslurry for future use (Karki and Expert, 2006; Groot and Bogdanski, 2013; Bonten et al., 2014). The methods used for storing bioslurry may have a negative impact on bioslurry quality. Generally, the quality or nutrient content of bioslurry is affected by the storage system, duration and conditions (Bagge et al., 2005; Paavola and Rintala, 2008). Tran et al. (2011) found that N was lost when bioslurry was stored in uncovered storage systems compared to covered storage systems. Storing liquid bioslurry in underground uncemented storage pits may lead to nutrients losses through leaching. Groot and Bogdanski (2013) showed that K, zinc (Zn) and N were lost through leaching when bioslurry was stored in uncemented storage pits. This implies that bioslurry nutrient contents can change during storage due to the storage system used.

2.5 The effect of bioslurry on crop performance

High increment in crop yield was reported when bioslurry was applied in combination with chemical fertilizer (Islam, 2006; Warnars and Oppenoorth, 2014) and when applied as a separate application (Islam, 2006; Karki and Expert, 2006). However, there are also reports in some areas that bioslurry has no impact on crop production (Galli and Pulchok, 2001). Its enhancement on crop yield is more pronounced when it is applied as composted bioslurry than when it is applied as liquid (Galli and Pulchok, 2001; Karki and Expert, 2006). This could be due to the organic materials added to bioslurry during composting, which improved the bioslurry quality. Bioslurry has been tested in different crops, including maize (Karki and Expert, 2006; Rahman et al., 2008; Lansing et al., 2010; Shahabz, 2011; No, 2012), wheat (Gurung, 1997; Warnars and Oppenoorth, 2014), rice (Islam et al., 2014), barley (Terhoeven-Urselmans et al., 2009; Warnars and Oppenoorth, 2014), millet (Shahabz, 2011; Warnars and Oppenoorth, 2014) and vegetables (Islam, 2006; Islam et al., 2010; Jeptoo et al., 2012; Groot and Bogdanski, 2013). Generally, the application of bioslurry has been shown to increase plant performance in these crops (Warnars and Oppenoorth, 2014).

2.6 Other uses of bioslurry

Bioslurry can serve different purposes besides improving soil fertility and health. Bioslurry can be used as pesticides, animal feed and can be used in seed treatment (pelleting, coating, dressing and soaking) (Warnars and Oppenoorth, 2014). There is also potential to use bioslurry as a mulch. Bioslurry has many characteristics that qualifies it as an organic mulch. Bioslurry has an ability to suppress weed growth (Karki and Expert, 2006). Furthermore, bioslurry contains organic matter and fibre which could improve soils ability to retain soil moisture (Karki and Expert, 2006). To the best of my knowledge there are no reports in the literature on the use of bioslurry from animal excreta as an organic mulch.

2.7 The effect of mulches on crop production

Mulches play significant role in crop production. Mulches have indirect ways of improving water use efficiency (Mcmillen, 2013). For example, mulches suppress weed growth by limiting light penetration into the soil surface and by so doing reduce the competion for water between crop and weeds (Mcmillen, 2013). Mulching could reduce soil evaporation and hence overall evapotranspiration leading to improve water use efficiency. Additionally, during decomposition of organic mulch humus is added into the soil which increases soil water holding capacity. Mulches can shield the soil from solar radiation as a result reducing soil evaporation. Also water runoff and erosion can be reduced by mulches since mulches can hold rainwater at the surface thereby allowing it to penetrate into the soil (Mupangwa et al., 2007).

Inorganic mulch includes the use of gravel stones and plastic such as black polyethylene. Organic mulch is relatively cheaper than inorganic mulch since is made from locally sourced materials. The common examples of organic mulch in rural areas are crop residues, animal excreta compost, grass clippings and live mulches (Erenstein, 2003). Organic mulch such as grass clippings, crop residues and live mulches (cover crops) have an ability to replenish soil nutrients after decomposition (Sharma et al., 2010). However, live mulches may have negative impact on crop production by competing for growth resources with crop.

2.7.2 Types of mulches

Crop residue mulch refers to the residues of previous crop used to cover at least 30% of the soil surface at the time of crop emergence (Erenstein, 2002). Live mulch refers to the use of a living plant for ground cover such as a low growing intercrop (Aladesanwa and Adigun, 2008). A common example of live mulch in rural areas is intercropping maize with pumpkins (*Cucurbita*). This type of an intercrop or mulch conserves water and controls weeds (Li et al., 2011). However, pumpkin is reported to have an antagonistic effect by competing for water and nutrients with maize plants in a maize-pumpkin intercrop resulting in low maize yield (Tembakazi Silwana and Lucas, 2002; Momirović et al., 2015).

Grass clippings mulch has been shown to improve soil moisture (Sinkevičienė et al., 2009) and crop yields (Das et al., 2013). The legume live mulches demonstrated to improve both soil moisture content and crop yield (Sharma et al. (2010). Pumpkin live mulch has been reported to increase moisture content (Olasantan, 2007) but reduced maize yield by competing for growth resources with maize in maize/pumpkin intercrop (Tembakazi Silwana and Lucas, 2002; Mashingaidze, 2004; Momirović et al., 2015).

2.8 Scope of study

Maize yields in small-scale farms in South Africa are low. This can be attributed to a number of factors including low soil fertility and intra-seasonal dry spells which aggravate soil evaporation while reducing soil moisture. In the KwaZulu-Natal province of South Africa, small-scale farmers rely on rainfed production and can rarely afford chemical fertilizers to increase soil fertility. It is, therefore, important to find ways to increase crop productivity by small-scale farmers in this province. One option to achieve this is through the use of organic mulches to improve on soil water content and to replenish soil nutrients from the decomposition of the mulch. The review of the literature demonstrated that bioslurry has potential as a mulch since it can suppress weeds and it contains organic matter and fibre which could improve its ability to conserve soil moisture. Although a considerable amount of research has reported different effects of bioslurry on crop production, there is little information with regard to the form of bioslurry (whether fresh/liquid, dried or composted bioslurry) that was used.

Few studies also mention the type of feeding subtsance fed to the biosgas digester to produce bioslurry. In addition, most of the reports are not clear about the method and mode of application of bioslurry used. There is, therefore, a need to undertake further studies that will increase the understanding of the use of bioslurry with particular attention given to the type of feeding susbtance, application methods and forms to get comprehensive information on the effect of bioslurry on crop production. In addition, literature showed that bioslurry may have potential use as mulching material. However, not many studies have reported on the use of bioslurry as mulch. Therefore, a need to investigate whether bioslurry can be used as a mulch in crop production, especially under rainfed conditions which are typically characterised by prolonged periods of dry spells. In addition, many farmers in rural communities practise intercropping. For example the planting of maize/pumpkin intercrop is common in rural areas. However, information on using pumpkins as a live mulch in a maize/pumpkin intercrop in relation to water conservation is scant. The effects of such intercrops on productivity per unit area and water conservation need to be investigated. In this study, the potential use of bioslurry as mulch and pumpkin live mulch in rainfed maize production will be evaluated, as this will contribute to increase maize yields during dryspells.

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CHAPTER 3

Effect of bioslurry, grass clippings and pumpkin live mulch on soil water content and maize (*Zea mays* L.) yield

Abstract

Maize yields obtained by small-scale farmers under rainfed agriculture are low (1 ton ha^{-1}) compared to a potential yield of 3 tons ha^{-1}. This has been attributed to low soil fertility, prolonged dry spells and erratic rainfall occurring especially during the reproductive stage. The aim of the study was to investigate the potential use of different materials (bioslurry, pumpkin live mulch and grass clippings) as mulches to conserve moisture in maize production. The study tested the hypothesis that bioslurry would result in the highest maize yield as it could act as a nutrient source to improve soil fertility and it could improve soil moisture conservation through its formation of a hard cap that could reduce evaporation. The experiment was conducted at Okhombe, a ward in the northern Drakensberg of KwaZulu-Natal, in a farmer's field. It was laid out as a single factor treatment using a randomized complete block design (RCBD) with the following treatments: (bioslurry, pumpkin live mulch, grass clippings and control (maize with no mulch applied), replicated four times giving a total of 16 experimental units (5 m x 5 m plots planted with maize). The bioslurry was applied at the rate of 80 litres per 25 m^2 on the soil surface in each plot during the growing season. In the grass clippings mulch treatment maize plots were covered 100% with grass clippings and in the live mulch treatment pumpkins were planted as an intercrop between the maize rows. Data were collected on the following variables: soil water content, leaf area, plant height, stem girth, thousand seed weight, stover yield and maize yield. Water conserved by the mulches was measured as the soil water content using a HydroSense II Probe system (H_2PS; Campbell Scientific, Africa). The results showed that the mean soil water content over the growing season was significantly higher (21.55%; $P < 0.01$) in the bioslurry treatment than the control (18.39%), but did not differ significantly ($P > 0.05$) from the grass clippings mulch (19.88%) and pumpkin live mulch treatments (21.30%). Leaf area and thousand seed weight were significantly higher ($P < 0.05$) under the bioslurry treatment compared to pumpkin live mulch and the control treatments. Bioslurry was not significantly different from grass clippings with respect to plant height, thousand seed weight, harvest index and grain yield. Improved maize growth was observed in the bioslurry treatment which was evident from the higher leaf area (154.9 cm^2), stem girth (82.1 mm) and yield (3498 kg

ha^{-1}) in plots where bioslurry was applied compared to the other mulches. The different mulching materials used in this study significantly improved yield (1332-3498 kg ha^{-1}) compared to the farmer's practice of no mulch (1017 kg ha^{-1}). The results indicate that mulch is beneficial for soil moisture conservation and maize growth. Therefore, farmers should be encouraged to include mulching in their crop management. It was concluded that mulching treatments increased maize growth and yield compared to the control and the bioslurry mulch performed the best in this respect. The positive effect of bioslurry on maize growth and yield could be associated with the nutrients contained in the bioslurry or with a hard cap formation on top of soil that minimized water evaporation.

Keywords: Small-scale Farmers; Dry Spells; Rainfed Agriculture; Soil Moisture Conservation

3.1 Introduction

In the Upper Thukela region of the KwaZulu-Natal province, maize *(Zea mays* L.) is grown by both commercial and small-scale farmers. This area receives an annual rainfall that ranges between 800-1265 mm (Mupangwa et al., 2007; Salomon, 2011). Despite the high rainfall, there are frequent dry spells in mid-summer (Salomon, 2011), which can affect maize crop production. These dry spells occur in early January (Walker and Schulze, 2006) when the maize crop is likely to be in reproductive growth stage. Drought at this stage reduces maize growth and negatively affect grain filling by dis-synchronization of pollen and silk emergence leading to yield reduction (Barron and Okwach, 2005; Walker and Schulze, 2006). This threatens food security in this area since maize is the most important staple crop grown in the area (Jones and Thornton, 2003). The problem of food insecurity is worsened by the fact that maize is grown under rainfed agriculture. Small-scale farmers in the Upper Thukela region of South Africa cannot afford irrigation systems since poverty is high and most families rely on those family members who can claim the state pension (Walker and Schulze, 2006). The maize yield of this area is generally low (1 ton ha^{-1}) (Barron and Okwach, 2005) and far below the potential yield of 3 tons ha^{-1} (Machethe et al., 2004).

Strategies to minimize the negative impacts of drought could include practices aimed at reducing water evaporation from the soil and conserving moisture. The use of mulches where organic or inorganic material is applied around the plant has been shown to prevent excessive soil water evaporation or erosion, enrich the soil and suppress weed growth (Ramakrishna et al., 2006; Mupangwa et al., 2007). Mulching can have the ability to improve crop productivity because of its potential to conserve soil moisture and to enhance soil fertility. Mulching conserves water by enhancing water infiltration, reducing run-off and holding rainwater in the soil surface (Erenstein, 2003; Mupangwa et al., 2007). An ideal mulching material should be able to suppress weed growth, conserve water and must be renewable, biodegradable, durable and permeable to water and must be affordable (Haapala et al., 2014).

The use of organic mulch such as grass clippings, animal manure or compost and live mulch is common in developing countries (Aladesanwa and Adigun, 2008). A common example of live mulch in rural areas is the use of pumpkin *(Cucurbita)* in intercrop with maize. This type of an intercrop or mulch can increase crop productivity per unit area (due to edible pumpkin leaves and fruits), conserve water and control weeds (Li et al., 2011).

However, pumpkin has been reported to have an antagonistic effect by competing for water and nutrients with maize resulting in low maize yield (Tembakazi Silwana and Lucas, 2002; Momirović et al., 2015). The information on using pumpkin as a live mulch in a maize/pumpkin intercrop in relation to water conservation is scant.

Digested animal manure (known as bioslurry) can also be used as an organic mulch since it shows some characteristics of mulching material such as weed suppression and improved soil water holding capacity (No, 2012). Bioslurry is the effluent produced as a by-product of biogas production from the anaerobic digestion of organic material in a biogas digester (Nasir et al., 2012). Bioslurry can be produced from cattle, pig and poultry manure and kitchen garbage (Arnott, 1985). It is rich in micro and macro-nutrients and it is therefore considered a good source of soil nutrients (Nasir et al., 2012). Bioslurry contains organic matter and fibre which hold soil moisture and therefore, improves soil organic matter content as well as water holding capacity when applied to the soil (Kumar et al., 2010). Bioslurry can also form a mulch when applied on the soil surface. This is because after application it covers the soil surface and forms a hard cap of organic material which can reduce soil evaporation.
Conversely, the cap may reduce water infiltration and reduce soil water content. There is a need to evaluate further the effect of bioslurry as a mulch on soil water content present and rainfall infiltration.

The aim of the present experiment was, to compare the effect of bioslurry, grass clippings and pumpkin live mulch on maize growth, yield performance and on soil water content under rainfed conditions. In this experiment, it was hypothesized that bioslurry mulch could conserve more water than pumpkin live mulch and grass clippings mulch, thus, resulting in higher maize yield because of the formation of a hard cap after the application of bioslurry to the soil surface which would minimise water loss through soil evaporation.

3.2 Materials and methods

3.2.1 Planting material

Open-pollinated maize seeds were sourced from Mr. Khumalo, a local farmer who has a traditional practice of retaining seeds from a previous crop. Pumpkin seeds (cultivar Flat White Boer) were purchased from a local seed company (McDonalds Seeds, Pietermaritzburg). The Flat White Boer cultivar was selected because it grows into compact bushes with a large leaf canopy, which can act as a mulch to reduce soil evaporation and thus expected to conserve soil moisture.

3.2.2 Site Description

The study was conducted at Okhombe (28°42'S; 29°05'E), in the ward under the Amazizi tribal authority in the northern Drakensberg of KwaZulu-Natal, South Africa. Okhombe falls within the uThukela district municipality in the Ukhahlamba Drakensberg mountains region and comprises of six sub-wards, namely Enhlanokhombe, Mahlabathini, Mpameni, Ngubhela, Oqolweni and Sgodiphola (Everson et al., 2007). The current study was carried out at Mahlabathini.

The Upper Thukela has an altitude range from 1200 to 1800 m above sea-level and Okhombe lies on longitude 28° 42' south and latitude 29° 05' east. The climate is sub-humid and the area receives an annual rainfall that ranges from 800-1265 mm (Salomon, 2011). The wet season is from October to March (Walker and Schulze, 2006). In spite of the high rainfall received in this area, there are frequent dry spells in mid-summer (Salomon, 2011) which affect both crop and livestock production. Hail and thunderstorms also occur often in this area which can damage crops. The high temperatures (33° C) of this area are expected from November to February and low temperatures (11.5° C) from May to July (Marx, 2011). The soils in this area are highly acidic (Walker and Schulze, 2006) and this could be associated with the leaching of soil nutrients due to high rainfall received in this area.

Small-scale farmers in the area rely on rainfed maize production. The farmers have limited access to external inputs such as fertilizers, irrigation systems and lime as the nearest town (Bergville) is 50 km away. In addition, not all small-scale farmers can afford these external inputs since most of the families rely on those who can claim the state pension (Walker and Schulze, 2006). Therefore, there is a need for inexpensive and locally sourced fertilizers that can substitute for chemical fertilizers for small-scale farmers. Strategies aiming at reducing soil evaporation and conserving moisture are also essential for these farmers since they rely only on rainfall for their crop production.

The area was chosen because of the potential to integrate food and energy (biogas) production with soil water conservation. The experiment was carried out at a homestead of a community member (Mr Khumalo) where the Water Research Commission (WRC) had funded the installation of a biogas digester. The digester produces biogas for energy and a liquid effluent called bioslurry (Fig. 3.1) which is potential mulch for soil water conservation.

Figure 3. 1 Liquid bioslurry from a biogas digester.

3.2.3 Experimental design

The field experiment was laid out as a single factor experiment arranged in a randomized complete block design (RCBD) with maize as the main crop and four mulching treatments: bioslurry, grass clippings, pumpkin live mulch and no mulch (control). The mulching treatments were replicated four times, giving a total of 16 experimental units. Blocks were treated as replicates.

3.2.4 Soil sampling and analysis

Soil samples were collected at 0-150 mm depth (top soil) as described by Roberts (2010). Soil samples were randomly collected with four replications in each plot. Furthermore, collected samples were air dried, packed and sent to Cedara, the Soil Fertility and Analytical Services section (KwaZulu-Natal, Department of Agriculture and Rural Development) for physical and chemical analysis. The following variables were analysed prior to planting and after harvesting to determine the effect of bioslurry on soil properties: bulk density, exchangeable acidity, total cations, acid saturation, organic carbon, N, P, K, calcium (Ca), magnesium (Mg), zinc (Zn), copper (Cu), manganese (Mn) and pH (KCl).

The bioslurry sample was analysed for chemical properties (Table 3.1) at the University of KwaZulu-Natal laboratory. The analysis of bioslurry was done to determine the N content and also to calculate how much N supplied by the bioslurry during the experiment. Total N and carbon were determined using the automated Dumas dry combustion method on a LECO CNS 2000 (Leco Corporation, St. Joseph, MI), as described by Etheridge et al. (1998). Phosphorus and K were determined by inductively couple plasma optical emission spectrometry (ICP-OES) after nitric digestion in MARS6–CEM microwave system (CEM microwave technology Ltd, CEM UK), according to Esslemont et al. (2000).

Table 3. 1 Chemical properties of bioslurry.

Site	**Bioslurry moisture content (%)**	**pH (%)**	**Total N (%)**	**Total organic carbon (%)**	**Phosphorus (mg/L)**	**Potassium (mg/L)**
Okhombe	96.69	7.18	1.78	39.74	16.53	36.02

3.2.5 Agronomic practices and management

Most of the agronomic practices were carried out to simulate the farmer's normal practices, including land preparation, planting date and harvesting time. The land was prepared through ploughing and disking to achieve a fine seed bed. Mulching treatments and soil nutrient analyses were introduced in addition to the farmer's practices to test if mulches would improve the farmer's maize yield by conserving soil water.

The maize was planted in the farmer's cropping field at Okhombe on 25th November 2014. Maize was planted according to Smith (2006) at an intra-row spacing of 0.4 m and 0.75 m between rows, which gave 84 plants per plot (5 m x 5 m). In the intercrop treatment (pumpkin live mulch), maize and pumpkins were planted simultaneously. Pumpkin seeds were planted between the maize rows and the seeds were spaced at 0.5 m within the rows.

Two maize seeds were sown per station and three pumpkin seeds were sown per station. Both crops were thinned to one seedling per station at the first weeding.

At planting, the application of nutrients was standardized across all treatment plots. This was achieved by analysing the bioslurry and the soil prior to planting and adjusting the nutrient inputs accordingly (see calculations in Appendix 1). Since bioslurry has the potential to act as both mulch for soil water conservation and as a nutrient source, it was necessary to alter the method of application to account for this. Therefore, when it was applied as a nutrient source it was incorporated into the soil, but when it was applied as a mulch it was left on the soil surface. In the latter case, volatilization losses of N from the bioslurry applied on the surface limited the value of bioslurry as an N source.

Following the soil analysis, N fertilizer was applied to the control, grass clippings and live pumpkin mulch plots, according to the maize crop fertilizer recommendation received from the Cedara Soil Fertility and Analytical Services department. The fertilizer was applied as monoammonium phosphate (MAP 30%) at the rate of 40 kg ha^{-1}. In the bioslurry treatment plots, the initial bioslurry application was applied as the source of N fertilizer and it was therefore incorporated into the soil. Each bioslurry plots received 5.6 kg of bioslurry as the source of fertilizer N at planting (for details see calculations in Appendix 1). Later on, when the mulch treatments were implemented, bioslurry was added on top of the soil surface as a mulch. Each plot received 320 litres of bioslurry as mulch during the growing season as it was applied four times at the rate of 80 litres per 25 m^2. The bioslurry mulch treatments were applied twice a month (fortnightly) to the respective plots until the maize was at 100% silking stage. Repeated applications of bioslurry on the soil surface resulted in the formation of a hard cap mulch layer that remained intact around and between the plants.

Plots were weeded manually before the application of treatments. Bioslurry and dry grass clippings mulch were applied to respective plots on the third week (16th December 2014) after planting to ensure that emerging plants were not buried by the treatments. Under the grass clippings treatment, plots were 100% covered with grass clippings. To simulate the farmer's practices under rainfed conditions no additional water was applied to the experimental plots. Maize plants were manually harvested on the 5th of June 2015 at dry down stage, when the whole plant had senesced and turned brown.

3.2.6 Data collection

Data collection started two weeks (V4 stage) after treatments application which was equivalent to six weeks after planting (WAP). Data were collected fortnightly from 6 WAP up to 13 WAP. The following variables were measured: soil water content, maize plant growth variables (plant height, maize stem girth, and leaf area) and yield variables (grain yield, 1000 seed weight and ear length).

Soil water content measurements commenced two weeks after treatment application and every fortnight thereafter (before re-application of bioslurry). The measurements were taken from January to March. To simulate the farmer's practices, no additional water was applied to the experimental plots since the farmer relies on rainfed crop production. Soil water content was measured using a HydroSense II Probe system (HS_2P; CS659P; Campbell Scientific, Africa) at a depth of 12 cm which is the fixed rod length of this HydroSense. It is suitable for measuring the soil water content from sandy clay, loam or clay loam soil. Measurements were taken four times randomly in each plot and the mean was calculated.

Maize plant height, stem girth and leaf area was measured from a repeated measures sample of five plants marked with tags. Five plants were randomly selected from the center rows of each plot to avoid the effect of border plants. The mean from five plants was then determined for each of the measured variable. Maize plant height (m) was measured from the soil surface up to the fully expanded photosynthetically active leaf (flag leaf) using a measuring tape. Stem girth (mm) was measured with a tailor's tape measure. Maize leaf area (cm^2) was determined using a non-destructive length and width method as described by Onasanya et al. (2009). The maize leaf area was calculated as follows;

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

Where LA, L and W are leaf area, leaf length and leaf width respectively, and 0.75 is a constant. Leaf area was determined from the flag leaf.

Ear length, stover yield, one thousand seed weight, maize grain yield and harvest index (HI) were measured from a sample of five plants after harvesting. Stover yield (kg ha^{-1}) was determined from dried stover weight after oven drying at 60°C for 48 hours. Length (mm) of dehusked ear was measured after harvesting. Ear length is an important component of maize grain yield which affects maize grain yield. Grain moisture content was measured using a digital grain moisture meter analyser (Zhejiang top instrument CO., LTD, China). Grain samples were air dried for three weeks following shelling of the grain from the maize ear. Thousand (1000) seed weight (kg), maize grain yield (kg ha^{-1}) and harvest index were determined from seeds when the moisture content was approximately 12%. Maize grain yield was determined by weighing the grain produced in each plot. Harvest index was determined by dividing the seed weight per plant by total biomass (stover weight and seed weight) after adjusting for moisture content (Unkovich et al., 2010). The harvest index is the ratio of harvested grain to the above ground dry matter, and it is an indicator of the relationship between biological yield and economic yield. Harvest index can be used to measure the crop productivity as well as the ability of the crop to convert total dry matter into economic yield.

3.2.5 Statistical analysis

The Data were analysed using the statistical software package GenStat 16th version (VSN International, UK). The analysis of variance (ANOVA) procedure was used and treatment means compared using the contrasts function at the 5% level of significance. The tested assumptions of the single factor ANOVA showed that the distributions of the residuals were normal and the variances were equal.

3.3 Results

3.3.1 Soil analysis results before and after application of mulch

The application of mulching treatments (bioslurry, grass clippings and pumpkin live mulch) had no effect on soil chemical properties (NPK) and physical properties (Table 3.2).

Table 3. 2 Soil analysis before and after mulch application.

Treatment		**P (mg/L)**	**K (mg/L)**	**Ca (mg/L)**	**Mg (mg/L)**	**pH (KCl)**	**Organic Carbon (%)**	**N (%)**	**Clay (%)**
Bioslurry	Before	10	333	737	297	4.42	2.4	0.25	26
	After	8	226	1149	214	4.91	1.9	0.22	27
Grass clippings	Before	10	224	689	152	4.37	2.4	0.25	26
	After	12	263	949	194	4.62	1.9	0.23	26
Control	Before	9	221	766	172	4.37	2.5	0.25	25
	After	13	214	852	185	4.39	1.6	0.19	27
Pumpkin live mulch	Before	8	264	712	328	4.43	2.3	0.24	26
	After	12	255	757	179	4.41	1.4	0.19	26

3.3.2 Soil water content

The on-farm experiment was conducted to compare the effect of bioslurry, grass clippings and live mulch (maize-pumpkin intercrop) on soil water content, maize growth performance and maize yield. The soil water content recorded during the whole growing season under different mulches showed that water content was higher under the bioslurry treatment (21.55%) followed by pumpkin live mulch (21.30%), grass clippings (19.88%) and the control with 18.39% (Fig. 3.2). The soil water content in the bioslurry treatment was significantly higher than the control ($P< 0.01$) but did not differ significantly from the grass clippings mulch and pumpkin live mulch treatments (Fig. 3.2). Pumpkin live mulch was significantly higher than the control ($P< 0.01$) but it did not differ significantly from the grass clippings mulch (Fig. 3.2). The results showed that there was no significant interaction ($P> 0.05$) between time (date) and mulching treatments with respect to soil water content (Appendix 2). However, as expected, soil water content was closely related to rainfall (Fig. 3.3). During the cropping period rainfall was low in January and March and most of rainfall fell in February. The results of the experiment clearly demonstrated that the different mulches conserved soil water, especially after a rain event (Fig. 3.3). Soil water content therefore ranged from 18.60% to 21.45% in the control and from 23.21 to 28.18% in the mulch treatments in February and it was less than 15% in March in all the treatments including the control.

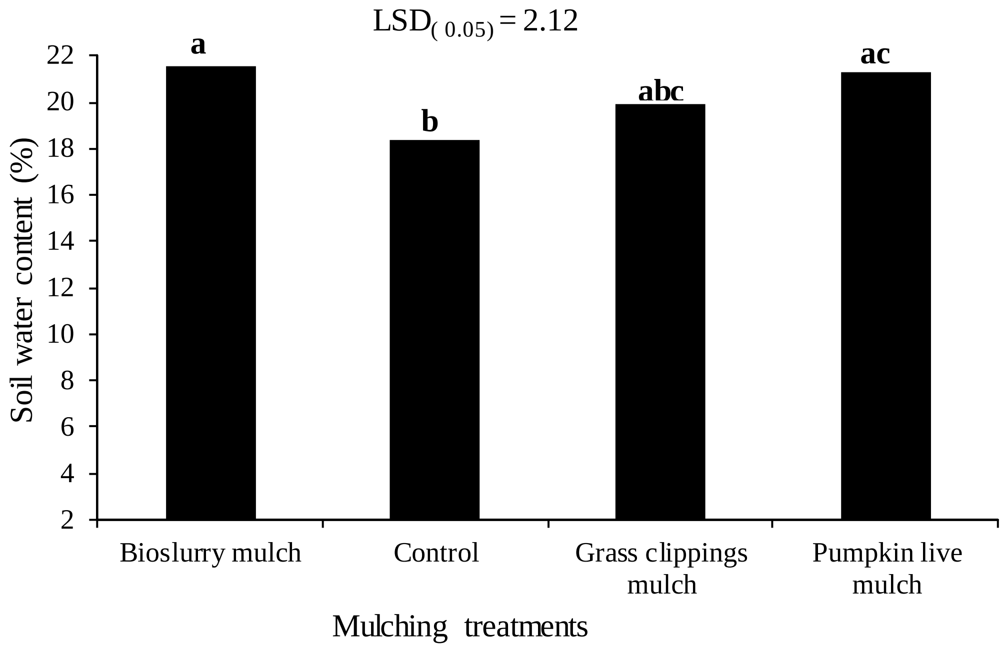

Figure 3. 2 Effect of mulching treatments on soil water content. Notes: The columns with the same letter are not significantly different at $p < 0.05$.

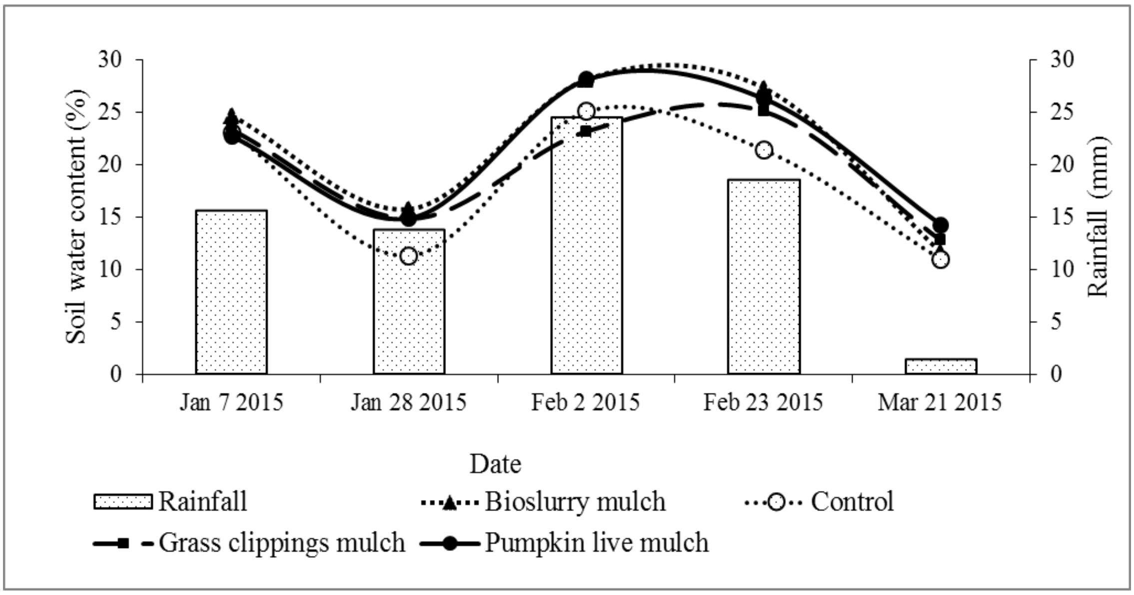

Figure 3. 3 Effect of mulching treatments and rainfall on soil water content.

3.3.3 Growth variables

3.3.3.1 Maize plant height, stem girth and leaf area

All mulching treatments resulted in a significantly higher plant height (1.18-1.23 m; $P < 0.05$) than the control (0.99 m) (Table 3.3). However, grass clippings mulch produced the tallest plants compared to the other treatments (Table 3.3). There were no interactions ($P > 0.05$) between mulching treatments and time (Weeks after planting) with respect to the plant height, stem girth and leaf area.

Stem girth was significantly increased by mulching with bioslurry (82 mm) followed by grass clippings (79 mm), pumpkin live mulch (78 mm) and the control (74 mm). The bioslurry treatment was significantly different ($P < 0.05$) from the control but not different ($P > 0.05$) to other mulching treatments with respect to stem girth (Table 3.3).

There were significant differences ($P < 0.05$) in mulching treatments with respect to leaf area. The highest and lowest leaf area were recorded in plots treated with bioslurry (154.9 cm^2) and the control (124.0 cm^2), respectively. The leaf area was not significantly different ($P > 0.05$) between the grass clippings, pumpkin live mulch and control treatments while in the bioslurry treatment it was significantly higher ($P < 0.05$) than the other treatments (Table 3.3).

Table 3. 3 Effect of mulching material on plant growth variables.

Treatments (Mulching material)	Plant height (m)	Stem girth (mm)	Leaf area (cm^2)
Bioslurry	1.21a	82.1a	154.9a
Control	0.99b	74.0b	124.0b
Grass clippings	1.23a	79.1ab	133.2bc
Pumpkin live mulch	1.18a	78.1ab	134.4bc
LSD $_{(0.05)}$	0.20	6.95	15.13
CV (%)	24.0	12.5	15.6

Notes: Means within columns not followed by the same letter are significantly different at $P < 0.05$; LSD = Least significant differences; CV = Coefficient of variation.

3.3.4 Yield components and stover yield

3.3.4.1 Grain yield, 1000 seed weight and ear length

Mulching treatments were significantly different (P< 0.01) with respect to grain yield. The highest grain yield was obtained from the bioslurry mulch treatment (3498 kg ha^{-1}) which was significantly higher than that for pumpkin live mulch (1332 kg ha^{-1}) or the control (1017 kg ha^{-1}) (Table 3.4). Bioslurry and grass clippings did not differ significantly (P> 0.05) in terms of grain yield (Table 3.4).

The maximum 1000 seed weight recorded in plots mulched with bioslurry was 0.49 kg, which was significantly higher (P< 0.05) than that recorded in the control plots (0.22 kg). All other mulching treatments also had significantly higher (P< 0.05) thousand seed weight (0.34 to 0.49 kg) than the control (0.22 kg) (Table 3.4). There were significant differences (P< 0.05) between mulching treatments in terms of harvest index (Table 3.4). However, bioslurry (0.76) was not significantly different to the grass clippings mulch (0.79) with respect to harvest index. Pumpkin live mulch (0.55) also did not differ significantly from the control (0.61) (Table 3.4).

The effect of the grass clippings mulch on ear length was not different to that of bioslurry and pumpkin live mulch which ranged from 166.7 mm to 171.1 mm (Table 3.4). However, that of the control (with no mulch) was significantly lower (135.1 mm; P< 0.05) (Table 3.4). There were no significant differences (P> 0.05) in the effect of different mulching treatments with respect to ear girth.

3.3.4.2 Stover yield

The highest stover yield (1147 kg ha^{-1}) was observed in the bioslurry mulch treatment which differed significantly (P< 0.05) from the control (633 kg ha^{-1}). There were no significant differences (P> 0.05) in stover yield between bioslurry, grass clippings and the pumpkins live mulch treatments (Table 3.4).

Table 3. 4 The effect of mulching materials on maize stover yield and grain yield components.

Treatments (Mulching material)	Harvest Index (HI)	1000-seed weight (kg)	Ear length (mm)	Stover yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Bioslurry mulch	0.76a	0.49a	166.7a	1147a	3498a
Control	0.61b	0.22b	135.1b	633b	1017b
Grass clippings mulch	0.79a	0.41ac	171.5a	928ab	3420a
Pumpkin live mulch	0.55bc	0.34bc	164.3a	1073a	1332bc
$LSD_{(0.05)}$	0.11	0.17	26.5	349.2	453.1
CV (%)	9.9	29.2	10.4	23.1	12.2

Note: Means within columns not followed by the same letter are significantly different at $P < 0.05$; LSD = Least significant differences; CV = Coefficient of variation.

3.4 Discussion

3.4.1 Soil analysis results before and after application of mulch

Application of mulching treatments had no impact on soil chemical properties (NPK) and physical properties (Table 3.2). This might be due to the nutrients taken up by the plants during the growing season.

3.4.2 Soil water content

Water and essential nutrients are important factors for crop growth, development and yield (Glass, 2003; Parry et al., 2005). Insufficient amounts of these during crop production can result in low maize yields. Organic mulches such as bioslurry and grass clippings can be used to conserve moisture and improve maize productivity. The results have shown that different mulching materials conserved more soil water than unmulched soil (control). This could possibly be attributed to the fact that mulches reduce soil water evaporation thus increasing soil water content.

The maximum soil water recorded in the wet period (February) was close to field capacity, while the lowest soil water in the dry period (March) was close to the plant wilting point. Plant available water was therefore estimated to be 13.88%. During the very dry period in March, the low soil water content (<15%) indicated that the different mulches were not able to conserve soil water under these dry conditions.

In this experiment, it was observed that the amount of water conserved in the profile to a soil depth of 12 cm was significantly greater under the bioslurry mulch treatment than the control (Fig. 3.2). This could be attributed to more rapid evaporation of rainwater from unmulched plots (control) than mulched plots. Furthermore, organic matter in the bioslurry compared to other mulching materials may explain the higher water retention in the plots treated with bioslurry compared to the other mulching treatments (Arnott, 1985). In addition, it is also possible that the hard cap formed after applying the bioslurry on the soil surface could reduce evaporation from the soil surface.

Pumpkin live mulch conserved more water than grass clippings mulch although the differences were not significant (Fig. 3.2). This could be due to the fact that pumpkins are living plants and have the ability to cover the ground rapidly and hence reduce soil evaporation, while grass clippings are inert and they decompose faster. Results showed that pumpkin live mulch (maize/pumpkin intercrop) had higher soil water content than the control (unmulched plots). These results are in agreement with those obtained by Olasantan (2007) who concluded that high soil water content in pumpkin live mulch is related to the rapid ground cover of pumpkin, which further reduces soil evaporation, hence increasing soil water. High water content was also reported from pumpkin live mulch by Salau et al. (2015).

Grass clippings conserved less water than pumpkins and bioslurry mulch (Fig. 3.2) which could be attributed to the fact that grass decomposed faster and therefore lost its ability to reduce soil evaporation after decomposition. However, grass clippings conserved more water than the control. These results concur with the findings of Sinkevičienė et al. (2009) who also observed that grass clippings conserved less water than other mulching treatments, but performed better than the control (unmulched). There were no significant differences between the bioslurry, grass clippings and pumpkin mulch with respect to soil water content. The reason for lack of significant differences between the three mulches is not clear since bioslurry contained additional water which could increase soil water than the other mulches and one could argue that grass clippings are inert whereas the pumpkin live mulch could have contributed to reduced water content through evapotranspiration.

3.4.3 Growth variables

3.4.3.1 Maize plant height, stem girth and leaf area

Maize growth was increased by mulching materials compared to the farmer’s practice in which no mulch treatment was used (Table 3.3). Bioslurry produced the maximum mean leaf area (154.9 cm^2) and stem girth (82.1 mm) which was significantly higher than in the other mulching treatments (Table 3.3). This could be attributed to N supplied by the bioslurry (Table 3.1), which could have contributed to an increase in the leaf area (Table 3.3). Valadabadi and Farahani (2010) reported that N plays an important role in developing leaf area. These results are in agreement with findings of Islam et al. (2010) who observed an increase in leaf area and stem girth after applying cattle bioslurry to maize fodder. In addition, the high stem girth and leaf area value may be due to high soil water content observed in plots mulched with bioslurry (Fig. 3.2) as well as the high moisture content in the bioslurry (Table 3.1). However, grass clippings had the tallest plants compared to bioslurry, pumpkin live mulch and the control (Table 3.3). Grass clippings mulch resulted in higher maize growth than pumpkin live mulch with respect to plant height and stem girth (Table 3.3).

Pumpkin live mulch had a lesser effect on maize growth than bioslurry and grass clippings mulch. Maize plants under pumpkin live mulch were shorter and had small leaf area (Table 3.3). This could be attributed to the competition for space and nutrients between maize and pumpkins plants under pumpkin live mulch treatment (Tembakazi Silwana and Lucas, 2002), since pumpkin live mulch was able to conserve soil moisture.

3.4.4 Yield components and stover yield

3.4.4.1 Grain yield, 1000 seed weight and ear length

The highest grain yield (3498 kg ha^{-1}) and thousand seed weight (Table 3.4) were recorded from plots mulched with bioslurry compared with other mulching treatments. This could be attributed to an increase in leaf area in plots mulched with bioslurry (Table 3.3) resulting in increased light interception and thus high photosynthetic activity and increased yield (Valadabadi and Farahani, 2010). High grain yield and thousand seed weight observed under bioslurry treatments (Table 3.4) could also be explained by the high moisture content in the bioslurry (Table 3.1) or high soil water content recorded in this treatment (Fig. 3.2). It is also possible that the hard cap formed after applying the bioslurry on the soil surface could reduce soil evaporation thus, increasing maize yield. Bioslurry is reported to supply nutrients that are readily available for plant uptake (Karki and Expert, 2006; Islam et al., 2010). This could be one of the reasons why bioslurry increased maize yield.

Grain yield, ear length, stover yield and one thousand seed weight were higher in plots mulched with grass clippings than those treated with pumpkin live mulch and control plots. This suggests that, there is a possibility that water conserved by grass clippings improved maize yield. High grain yield obtained from grass clippings than live mulch demonstrated that pumpkin competed for growth resources with maize as a result reduced the maize yield.

The current study revealed that pumpkin live mulch resulted in significantly lower maize grain yield compared to grass clippings mulch and bioslurry. This could be attributed to the fact that pumpkins are living plants and probably competed with the maize plants for resources thus reducing maize yield. Similar observations with regard to reduced maize yield in the pumpkin live mulch treatment have been reported in previous studies (Tembakazi Silwana and Lucas, 2002; Mashingaidze, 2004; Momirović et al., 2015). These results are also in agreement with those obtained by Liedgens et al. (2004) who concluded that living mulches may have an antagonistic effect by competing with maize for water, light and nutrients thus resulting in low maize yield.

3.5 Conclusions

In conclusion, it was clear that bioslurry, grass clippings and pumpkin live mulch improved maize growth and yield as well as soil water content compared to the farmer's practice of no mulch. The results indicate that mulch is beneficial for soil water conservation and maize production. Therefore organic mulches such as bioslurry mulch, grass clippings mulch and pumpkin live mulch can be introduced to small-scale farmers whose maize yields are low due to low soil fertility and soil moisture associated with dry spells. The soil water content results clearly demonstrated that the different mulches conserved soil water, especially after a rain event. Although bioslurry mulch performed the best, the high water content of the bioslurry did not result in significantly higher soil water content than grass clippings mulch and pumpkin live mulch. Bioslurry had high grain yield than other mulches but it did not differ significantly with grass clippings mulch. The positive effect of bioslurry may be due to the nutrients supplied by the bioslurry to the crop and/or enhanced soil moisture conservation. Further studies are required to determine which properties of the bioslurry mulch treatment are responsible for the increased soil water content. Since there is little information on the ability of bioslurry to conserve soil water through the formation of a hard cap, a controlled on-station experiment was carried out to determine these affects.

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CHAPTER 4

Effect of bioslurry application on soil water infiltration and maize growth under irrigated and non-irrigated conditions

Abstract

Maize production among small-scale farmers in most parts of South Africa is limited by poor and erratic rainfall. It is therefore important to find ways of conserving the limited moisture to increase maize yields. This study examined the effect of a hard cap formed after bioslurry application on soil water content under different temperature regimes. The study also assessed the effect of the hard cap formed after bioslurry application on soil water content and water infiltration rate and maize growth under field conditions. For the first objective a pot experiment was conducted under controlled conditions in growth chambers with three different temperatures [T_{25}= temperature at 25 °C, T_{30}= temperature at 30 °C and T_{35}= temperature at 35 °C] and applications of 0.288 litres bioslurry, 0.288 litres water or no application (the control). The experiment was laid out in a completely randomized design with three replicates giving a total of 9 experimental units. Soil water content was measured in each pot using a HydroSense II Probe system. The results showed that at 35 °C the water content recorded in all the three treatments was 0%. At 30 °C the pots with bioslurry had higher water content (0.5%) than the water treatment (0.2%) and the control (0%). The soil water content in the bioslurry treatment was 2.1% at 25 °C while the water and control treatments had 1.7 and 0.9%, respectively. These results indicate that at high temperatures of 35 °C, the application of bioslurry mulch has no benefits with respect to increasing soil water content. However, at 25 and 30 °C, bioslurry mulch retained significantly more soil water than the control with no mulch. For the second objective, the experiment was laid out in a split-plot arranged in a completely randomized design with irrigation (irrigated and non-irrigated) as main plot and mulching treatments (bioslurry mulch and control of no bioslurry mulch) as sub-plot. Treatments were replicated three times, giving 12 experimental units (2 m x 2 m plots). Measured variables were soil water content, maize growth (leaf area, plant height, leaf number, stem girth) and water infiltration rate. No significant differences were observed in soil water content and maize growth ($P> 0.05$), under non-irrigated bioslurry and

control treatments, whereas in the irrigated plots the bioslurry treatment had significantly higher soil water (20.32%; $P< 0.05$) than the control (17.04%). Irrigated plants with bioslurry mulch were significantly taller (0.49 m; $P< 0.05$) than the irrigated plants with no bioslurry (0.40 m). Bioslurry mulch under irrigation significantly increased the average maize leaf area (105 cm^2; $P< 0.05$) compared to the control (90.2 cm^2). The initial infiltration rate (F_o) (4.5 mm min^{-1}) of water was lower under bioslurry treatments compared to the control plots (7.7 mm min^{-1}) under irrigated conditions. This indicates that when the initial soil water contents are high under irrigated conditions, water infiltration is reduced. A possible explanation for the lower infiltration rate under bioslurry could be that the hard cap formed by the bioslurry sealed the surface pores thus reducing water infiltration rate. It was concluded that under irrigated or rainfed conditions where temperatures ranged from 25 to 30 °C, bioslurry mulch retained significantly more soil water than the control with no mulch. This was supported by the higher maize growth in the bioslurry mulched plots. Therefore, based on these results, bioslurry mulch can improve maize growth under irrigated or rainfed conditions and can be recommended to rural farmers to improve maize production.

Keywords: Maize Production; Temperature Regimes; Small-Scale Farmers

4.1 Introduction

In rural communities where small-scale farmers rely on rainfed crop production for their livelihood, mulches can be used to improve soil water for plant growth. Mulches can improve soil water infiltration by holding rainwater at the soil surface thus giving it time to infiltrate (Erenstein, 2003; Mupangwa et al., 2007). An ideal mulch should be permeable to rain and irrigation water (Haapala et al., 2014). In addition, mulches should be able to conserve soil water at different temperature regimes since temperature variation causes fluctuation in soil water content (Czarnomski et al., 2005). One factor that reduces soil water content is evaporation, which is the process whereby water is transferred from the soil compartment and/or vegetation layer to the atmosphere (Verstraeten et al. 2008). At high temperatures, soil water content tends to be rapidly lost from soil as a result of evaporation. The higher the air temperature the higher the evaporation rate since warm air increases the rate of evaporation (Davidson et al. 1998).

One factor that increases soil water content is infiltration which is the process through which rain or irrigation water enters the soil. Infiltration rate, measured in millimeters per unit time is the time taken for water to penetrate the soil (Musa and Adeoye, 2010; Alhassoun, 2011). Infiltration rate is important for crop water availability because it governs the amount of water that goes into the soil (Lal and Shukla, 2004). Infiltration rate is controlled by a number of factors including soil texture (amount of clay, silt and sand), initial soil water content, vegetation cover, soil temperature and rainfall intensity (Telis, 2001). Sandy soils have a high infiltration rate because they have large particles which create more pores between the soil particles consequently increasing water infiltration. In addition, course textured soils are expected to have a high infiltration rate compared to fine textured soils and this is associated with their larger pore size (Lal and Shukla, 2004).

Soils with low initial soil water content have high infiltration rates due to their higher matric potential (negative tension) when compared to wet soils (a process termed hysteresis) (Lal and Shukla, 2004). Soils with vegetation cover tend to have a higher infiltration rate compared to bare soils. This is because vegetation cover prevents rainfall impact and sealing of pores on the surface. Furthermore, vegetation cover reduces the soil crusting by absorbing the energy of falling raindrops that cause soil erosion and crusting when they hit bare soil (Adekalu et al., 2007; Kukal and Sarkar, 2010). High infiltration rate is considered to be important soil property since it protects soil against degradation or erosion (Alhassoun, 2011).

Bioslurry (an effluent made from a mixture of animal manure and water under anaerobic conditions) has been reported to have potential mulching characteristics. This is because bioslurry has been reported to be able to suppress weed growth (Karki and Expert, 2006) and it contains organic matter and fibre which could improve its ability to retain soil moisture (Arnott, 1985; Karki and Expert, 2006). However, to date, no studies have reported on the use of digested animal manure (bioslurry) as a mulch as well as its effect on water infiltration. There is also little information in the literature on the permeability of the hard cap layer formed after bioslurry application. The information on the ability of the hard cap to conserve water under different temperatures is not well documented. Therefore, the aim of this study was to investigate whether the hard cap formed after bioslurry application had a negative effect on soil water by reducing soil water infiltration or if it had a positive effect on soil water by reducing evapotranspiration. The specific objectives of the study were:

- To determine the effect of the hard cap formed after bioslurry application on soil water content under different temperature regimes.
- To assess the effect of bioslurry mulch on soil water content, soil infiltration rate and maize growth performance in a controlled on-station experiment.

The hypotheses of the objectives were:

- In this study, it was hypothesized that bioslurry mulch would decrease soil water loss under high temperatures because the high organic content would conserve more water.
- It was hypothesized that bioslurry would increase soil water content and eventually improve maize performance. It was also hypothesized that the hard cap formed after bioslurry application would not reduce the soil infiltration rate because the cap is made from organic material, which is not water resistant.

4.2 Materials and Methods

4.2.1 Controlled temperature pot experiment

A pot experiment was conducted in a growth chamber at the controlled environmental facilities at the University of KwaZulu-Natal to determine the effect of bioslurry on soil water loss under different temperature regimes. The sealed pots (with no drainage holes) with a volume of 3.4 litres, diameter of 212 mm and depth of 150 mm were half filled with soil collected from a field at Okhombe (28°42’S; 29°05’E). Soils were air-dried to 5.4% soil water content before the application of bioslurry and water to ensure that soils had the same water content. The experiment was designed using a completely randomized design and each treatment was replicated three times giving a total of nine pots (experimental units). The pots were then subjected to three treatments: bioslurry (0.288 litres), water (0.288 litres) and a control treatment in which there was no addition of water or bioslurry. The water treatment was to simulate the same liquid application as the bioslurry treatment and therefore acted as a control for the bioslurry treatment. The amount of bioslurry (0.288 litres) used was calculated to be equivalent to 128 000 kg ha^{-1}). The pots were then placed at three different temperatures [T_{25}= temperature at 25 °C, T_{30}= temperature at 30 °C and T_{35}= temperature at 35 °C]. These temperatures represented the range of temperatures characteristic of the summer growing season in the KwaZulu-Natal province. Since the growth chamber had limited space, each temperature regime run for 30 days one after the other. Bioslurry and water were applied at the beginning of the experiment and were left to equilibrate for 30 days. Soil water content measurements commenced after that.

Soil water content was measured in the pots at the end of the four week (30 days) period using a HydroSense II Probe system (Campbell Scientific, Africa) with 12 cm rods. The HydroSense uses the principle of time domain reflectometry to estimate the volumetric water content in percentage. Measurements were taken three times randomly near the centre in each pot. Data were entered in a spreadsheet using Microsoft Office® Excel 2010 and the mean and standard deviation was computed.

4.2.2 Field experiment

Site Description

The on-station field experiment was conducted at the University of KwaZulu-Natal, Pietermaritzburg, South Africa. The experimental was conducted to assess the effect of the hard cap formed by bioslurry on the soil water content, water infiltration rate and maize growth under irrigated and non-irrigated conditions. To simulate conditions at the on-farm experimental site at Okhombe, maize seeds were obtained from the farmer at Okhombe in KwaZulu-Natal province, South Africa.

Figure 4. 1 The hard cap formed after bioslurry application.

Experimental design and agronomic practices

The experiment was laid out in a split-plot arranged in a completely randomized design with irrigation (irrigated and non-irrigated) as main plot and mulching treatments (bioslurry mulch and control of no bioslurry mulch) as sub-plot. Treatments were replicated three times, giving 12 experimental units (2 m x 2 m plots). Maize was planted on the 31st of March at an intra-row spacing of 0.4 m and an inter-row spacing of 0.75 m according to Smith (2006), giving 14 plants per 4 m^2. Two maize seeds were sown per station and seedlings were thinned to one seedling per station at the first weeding.

At planting, bioslurry was applied as the source of N fertilizer and it was incorporated into the soil only in bioslurry treatment plots. This was standardized by applying nitrogen fertilizer to the control plots (plot with no bioslurry) according to the maize crop fertilizer recommendations. Nitrogen was applied as monoammonium phosphate (MAP 30%) at the rate of 20 kg ha^{-1}. Bioslurry was applied as mulch on the 4th of April 2015 to ensure that emerging maize seeds were not buried by the bioslurry. To simulate conditions at the on-farm experiment, bioslurry was applied twice a month (fortnightly) as mulch in respective plots until the maize was at 100% silking stage. Each plot received 51.2 litres of bioslurry which is equivalent to 128 000 kg ha^{-1} used in the on-farm experiment at Okhombe (Chapter 3). The plots were irrigated with 45 mm of water twice a month, a week after bioslurry application to compare the effect of bioslurry under wet and dry conditions. A brief description of the bioslurry's physical and chemical properties is given below (Table 4.1).

Table 4. 1 Chemical properties of bioslurry.

Site	**Bioslurry moisture content (%)**	**pH (%)**	**Total N (%)**	**Total organic carbon (%)**	**Phosphorus (mg/L)**	**Potassium (mg/L)**
Okhombe	96.69	7.18	1.78	39.74	16.53	36.02

4.2.2 Data collection

Data collection started on the 15th of April 2015 which was the 5th week after planting (WAP) till the 12 WAP. The following plant growth variables were measured: maize leaf area, leaf number, height and stem girth (refer to Chapter 3 for detailed descriptions). Yield was only measured based on stover yield (biomass) since grain yield of maize was not obtained due to animal (monkey) damage of maize cobs. Soil water content was measured using the HydroSense probe as described in Chapter 3.

Infiltration rate was measured in June 2015 (13 WAP) after the required bioslurry was applied over the soil surface. Water infiltration rate was measured using double-ring infiltrometers made of concentric metal rings. The inner ring and the outer ring, with a diameter of 95 mm and 175 mm respectively, were driven into the soil to a depth of 15 mm. Water was poured into both rings and the infiltration rate was measured from the inner ring as described by Gillies (2008). Water in the outer ring ensures that water in the inner ring infiltrates downward and not laterally. The time taken for the water to infiltrate in 5 mm increments was recorded with a stop watch until the infiltration was constant. The infiltration rate was calculated using Microsoft Office® Excel 2010 (Appendix 3).

4.2.3 Statistical analysis

Data, unless otherwise stated, were subjected to analysis of variance (ANOVA) using GenStat 16th version (VSN International, UK) at the 5% level of significance. The assumptions of the ANOVA (normality and homogeneity of the variances of the residuals) were met. Duncan's multiple comparison test was used to separate the means treatments in GenStat at the 5% level of significance. Interactions were considered but reported only when significant.

4.3 Results

4.3.1 Controlled temperature chamber pot experiment

The results of the controlled temperature growth chamber experiment showed that water content decreased more rapidly with increasing temperature (Fig. 4.2). At the highest temperature (35°C), all the treatments conserved no water since soil water content recorded was zero after 30 days. At 30°C, the bioslurry conserved 0.5% soil water while the control and the water treatment had the soil water of 0 and 0.2% respectively (Fig. 4.2). At 25°C, the soil water content of the bioslurry treatment (2.1%) was significantly higher than the water treatment (1.7%) and the control (0.9%) after 30 days of treatments application.

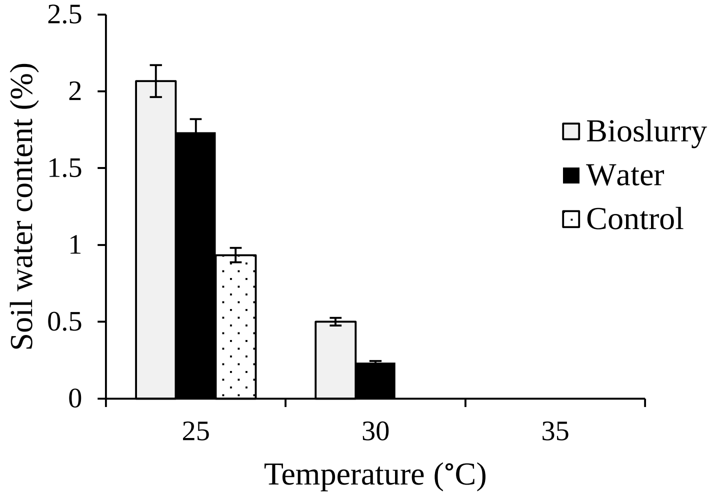

Figure 4. 2 The effect of different temperatures on soil water content for 30 days after treatments application.

4.3.2 Field experiment

Soil water content

No significant differences (P> 0.05) were observed between the soil water content in the bioslurry and control treatments in the non-irrigated plots, whereas in the irrigated plots the bioslurry treatment had significantly higher moisture (20.32%; P< 0.05) than the control (17.04%) (Fig. 4.3). The results showed that there were no significant interactions (P> 0.05) between time (date), irrigation and mulching treatments with respect to soil water content. However, as expected, soil water content was closely related to rainfall (Fig. 4.4). During the experimental period rainfall was low, with the highest rainfall (5 mm) recorded in a single rain event in April.

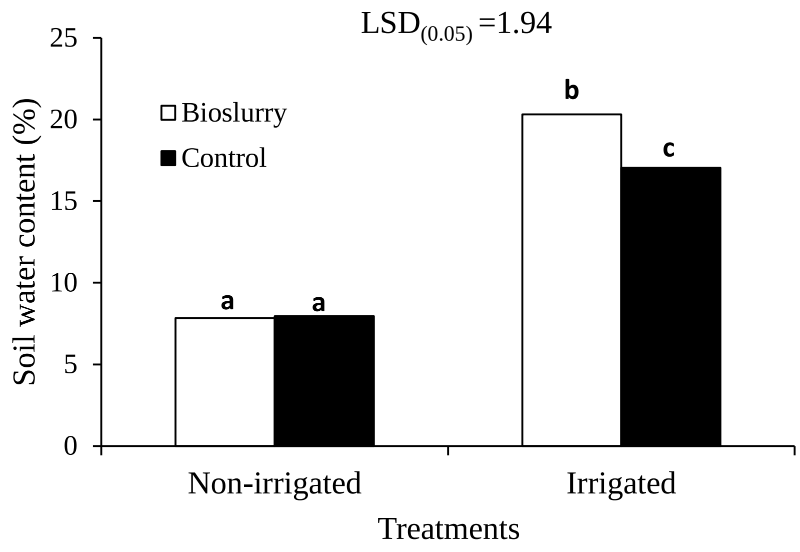

Figure 4. 3 Effect of mulching treatments and irrigation on soil water content for every fortnight.

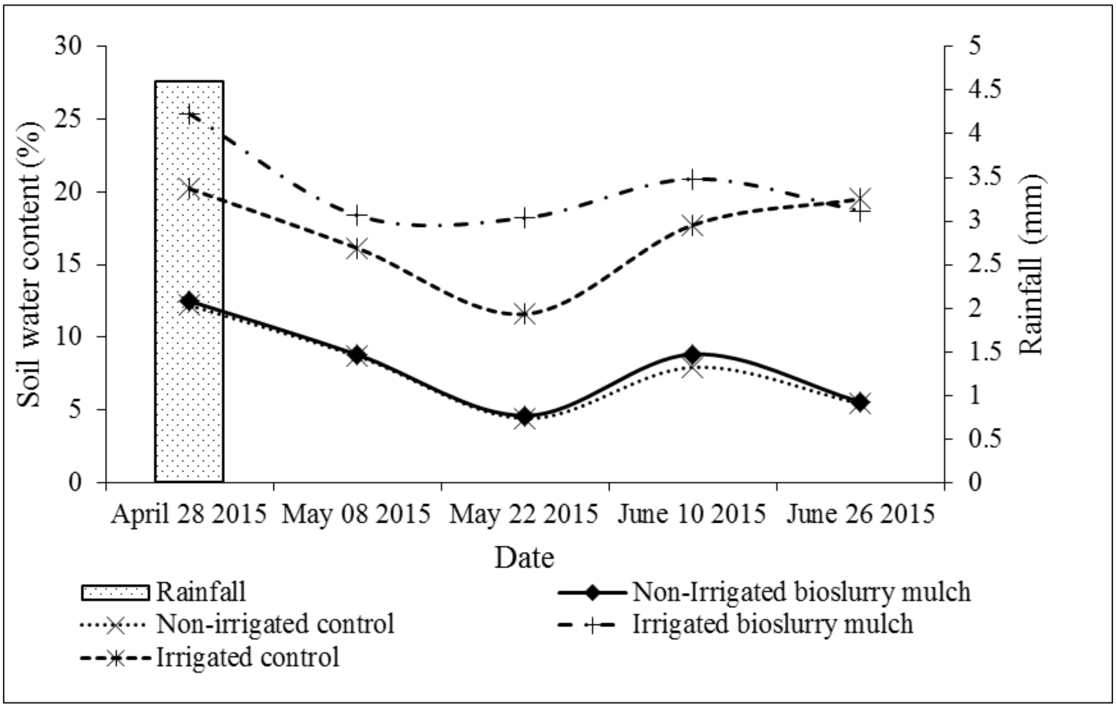

Figure 4. 4 Effect of rainfall and bioslurry mulch on soil water content.

Growth variables (Maize plant height, leaf number, stem girth, leaf area and stover yield)

Bioslurry and the control had the same effect on maize growth variables under non-irrigated conditions (Table 4.2). By contrast, irrigated plants with bioslurry mulch were significantly taller (0.49 m; $P < 0.05$) than irrigated plants from the control plots (0.40 m). In addition, taller plants (0.49 m) were observed under irrigated plots with bioslurry mulch compared to non-irrigated plots with bioslurry mulch (0.30 m) (Table 4.2). There was a significant interaction ($P < 0.05$) with respect to irrigation and mulching treatments for plant height, leaf number, leaf area and stem girth. The interaction of irrigation, mulching treatments and time (WAP) was not significant ($P > 0.05$) with respect to maize plant height.

It was observed that the average leaf number was higher in plots mulched with bioslurry compared to the control (unmulched plots) in both irrigated and non-irrigated plots (Table 4.2). Significant differences ($P < 0.05$) were observed in leaf number for maize mulched with bioslurry and maize without mulch under irrigation. However, bioslurry and the control under non-irrigated conditions were not significantly different ($P > 0.05$) from each other with respect to leaf number.

Bioslurry increased the leaf area compared to the control (unmulched plots) in both irrigated and non-irrigated conditions (Table 4.2). In addition, mulching with bioslurry under irrigation significantly increased the average leaf area (105 cm^2; $P < 0.05$) of maize plants when compared to irrigated non-mulched plants (90.2 cm^2). There was no significant interaction ($P > 0.05$) among irrigation levels and mulching treatments over time with respect to leaf area. A similar trend to leaf area was observed for stem girth whereby bioslurry resulted in greater growth than the control.

Table 4. 1 The effect of irrigation and mulching on maize growth variables.

Irrigation	Mulching treatments	Plant height (m)	Leaf number	Leaf area (cm^2)	Stem girth (mm)
Non-irrigated	Bioslurry mulch	0.30 a	6.87 a	80.3 a	50 a
	Control	0.29 a	6.47 a	76.7 a	50 a
Irrigated	Bioslurry mulch	0.49 c	9.60 c	105.3 c	80 c
	Control	0.40 b	8.00 b	90.2 b	60 b
LSD $_{(0.05)}$		0.01	0.22	2.08	4
CV (%)		7.5	7.8	6.5	9.6

Notes: Means within columns not followed by the same letter are significantly different at p < 0.05; LSD= Least significant differences; CV = Coefficient of variation

There was no interaction (P> 0.05) between mulch and irrigation regards to stover yield (Appendix 3). Mulching had a significant effect (P< 0.05) on stover yield. Stover yield was significantly greater (1967 kg ha^{-1}; P< 0.05) in maize grown from plots mulched with bioslurry than the control (1068 kg ha^{-1}) (Fig. 4.5).

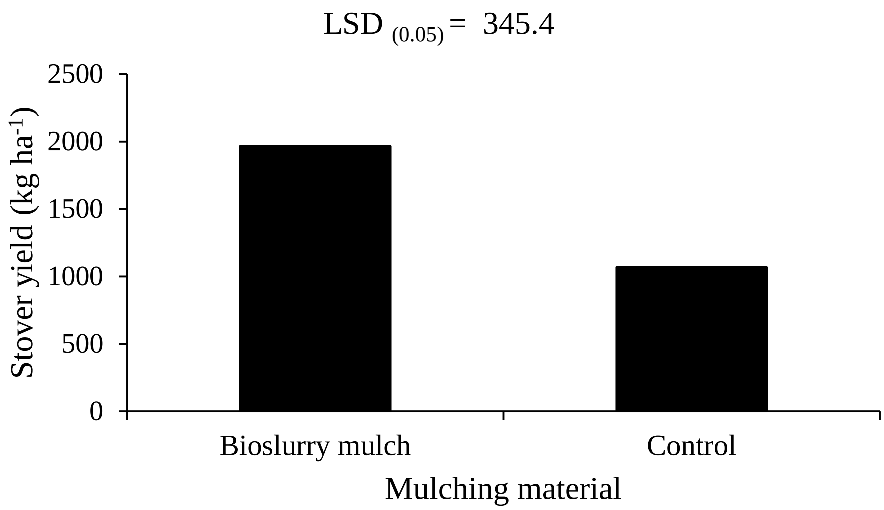

Figure 4. 5 The effect of bioslurry mulch on stover yield.

Water infiltration rate

The highest initial water infiltration rate (F_o) was observed from non-irrigated plots compared to irrigated plots (Fig. 4.6). Additionally, in both irrigated and non-irrigated treatments, plots mulched with bioslurry had low initial infiltration rates compared to the control. Low water infiltration rate was observed in plots mulched with bioslurry (4.5 mm min^{-1}) compared to the control plots (7.7 mm min^{-1}) under irrigated conditions. A similar trend was also observed under non-irrigated conditions where the initial infiltration rate of water in bioslurry mulch and the control was 8.3 and 11.5 mm min^{-1} respectively. The bioslurry treatments under irrigated conditions reached the steady state infiltration rate earlier than the other treatments (Fig. 4.6).

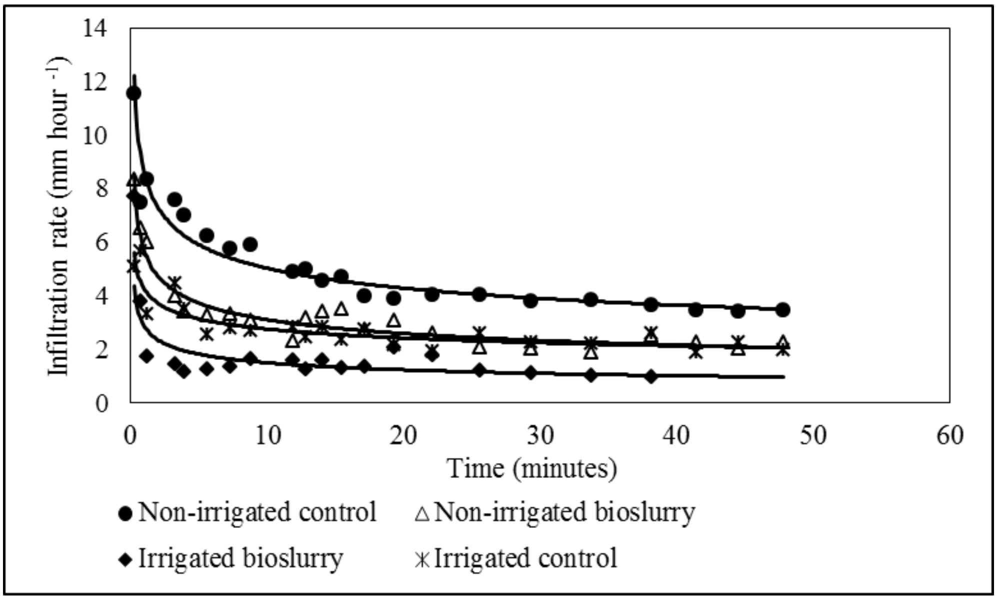

Figure 4. 6 Infiltration rate in bioslurry and control plots.

4.4 Discussion

4.4.1 Controlled temperature chamber pot experiment

Temperature can influence soil evaporation rates and water content. Soil water content is likely to be reduced at high temperatures due to higher evaporation rates (Davidson et al., 1998). This experiment sought to determine the effect of the hard cap formed after bioslurry application on soil water conservation under different temperature regimes. The results showed that greatest soil water loss occurred at higher temperatures (Fig. 4.2). At the highest temperature (35°C) the soil water content recorded was zero in all the treatments (Fig. 4.2) after 30 days of treatments application. This indicated that at high temperatures when evaporation demand was high, bioslurry mulch had no benefits in terms of soil water conservation, even though its moisture content was 97%. These results indicated that at high temperatures soil loses more water through evaporation from the soil surface than at lower temperatures. Similar findings were reported by Davidson et al. (1998) who also observed that soil loses more water at higher temperatures. The results of the study indicated that the hard cap formed by the bioslurry was not efficient in conserving water at the highest temperature (35°C) but could be effective at conserving soil water at temperatures below 35°C. This was evident from the significantly higher soil water content in the bioslurry treatment (2.1%) than the control (0.9%) at 25°C (Fig. 4.2) after 30 days of treatments application. These higher values in the bioslurry mulch treatments may be due to the hard cap formed which reduced evaporation from the soil surface.

4.4.2 Field experiment

Soil water content

Irrigation could provide much needed water for crop production in areas with poor and uneven rainfall distribution. Most rural small-scale farmers cannot afford irrigation systems due to poverty (Goga and Pegram, 2014). The use of mulches to improve soil water during dry conditions could provide effective, affordable and sustainable alternatives. Ideal mulches are those that are permeable to rainwater thus improving infiltration rate and consequently result in better soil water conservation (Haapala et al., 2014). In the on-station field experiment the effect of the hard cap formed after bioslurry application on soil water content and water infiltration rate and maize growth under irrigated and non-irrigated conditions was determined. The results showed that irrigated plots with bioslurry mulch had higher soil water content than irrigated plots with no mulch. This could be attributed to the hard cap reducing evaporation from the soil surface when compared to the control (Fig. 4.3). Both non-irrigated plots with bioslurry and with no mulch had low soil water content (Fig. 4.3). This may be attributed to the fact that plants utilized all the available water in the soil and the fact that there was no water to conserve under non-irrigated plots.

Maize plant height, leaf number, stem girth, leaf area and stover yield

The current study showed that maize plants grown under irrigation were taller and had higher maximum leaf number, stem girth and leaf area than non-irrigated plants (Table 4.3). The higher growth observed under irrigated plots may be explained by the fact that irrigation increased water availability for plant uptake and metabolic activity thus promoting high plant growth (Nagy, 2003). Under irrigation treatments maize growth variables such as plant height, leaf number, stem girth and leaf area were significantly higher in plots mulched with bioslurry mulch than in the control with no mulch. This may be explained by the higher soil water content recorded in plots mulched with bioslurry under irrigated conditions (Fig. 4.3) which were highly beneficial to maize growth. Plots treated with bioslurry mulch had higher stover yield compared to plots with no mulch (Fig. 4.5). It is possible that the hard cap formed after applying the bioslurry on the soil surface could reduce soil evaporation thus, increasing stover yield.

Water infiltration rate

Infiltration rate decreased with increasing time as would be expected. When water penetrates the soil it fills up the soil pores rapidly. As the soil pores are filled up with water, the soil reaches saturation point where it cannot take more water (Gillies, 2008) and this reduces the infiltration rate. The highest initial infiltration rate (F_o) was observed from non-irrigated plots compared to irrigated plots (Fig. 4.6). Generally, dry soils have a high matric potential (negative tension) which is associated with high infiltration rates (Gillies, 2008). The highest initial infiltration rate was observed from the control (11.5 mm min^{-1}) compared to 8.3 mm min^{-1} recorded for bioslurry mulch (Fig. 4.6). A possible explanation could be that the hard cap formed by the bioslurry reduced the soil infiltration rate by sealing surface pores thus reducing the water infiltration rate which may result in runoff. It is, therefore, important to consider the bioslurry application rate and its concentration when applied as mulch as this could affect the absorption of water by the soil. Bioslurry mulch under irrigation had a lower initial infiltration rate of 4.5 mm min^{-1} than irrigated control plots which had 7.7 mm min^{-1} (Fig. 4.6). The low initial infiltration rate observed in plots mulched with bioslurry under irrigated conditions could have been due to the high soil water content recorded under these treatments (Fig. 4.3). This may support the theory of Lal and Shukla (2004) who mentioned that soils with high initial moisture conditions initial have a tendency to have a low infiltration rate.

It can be concluded that under high temperatures of 35°C, soil water loss is also high and the application of bioslurry mulch has no benefits with respect to conserving soil water. However, under irrigated or rainfed conditions, where temperatures range from 25°C to 30°C, bioslurry mulch conserved significantly more soil water than the control with no mulch. The results of this experiment therefore indicated that the hard cap formed by bioslurry mulch application reduced evaporation under these conditions. This was supported by the higher maize growth in the bioslurry mulched plots. Based on these results, it is concluded that bioslurry mulch can improve maize growth under irrigated or rainfed conditions and can be recommended to rural farmers to improve maize production. However, the hard cap formed after application of bioslurry on the soil surface reduced the water infiltration rate, which may result in runoff. Therefore, studies to determine the correct application rate of bioslurry as a mulch and its concentration (the amount of water added to the manure during the production of bioslurry) are essential to promote a higher infiltration rate.

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CHAPTER 5

General discussion

Food insecurity, due to low soil fertility and water scarcity, is a major problem in sub-saharan Africa. Low soil fertility and water scarcity reduce crop production thus limiting food availability and accessibility by the communities. Mulches have been shown to have advantageous effects on soil moisture conservation, crop growth and yield. The studies presented in this thesis were based on the proposition that bioslurry, which is the by-product of biogas production, can be used as a mulch when growing maize with added benefits of fertilizing the soil. Using bioslurry as a mulch has the potential to minimize soil water loss through soil evaporation since it forms a hard cap when applied onto the soil surface, thus increasing the moisture available for crop production. The potential use of bioslurry as a mulch is significant in view of the low agricultural productivity as a result of low and erratic rainfall as well as poor soil fertility. Bioslurry was compared to other locally sourced organic mulches such as grass clippings and live pumpkin mulch which can be easily accessed by the farmers. Thus the study objectives were (1) to compare the effects of bioslurry mulch, grass clippings mulch and pumpkin live mulch on maize growth, yield performance and on soil water content under rainfed conditions; (2) to assess the effect of bioslurry mulch on soil water conservation under different temperature regimes and; (3) to assess the effect of bioslurry mulch on soil water content, soil infiltration rate and maize growth performance in a controlled on-station experiment.

The effects of bioslurry mulch, grass clippings mulch and pumpkin live mulch on maize yield and on soil water content

The maize experiment (Chapter 3) was conducted in a farmer's fields at Okhombe, a ward in the Upper Thukela district of KwaZulu-Natal, in which bioslurry, grass clippings and pumpkin mulch was compared to a control (no mulch). The application of mulch was shown to be clearly effective in conserving soil water compared to the unmulched control. Interestingly, there were no significant differences between the bioslurry, grass clippings and pumpkin mulch with respect to soil water content. The reason for lack of significant differences between the three mulches is not clear since bioslurry contained additional water which could increase soil water than the other mulches and one could argue that grass clippings are inert whereas the pumpkin live mulch could have contributed to reduced water content through evapotranspiration. Although the three mulching materials did not differ significantly, the use of bioslurry would have an advantage because of the addition of plant nutrients that may be readily available for plant uptake. In fact, this was evident from the observed better performance of maize plants in plots treated with bioslurry. The results showed that bioslurry and grass clippings mulch significantly improved maize yield compared to the pumpkin live mulch and the control of no mulch. In addition, bioslurry produced the maximum mean leaf area which was significantly higher than in the other mulching treatments. This could be attributed to nitrogen supplied by the bioslurry which could have contributed to an increase in the leaf area in the maize plots mulched with bioslurry. The better performance of the maize in plots with bioslurry mulch was because of the high soil water content under bioslurry and nutrients supplied by the bioslurry to the crop. It was also observed that bioslurry and pumpkin live mulch significantly increased stover yield when compared to the control and grass clippings mulch. These results have major implications with regard to sustainable and integrated crop-livestock production systems. Crop residues (stover) after harvesting the maize can be used as livestock feed in winter when the sourveld has low quality. This will decrease the grazing pressure on the continuously grazed rangeland thus allowing recovery. Animal excreta collected after the cows have grazed the stover in the maize fields could then be fed into biogas digesters for the production of biogas for energy for cooking. The bioslurry effluent from the biogas digester can be used as a mulch in the maize fields to conserve water and supply nutrients to produce maize. In addition, farmers would have easier access to bioslurry when practising integrated crop-livestock systems. Access to grass clippings would be limited by shortage of forage which is common during winter. The use of live pumpkin mulch would be limited and not sustainable in the long term because of the risk of crop failure when the weather conditions are dry. Pumpkin live mulch may also contribute to increased water losses through evapotranspiration during hot and dry weather conditions. There is an increased likelihood of such occurrences in South Africa given the likelihood of increased drought risks as a result of climate change.

The effect of bioslurry mulch and temperature on soil water conservation

The effect of the hard cap formed after application of bioslurry on soil water content was assessed in a controlled growth chamber under different temperature regimes to simulate dry weather conditions typical of small-scale farming environments. The results indicated that the hard cap formed by the bioslurry was not efficient in conserving water at the highest temperature (35°C). This may be explained by the evaporative demand which resulted in high evaporative losses. Such conditions are currently being experienced by rural farmers in South

Africa where extremely hot weather conditions result in high evaporative losses from the soils moisture. However, the results showed that bioslurry could be effective at conserving soil water at temperatures below (35°C). The significantly higher soil water content in the bioslurry treatment when compared to the control may be due to the hard cap formed which reduced evaporation from the soil surface.

The effects of bioslurry mulch on soil water content, water infiltration and maize growth performance

Under non-irrigated conditions no significant differences were observed between the bioslurry and control treatments with respect to soil water content and maize growth. This may be due to the fact that there was no water to conserve due to low rainfall. The findings of the study showed that bioslurry increased soil water content and maize growth over the control under irrigated conditions. Maize growth variables such as plant height, leaf number, stem girth and leaf area in irrigated plots with bioslurry mulch were significantly higher than the control. This may be explained by the higher soil water content recorded under these treatments which were highly beneficial to maize growth. Bioslurry mulch had a low water infiltration rate compared to the control of no mulch under irrigated and non-irrigated conditions. The lower infiltration rate observed in the bioslurry mulch treatment can be due to the hard cap sealing the soil surface pores thus reducing the water infiltration rate which may result in runoff. Conversely, the hard cap can be beneficial in conserving soil water since it decreased evaporation when temperatures were below 35°C. It is, therefore, important to consider the bioslurry application rate and its concentration when applying bioslurry as a mulch to promote higher infiltration rate.

In conclusion, the results of the study have clearly shown that the use of bioslurry as a mulch can significantly increase maize yield. Although there were no significant differences in soil water content between bioslurry mulch, grass clippings mulch and pumpkin live mulch, there are clear advantages with regard to the use of bioslurry as a mulch to conserve soil water. Unlike grass clippings which are heavily grazed by livestock and therefore difficult to collect, bioslurry mulch is readily available in households with biogas digesters. Bioslurry can be advantageous over pumpkin live mulch because pumpkin live mulch may also contribute to increased water losses through evapotranspiration during hot and dry weather conditions. Bioslurry has the added advantage that it is processed from livestock manure and therefore forms a major component of integrated crop-livestock systems that could contribute to sustainable crop-livestock production systems and improved rural livelihoods and food security.

Research recommendations

Further research is still needed to address the use of bioslurry as a source of mulch. The research should focus on the determination of optimal quantities, application rates and quality of bioslurry mulch to maximize its effectiveness. Quantification of these aspects would enable recommendations on whether the use of bioslurry could supplement or contribute to a reduction in the use of chemical commercial fertilizers by small-scale farmers. Such studies are critical for the development of concrete recommendations with regard to the use of bioslurry as a fertilizer source by small-scale farmers. Additionally, further studies that look at the impact of bioslurry on the quality of crop residues in mixed crop-livestock production systems are needed. Crop residues are used as a supplementary feed in sourveld areas in winter when the quality of natural veld is poor. Higher quality crop residues produced through bioslurry application could enhance livestock production. Storage of bioslurry during winter (the non-growing season) is currently a challenge for rural farmers in KwaZulu-Natal. Further research is needed on the potential advantages and disadvantages of wet and dry storage on bioslurry quality.

Appendix 1: Calculations of amount of N supplied by bioslurry

Bioslurry used contained 1.78% N

∴ 1% ≈ 10 000 mg /kg

$$x = \frac{1.78\%\ x\ 10\ 000\ mg/kg}{1\%}$$

x = 17 800 mg/ kg N

∴ 1 kg of bioslurry contains 17 800 mg N

$$x = \frac{17\ 800\ mg\ N\ x\ 10{-}^{6}\ \ mg/kg}{1\ mg}$$

x = 0.0178 kg N

Soil fertility analysis results showed that to achieve a maize yield of 4 t ha^{-1} N must be applied at 40 kg ha^{-1}

If 40 kg N is needed in a hectare to achieve a maize yield of 4 t ha^{-1},then the amount of N needed in 25 m^{2} is= :

$$x = \frac{40\ Kg\ N\ x\ 25m^{2}}{10\ 000\ m^{2}}$$

x = 0.1 kg N

The amount of bioslurry required to supply 0.1 kg N is:

$$x = \frac{0.1\ Kg\ N}{0.0178\ N}$$

x= 5.6 kg of bioslurry

Appendix 2: List of ANOVAs for Chapter 3

Variate: Soil water content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1530.69	510.23	45.46	
Block.*Units* stratum					
Date	4	2653.16	663.29	59.09	<.001
Mulch	3	126.83	42.28	3.77	0.015
Bioslurry vs Control	1	99.23	99.23	8.84	0.004
Bioslurry vs pumpkin	1	0.63	0.63	0.06	0.814
Bioslurry vs grass	1	27.64	27.64	2.46	0.122
Pumpkin vs control	1	84.10	84.10	7.49	0.008
Pumpkin vs grass	1	19.95	19.95	1.78	0.188
Grass vs Control	1	22.13	22.13	1.97	0.166
Date.Mulch	12	105.31	8.78	0.78	0.666
Date.Bioslurry vs Control	4	35.79	8.95	0.80	0.532
Date.Bioslurry vs pumpkin	4	24.86	6.21	0.55	0.697
Date.Bioslurry vs grass	4	39.45	9.86	0.88	0.483
Date.Pumpkin vs control	4	30.08	7.52	0.67	0.616
Date.Pumpkin vs grass	4	36.85	9.21	0.82	0.517
Date.Grass vs Control	4	43.60	10.90	0.97	0.430
Residual	57	639.81	11.22		
Total	79	5055.81			

Variate: Height of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	3	1.21239	0.40413	5.34	
Blocks.*Units* stratum					
WAP	3	20.85016	6.95005	91.80	<.001
Mulch	3	0.59251	0.19750	2.61	0.063
Bioslurry vs Pumpkins	1	0.00845	0.00845	0.11	0.740
Bioslurry vs Grass	1	0.00249	0.00249	0.03	0.857
Bioslurry vs Control	1	0.39872	0.39872	5.27	0.026
Pumpkins vs Grass	1	0.02010	0.02010	0.27	0.609
Pumpkins vs Control	1	0.29108	0.29108	3.84	0.056
Grass vs Control	1	0.46417	0.46417	6.13	0.017
WAP.Mulch	9	0.46464	0.05163	0.68	0.721
WAP.Biolsurry vs Pumpkins	3	0.11429	0.03810	0.50	0.682
WAP.Bioslurry vs Grass	3	0.03454	0.01151	0.15	0.928
WAP.Bioslurry vs Control	3	0.11507	0.03836	0.51	0.680
WAP.Pumpkins vs Grass	3	0.14410	0.04803	0.63	0.597
WAP.Pumpkins vs Control	3	0.24674	0.08225	1.09	0.365
WAP.Grass vs Control	3	0.27455	0.09152	1.21	0.317
Residual	45	3.40676	0.07571		
Total	63	26.52645			

Variate: Leaf number of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	3	9.4869	3.1623	4.51	
Blocks.*Units* stratum					
WAP	3	270.6569	90.2190	128.55	<.001
Mulch	3	21.1669	7.0556	10.05	<.001
Bioslurry vs Pumpkins	1	9.6800	9.6800	13.79	<.001
Bioslurry vs Grass	1	6.1250	6.1250	8.73	0.005
Bioslurry vs Control	1	20.1612	20.1612	28.73	<.001
Pumpkins vs Grass	1	0.4050	0.4050	0.58	0.451
Pumpkins vs Control	1	1.9013	1.9013	2.71	0.107
Grass vs Control	1	4.0613	4.0613	5.79	0.020
WAP.Mulch	9	6.6406	0.7378	1.05	0.416
WAP.Bioslurry vs Pumpkins	3	3.2700	1.0900	1.55	0.214
WAP.Bioslurry vs Grass	3	2.2050	0.7350	1.05	0.381
WAP.Bioslurry vs Control	3	4.1138	1.3713	1.95	0.135
WAP.Pumpkins vs Grass	3	1.9050	0.6350	0.90	0.446
WAP.Pumpkins vs Control	3	0.8537	0.2846	0.41	0.750
WAP.Grass vs Control	3	0.9338	0.3113	0.44	0.723
Residual	45	31.5831	0.7018		
Total	63	339.5344			

Variate: Leaf area of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	3	12672.0	4224.0	9.35	
Blocks.*Units* stratum					
WAP	3	130000.3	43333.4	95.93	<.001
Mulch	3	8127.8	2709.3	6.00	0.002
Bioslurry vs Pumpkins	1	3357.9	3357.9	7.43	0.009
Bioslurry vs Grass	1	3745.5	3745.5	8.29	0.006
Bioslurry vs Control	1	7607.6	7607.6	16.84	<.001
Pumpkins vs Grass	1	10.6	10.6	0.02	0.879
Pumpkins vs Control	1	857.0	857.0	1.90	0.175
Grass vs Control	1	677.1	677.1	1.50	0.227
WAP.Mulch	9	7569.7	841.1	1.86	0.083
WAP.Bioslurry vs Pumpkins	3	3445.7	1148.6	2.54	0.068
WAP.Bioslurry vs Grass	3	4450.8	1483.6	3.28	0.029
WAP.Bioslurry vs Control	3	6243.2	2081.1	4.61	0.007
WAP.Pumpkins vs Grass	3	238.2	79.4	0.18	0.912
WAP.Pumpkins vs Control	3	448.6	149.5	0.33	0.803
WAP.Grass vs Control	3	312.8	104.3	0.23	0.874
Residual	45	20327.4	451.7		
Total	63	178697.2			

Variate: Stem girth of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	3	1410.69	470.23	4.93	
Blocks.*Units* stratum					
WAP	3	9102.69	3034.23	31.84	<.001
Mulching	3	541.19	180.40	1.89	0.144
Bioslurry vs Pumpkins	1	128.00	128.00	1.34	0.253
Bioslurry vs Grass	1	72.00	72.00	0.76	0.389
Bioslurry vs Control	1	528.12	528.12	5.54	0.023
Pumpkins vs Grass	1	8.00	8.00	0.08	0.773
Pumpkins vs Control	1	136.12	136.12	1.43	0.238
Grass clippings vs Control	1	210.12	210.12	2.20	0.145
WAP.Mulching	9	237.56	26.40	0.28	0.978
WAP.Bioslurry vs Pumpkins	3	129.00	43.00	0.45	0.718
WAP.Bioslurry vs Grass	3	133.00	44.33	0.47	0.708
WAP.Bioslurry vs Control	3	79.38	26.46	0.28	0.841
WAP.Pumpkins vs Grass	3	65.00	21.67	0.23	0.877
WAP.Pumpkins vs Control	3	61.38	20.46	0.21	0.886
WAP. Grass vs Control	3	7.38	2.46	0.03	0.994
Residual	45	4288.31	95.30		
Total	63	15580.44			

Variate: Ear Length of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	3	3359.4	1119.8	4.08	
Blocks.*Units* stratum					
Mulch	3	3263.1	1087.7	3.96	0.047
Bioslurry vs Pumpkins	1	10.6	10.6	0.04	0.849
Bioslurry vs grass	1	47.5	47.5	0.17	0.687
Bioslurry vs Control	1	1994.0	1994.0	7.26	0.025
Pumpkins vs Grass	1	103.0	103.0	0.37	0.555
Pumpkins vs Control	1	1714.1	1714.1	6.24	0.034
Grass vs Control	1	2657.2	2657.2	9.68	0.013
Residual	9	2471.3	274.6		
Total	15	9093.8			

Variate: Thousand seed weight of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	3	0.02107	0.00702	0.60	
Blocks.*Units* stratum					
Mulch	3	0.13363	0.04454	3.81	0.052
Bioslurry vs Pumpkins	1	0.04883	0.04883	4.17	0.071
Bioslurry vs Grass	1	0.01575	0.01575	1.35	0.276
Bioslurry vs Control	1	0.12450	0.12450	10.64	0.010
Pumpkins vs Grass	1	0.00911	0.00911	0.78	0.400
Pumpkins vs Control	1	0.01739	0.01739	1.49	0.254
Grass vs Control	1	0.05168	0.05168	4.42	0.065
Residual	9	0.10528	0.01170		
Total	15	0.25998			

Variate: Maize stover yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	3	98942.	32981.	0.69	
Blocks.*Units* stratum					
Mulch	3	618208.	206069.	4.32	0.038
Bioslurry vs Control	1	10756.	10756.	0.23	0.646
Bioslurry vs Grass	1	95339.	95339.	2.00	0.191
Bioslurry vs pumpkin	1	527022.	527022.	11.06	0.009
Pumpkins vs Grass	1	42050.	42050.	0.88	0.372
Pumpkins vs Control	1	387200.	387200.	8.13	0.019
Grass vs Control	1	174050.	174050.	3.65	0.088
Residual	9	428825.	47647.		
Total	15	1145975.			

Variate: Maize grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	3	34044.	11348.	0.14	
Blocks.*Units* stratum					
Mulch	3	21095622.	7031874.	87.66	<.001
Bioslurry vs Control	1	9388889.	9388889.	117.04	<.001
Bioslurry vs Grass	1	12272.	12272.	0.15	0.705
Bioslurry vs Control	1	12317339.	12317339.	153.54	<.001
Pumpkins vs Grass	1	8722272.	8722272.	108.73	<.001
Pumpkins vs Control	1	198450.	198450.	2.47	0.150
Grass vs Control	1	11552022.	11552022.	144.00	<.001
Residual	9	721978.	80220.		
Total	15	21851644.			

Variate: Harvest Index of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	3	0.000989	0.000330	0.07	
Blocks.*Units* stratum					
Mulch	3	0.154655	0.051552	11.48	0.002
Bioslurry vs Control	1	0.081739	0.081739	18.21	0.002
Bioslurry vs Grass	1	0.001964	0.001964	0.44	0.525
Bioslurry vs Control	1	0.045192	0.045192	10.07	0.011
Pumpkins vs Grass	1	0.109043	0.109043	24.29	<.001
Pumpkins vs Control	1	0.005375	0.005375	1.20	0.302
Grass vs Control	1	0.065997	0.065997	14.70	0.004
Residual	9	0.040398	0.004489		
Total	15	0.196043			

Appendix 3: List of ANOVAs for chapter 4

Variate: SWC

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	18.258	9.129	1.32	
Reps.*Units* stratum					
Date	4	389.960	97.490	14.15	<.001
Irrigation	1	1743.676	1743.676	253.00	<.001
Treatments	1	37.542	37.542	5.45	0.025
Date. Irrigation	4	40.601	10.150	1.47	0.230
Date.Treatments	4	24.117	6.029	0.87	0.488
Irrigation.Treatments	1	43.128	43.128	6.26	0.017
Date. Irrigation.Treatments	4	26.169	6.542	0.95	0.446
Residual	38	261.898	6.892		
Total	59	2585.350			

Variate: Height of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.0017100	0.0008550	1.11	
Replication.*Units* stratum					
Irrigation	1	0.3412604	0.3412604	444.77	<.001
Mulch	1	0.0413438	0.0413438	53.88	<.001
WAP	4	3.4510608	0.8627652	1124.45	<.001
Irrigation. Mulch	1	0.0315104	0.0315104	41.07	<.001
WAP.Irrigation	4	0.2090792	0.0522698	68.12	<.001
WAP. Mulch	4	0.0049792	0.0012448	1.62	0.189
WAP. Irrigation. Mulch	4	0.0042708	0.0010677	1.39	0.255
Residual	38	0.0291567	0.0007673		
Total	59	4.1143712			

Variate: Leaf area of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	99.11	49.55	1.53	
Replication.*Units* stratum					
Irrigation	1	5577.70	5577.70	171.68	<.001
Mulch	1	1311.34	1311.34	40.36	<.001
WAP	4	26760.19	6690.05	205.92	<.001
Irrigation. Mulch	1	495.94	495.94	15.27	<.001
WAP.Irrigation	4	193.94	48.49	1.49	0.224
WAP.Mulch	4	286.64	71.66	2.21	0.087
WAP.Irrigation. Mulch	4	264.12	66.03	2.03	0.109
Residual	38	1234.56	32.49		
Total	59	36223.55			

Variate: Leaf number of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	2.0333	1.0167	2.77	
Replication.*Units* stratum					
Irrigation	1	68.2667	68.2667	185.74	<.001
Mulch	1	15.0000	15.0000	40.81	<.001
WAP	4	279.2333	69.8083	189.93	<.001
Irrigation. Mulch	1	5.4000	5.4000	14.69	<.001
WAP. Irrigation	4	3.2333	0.8083	2.20	0.087
WAP.Mulch	4	1.1667	0.2917	0.79	0.537
WAP.Irrigation .Mulch	4	1.4333	0.3583	0.97	0.433
Residual	38	13.9667	0.3675		
Total	59	389.7333			

Variate: Stem girth of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	37.63	18.82	0.59	
Reps.*Units* stratum					
Irrigation	1	5510.42	5510.42	174.06	<.001
Treatments	1	770.42	770.42	24.34	<.001
WAP	4	18720.17	4680.04	147.83	<.001
Irrigation.Treatments	1	633.75	633.75	20.02	<.001
WAP. Irrigation	4	431.83	107.96	3.41	0.018
WAP. Treatments	4	48.50	12.12	0.38	0.819
WAP. Irrigation.Treatments	4	76.83	19.21	0.61	0.660
Residual	38	1203.03	31.66		
Total	59	27432.58			

Variate: Stover yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	166230.	83115.	0.88	
Replication.*Units* stratum					
Irrigation	1	2424004.	2424004.	25.52	0.002
Mulch	1	2424004.	2424004.	25.52	0.002
Irrigation. Mulch	1	3115.	3115.	0.03	0.862
Residual	6	569800.	94967.		
Total	11	5587152.			

Infiltration rate calculations

Time (h:mm:ss)	Time (Sec)	Time (Min)	Midpoint of time interval (min)	Time difference (min)	I(mm/min)
0	0	0	0	0	0
0:00:59	59	0.983	0.492	0.983	5.08647
00:01:52	112	1.867	1.425	0.884	5.656109
00:03:22	202	3.367	2.617	1.5	3.333333
00:04:29	269	4.483	3.925	1.116	4.480287
00:05:26	326	5.433	4.958	0.95	5.263158
00:06:52	412	6.867	6.15	1.434	3.48675
00:07:50	470	7.833	7.35	0.966	5.175983
00:09:47	587	9.783	8.808	1.95	2.564103
00:11:34	694	11.567	10.675	1.784	2.802691
00:13:25	805	13.417	12.492	1.85	2.702703
00:15:11	911	15.183	14.3	1.766	2.831257
00:16:31	991	16.517	15.85	1.334	3.748126
00:18:17	1097	18.283	17.4	1.766	2.831257
00:20:42	1242	20.700	19.492	2.417	2.06868
00:22:31	1351	22.517	21.609	1.817	2.751789
00:24:49	1489	24.817	23.667	2.3	2.173913
00:27:24	1644	27.400	26.109	2.583	1.935734
00:31:28	1888	31.467	29.434	4.067	1.229407
00:33:23	2003	33.383	32.425	1.916	2.609603
00:35:35	2135	35.583	34.483	2.2	2.272727
00:37:50	2270	37.833	36.708	2.25	2.222222