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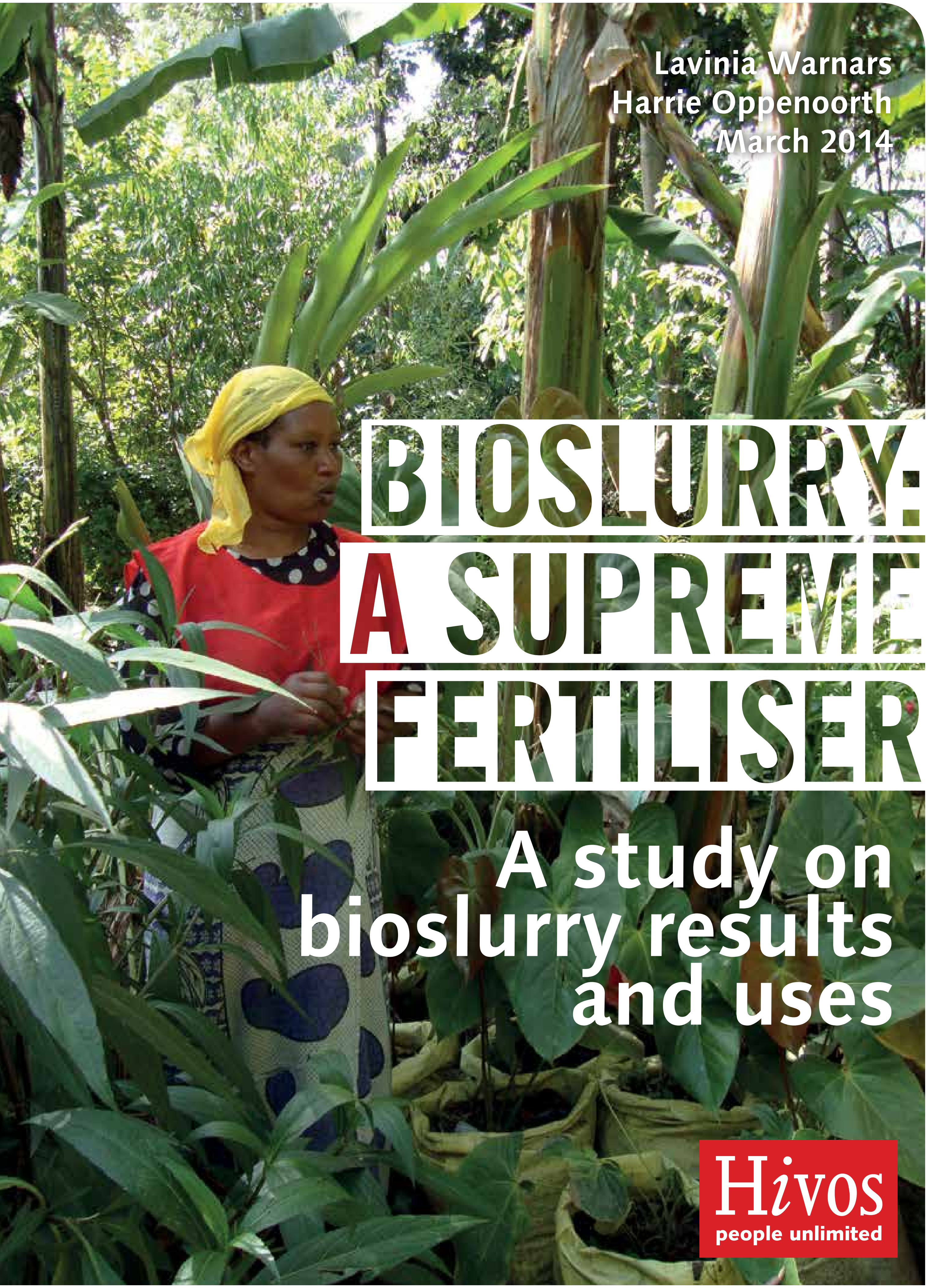
March 2014

BIOSLURRY: A SUPREME FERTILISER

A study on bioslurry results and uses



Hivos
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ISBN/EAN 978-90-70435-07-3
This book should be cited as: Warnars and Oppenoorth, 2014
Editing: Kelly Atkinson
Design: SAZZA
Printing: Deltahage

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1 EXECUTIVE SUMMARY

Biogas produced from cattle, pig, and buffalo dung (and other excrement, e.g. human), together with the by-product bioslurry, can be a solution to poor access to modern energy services, poverty, climate change, and soil fertility problems. It is a simple and affordable energy supply which is uncomplicated to handle and easy to maintain. Indeed, it is the cheapest option so far for clean energy provision to rural households. This makes it ideal for smallholder farmers and families with just a few cattle. The potential of biogas is significant in developed as well as developing countries.

A biogas installation can be filled with locally available raw materials, crop residues, and animal (pig, poultry and cattle) and human waste such as urine and dung. The by-product, bioslurry, can be used to improve soil fertility, soil structure, and crop productivity. It can be an interesting link between the biogas use aimed at substituting biomass or fossil fuels for cooking and sustainable agriculture. However, not many farmers are familiar with the advantages of bioslurry.

The composition of bioslurry depends upon several factors: the kind of dung (e.g. animal or human), water, breed and age of animals, types of feed and feeding rate. Bioslurry can be used to fertilise crops directly or added to composting of other organic materials. Bioslurry is an already-digested source of animal waste and if urine (animal and/or human) is added, more nitrogen is added to the bioslurry which can speed up the compost-making process. This improves the carbon/nitrogen (C/N) ratio in the compost[1]. But this also depends on the kind of digester. With the right amounts of materials, the composition of the bioslurry can exist of 93% water and 7% of dry matter, of which 4.5% is organic matter and 2.5% inorganic matter. The bioslurry also contains phosphor, potassium, zinc, iron, manganese and copper, the last of which has become a limited factor in many soils. Bioslurry can be used to build healthy fertile soil for crop production. Indeed, bioslurry form and content stabilises with double nitrogen content, which is different from Farmyard Manure (FYM). Furthermore, the quantity of the bioslurry is also more than regular FYM. Bioslurry contains readily-available plant nutrients and it contains higher amounts of nutrients and micronutrients than FYM and composted manure do. The effects of bioslurry application are comparable to the effects of the application of chemical fertilisers. As such, bioslurry can be a serious alternative to chemical fertilisers.

1 'C/N ratio should never be more than 35, with an optimum of 30. If the C/N ratio is very high, nitrogen will be consumed rapidly and the rate of reaction will decrease. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia, which is toxic under certain conditions.' (Centre for Energy Studies, Institute of Engineering, 2001, p. 43).

2 INTRODUCTION AND BACKGROUND

Bioslurry is used to improve soil fertility, soil structure and crop productivity. It can also be an interesting link between the biogas programs aimed at substituting biomass or fossil fuels for cooking and sustainable agriculture promotion. Bioslurry has so many advantages that it can be referred to as 'bio gold'. However, not many households are familiar with the advantages of bioslurry[2]. This document aims to summarise the benefits and application possibilities of bioslurry, thus increasing the knowledge and improving practice regarding bioslurry use.

2.1 Population, agriculture and climate change

The world population is growing exponentially due to medical progress and massive incremental increases in agricultural productivity. In 2050, the global population will reach around 9 billion, a 50% increase since 2007. These people need to be fed; therefore agricultural production and efficiency must be increased. Agricultural lands currently occupy 40% of land surface worldwide and the sector contributes 4% to the global GDP, providing employment to 1.3 billion people. However, climate change has a significant impact on agriculture and vice versa: agriculture is GHG-intensive. Indeed, the IPCC[3] concludes that the direct effects of agriculture account for 14% of global GHG emissions in CO_2 equivalents (5.1 to 6.1 Gt CO_2-eq/yr in 2005) and indirectly they account for 17% of emissions when biomass burning, deforestation, and conversion to cropland and pasture are included[4]. As such, climate change and agriculture are interrelated[5]. The changes in the global climate system and the demand for more food – together with more nutrients and meat – for the growing population will require innovations in policy as well as institutions. A solution can be found in a combination of energy-efficient and agricultural-productivity-improving technology such as biodigesters[6]. '*Animal production systems are a major source of pollution affecting the quality of water, soil and air […]*' (mainly in developed countries)[7]. Furthermore, livestock and poultry production has increased in size while land availability has decreased due to urbanisation.

2 PDBP, n.d.

3 Smith et al., 2007.

4 Lybbert and Sumner, 2010.

5 Smith et al., 2007; Rosenzweig and Parry, 1994.

6 Lybbert and Sumner, 2010.

7 Liedl, Bombardiere and Chatfield, 2006, p. 69.

Due to outside pressures, farmers are forced to increase their manure application rates, resulting in negative environmental side effects[8]. Biodigesters can mitigate these effects.

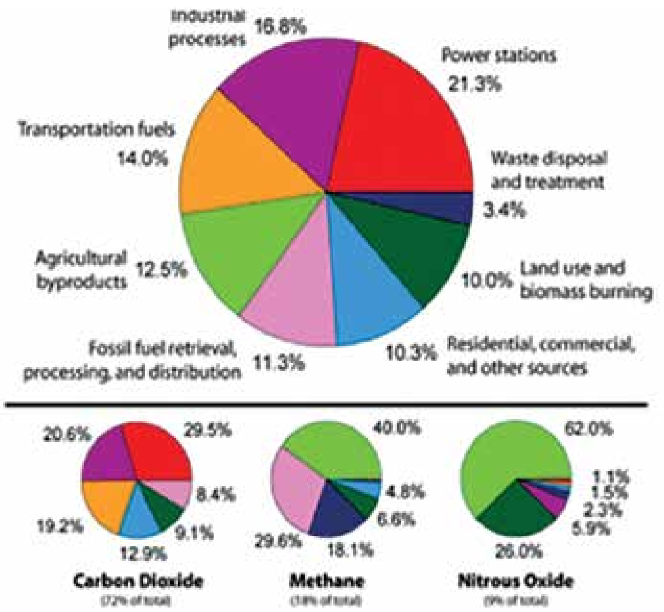

Figure 1: Annual Greenhouse Gas Emissions by Sector
Source: Wikipedia (2013).

2.2 Energy

Energy is a vital requirement for development and is a catalyst for a country's economy. *'The lack of access to affordable and efficient energy keeps a huge mass of people in developing world in a poverty trap'*[9]. Over 2 billion people lack access to clean, safe and sustainable energy. The lack of this access is a constraint to development. Many developing countries have insufficient generation capacity, unreliable supply, high energy prices and a poor energy infrastructure. As a result, poor and marginalised people often use firewood and/or LPG for cooking, kerosene for lighting, and diesel for electricity and mechanical power. These are energy sources with serious negative impacts. Kerosene and diesel can be expensive and unreliable, and are also harmful to

8 Liedl, Bombardiere and Chatfield, 2006, p. 69.

9 Centre for Energy Studies, Institute of Engineering, 2001, p. 24.

the environment. The use of firewood causes **2 million deaths per year due to the soot and smoke.** Women and children not only have to face respiratory and eye diseases but also often suffer burns. On the national level, the use of firewood increases deforestation in many areas, and firewood collection is physically intensive. In addition agricultural and animal waste is often used for cooking, reducing biomass and nutrient availability, which results in decreasing soil fertility and reduced crop yields. Hence, there is a great demand for affordable, reliable, renewable and environmentally clean energy. This can come from wind, solar, (micro) hydro energy, and biogas.

2.3 Hivos's and SNV's biogas programs

Hivos and SNV are implementing biogas programs in eight African countries, eight Asian countries and Nicaragua, with some new countries in the pipeline. The focus of the programs is on developing a new and clean energy source, while replacing wood as the main fuel source. The overall objective of these programs is to contribute to the achievement of the Millennium Development Goals through the dissemination of domestic biogas plants as a local, sustainable energy source.
This is done with the development of a commercially viable, market-oriented biogas sector[10]. Farmers buy biodigesters from biogas construction enterprises or providers. Builders and installers are trained and companies created and supported with business development skills; vocational training institutions are invited to include a biogas module; credit provision for end users and the created companies is arranged with existing finance and credit institutions; bioslurry (the effluent of the digesters, a potent organic fertiliser, see below) application trainings are provided by agricultural extension organisations; a quality assurance and guaranty system is put in place, and; finally, carbon credits are developed and provide finance that is ploughed back into the programmes. In all countries this approach has been very successful and in just three or four years more digesters were installed in each country than in the previous four decades[11].

2.4 Biogas and biodigesters

Biogas produced from cattle, pig, and buffalo dung (and other excrement, e.g. human), together with the by-product bioslurry, can be a solution to poverty, climate change, poor access to modern energy services, and soil fertility problems. *'Biogas is a combustible gas produced by anaerobic fermentation of organic materials by the action of methanogenic bacteria'*[12]. It is a simple, affordable energy supply which is uncomplicated to handle and easy to maintain. Indeed, it is the cheapest option so far for clean energy at this scale. *'This makes it an ideal renewable energy source for smallholder farmers with a few cattle'*[13].
The potential of biogas is significant in developed as well as developing countries. In a biogas installation, dung has to be loaded with a certain loading rate (i.e. with a fixed dome construction of 4m³ volume size, the minimum feeding is 20kg / day)[14]. The biogas consists of methane and carbon dioxide and the flame from the gas is smokeless and non-toxic. However, small biogas installations can only be used for cooking while bigger ones can be used for lighting, electricity generation (refrigeration, lighting) and mechanical power (engines). The minimal daily feed for a 4m³ digester is 20kg of animal dung (around two adult cows / buffaloes or five pigs). Generally, a biogas plant can **last from 2 to 20 years**, but it also needs operation and maintenance and it depends upon the materials used. For instance, plants made from PVC and polyethylene have a shorter lifespan than the brick- and block-built biodigesters[15]. The cost of a biogas plant in Asia lies between US $350 and US $800. In Africa the cost is between $600 and $1000 due to the higher costs of cement, labour and other requirements[16].

'Biogas production is practiced on a high proportion of farms, but there is a lack of experience to operate these systems efficiently'[17]. Biodigesters and the biodigester market will tremendously improve living conditions in poor households thanks to their enabling independent production of clean energy and fertiliser. Biogas installation and use has many positive effects. **The biogas production of 25kg of dung per day replaces 5kg of firewood, 1.5kg of charcoal and 0.6 litres of kerosene per day.** It creates employment, saves the use of traditional cooking fuels and increases the availability of clean fuels. It caters for rural cooking and lighting needs which account for 95% of rural domestic energy use. It reduces the workload of women and children in particular, by removing the need to collect firewood, tend the fire and clean the utensils of soot or smoke, tasks which occupy 2 to 3 hours per household per day or even more in some regions. This will leave more time available for activities other than wood collection. Employment opportunities also increase through the newly-established domestic biodigester business sector. It contributes to a cleaner indoor environment as well, as it does not produce smoke or gas – unlike firewood and dung. A study in Indonesia showed that a biogas installation can significantly decrease the incidence of various problems: eye irritations by 22%, eye infections by 10%, coughs by 21%, and breathing difficulties by 21%[18]. Cooking with a biogas installation can be done in an upright position, rather than kneeling down. Furthermore, the kitchen is cleaner and the women themselves stay cleaner as there is less soot and smoke. All of these factors contribute to an increase of self-esteem and dignity in women. All in all, biogas avoids smoke and smoke-related diseases and increases the availability of lighting for reading, education and social and economic activities in the evenings[19].

10 *Hivos, Tor, 2011.*
11 *Hivos, 2013.*
12 *Centre for Energy Studies, Institute of Engineering, 2001, p. 41.*
13 *Warnars, 2012, p. ii.*
14 *SNV, 2011, a & b.*
15 *SNV, 2011, b.*
16 *SNV, 2011, a.*
17 *Vu et al., 2007, p. 296.*
18 *Mucharam, Pariatmoko and de Groot, 2012.*
19 *SNV, 2011, a.*

Biodigesters improve sanitary conditions and lower the exposure of household members to infections related to polluted water and poor sanitation. On a broader scale, biogas installations contribute to national policies on sustainable development (clean energy, combating deforestation and increased agricultural productivity) and can stimulate the involvement of women and other disadvantaged groups in democratic decision-making in their regions and/or countries[20]. Biogas installations also reduce carbon dioxide, nitrogen oxide and methane emissions as these gases are captured. CO_2, CH_4, and nitrous oxide reductions are related to the fuel switch from wood to gas, while CH_4 is also reduced due to the process of oxidisation to CO_2 and water. This is significant since CH_4 is 25 times higher in global warming potential than CO_2[21].

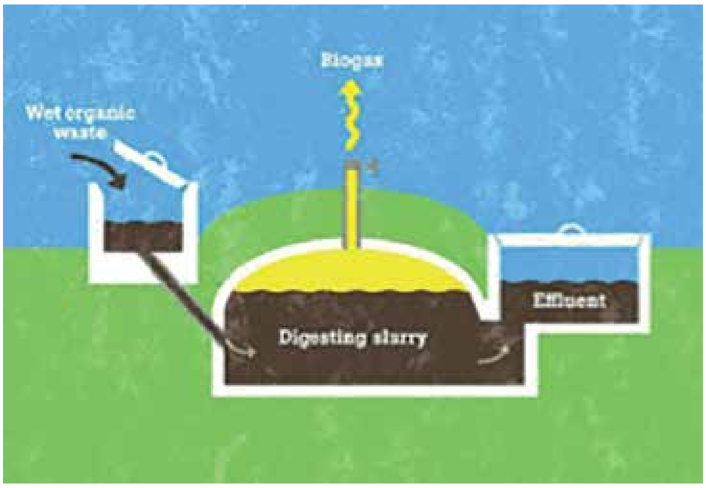

Figure 2: Basic components of a fixed-dome biogas digester plant
Source: Ejigu (2010, p. 3)

2.5 Composting and bioslurry

2.5.1 Composting: the basics

Plants need different nutrients for growth and enzymatic processes. They also need a certain climate and soil composition. The soil consists of physical, biological and chemical aspects. The last of these can be divided into nutrient availability, pH value, caution exchange capacity (measuring fertility), oxidation reduction and salinity. Mineral nutrition includes the supply, absorption and utilisation of essential nutrients for growth and yield of crop plants. Macro (e.g. carbon, nitrogen, oxygen, calcium) and micro (iron, manganese, chlorine) nutrients are equally important for a plant and its growth rate. A plant consists of 42% carbon, 44% oxygen, 7% hydrogen and 7% nutrients (of which nitrogen and potassium account for the largest part). The higher the yield of a plant, the higher the uptake of nutrients. A plant can experience deficiency as well as nutrient absorption and assimilation problems. Using high-quality compost supports the soil and crops in their nutrients and fertility. Below we explain what bioslurry can mean in this sense[22].

Figure 3: The components for making compost
Source: ISD (n.d., p. 3)

2.5.2 Bioslurry: an introduction

A biogas digester can be filled with locally-available raw materials, crop residues, and animal (pig, poultry, and cattle) and human waste such as urine and dung. *'During digestion, about 25-30% of the total dry matter (total solids content of fresh dung) of animal/human wastes will be converted into a combustible gas and a residue of 70-75% of the total solids content of the fresh dung comes out as sludge which is known as digested slurry or biogas slurry'*[23]. Biogas and bioslurry offer several benefits by improving fertiliser qualities, reducing odours and pathogens and providing renewable energy and fuel[24]. The composition of bioslurry depends upon several factors: the kind of dung (animal, human, or other feedstock), water, breeds and ages of the animals, types of feed and feeding rates[25]. Bioslurry can be used to fertilise crops directly or added to composting of other organic materials. Bioslurry is an already-digested source of animal waste and if urine (animal and/or human) is added, more nitrogen is added to the bioslurry which can speed up the compost-making process. This improves the carbon/nitrogen (C/N) ratio in the compost[26]. But this also depends on the kind of digester. With the right amounts of materials, the composition of the bioslurry can consist of 93% water and 7% dry matter, of which 4.5% is organic matter and 2.5% inorganic matter. The bioslurry also contains nitrogen, phosphor and potassium as well as zinc, iron, manganese and copper, the last of which has

20 SNV, 2011, a.
21 SNV, 2011, b; Warnars, 2012.

22 SNV 2011, a & b.
23 Gurung, 1998, p. 4.
24 Holm – Niesen, Seadi, and Oleskowicz- Popiel, 2009.
25 Centre for Energy Studies Institute of Engineering, 2001.
26 'C/N ratio should never be more than 35, with an optimum of 30. If the C/N ratio is very high, nitrogen will be consumed rapidly and the rate of reaction will decrease. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia, which is toxic under certain conditions.' (Centre for Energy Studies, Institute of Engineering, 2001, p. 43).

Table 1: Comparison of effects of various fertilisers on cabbage, mustard and potato in yield

S. No	Treatment %	Cabbage % increase	Mustard % increase	Potato % increase
1	Control	-	-	-
2	Farmyard manure (FYM)	18.67	25.8	25.33
3	Slurry	20.63	45.75	34.75
4	Slurry – Single superphosphate	29.7	49.75	
5	Slurry + Rock phosphate	15.9	35.25	
6	Slurry + Potash	24.9	-	-
7	Farmyard manure + Phosphate	-	33.98	

Source: Gurung (1998, p. 32)

become a limited factor in many soils[27]. Indeed, bioslurry form and content stabilises with double nitrogen content, which is different from FYM. The quantity of the bioslurry is also more than regular FYM. '*About 25 to 30% of organic matter is converted into biogas during the anaerobic fermentation process, while the rest becomes available as manure (bio-slurry)*'[28]. The eventual output of bioslurry coming from a biodigester is almost equal to the input.

The effects of bioslurry application are comparable to the effects of the application of chemical fertilisers. As such, bioslurry can be a serious alternative to chemical fertilisers[29]. '*The lack of effective extension services on animal waste treatment represents a serious knowledge gap for farmers undertaking commercial-scale pig production*'[30].
Animal waste is a major pollution source affecting water quality all over the globe. In addition, ever more land is taken by urbanisation and farmers are therefore pushed to apply manure at higher rates than recommended. Application is however often done inaccurately and at the wrong time[31].

Bioslurry can be used to build healthy fertile soil for crop production. The bioslurry can be used in liquid, compost, and dry form and is a very good fertiliser/composting substance for agricultural crops. If the dung is available in dry form, more water needs to be added. Bioslurry is a more easily available form of compost than traditional compost. It is also an attractive option to mix it with vegetative waste compost and enrich it with bioslurry (one part bioslurry to three parts compost). Bioslurry contains readily-available plant nutrients and it contains higher amounts of nutrients and micronutrients than FYM and composted manure. A family owning a biogas plant will have clean and cheap biogas and a continuous and readily available supply of high quality manure for crops. **'[...] bio-slurry increases crop revenues with an average of 25 percent [...]**[32].

Bioslurry can increase cereal crop productions by 10 to 30% compared to ordinary manure[33]. Regarding increased yields, the most responsive crops to bioslurry and bioslurry compost are vegetables, root crops, potatoes, fruit trees, maize, and rice (also see Table 2 and Figure 4 for an overview). Furthermore, bioslurry has the potential not only to improve soil fertility and soil structure, but also to act as a plague repellent. Finally, seeds treated with bioslurry have given better germination rates[34].

Table 2: Crop increase in yields compared to control plot

Crop	% increase in yield over control plot
Rice	46%
Tomato	108% and 33%
Chillies	0%
Rice	40%, 23% and 14%
Eggplant	33% and 77%
Maize	92%
Cabbage	20%
Potato	34%

Source: Gurung, 1998, p. 32 – 33

2.5.3 Kinds, application and forms of bioslurry

Bioslurry can be found in different forms and varies according to the digester and feeding substances. The fully-digested bioslurry can be easily identified (like regular compost: smells good, is black or dark brown in colour, can contain small living organisms, and no substances can be identified) and can be used as manure to improve soil fertility and increase crop yields and production. All the feeding substances, application amounts and

27 Gurung, 1998.
28 Jeptoo, Aguyoh, and Saidi, 2012, p. 165.
29 Serge, 2012, p. 65.
30 Vu et al., 2007, p. 296.
31 Holm – Niesen, Seadi and Oleskowicz- Popiel, 2009.
32 Warnars, 2012, p. 64.
33 Gurung, 1998, p. 31.
34 Gurung, 1998.

rates, and forms of bioslurry affect the production of crops, so all of these issues are described here.

2.5.3.1 Feeding substance

There are different effluent types possible such as cow, poultry, sheep or pig manure, and even guinea pig manure and kitchen garbage effluent (KGE). All the manures have considerable amounts of nutrients although poultry-based bioslurry is especially suitable for acid soils due to its strong buffering effect[35]. Animals can be fed with paddy straw, dried groundnut plants, maize stalks and groundnut oil cake, rice bran and cotton seed cake / meal [36]. KGE can also be used as an input for the biodigester. It has the benefit that it can be used as a quick-release fertiliser for vegetable production. KGE is rich in N and K and as such is comparable to chemical fertilisers, but it is lower in other nutrients (see below: 'Nutrient values of bioslurry'). However, KGE is probably not practical when the water content in the soil is high and when the soil itself is impermeable and the smell of this kind of bioslurry is less favourable[37]. *'Germination and growth chamber experiments revealed a higher maturity of digested slurry (DS) than raw slurry (RS)'*[38].

2.5.3.2 Application

During digestion nutrients are transformed from organic states to dissolved states, making them more useful for plant uptake[39]. From experience, it is generally recommended to apply the bioslurry at a rate of **10 to 20 tons/ha in irrigated areas and 5 tons/ha in dry farming**[40] in order to achieve a significant increase in yield. Applying more is sometimes suggested by other literature, but the additional increase in yield is not so significant after around 25 t/ha. The appropriate rate may depend on the crop and soil (sand, clay, loam). For instance, with a banana plant growing on a loamy soil, a jerrycan (20 litres) is applied every cropping season, which is equivalent to two jerrycans (40 litres) per year[41]. With alfalfa, though, the rate might be once every 7, 14, 21 or 28 days.

The bioslurry can be applied: (1) as a foliar fertiliser, being sprayed onto the crops; (2) in liquid form (diluted) onto the roots, or; (3) in dry and composted form (combined with irrigation techniques so that crops have sufficient water). With regards to tillage, note that immediate incorporation of pig bioslurry through tillage would increase the N value and favour greater N/P fertiliser value[42] (see below). However, it is imperative to take into account the risks associated with spreading the bioslurry directly on the crops or incorporating it into the soils[43]. '*It is many times falsely believed that the anaerobic digestion process inevitably kills all pathogens present in animal manures'*[44]. The same applies to nematodes and viruses. The three bioslurry forms, liquid, dried and composted, are described in more detail below.

2.5.3.3 Forms of bioslurry

Liquid form

The liquid form can be applied through foliar spraying, a bucket, or irrigation canal. In this way the bioslurry can be applied directly to the crops. It can also be applied to the soil as a basal and/or top dressing. If it is applied to standing crops, it must be diluted at different rates, depending upon the biodigester type (see below for table and dilution rates). Otherwise, the high concentration of ammonia and soluble phosphorus in the bioslurry will produce toxic effects on the plant growth and will burn the leaves away[45]. Irrigation has its limitations, because: (1) year-round irrigation is not always available for farmers; (2) when the irrigation is applied from one crop to another the bioslurry can settle in the first plot due to the lowering of the application rate, which results in non-uniform distribution, and; (3) it is difficult to transport[46]. '*Hence, this method is suitable for farmers growing vegetable in the kitchen garden or raising fish in the pond'*[47]. '*Similarly, foliar application of slurry has many beneficial effects on field crops, vegetables and fruits with respect to growth, quality and resistance to the diseases'*[48]. Furthermore, some production systems using liquid bioslurry will require ammonia conversion and/or supplementation for nutrient availability since the liquid form is lower in ammonia and nitrogen[49].

Table 3: Dilution rates for different kinds of biodigesters

Biodigester	Digester feeding	Required additional dilution of slurry for liquid application
Plug flow/tubular	1:3	1:1
Fixed dome / floating drum	1:1	1:3
Solid state	1: +/- 0	1:6

Dried form

Many farmers prefer the dry form of bioslurry as it is easier to transport than the liquid form. However, the dried bioslurry loses part of its nitrogen (particularly ammonium) and therefore the nutrient value of the bioslurry is decreased. Therefore the bioslurry needs to be applied as soon as possible to avoid loss in nutritional value. Due to this, the dried form is the least efficient

35 Ullah et al, 2008.
36 Balasubramanian and Kasturai Bai, 1992.
37 Furukawa and Hasegawa, 2006.
38 Marcato et al., 2009, p. 260.
39 Lansing et al., 2010, p. 1712.
40 SNV, 2011, c.
41 Farmer N. Musisi, 2013.
42 Cavanagh, Gasser and Labrecque, 2011
43 De Groot and Bogdanski, 2013
44 De Groot and Bogdanski, 2013, p. 1.
45 SNV, 2011, c.
46 Centre for Energy Studies, Institute of Engineering, 2001; SNV, 2011, c.
47 Centre for Energy Studies, Institute of Engineering, 2001, p. 89.
48 Karki, 2001, p. 14.
49 Karki, 2001, p. 24.

method of bioslurry application[50]. '*A well-digested BSS {slurry} contains 1.4 – 1.8% N, 1.0 – 2.0% P_2O_5, 0.8-1.2% K_2O and 25-40% organic carbon*'[51]. '*But dried slurry was somewhat inferior to a mixture of ammonium sulphate and single superphosphate containing equivalent quantities of nitrogen and phosphate*'[52, 53]

Box 1: Enthusiast in Kenya!
A farmer in Kenya stated that he takes the slurry out before the anaerobic process has completed, as he is so enthusiastic about the content and its usage for its crop. It shows what slurry can do for a farmer and his household. However, doing this is not recommended because the slurry has to be fully digested before use, and the pressure in the digester from substance to gas and effluent is reduced. This results into lower-quality slurry and low gas pressure.

Composted form

The composted form of bioslurry is the best way to overcome the transportation issue related to liquid bioslurry and the nutrient loss of the dried form[54]. Indeed, '*One part of the slurry will be sufficient to compost about three to four parts of dry plant materials. This results in the increase in the amount of compost on the farm*'[55].

Box 2: Coffee and slurry – a perfect combination
Small-scale coffee producers from Honduras, La Labor Ecological Coffee Cooperative (COCAFELOL), have reported that using biofertiliser generated through a biodigester system implemented by SNV has reduced the impact of the coffee rust disease on their trees.
The coffee rust disease is produced by the Hemileiavastatrix fungus, which attacks the trees' leaves and causes them to fall off. This results in reduced foliage and, consequently, lower coffee production.
Laboratory analyses of the biofertiliser confirmed that it contains elements of high nutritional value, which have increased the plants' resistance to the disease. The use of the biofertiliser has been evaluated on several farms which are members of the COCAFELOL cooperative' (Gallozzi and Ponce, 2013, p. 1).

Furthermore, the water contained in the bioslurry will be absorbed by the dry materials. As such, the manure will become moist and pulverised and can then be easily transported. Additionally, dry materials like litter and kitchen waste can be properly used. And finally, to minimise the loss of nutrients in the compost, it should be taken to the crops only when required and should be mixed with the soil as soon as possible. The composted form can also be used for algae production.[56]

2.6 Values and financial profitability of bioslurry

2.6.1 Nutrient values of bioslurry

Plants need nutrients for their growth and health. Nitrogen is one of the most important nutrients and is needed in large quantities to reach maximum yields, but it has to be in balance with other nutrients (see Figure 6)[57]. Lack of N or excessive application can decrease yield and quality (and can even damage crops)[58]. '*For a high N use efficiency (NUE), it is essential that adequate amounts of N be present during periods of high plant N demand, whereas minimal amounts of N should be present during periods of little N uptake*'[59]. N is generally added through chemical fertilisers.

However, bioslurry has been shown to be a promising alternative to fertilisers (see below). Bioslurry is well known for its plant nutrient availability, and as such can increase crop yields and soil properties significantly. The fresh bioslurry can be low in nutrients while the carbon/nitrogen ratio can be low in sun-dried bioslurry and high in fresh bioslurry[60]. Solid and liquid forms have different nutrient compositions. The nutrient composition of bioslurry varies between studies, and it always depends on the original substrate, the type of digester and the anaerobic process[61]. However, we can state here is that bioslurry is not only rich in mineral and organic dry matter, but also in nutrients like N, P, K, Ca, Mg, Fe, Mn, organic matter, different amino acids and metals like copper and zinc[62]. There seems to be a good match between soil N supply and plant N demand of liquid bioslurry[63].

Compared to chemical fertilisers, bioslurry decomposes with a slow process which is better for nutrient uptake and assimilation for plants[64]. The total N concentration of FYM can be up to 30% lower than in bioslurry[65]. Additionally, '*this organic matter could accelerate the soil nitrification process which will lessen the nitrate*

50 Centre for Energy Studies, Institute of Engineering, 2001; SNV, 2011, c.
51 Debnath et al., 1996, p. 98.
52 Dahiya and Vasudevan, 1985, p. 68.
53 Furthermore, the nutrient composition of slurry in the study of Singh et al (2007) was for C 55, N 0.87, P, 0.65 and K 0.70. The average nutrient composition was 0.8 – 1.5% of nitrogen, 0.5 – 0.75% of phosphate, 0.6- 1.35% of potassium and 31.5 – 45% of total organic carbon in a study of Gnanamani and Kasturi Bai (1991).
54 De Groot and Bogdanski, 2013.
55 Centre for Energy Studies Institute of Engineering, 2001, p. 8-9.
56 Centre for Energy Studies Institute of Engineering, 2001; SNV, 2011, c.
57 Nachurs, 2013.
58 Sánchez and González, 2005, p. 1122.
59 Möller et al, 2008, p. 210.
60 Centre for Energy Studies, Institute of Engineering, 2001; SNV, 2011, c.
61 De Groot and Bogdanski, 2013, p. 19.
62 De Groot and Bogdanski, 2013.
63 Möller and Stinner, 2009, p. 11.
64 Yu, et al, 2009, p. 267.
65 Möller et al, 2008.

Figure 4: Pumpkin in Ethiopia treated with bioslurry

Source: farmer Niguse's farm in Sodo Zuria district, Ethiopia.

accumulation in soil and further decrease NO_3 – N uptake'[66]. Although the solid and liquid forms of bioslurry have different nutrient compositions, they can help to meet the nutrient management aims of farmers worldwide[67]. However, bioslurry, being low in Carbon / anaerobic Nitrogen ratio, will cause quick mineralisation of soil organic matter. So the addition of bioslurry to the soil can cause a loss of organic matter[68]. Nitrogen and potassium levels can be recovered with bioslurry after anaerobic digestion. Ammonia nitrogen can increase by 70% and phosphorous can be reduced by 30% over the influent nutrient content. '*It was also observed that the correlation of nutrients with total solids was greater in the effluent than in the influent*'[69,70]. Pig bioslurry can be rich in Fe and Al, and have smaller quantities of Zn, Cu and Mn. Pb and Mo were found in small amounts[71]. Möller and Stinner[72] conclude that the use of bioslurry results in a win-win situation since it increases energy yield while lowering nitrate leaching risks and nitrous oxide emissions. However, the study also shows that the tendency to ammonia volatilisation was higher with bioslurry compared to the control. In addition, Vallejo et al[73] concludes that the anaerobic digestion and separation can improve the pig bioslurry quality and is therefore an option to mitigate denitrification of the soil and N_2O emissions. In terms of NO fluxes however, no significant effect was observed. It must also be mentioned that '[…] *better synchronisation of crop N demand and N supply on arable land can be achieved from digested slurry only if it is incorporated into the soil immediately after field spreading*'[74].

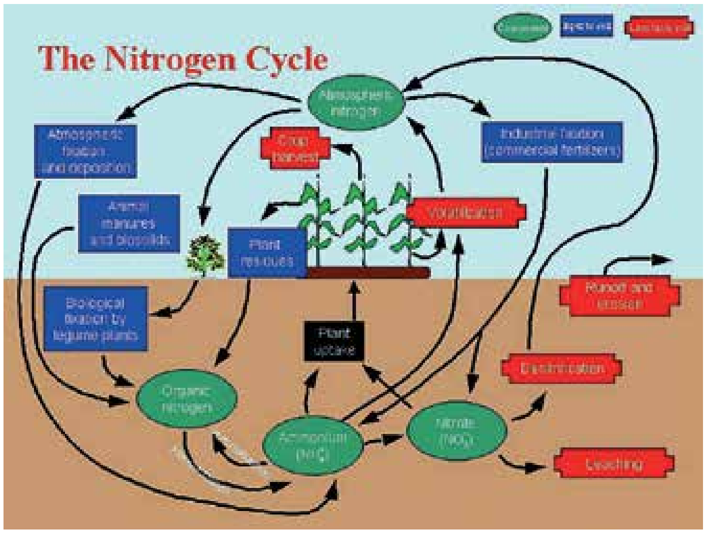

Figure 5: The Nitrogen Cycle

Source: stewartsstruggles2.blogspot.com, 2013.

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66 *Yu, et al, 2009, p. 267.*
67 *Liedl, Bombardiere and Chatfield, 2006.*
68 *Sánchez and González, 2005.*
69 *Balasubramanian and Kasturi Bai, 1992, p. 380.*
70 *This relation of effluent and nutrients is also suggested by Lansang et al (2010).*
71 *Sánchez and González, 2006.*
72 *Moller and Stinner, 2009.*
73 *Vallejo et al., 2006, p. 2792.*
74 *Möller et al., 2008, p. 230.*

Table 4: NPK values of FYM, ordinary compost, fresh & composted bioslurry

Kinds of slurry Manure	Nitrogen %	Phosphorus %	Potash %	Author
Digested slurry	1.5 to 2.0	1.0	1.0	Khandewal et al., 1986
Digested slurry	1.03	0.82	1.07	Gupta 1991
Digested slurry Sun-dried slurry	to 1.8 1.4 to 1.8	0.8 to 1.2 1.1 to 2.0	0.8 to 1.0 0.8 to 1.2	Gupta 1991
Digested slurry	3.6	1.8	3.6	Wim J. van Nes undated
Oven-dried slurry Sun-dried slurry	1.6 to 3.7 0.97 1.0	1.6 to 2.2 0.24 0.23	0.8 to 3.6 0.97 0.84	BSP/SNV, 1995 Gupta 1991 Gupta 1991
Slurry compost	0.57 to 2.23	0.072 to 2.11	0.0 to 5.1	Average value of 100 slurry compost samples analysed by Soil section NARC Khumaltar. 1996
Ordinary compost	0.5 to 1.0	0.1 to 0.3	0.5 to 0.7	Maskey. Dept. Of Agriculture
Farmyard manure (FYM)	0.3 to 0.5	0.1 to 0.2	0.5 to 0.7	Maskey. Dept. Of Agriculture
Biogas effluent Biogas sludge	0.03 to 0.08 0.8 to 1.5	0.02 to 0.06 0.4 to 0.6	0.5 to 0.10 0.6 to 0.12	APRBRTC, 1983: 155
Slurry – Compost Sun-dried slurry Fresh slurry	1.31 3.75 1.73 2.92 0.06 0.87	1.18 3.37 0.69 1.17 0.04 0.58	0.88 2.52 0.68 1.15 0.06 0.87	Wet basis ATC 1997 Dry basis Dry basis
Slurry without toilet attached	0.05 0.87	0.04 0.65	0.07 1.07	Dry basis
Slurry with toilet attached	0.06 0.85	0.04 0.51	0.06 0.83	Dry basis

Source: Gurung (1998).

2.6.2 Chemical fertilisers and FYM vs. bioslurry

Chemical fertilisers can increase the soil's nutrients. However, chemical fertilisers only replenish a small part of those nutrients. Poor management and application of Farmyard Manure (FYM), means that soils are not replenished fully with the necessary nutrients either. Farmers use chemical fertilisers to increase crop production. However, this means that only mineral fertilisers are added to the soil, without organic manure. This decreases soil productivity. If only organic manure is added, the desired crop yield increase may not be achieved either. Sometimes optimum crop yield and soil fertility levels can be achieved through the combination of chemical and organic fertilisers. However, chemical fertilisers are expensive and most small-scale farmers cannot afford them. The high costs involved make it essential for developing countries to find an alternative to chemical fertilisers[75]. '*Nitrate and nitrite contamination in vegetables is produced mainly by overuse of chemical fertilisers besides low light intensity in protected systems*'[76]. Intense and continuous use of such chemical fertilisers creates crops that are susceptible to insect attacks, microbial pathogens and intrusive weeds. The effect of reduced tillage on nitrous oxide (N_2O) may depend on the soil and climatic conditions. '*Since a substantial proportion of the GHGs produced by agriculture are attributable to the production and application of nitrogen fertiliser alone […] breakthroughs in nitrogen use efficiency could substantially mitigate emissions in agriculture*'[77]. Furthermore, over-fertilisation can be problematic since for instance '*high P soil concentrations can lead to significant P losses to drainage waters resulting in eutrophication*'[78]. Additionally, high ammonia emissions due to over-fertilisation with N can create negative environmental effects. These and the other environmental negative effects of chemical fertilisers are a growing, global concern[79]. Furthermore, often the bioslurry combined with chemical fertilisers shows better yields than bioslurry utilisation on its own[80].

75 Daiya and Vasudevan, 1985, p. 71.
76 Liu et al., 2009, p. 302.
77 Lybbert and Sumner, 2010, p. 7.
78 De Groot and Bogdanski, 2013, p. 18.
79 Ejigu, 2010.
80 Extension specialist, 2011.

Table 5: Nutrients available in composted manure, FYM and digested bioslurry

Nutrients	Composted Manure Range | Average	Farmyard Manure Range | Average	Digested Slurry Range | Average
Nitrogen (N)	0.5 to 1.5 | 1	0.5 to 1.0 | 0.8	1.4 to 1.8 | 1.6
P205	0.4 to 0.8 | 0.6	0.5 to 0.8 | 0.7	1.1 to 2.0 | 1.55
K20	0.5 to 1.9 | 1.2	0.5 to 0.8 | 0.7	0.8 to 1.2 | 1.0

Source: SNV, 2011, c, p. 29

Expanding the area or using more effective irrigation practices not only reduces the water usage of agricultural practice, but can also enhance carbon storage in soils through the enhancement of yields and residue return. However, some of this storage may be offset due to the energy used to deliver the water, or through the emission of N_2O due to the higher moisture of the crops and N fertiliser inputs. The drainage in humid regions may increase the yields' productivity and suppress the release of N_2O. Bioslurry can therefore be the solution for this combination of environmental and cost issues involved in the use of chemical fertilisers and N fertilisers. However, it must also be mentioned that '[…] *in wheat, bajra, jawar and mustard, replacement of nitrogenous fertiliser through slurry decreased the yields while higher yields were obtained by replacing the half and total nitrogenous fertiliser in vegetables and fodders respectively'* (fodders: i.e. berseem and guar)[81]. It must also be mentioned that in another study done by Cavanagh et al[82] the conclusion was that the N in bioslurry is two times less efficient than mineral fertilisers, probably because ammonia volatilisation occurs both at the time of spreading and afterwards. However, it was also suggested that nitrate leaching with bioslurry application could be reduced by using lower doses of bioslurry[83].

It is important to mention the difference between sun-dried bioslurry, fresh bioslurry and FYM: they increased the yields of wheat by 53.8, 16.8 and 20% respectively[84]. In addition, '*compared with chemical fertilisers, the biodegradation of organic matter in slurry is a slow process which is better for nutrient assimilation by the plant […]*'[85]. All in all, bioslurry can be used together with chemical fertilisers, although it is here strongly recommended to avoid the use of such fertilisers due to their high cost in both economic and environmental terms (see below).

Frequent bioslurry application on cassava can give higher yields of leaf biomass with high protein contents than manure application. Chau[86] also stated that bioslurry gives higher yields of cassava with higher protein content compared to application of nitrogen from raw pig and cattle manure. However, he concludes that raw manure and the effluent of a biodigester are equally effective in improving soil fertility. '*An average quantity of FYM contains 0.5-1.0% N, 0.15-0.20% P_2O_5, 0.5 – 0.6% K_2O and 12-16% organic carbon on a dry-weight basis*'[87]. This is significantly lower than bioslurry and it is therefore apparent that bioslurry contains higher percentages of nutrients compared to FYM. '*When untreated or poorly managed, animal manure becomes a major source of air and water pollution. Nutrient leaching, mainly nitrogen and phosphorous, ammonia evaporation and pathogen contamination are some of the major threats*'[88]. When treated properly, bioslurry can be a good source which mitigates these threats and pollution. Additionally, a study of SNV indicates that nutrient content of cow dung bioslurry and poultry manure bioslurry was higher in aerobically decomposted bioslurry than in non-decomposted forms[89].

Table 5 shows the nutrients in composted manure, FYM, and digested bioslurry. It shows that the range and average of nutrients in the digested bioslurry is significantly higher than that of composted manure or FYM. Indeed, a Chinese study indicates that bioslurry is of superior quality than FYM[90].

2.6.3 Financial profitability

It must be noted that, although many farmers do not realise the importance and potential of bioslurry, it has numerous advantages and is of great (financial) value for farming and crop yields. The study by the Centre for Energy Studies Institute of Engineering[91] in Nepal concludes that the financial returns of a biogas plant can be calculated (discounted at the interest rate and measuring the outcome over the 10 or 20 years lifetime of the biogas installation) with different biogas digester sizes). The savings made on kerosene and firewood and the quantity of nutrients in the bioslurry increase with the size of the plant, but

Box 3: Remarkable!
Slurry is shown to have strong effects on plant tolerance to diseases (e.g. late blight, potato wilt, cauliflower mosaic virus, etc). Moreover, plants can become cold-resistant. For instance, rice seedlings which are soaked with digested slurry have a high germination rate, grow well and are resistant to diseases. The slurry can also be sold on the market, increasing households' income (Ejigu, 2010; SNV, 2011, c).

81 *Daiya and Vasudevan, 1985, p. 71.*
82 *Cavanagh et al , 2011.*
83 *Cavanagh et al, 2011.*
84 *Daiya and Vasudevan, 1985, p. 68.*
85 *Yu et al, 2010, p. 267.*
86 *Chau , 1998a.*
87 *Debnath et al, 1996, p. 98.*
88 *Holm-Nielsen, Seadi, and Olexkowicz-Popiel, 2009, pp. 5478.*
89 *SNV, 2013.*
90 *SNV, 2011, c.*
91 *Centre for Energy Studies Institute of Engineering, 2001.*

the costs of the installation do not increase at the same rate. Crop productivity can be increased if the bioslurry is applied together with an appropriate dose of chemical fertilisers. However, as we have described above, (N) chemical fertilisers are harmful to the soil, water quality, and global climate system. Fertilisers also affect the soil quality in the long run through the constant loss of humus and micronutrients. Furthermore, the prices of such chemical fertilisers are rising and many farmers find it difficult to use the fertilisers even at low levels (<25kg/ha) as the price is increasing at a higher rate than farm income is increasing. Avoiding high fertiliser prices by using bioslurry increases the profitability of a biogas plant even more[92]. In addition, '*The importance of compost in sequestering carbon in the soil is recognised as one of the means to mitigate and adapt to the challenge of climate change*'[93]. The use of bioslurry is therefore a great innovative and profitable alternative compared to chemical fertilisers. Warnars[94] calculated the break-even point of a biogas plant in Tanzania and states that '*Farmers in Tanzania can increase their crop revenues with an average of 25 per cent by actively using bioslurry as a fertiliser*'[95]. With a plot of arable land of between 0.2 and 2 ha, he concludes that the break-even point of the biogas plant (the payback time of a plant) is less than 22 months. Warnars also calculated the Return on Investment (ROI) for 1, 5, 10, 15 and 20 years. As such, one can conclude that a biogas plant, together with the use of bioslurry, is highly profitable and interesting for small and medium-scale farmers. The bioslurry has more specific benefits than described here[96]. The comprehensive biodigester user survey of 2010 shows that the average family saves US $14 per month on energy, firewood (2200kg/year) and kerosene while over US $50 per year in savings is achieved by replacing chemical fertilisers with bioslurry[97]. In addition 'Considering both its fertiliser value and the increasing cost of chemical fertilisers, the economic value of slurry is beyond doubt'[98].

2.6.4 Carbon and nitrogen emissions

The use of domestic size biogas plants has been proven to have a significant impact on GHG emission reductions, with around 3 to 6 tons of CO_2 equivalent per plant per year. This is due to the replacement of non-renewable biomass, replacement of fossil fuel use and methane emission reductions through manure management. However, neither the N_2O emissions reductions through the replacement of chemical fertilisers with bioslurry are incorporated into this figure, nor the energy necessary for making the chemical fertilisers[99]. Several authors concluded that N_2O and NO emissions increased after application of bioslurry[100]. If we look at the production increase of the crops, we could also suggest that it increases the sequestration rate of carbon dioxide and thus contributes to combatting climate change. Solutions to the problem of N_2O emissions from N fertilisers can have co-benefits for other issues. For instance, the reduction of chemical fertilisers (N) reduces N_2O emissions as well as nutrient leakage into groundwater, thus increasing the water quality. However, the reduction of chemical fertiliser use can reduce yields and crop growth, thus reducing the carbon sink function of crops. But if rice yields and crop growth decrease due to non-fertilisation, CH_4 emissions can be reduced. Interactions are also apparent with the mitigation and adaptation of climate change for agriculture, and these differ in spatial and geographic circumstances. Yet it must be noted that the reduction of emissions from fertilisers is difficult to measure, and it is even more complicated to monitor these emissions. The use of bioslurry instead of FYM could be one of the mitigation strategies for methane emissions in wet rice cultivation and for sustaining crop productivity and soil fertility[101]. However, this is a mere suggestion and further research needs to be done on this topic.

2.7 Risks related to bioslurry

It seems as if bioslurry is good for everything. However, its production and use also carries risks. '*The PH-value of BGS (bioslurry) is usually higher than that of FYM which bears the risk of an elevated release of ammonia. High concentrations of ammonia cause damage to vegetation and lead to acidification and eutrophication of soils*'[102]. In addition, not all pathogens present in the manure are always fully eliminated during the digestion process, and they can therefore cause diseases. This is even more likely when using farmyard manure.

2.8 To summarise and conclude

Bioslurry has many positive effects in addition to being a great source of nutrients, and it can be used for the following applications.

On the positive side:

- As a basal manure and as a foliar application or spray, or together with irrigation water.
- As an insect repellent.
- To increase soil fertility (caution exchange capacity), and improve the soil structure and water holding capacity.
- To decrease soil erosion.
- To treat seeds for higher germination, disease resistance, better yields, improved coloration of fruits and vegetables, and tenderness and taste of leafy vegetables.
- To increase the feed value of fodder with low protein content.

92 *Centre for Energy Studies Institute of Engineering, 2001; SNV, 2011, c.*
93 *Edwards and Ejigu, 2011, p. 3.*
94 *Warnars , 2012.*
95 *Warnars, 2012, p. 76.*
96 *SNV, 2011, c.*
97 *NBP, 2011.*
98 *Sánchez and González, 2004, p. 1117.*
99 *NBP, 2011.*
100 *Vallejo et al., 2006, p, 2783.*
101 *Debnath et al., 1996.*
102 *de Groot and Bogdanski, 2013, p. 22.*

- For concentrated feed for cattle, pigs, and fish, and the production of earth worms and algae.
- For the production of vitamin B12 and amino acids for animal growth. In addition, it contains enzymes which stimulate hunger for more food intake and better nourishment of animals.
- As a means of increasing quality and quantity of organic grown flowers and vegetables.
- To increase the availability of nutrients for soil micro-flora like nitrogen fixing and phosphor solubilising organisms.
- To reduce the use of phosphate, a non-renewable source which is being depleted globally.
- To reduce wastewater, water pollution, greenhouse gas emissions and noxious odours.
- To reduce weed growth and to diminish attractiveness to insects or flies.

On the negative side

- Bioslurry reduces pathogens in the anaerobic environment through sanitation and as such, it is almost pathogen-free. Although it does not always kill all pathogens, nematodes or viruses[103], the occurrence of these is much lower compared to FYM. For this reason, if applied to fruits and vegetables that are to be consumed fresh, they should always be carefully washed and cleaned before consumption.
- Bioslurry use can increase release of N_20 and ammonia.

2.9 What's next?

The following chapters contain specific descriptions of crops, research results of bioslurry application on the crops and the incremental yields of the bioslurry. This research is mainly based on a literature study of different sources regarding bioslurry application. There is also a lot of anecdotal evidence on crops which have not yet been the subject of much research. This evidence was gathered through a short questionnaire sent to the bioslurry extension officers of the African Biogas Partnership Program, the Indonesian Domestic Biogas Program, a consultant of the National Domestic Biogas Program Cambodia, SNV, and ISD.

103 Centre for Energy Studies Institute of Engineering, 2001; De Groot and Bogdanski, 2013, p. 14; Extension specialist, 2011; Gurung, 1997; Gurung, 1998; Holm-Nielsen, Seadi and Oleskowicz-Popiel, 2009; Lansing et al, 2010; Shahabz, 2011; SNV, 2011, c; Vu et al., 2007; Yu et al., 2010.

3 BASIC STAPLES

3.1 Banana

Banana is a common name for an edible fruit produced in the lower hemisphere of the planet. It can vary in size, colour and firmness, but is generally elongated and curved, with soft flesh rich in starch covered with a rind (yellow, purple or red). There are bananas which can be eaten raw, but also cooked (baked banana). The fruit is a great source of vitamin B6, soluble fibre, vitamin C, manganese, and potassium. It is good for reducing the risk of cancers and can have an anti-laxative effect[104].

> ***Box 4: Banana in Uganda***
>
> *Nooh Musisi from Uganda used both liquid and composted slurry for banana crops during the two rainy seasons in Uganda. Musisi used jerrycans to transport the slurry to the plants and used one jerrycan (20 litres) per plant twice a year. Liquid bioslurry can be composted in a pit dug between the banana plants. The pits are in the middle of four banana plants which are spaced 10 ft from each other. The increase in growth was significant at 20 to 30%. Next to the general additional values of harvesting one or more crops, cost savings, savings on chemical fertilizers, and drought resistance, the plant also showed more resistance to diseases such as Banana Bacterial Wilt and insect pests like banana weevils were controlled.*
>
> *Sources: Survey results, 2013*

Bioslurry application can increase the yield and size of banana significantly[105]. For instance, banana plants show an increase of yield of 4.69% compared to an untreated plot. Furthermore, a local resident of Lentae Kebele in Arbaminch in Ethiopia, Terefe Mekuriya, states that the application of bioslurry showed significant results in making the banana plant green within less time than general compost. Banana leaves can also be used to protect the bioslurry compost from rain and evaporation[106]. Farmer Godfrey from Tanzania[107] used wet slurry throughout the year to improve the existing land and crops with irrigation canals. The farmer divided the land into four portions and treated each with the slurry every two months. The slurry is applied around the stem of the banana plant, making a hole of one foot deep and at a distance from the banana stem of two feet, allowing the slurry to fill the hole. The hole is then covered by topsoil. The soil content changes with the use of slurry, and its composition is improved. On a loamy soil, the yield of banana can increase by 20 to 30%. The crop is more resistant to drought and diseases like BBW (Banana Bacterial Wilt)[108]. In one case, red worms/weevil were affecting the plants significantly before the slurry was used, but with the slurry, this effect decreased[109]. Due to the increase in yields, the likelihood of selling the crops on the market also increases. Taking into account the data in Box 4 above, we suggest to use 20 litres of slurry per plant per season.

Figure 6: Banana and slurry

Source: Farmer Godfrey, Tanzania, survey results, 2013.

104 Wikipedia, 2013.
105 Beyene, 2011.
106 Beyene, 2011; Gurung, 1997).
107 Survey results, 2013.
108 Farmer Musisi, Uganda, survey results, 2013.
109 Farmer Godfrey, Tanzania, survey results, 2013.

Figure 7: Barley
Source: Øyvind Holmstad.

3.2 Barley

Barley is a member of the grass family and is a major cereal grain widely used all over the globe. It is used for animal fodder, as a source for brewing beer and other distilled beverages, and also as a component of various health foods. It is used for soups and stews as well as for baking bread[110].

With barley, liquid bioslurry from a plug and flow digester can be applied every seven and 15 days at a 75% (25% water) and 100% concentration. With plots of 25m², this can be repeated three times. This can increase the heights of the plants by up to 54%[111]. Slurry also leads to N transfer into the barley's above-ground biomass[112]. Applying around 10 to 20 t/ha onto the crop is suggested.

3.3 Cassava

Cassava, also referred to as yuca, mogo, manioc, mandioca, and kamoteng kahoy, is a woody shrub species originating from South America. The crop is healthy and used widely in developing countries, For instance Nigeria is the largest producer of the crop. It is a good source of carbohydrates, but low in protein. Some varieties contain anti-nutrition factors and toxins and must therefore be properly prepared before eating[113].

'*The major production problem for cassava is soil erosion, which has resulted in soil degradation and declining soil fertility*'[114]. Frequent slurry application on cassava can give higher yields of leaf biomass with high protein contents than manure application does. Chau[115] also stated that slurry gives higher yields of cassava leaf biomass with higher protein content than does the application of nitrogen from raw manure. They planted cassava stem cuttings in rows with a distance of 50cm between rows and plants. Applying between 10 and 40 t/ha of slurry to the crop is suggested.

3.4 Maize / Corn

Maize is one of the best known basic food crops, used for different purposes worldwide: for cooking as well as biofuel. The sugar-rich species are referred to as sweetcorn (see 'Vegetables'). Maize is the most widely-harvested crop in the Americas, with 332 million metric tons annually in the US alone. Additionally, around 40% of the crop (130 million tons) is used as a biofuel[116]. Genetically modified corn made up 85% of the corn in the US in 2009. The crop contains numerous nutritional substances: from fat to vitamin C and from iron to zinc.

With 10 t/ha of bioslurry application, maize yields increase. The combination of liquid slurry and chemical fertilisers enhances the

110 Wikipedia, 2013.
111 Gutierrez, 2012.
112 Terhoeven – Urselmans et al., 2009.
113 Wikipedia, 2013.
114 Chau, 1998a, p. 2.
115 Chau, 1998a.
116 Wikipedia, 2013.

carbon nitrogen transformation on the crop and increases the yield by 37.8%, compared to 16.8% and 9.4% for treatment with chemical fertiliser[117]. Another study shows increase in yield by an average of 40%, which is a better result than with FYM[118]. Some other studies show other increments, but all show a significant increase with bioslurry use, more than with farmyard manure. The effect of bioslurry concentration depends on the absorption rate of the crop at the time of application. Dhussa[119] states that the yield of corn can increase by 7% and SNV[120] shows it can increase by 8.9%. Combining with fertilisers can increase the yield even more. Other research shows that an application of 12 t/ha can increase the yield and nutritional value of maize more than 10 t/ha or 14 t/ha of cattle manure application[121]. '*Maize plant height and stem circumference were significantly influenced by increasing the rate of biogas slurry 14, 28, 42, and 56 days after sowing*'[122]. The number of leaves does not increase significantly, but the leaf area can differ with different treatment application numbers. The highest maize fodder biomass yield can be observed with 54.12 t/ha-1 of bioslurry[123].

Application of slurry compost at 10 t/ha resulted in the highest yield increment of 23% compared to the control[124]. Another study concluded that corn yields can increase more than raw manure when treated with slurry[125]. The application of digested slurry with ammonium bicarbonate (chemical fertiliser) can increase the maize yield by 37.6% compared to FYM application. The use of slurry reduces costs, as chemical fertilisers are no longer necessary and crop production increases. Due to the results of the different studies and taking into account environmental effects and costs of chemical fertilisers, using around 10 to 15 t/ha of bioslurry is suggested, starting fertilising after ploughing and three to four weeks before planting. Once the sprouts are above ground bioslury application shoud be done solely by spreading it onto the roots of the plant at noon while mixing it with the soil[126].

Table 6: Comparison of the effects of effluent and FYM on the yield of rice, maize, wheat, and cotton

Crop	Yields: kg / ha		Incremental yield	
	Digester	FYM	KG	%
Rice	634.4	597.5	38.9	6.5
Maize	555.9	510.4	45.5	8.9
Wheat	450.0	390.5	59.5	15.2
Cotton	154.5	133.5	21.5	15.7

Source: Gurung, 1997, p. 26

Table 7: Effect of slurry on the yield of different crops in India

Crop	No. of demonstration	% increase in yield over control plot
Rice	8	28.87 (Average)
Tomato	2	70.5 (Average)
Chillies	1	0
Brinjal	1	74.00
Bajra	1	33.00
Maize	2	56.75 (Average)
Cabbage	1	20.00
Potato	1	34.74
Black Gram	1	67.00
Groundnut	1	24.00

Source: Gurung, 1997, p. 29.

Table 8: Summary of results of slurry demonstrations conducted by concerned state departments/agencies in India (1984/85 to 1990/91).

Crop	No. of demonstration	Overall average of % increase in crop yield in slurry treated plot over untreated plot
Paddy	88	31.95
Wheat	127	24.69
Maize	14	40.46
Millet	4	40.46
Turmeric	1	27.05
Potato	5	30.85
Chillies	2	24.25
Tomato	3	126.10
Groundnut	8	23.99
Banana	3	4.69
Brinjal	4	103.23
Sugar cane	2	6.29

Source: Gurung, 1997, p. 30-31

117 *Gurung, 1997.*
118 *Gurung, 1997; Gurung, 1998.*
119 *In; Shahabz, 2011.*
120 *SNV, 2011, c.*
121 *Rahman et al, 2008.*
122 *Shahabz, 2011, p. 28.*
123 *Shahabz, 2011, p. 28.*
124 *Karki, 2001, p. 9.*
125 *Lansing, 2010.*
126 *Karki, 2001; Gurung, 1997; Islam et al., 2009; Shahabz, 2011; SNV, 2011, c.*

Table 9: Effect of biogas slurry on pod/cob size, plant height and yield of pea, okra, soybean and maize

S.N.	Crop	Treatment	Average length of pod/cob (cm)	Average plant height (cm)	Yield (q/ha)
1	Pea	T1	8,58	73.10	88.60
		T2	8.83	74.85	105.6
		T3	9.25	76.92	125.6
		T4	8.10	72.26	76.80
		CD. (5%)	----	-------	12.68
2	Okra	T1	8.68	73.34	105.78
		T2	9.45	75.13	114.54
		T3	11.27	78.81	130.10
		T4	8.36	72.56	86.74
		CD. (5%)	-------	------	8.03
3	Soybean	T1	4.15	88.43	22.00
		T2	4.50	96.26	26.00
		T3	5.00	98.43	29.60
		T4	4.10	68.03	20.40
		CD. (5%)	------	----	3.70
4	Maize	T1	18.14	160.58	19.10
		T2	19.86	165.12	22.42
		T3	21.46	176.51 1	29.17
		T4	18.05	59.54	18.80
		CD. (5%)	----	----	2.45

Source: Gurung, 1997, p. 39

Table 10: Effect of biogas manure on crop yield in Egypt

Crops	Yield increase (%)
Cotton	27.50
Wheat	12.50
Rice	5.90
Broad bean	6.60
Spinach	20.60
Carrot	14.40
Maize	35.70

Source: Gurung, 1997, p. 44

3.5 Finger and pearl millet

Millet is a group of grasses, internationally grown as a cereal crop and used as human food as well as fodder. The best-known of these crops is pearl millet (or bajra), from India and parts of Africa. Protein and fats are commonly found in the crop. It is not only enriched with iron and phosphorous but also with vitamin B, calcium, iron, potassium, magnesium, and zinc. Millets contain no gluten and can be used to make flatbread[127]. Bioslurry can have a significant positive effect on finger millet. The average number of tillers (from 12 to 20 per plant, with a maximum of 32) shows an increase of the number of grains from 30 to 98 per head and yield from 24 t/ha to 36 t/ha with compost. When pearl millet is treated with bioslurry it can report yield increases of around 40%[128]. Crop performance increases and straws are thick, and it grows fast. However, yields are also found to be reduced when treated with slurry instead of chemical fertiliser N[129]. Using an application rate of 6 to 20 t/ha onto the roots is suggested in order to achieve the best results and, if possible, add Nitrogen as well.

3.6 Potato

Potato is a tuberous crop originally from the Andes of South America. It is the world's fourth-largest food crop, after rice, wheat, and maize. The crop contains essential vitamins and minerals: vitamin C and B6, potassium, iron, and zinc. The crop's resistant starch provides bulk, offering protection against colon cancer and improving glucose tolerance and insulin sensitivity[130].

Bioslurry application at 10 t/ha for potato shows better yields than FYM[131]. Slurry can be a good substitute for pre-composted manures when fertilising potato crops[132]. The quality and size also increase when slurry is used. In the table below, the application of slurry shows a 34.75% increase in potato yield compared to the control plot. Farmyard manure contributes to a 25.33% increase in yield compared to the control plot[133]. A study by Garfí[134] concludes that potato yields treated with guinea pig manure increased by 27.5% and the forage yields increased by 1.4% compared to the control. Islam[135] showed that the application of 2 tons of slurry together with 20kg N/ha can harvest 20 tons of seed potato plus 5 tons of table potato. The yield is also higher than crops treated with chemical fertilisers. Using 10 t/ha of bioslurry for potato crops is suggested, without any chemical fertilisers, due to the associated environmental and economic cost.

3.7 Rice and paddy

Rice is one of the other major cereal grains, most widely used as a staple food. It is the second-most-consumed crop after maize. With regards to nutrition, the crop varies due to a number of factors. Generally, rice is very important for human nutrition and calorie intake: it accounts for more than one-fifth of the total calories consumption worldwide. It is an annual plant and well-suited to countries with low labour costs and high rainfall, as the crop needs to be wet in order to grow[136]. However, the crop also has a downside: wet rice cultivation releases methane gas into the atmosphere, contributing to global climate change.

Rice yields can increase by 7% when slurry is applied. Combining

127 Wikipedia, 2013.

128 Gurung, 1997; Shahabz, 2011.
129 Dahiya and Vasudevan, 1985, p. 71.
130 Wikipedia, 2013.
131 Gurung, 1998.
132 De Groot and Bogdanski, 2013, p. 8.
133 Gurung, 1997.
134 Garfí, 2011.
135 Islam, 2001.
136 Wikipedia, 2013.

the slurry with fertilisers and nutrients such as zinc sulphate increases the yield of rice significantly. The rice yields can increase even more when treated with compost, N, P and K. Shahabz[137] states that applying a rate of 10 to 20 t/ha to rice can be beneficial to the crop. '*Grain and straw yields of rice were significantly higher in treatments that received compost application with N, P and K than in no compost with NPK treatments, thereby highlighting the beneficial effects of compost to increase the crop yield*'[138]. With the use of slurry, late and early rice yields can increase to 44.3 and 31%. If the slurry is combined with ammonium bicarbonate, the rice yields can increase to 12.1%[139]. Gnanamani and Kasturi Bai[140] found a yield increase of 15 g/pot at a 40 t/ha application rate, while 10 t/ha of slurry produced only 7.75 g/pot. Treatment with 40 t/ha of slurry alone increased the yield by 23%. Furthermore, they found that a treatment of 40 t/ha plus the recommended amount of NPK increases the yields by around 51%. The dry matter can increase by 70, 80.5 and 80.1% compared to the control with slurry application rate of 40 t/ha, 40 t/ha + NPK and 40 t/ha + N respectively[141]. Another study showed that rice yields increase by 23% compared to synthetic fertiliser application.

In Indonesia[142], rice paddies were treated with liquid bioslurry on a loamy soil type. When the crops are grown, the slurry is applied by spraying around the base and a little on the leaves. The treatment is executed eight times during the growing stage using 240-250 ml per crop. The rice yield without the slurry treatment was 1400kg/300m². With a 5kg treatment of urea, ZA 10kg, TSP 10kg, KCl 10kg and NPK "PHONSKA" 10kg together with the spraying of slurry eight times during the growing season, the yields increased up to 2000kg/300m². After this period, farmer Darto used 100% liquid slurry as a fertiliser. He saw production cost savings and increased revenue due to higher yields. He also saved 100% chemical fertilisers due to the benefits of slurry. With it, the leaves performance was good and greener in colour than before and the plant was more resistant to pests and diseases[143]. The rice also became fluffier and longer-lasting. '[…]CME[144] *can replace N top dressing of chemical fertiliser to paddy rice*'[145].
The use of bioslurry instead of FYM could be one of the mitigation strategies for methane emissions in wet rice cultivation and for sustaining crop productivity and soil fertility[146]. Due to the significant effect of slurry application on the crop, applying at least 40 t/ha is suggested and, if possible (when the financial situation allows), apply the recommended dose of NPK.

137 *Shahabz, 2011.*
138 *Shahabz, 2011, p. 32.*
139 *SNV, 2011, c.*
140 *Gnanamani and Kasturi Bai, 1991.*
141 *Gnanamani and Kasturi Bai, 1991.*
142 *Farmer Darto, Indonesia, survey results, 2013.*
143 *Farmer Darto, Indonesia, survey results, 2013.*
144 *Cattle Manure Effluent.*
145 *Furukawa and Hasegawa, 2006, p. 1939.*
146 *Debnath et al., 1996.*

Table 11: Mean yield of rice (grain) and berseem (dry fodder)

Treatment	Average of first three years (yield: g/pot)		Average of next two years (yield: g/pot)	
	Rice	Berseem	Rice	Berseem
Wet Slurry Dried	20.4	18.4	11.8	14.4
Slurry Farmyard	24.4	23.1	12.9	15.0
Manure	21.9	22.8	11.7	14.2

Source: Gurung, 1997, p. 22

3.8 Sorghum / Jawar

Sorghum is a grass species, native to the tropical and subtropical areas of all continents as well as the Pacific and Australasia. It is a nutritious crop containing calcium, phosphorous and iron[147].

It seems to be better to treat sorghum with slurry and added nutrients rather than slurry alone[148]. However, according to Dahyia and Vasudevan[149], higher yields of jawar can be obtained when whole N is supplied through chemical fertilisers. However, due to the environmental and economic costs, using slurry alone at a rate of 15 to 25 t/ha is suggested.

3.9 Teff

Teff is an annual grass, sometimes referred to as 'love grass', native to the Ethiopian Highlands in Northeast Africa. It accounts for a quarter of the total cereal production in Ethiopia. It is a good source of amino acids and contains many important nutrients, including calcium, copper, zinc, boron, barium and proteins[150].

Compost combined with chemical fertilisers gave the best yields with row planting. Compost alone showed better results in broadcast plots. The average number of tillers for teff increase ranges from 9 to 75 per plant (max. 120), spike length from 25 to 57.5cm (max. 80cm) and the yield from 12 q/ha to 25 q/ha for compost and 30 q/ha when treated with chemical fertiliser[151]. Other farmers used around 5 t/ha. The use of bioslurry increases the greening of the leaves, resistance against moisture stress and shot fly insect attacks. The use of bioslurry also saves on the cost of chemical fertilisers. With these figures and the survey results in mind, applying around 5 to 25 t/ha of bioslurry, a week or two before the planting, is suggested. Using broadcast planting and row planting to increase the yields is also recommended.

3.10 Wheat

Wheat is a cereal grain which is cultivated worldwide. In 2013 world production of the crop was 651 million tons, making it

147 *Wikipedia, 2013.*
148 *Karki, 2001.*
149 *Dahyia and Vasudevan, 1985.*
150 *Wikipedia, 2013*
151 *ISD annual report, 2010.*

Figure 8: Sorghum
Source: USDA/Larry Rana

the third-most-produced crop after maize and rice. It is the leading source of vegetable protein and can be used for different kinds of products such as pasta, bread, cereal, biscuits, and beer. It is also used as a biofuel. It is a rich source of vitamins, minerals and proteins[152].

According to Dahiya and Vasudevan[153], higher yields can be obtained of wheat when whole N is supplied through chemical fertilisers. Despite this, use slurry as a fertiliser for wheat is suggested here, due to the arguments stated in the general manual document. When slurry is applied on wheat, the average yield can increase by 15 to 24% compared to a control plot[154]. Additionally, spraying digested slurry on the crop can control the red spider and aphids which attack wheat. The average number of tillers per plant increased from 5 to 22 (max. 30), the number of grains per spike from 26 to 65 (max. 80) and spike length from 5.5cm to 7.5cm (max. 10cm)[155]. It is important to mention the difference between sun-dried slurry, fresh slurry and FYM: they increased the yields of wheat by 53.8, 16.8 and 20% respectively[156]. Using 15 t/ha of wet slurry onto the roots of the plant a week before planting of the crop is suggested, and it should be mixed with the soil before sun exposure. From the survey sent to extension specialists, it was found that the use of bioslurry could also increase the soil fertility for the next cropping season.

Table 12: Effect of biogas slurry (dry and fresh on wheat yield)

Treatments	Grain yield in kg/ha	Increment over control kg/ha
Control	1288	----
Biogas slurry (dry)	1450	162
Biogas slurry (wet)	1842	554
50% dry slurry + 50% chemical Fertiliser	2706	1418
75% dry slurry + 25% chemical fertiliser	1744	456
Chemical fertiliser	3503	2215

Source: Gurung, 1997, p. 22

152 *Wikipedia, 2013.*
153 *Dahiya and Vasudevan, 1985.*
154 *Gurung, 1997; Shahabz, 2011; SNV, 2011, c.*
155 *Gurung, 1997.*
156 *Dahiya and Vasudevan, 1985, p. 68.*

4 VEGETABLES

4.1 Introduction

Biogas contains readily-available nutrients, amino acids and bioactive substances which meet the needs of vegetable growth. Nitrate content can be decreased significantly when bioslurry is applied[157]. With it, bioslurry can enhance the yields of vegetables substantially. This has been shown with all the vegetables described below. There was little or no information available on other vegetables, but in general applying apply around 10 to 20 t/ha of bioslurry onto the crop can be recommended in order to significantly increase the yield and nutrient uptake of plants.

4.2 Alfalfa

Alfalfa is the name of a sprout vegetable and it is used in various different dishes as well as in sandwiches. Alfalfa looks like a mini bean shoot and is very healthy as it contains proteins, vitamins (C, D and E) and minerals[158].

Bioslurry based on cow dung can be applied to the crop. In a study, bioslurry, a plug and flow digester was used with manure and water content rate of 1:3. The slurry was diluted at a rate of 1:3. With this, at high altitudes (3000-4500m), it is best to apply the liquid slurry through irrigation at a rate of 100 litres three times during its growth cycle, on plots of 25cm separation. This increases the height of the plant by 1.10% while the leaf area increases by 1.30%. In the lower valleys (1500-3000m), it is best to apply 50 litres, three times during its growth cycle, on plots of 25cm separation. This increases the height by 1.27% and the leaf area by 1.15%. Foliar spraying can also be used to increase the crop's yields and height. At high altitudes this can be done with a foliar application rate of 10 litres of slurry mixed with 10 litres of water (50%). This increased the height by 1.07% and the area by 1.22%. In the lower valleys, the application of 5 litres mixed with 15 litres of water can increase the height by 1% and the leaf area by 1.14%[159].

4.3 Cabbage

Cabbage is a leafy green vegetable grown around the world as an annual. There are different cabbage species (red, white, and green) and the heads generally range from 0.5 to 4kg. Cabbage is a good source of beta-carotene, vitamin C and fibre. However, the vegetable is also sensitive to diseases, pests and bacteria. When it is contaminated, it can even be a source of food-borne illnesses[160].

The yield of cabbage increases by 18% when liquid bioslurry is applied[161]. The liquid form produces 6.6% higher yields than FYM. Furthermore, slurry in compost form produced around 11% higher yields than liquid slurry. Cabbage size also increases when slurry is used. As shown in the table below, when cabbage is treated with slurry, the yield increases to 56.50 ton/ha. Treatment of 16 ton/ha of compost and 250kg urea-Nitrogen appears to be a better combination for the growth of cabbage. Zou[162] concludes bioslurry application with 120kg per unit area, 0.6kg chemical fertiliser and 75kg slurry as top dressing increases the yield and vitamin C content of the crop by 16.06% and 16.21%. It also decreases the content of nitrate, cadmium, palladium and chrome in the vegetables. The soil pH value and organic matter content also increases. Additionally, cabbage yield can increase with an application rate of 250ml slurry as nutrient liquid fertiliser, mixed with 3 grams of urea, 2 grams of magnesium sulphate and 2 millilitres of trace element[163]. Karki[164] states that the highest yield of cabbage (68.6 t/ha) is produced with an application of the full recommended dose of fertilisers together with 20 t/ha of slurry compost. The second-highest yield was reached with just a slurry compost treatment at 20 t/ha. Zhu also found that slurry increases the yield of Chinese cabbage[165]. There is hardly any difference between liquid slurry and chemical fertiliser. However, due to the costs of fertilisers and their negative environmental effects, applying 20 t/ha of slurry compost to cabbage is suggested[166]. The slurry can be used before the crops are planted.

157 *Li, Yang and Du., 2009.*
158 *Happy seeds, 2013.*
159 *Silvestre and Martí-Herrero, 2010; Perez, Ramirez, and Martí-Herrero, 2010.*

160 *Wikipedia, 2013.*
161 *Karki, 2001.*
162 *In: Shahabz, 2011.*
163 *Shahabz, 2011.*
164 *Karki , 2001.*
165 *Liu et al., 2009.*
166 *Karki, 2001.*

Table 13: Effect of bioslurry on cabbage, brinjal and tomato yields

Treatments	Cabbage (t/ha)	Brinjal (t/ha)	Tomato (t/ha)
Control (native fertility)	10.00	5.50	6.50
100% RD	56.50	26.30	24.00
50% RD + CD bioslurry	58.60	24.00	25.00
50% RD + PL bioslurry	60.00	25.00	27.00
10% RD + CD bioslurry	44.00	15.00	16.00
10% RD + PL bioslurry	48.00	17.00	18.50

CD – cow dung, PL = poultry slurry.
Recommended dose for cabbage = N_{200} P_{60} K_{120} S_{30} kg/ha.
Recommended dose for brinjal – N_{150} P_{60} K_{120} S_{30} kg/ha.
Recommended dose for tomato – N_{150} P_{60} K_{120} S_{30} kg/ha.

Source: Islam, 2006, p. 9

Table 14: Cabbage yield (t/ha) as affected by integrated nutrient management system during the Rabi season of 2000/01 and 2001/02

Treatments	2000/01	2001/02
100% RD	67.36	61.82
70% RD	52.86	45.2
70% RD + cow dung (5 t/ha)	60.44	57.22
70% RD + cow dung (10 t/ha)	70.76	65.56
70% RD + poultry manure (5 t/ha)	73.32	74.86
70% RD + poultry manure (10 t/ha)	81.28	81.80
7-% RD + oil cake (2.5 t/ha)	84.88	84.62
70% RD + oil cake (5 t/ha)	87.25	86.94
Native fertility (Control)	22.14	19.74
CV (%)	5.6	6.4

RD = Recommended dose – N_{250} P_{36} K_{80} S_{40} B_2 Mo_1 kg/ha

Source: Islam, 2006, p. 12

4.4 Carrot

Carrot is a root vegetable. The most common colour is orange but carrots can also be purple, red, white or yellow. Normally the root is eaten, but the green leaves are also edible. Carrots contain beta-carotene and are well-known for their effects in improving eyesight[167]. As such, carrot is an important crop for a nutritious and healthy diet.

The yield, growth, and quality of carrots can increase significantly when the crop is treated with bioslurry. The application of 7.8 t/ha increases the yield by 8.8% in one season and by 23.5% in the following season. Leaf numbers, height, dry weights of shoot and roots, and root volume can also increase. As such, '*The study recommends 7.8 t/ha of bio-slurry manure for enhanced yield and quality of carrot*'[168].

Box 5: Sweetcorn in East Java, Indonesia
Farmer Sulton in East Java, Indonesia uses 0.25kg dry bioslurry per sweetcorn crop on a loamy soil. He applies it before planting the crops, pouring it manually onto the roots of the crops, and thereafter covers it with soil and ploughs it. He uses the slurry once in each crop season (every 3 months). He also uses wet bioslurry mixed with water (1:1), spraying it onto the plant using nearly 100 ml per plant. When the plants are a month old he starts using the wet bioslurry, spraying it onto the plant using 200ml once a week until harvest. He says the crop yields increase by around 40% compared to the use of chemical fertilizers alone. This means that he saves up to 100% of chemical fertilizer use, reducing his costs as well.
Sources: Survey results, 2013

Sources: Survey results, 2013

4.5 Chillies

Chillies are well-known worldwide and can be green, red, or yellow. Different species and sizes are available year-round. They can be eaten raw as well as boiled, fried, or baked. They are good sources of copper, fibre, iron, magnesium, manganese, niacin, potassium, protein, riboflavin, thiamine and vitamins A, B6, C, E, and K[169].
Bioslurry can increase the yield of chillies, though not significantly. It does stimulate plant growth and the general bulk of the vegetative parts of the crop[170]. Applying 10 t/ha onto the crop is suggested.

4.6 Sweetcorn

Sweetcorn has a high sugar content, the result of a recessive mutation in the genes controlling the conversion of sugar to starch inside the endosperm of the maize kernel. The vegetable is picked when it is still immature and can be prepared and eaten as a normal vegetable. Sweetcorn is susceptible to

Box 6: Mrs. Florence Mable Gogo grows Mushrooms
Gogo, from the Busamaga, Mbale district, Uganda, grows oyster mushrooms using slurry as a fertilizer. The slurry is applied during the growing season, year round, depending on the availability of spawns/mushroom seeds (which perform best during the cold season). Gogo uses the compost slurry as part of the substrate while growing mushrooms and manually mixes the composted bio-slurry with the substrate (cotton seed husk). Mushrooms are also grown on the substrate mixture. The incremental yield is around 30%! The mushrooms also show an increase in resistance to fungal pests and have a longer harvesting period (increased by six weeks).

Sources: Survey results, 2013

167 Wikipedia, 2013.
168 Jeptoo, Aguyoh, and Saidi, 2012, p.1.
169 Wikipedia, 2013.
170 Gurung, 2007.

deterioration so it must be eaten quickly after harvesting. When cooked, the crop has anti-cancer properties[171].

The growth of sweetcorn seedlings is strengthened significantly when they are treated with bioslurry (15.71% dry weight root increase and 6.37% seedling increase). Also the sugar/acid and solid acid increased significantly when bioslurry was applied. The iron and calcium contents decreased, but phosphorus, magnesium and manganese increased[172]. Diluted poultry slurry (DPS) has a positive impact on sweetcorn if no fertilisers are used. DPS has further potential for supplementing or replacing commercial fertilisers with sweetcorn, especially during the summer when the combination of chemical fertilisers (25%) and DPS of 70 m^3/ha has significantly higher results than the standard slurry application[173]. The researchers planted the sweetcorn 30cm apart in plots with four or six rows spaced 45cm apart. *'Plots were 90cm apart, and yield data were collected only from 5 m of the two inside rows in each plot'*[174]. Slurry application rates of 0, 23, 47, and 70 m^3/ha were used. '[…] one implication is that 70 m^3/ha of DPS exceeded the corn's requirements of nutrients[175]'. With these results in mind, we suggest applying the slurry before planting the crops, using a cropping system as described above and with 0.25kg and/or to a maximum 70m^3/ha of slurry application per crop[176].

4.7 Cucumber

Cucumber is a widely-cultivated vegetable with three varieties: slicing, pickling, and burpless. The crop is originally from India but is now grown internationally (Wikipedia, 2013). The crop contains antioxidants (carotene), vitamins (A, B, C, and K), potassium, magnesium and other nutrients[177].

Cucumber productivity increases by 50% over control with a slurry application of 15 t/ha. More than 15 t/ha had a smaller cucumber yield increase. Resistance to wilt disease can also increase with slurry application[178]. The survival rate can increase, and the fruit is of better quality. The crops can also become more resistant to pests and diseases and the soils become crumbly. Swine slurry has been found to be a good source of nutrients for water cucumber, compared to chemical fertilisers[179]. Treating cucumber with 15 t/ha is suggested. The slurry can be applied before the crops are planted[180].

4.8 Eggplant / brinjal

Eggplant, or brinjal, is a common vegetable worldwide. It is mostly fried and boiled. Frying brings out the soft, sweet taste nicely. The crop contains numerous nutritional values such as sugars, fat, protein, vitamins C and B6, calcium, iron, magnesium, manganese, phosphorus, potassium, and zinc[181].

Eggplant can be treated with slurry at a rate of 10 t/ha to increase the yields significantly (by around 40%) and it gives better results than FYM[182]. Using a 10 t/ha slurry application is suggested for growing eggplant.

4.9 Kohlrabi

Kohlrabi is a perennial vegetable which can be eaten raw or cooked. The vegetable is prone to a higher risk of nitrate accumulation in tissues[183].
When treated with slurry, kohlrabi had a lower nitrate concentration content than usual. The crop also showed better yields and quality than when mineral fertilisers were applied. The treated plot showed comparable rates of nutrients of N, P, K and Mg to mineral fertilisers[184]. Applying 10 to 20 t/ha of bioslurry for increased yields and a decrease in chemical fertiliser use is suggested.

4.10 Komatsuna

Komatsuna is a Japanese mustard spinach. It is used as fodder in many Asian countries, and can be eaten at any stage of growth. It is usually grown in spring and autumn due to its low tolerance for heat and cold[185].
Studies of the N uptake of komatsuna with Kitchen Garbage Effluent concluded that the crop grows similarly to when N fertiliser is applied[186]. Applying between 10 and 20 t/ha to the crop is suggested here to achieve increased yields and nutrient uptake.

4.11 Lettuce

Lettuce is an annual plant which is often used as a leaf vegetable, but sometimes the stem and seeds are used as well. The crop is easily cultivated, but requires low temperatures to prevent it flowering quickly. It is generally used for salads, soups, sandwiches, and wraps. The crop is a good source of vitamin A, vitamin K, calcium, iron, copper, potassium, and other vitamins and nutrients. It also contains some dietary fibre (concentrated in the spine and ribs), carbohydrates, protein, and a small amount of fat[187].

Lettuce crops treated with organic fertilisers grow better than untreated lettuce crops[188]. Research has also showed that treated soils have lower pH values and increased levels of organic matter, primary nutrients, soluble salts, and heavy

171 Wikipedia, 2013.
172 Shahabz, 2011.
173 Nakamoto, Lueng and Wanitprapha, 1993.
174 Nakamoto, Lueng and Wanitprapha, 1993, p. 26.
175 Nakamoto, Lueng and Wanitprapha, 1993, p. 27.
176 Farmer Sulton, Indonesia, survey results, 2013.
177 Nutrion and You, 2013.
178 Shahabz, 2011; SNV, 2011, c.
179 Furukawa and Hasegawa, 2006.
180 Farmer Hafidz, Indonesia, survey results, 2013.
181 Wikipedia, 2013.
182 Gurung, 1997; Shahabz, 2011
183 Wikipedia, 2013.
184 Losak et al, 2011.
185 Wikipedia, 2013.
186 Furukawa and Hasegawa, 2006).
187 Wikipedia, 2013.
188 Masaririambi et al, 2010; in Shahabz, 2011

metals[189]. Slurry increases lettuce yields significantly when compared to synthetic fertilisers[190]. However, lettuce production with liquid slurry is comparable to commercial hydroponic fertiliser[191]. The biomass of lettuce can increase after a diluted treatment at a rate of 1:4 or 1:5 (volume/volume, biogas slurry/ water)[192].

4.12 Mushroom

Mushroom is an edible fungus, generally grown above ground on soil or on food sources. The standard mushroom is the white button one, but there are many edible varieties. Dietary mushrooms contain B vitamins and essential minerals, selenium, copper, and potassium. Fat, carbohydrates and calories are low in the crop, and vitamin C and sodium are lacking. It is worth mentioning that when the fungus is exposed to ultraviolet light, natural ergosterols in mushrooms produce vitamin D[193]. Mushrooms must be grown in the dark for spawn colonisation, meaning that they are best grown in a structure made from local materials[194].

Box 7: Tomatoes in Uganda & East Java

Eric Serugo, a farmer in Uganda, applied 2.6 litres per plant around the roots, twice a week (e.g. 8 times per month). This resulted in an increase in growth and yield (from 15kg yield/ plant to 60kg yield per plant). Additional advantages of slurry use were additional harvest, cost savings due to non-use of chemical fertilizers, and an increase in drought and pest resistance.

Farmer Hafidz in East Java, Indonesia uses slurry together with chemical fertilizers for harvesting tomatoes. He applies 0.4 litres of wet slurry before planting the crop and again seven days after planting. He pours onto the roots by hand then covers it with soil. Hafidz states that the crops increase their yields by around 75% compared to the use of chemical fertilizers alone. Production costs are reduced and around 70% less chemical fertilizers are used. Survival rates increase, the crops are less vulnerable to diseases and pests, and the soil becomes crumbly.

Sources: Survey results, 2013

Fresh composted bioslurry can be a good source of growth material for mushrooms. Slurry with a ratio of 1:1 ordinary substrate gives the best results. Slurry use results in a prolonged harvest period and increased yields, and reduces the amount of substrate required (meaning that costs are reduced). The slurry substrate should be soaked during the night and after it is sterilised and cooled, it is inoculated with spawn inside black polythene bags. The bags are hung in a dark room for two to three weeks. When the mushrooms start to push out through the walls of the plastic bags, the bags should be ripped open, and the crops must then be watered and placed on a shelf to allow normal growth. The mushrooms show increased yields, costs are reduced, fungal pests are reduced and there is a longer harvesting period (increased by six weeks). To prevent contamination and other dangers to the health of the crop, light, temperature, cleanness, and humidity must be carefully controlled[195]. '*Moreover, important mineral nutrients viz., Na, K., Ca, Fe, Mn, Cu, Zn and P increased in mushroom fruit bodies when rice straw was supplemented with the above mentioned biogas residual slurry manures*'[196]. We recommend the above described treatment (1:1) of bioslurry on mushrooms in order to achieve the best possible yield and nutrient increase.

4.13 Okra

Okra, a flowering plant, is a well-known species of the Malvaceae family and is often referred to as lady's fingers. The green seed pods are edible. The crop is mostly grown in South Asia, Ethiopia, and West Africa. The crop is healthy and contains fibre, vitamin C, calcium, potassium and folate. Furthermore, it contains high values of antioxidants and oil. Due to the latter, okra oil might be suitable for use as a biofuel. The immature pods of the crop can be consumed fried or boiled or used in salads, soup, and stews. Okra contains different nutritional values such as nutrients, protein, minerals, vitamins, and oil[197]. The optimum temperature for growing okra ranges between 21 and 30 degrees Celsius. Soil fertility is vital to the growth rate and yield of the crop[198].

Shahabz's study[199] used a bed distance of 45cm for row to row and 75cm for plant to plant. When treated with slurry at a rate of 10 t/ha, okra yields show better results than FYM[200]. The nutrient levels also tend to increase when the crop is treated with slurry. Another study[201] shows that the combination of fertiliser and digested slurry significantly influence the yield of okra. The best results were with slurry treatment of 600kg/ha together with 50% less of recommended NPK fertiliser[202]. However, due to the costs and negative effects of chemical fertilisers, using 10 t/ha on okra is suggested in order to achieve the best results.

4.14 Onion

Onion is widely used worldwide and can be grown in a bulb or common form. It can be eaten (raw, fried, boiled) and is also

189 Hernandeze et al, 2010; in Shahabz, 2011.
190 De Groot and Bogdanski, 2013, p. 9.
191 Liedl, Bombardiere and Chatfield, 2006.
192 Liu et al., 2009, p. 305.
193 Wikipedia, 2013
194 Banik and Nandi, 2004; Namirembe, n.d.; Shahabz, 2011.
195 Banik and Nandi, 2004; Namirembe, n.d.; Shahabz, 2011.
196 Banik and Nandi, 2004, p. 319.
197 Wikipedia, 2013
198 Shahabz, 2011.
199 Shahabz , 2011.
200 Gurung, 1998.
201 See Singh, In: Shahabz, 2011.
202 Gurung, 1997; Shahabz, 2011.

used as a dye. It contains numerous vitamins and other healthy substances such as fat, protein, calcium, iron, phosphorous, magnesium, potassium, sodium and zinc[203].

Onion yield can increase significantly – by 50% - with the recommended dose of fertilisers plus 1 t/ha of bioslurry. A farmer therefore obtains 1.5 times more yield (15 – 17 t/ha) than usual[204]. Onion treated with bioslurry is also more vigorous than onion from control plots[205]. Dry slurry can be applied to the crops by spreading it during tilling, and a handful of slurry can be applied per hole or per plant during seedling transplantation. In addition, slurry can be applied as a dressing at the rate of 500ml per plant, with an interval of three weeks after transplantation for two months. The fermented bioslurry can be sprayed onto leaves and boosters, spread over 14 days. Application: Six buckets of dry slurry per 3m x 10m ridge. The use of slurry improves the soil quality and increases farmers' income due to savings on chemical fertilisers as well as increased crop production[206]. Use the general dose of 10 to 20 t/ha for the onions before planting the crops is suggested, or around 0.25 g/crop)[207].

4.15 Radish

Radish is an edible root vegetable, generally purple in colour, and is grown internationally in different varieties, varying in size, colour and harvesting duration. Some are grown for the oilseeds. Radish is rich in ascorbic acid, folic acid, and potassium.

Additionally, radish is a good source of vitamin B6, riboflavin, magnesium, copper, and calcium[208]. Shahabz[209] shows in the study of Weiping et al, that under equal N conditions, bioslurry treatment on radish can increase the quality of the crop and soil. Using the general dose of 10 to 20 t/ha for radish is suggested in order to increase the yield significantly.

4.16 Spinach

Spinach is a green, edible, flowering annual plant, native to central and southwest Asia. The crop contains high nutritional values and is rich in antioxidants. The latter is especially true when eaten fresh, steamed or quickly boiled. The crop is rich in Vitamin A, B2, B6, C, E, and K, magnesium, manganese, folate, betaine, iron, calcium, potassium, folic acid, copper, protein, phosphorus, zinc, niacin, selenium and omega 4 fatty acids. It is famous for its high iron content[210].

Spinach treated with bioslurry showed an increase in yield. The best results were with a slurry application rate of 28.1 t/ha. In addition, the phosphorus concentration of the leaves improved. However, bioslurry and chemical fertilisers can give similar yields. Chemical treatment can also reduce the costs of production[211]. Swine slurry is a good source of nutrients, compared to chemical fertilisers. Furthermore, the N uptake of spinach with Kitchen Garbage Effluent has been studied and it was concluded that the crop grows similarly to when treated with N fertiliser[212]. Due to the costs and environmental issues involved with chemical fertiliser use, applying bioslurry only, at the rate of 28.1 t/ha, is suggested.

4.17 Tomato

Tomato is a well-known vegetable, edible in raw, fried and boiled form. The vegetable can also be prepared as a beverage. The crop is originally from America, but has now spread all over the world, often grown in greenhouses. The crop is believed to be good for the heart and other organs. It contains lycopene (carotene), which is a very powerful natural antioxidant. It is further extremely rich in vitamin C, vitamin A, and anticyanin[213].

When tomato is treated with slurry at a rate of 10 t/ha, the yield gives better results than FYM. The best results are shown when the crop is treated with slurry 20 t/ha, added with NPK 45–60–30kg/ha[214]. With an application of 800 ml of slurry per plant, two or three days after irrigation, slurry had a significant effect on the cultivation of the crop, and also shows an increment in organic matter, available N, P and K, total N and P, electrical conductivity, increase of 16 kinds of amino acids, protein, soluble sugar, b-carotene, tannins and Vitamin C as well as R/S ratio and amounts of bacteria, fungi and actinomycetes[215]. However, liquid slurry application also shows that tomato production required supplementation and conversion of ammonium to nitrate, and the total N and P concentrations may be reduced[216]. Swine slurry was found to be a good source of nutrients as compared to chemical fertilisers to water tomato[217]. In another study, it showed that tomato plants treated with slurry had more vegetative growth and tended to flower and fruit earlier than usual. In addition, slurry improved the N, P and K components of the plant, next to an increase of amino acids, protein, b-carotene, soluble sugar, vitamin C and tannins. Nitrate also improved in the treated crop[218]. In addition, Liu et al[219] suggest using a rational crop rotation and application of inorganic fertilisers with differing application modes (spraying and root irrigation). Furthermore, '[…] *BGS significantly improved contents of soil-available N, P, and K as compared to the control (no fertiliser) and conventional methods […]*'[220]. Using a rational crop-rotation system and application of around 20 t/ha

203 Wikipedia, 2013.
204 Islam, 2006.
205 Shahabz, 2011.
206 Farmer Mr.Kabuka, Tanzania, survey results, 2013.
207 Farmer Suparyono, Indonesia, survey results, 2013.
208 Wikipedia, 2013.
209 Shahabz, 2011.
210 Wikipedia, 2013.
211 PDBP, n.d.
212 Furukawa and Hasegawa, 2006.
213 Wikipedia, 2013.
214 Islam, 2006; Shahabz, 2011.
215 Shahabz, 2011; Yu et al., 2010, p. 262.
216 Liedl, Bombardiere and Chatfield, 2006; Yu et al. 2010, p. 265.
217 Furukawa and Hasegawa, 2006.
218 Liu et al, 2009.
219 2009.
220 De Groot and Bogdanski, 2013, p.10.

of digested slurry before the planting of the crops is suggested. Inorganic fertilisers can be applied when really necessary.

Table 15: Comparative effects of different doses of slurry and slurry-chemical fertiliser combinations on tomato production

Treatments	Yield: t/ha	% Increase over control
Control	26.12	---
Fertiliser @ 90 – 120 – 60 kg/ha NPK	61.02	133.61
Slurry @ 5 t/ha	34.34	31.47
Slurry @ 10 t/ha	37.69	44.29
Slurry @ 15 t/ha	40.53	55.17
Slurry @ 20 t/ha	42.74	63.63
Slurry @ 5 t/ha + NPK @ 45–60–30kg/ha	47.33	81.20
Slurry @ 10 t/ha + NPK @ 45–60–30kg/ha	47.53	81.97
Slurry @ 15 t/ha + NPK @ 45–60–30kg/ha	49.12	88.06
Slurry @ 20 t/ha + NPK @ 45–60–30kg/ha	54.56	108.88

Source: Gurung, 1997, p. 26.

4.18 Turmeric

Turmeric belongs to the ginger family and can be used fresh, boiled or dried. It can be eaten as well as used for tea. It contains essential oils, curcumin, and other essential substances[221].

The yield of turmeric increases by around 27% when treated with slurry[222]. We suggest using the slurry at the standard rate of 10 to 20 t/ha.

Table 16: Summary of results of slurry demonstrations conducted by concerned state departments/agencies in India (1984/85 to 1990/91)

Crop	No. of demonstration	Overall average of % increase in crop yield in slurry treated plot over untreated plot
Paddy	88	31.95
Wheat	127	24.69
Maize	14	40.46
Millet	4	40.46
Turmeric	1	27.05
Potato	5	30.85
Chillies	2	24.25
Tomato	3	126.10
Groundnut	8	23.99
Banana	3	4.69
Brinjal	4	103.23
Sugar cane	2	6.29

Source: Gurung, 1997, p. 30-31

221 Wikipedia, 2013.
222 Gurung, 1997.

5 FRUITS

Figure 9: Mulberry

Source: B.Navez

5.1 Grapes

Grapes are kind of berry which can be eaten raw or can be processed for wine, jam, juice, grape seed extract, raisins, vinegar, and grape seed oil[223]. '*Foliar application in grapes have been found to increase yield, length of fruit-year, sugar content, fruit size, colour, and resistance to mildew diseases*'[224]. Using between 10 and 20 t/ha of bioslurry on the roots of the plants is suggested.

5.2 Blueberry

Blueberry is a perennial flowering plant native to North America, but the plant can now be found worldwide[225]. Blueberry yields are lower when slurry is applied compared to other fertilisers, but it increases the phosphorus level of the soil[226].

5.3 Mulberry

Mulberry is usually grown in southwest Asia (black berry) and North America (red berry). The fruit is often used for pies, wines, cordials, and tea. It is considered to be a multiple fruit and is rich in vitamins[227].

Mulberry yields increase by 25% when bioslurry is applied to the crop. Mulberry can also increase the soil contents of the slurry when used as a filter on the bioslurry pit[228]. Using the general rate of 10 to 20 t/ha of slurry compost on the plant is suggested.

5.4 Mango

Mango is a well-known fruit and is eaten worldwide. It is a tropical fruit which grows on trees and is native to South Asia. It is even the national fruit of India, the Philippines, and Pakistan. Not only is it used for consumption, but in several cultures its fruit and leaves are used as floral decorations during different festivities in rural areas. The fruit is rich in nutrients (potassium, copper), fibre, vitamin A, C, and B6 and amino acids. Using the general rate of 10 to 20 t/ha of slurry compost on the plant is suggested.

The fruit yield can be increased with the application of (liquid) bioslurry[229]. Composted slurry can be scattered manually by making a ring around the tree roots while mixing it with the soil. This can be done once a year, after harvesting but before the flowering of the tree. The amount applied depends on the age and size of the tree: a big tree needs 50kg of composted bioslurry while a smaller tree can use 25kg of bioslurry. The use of bioslurry can increase and improve the amount, size, taste, juice and flesh of the fruit. The soil fertility and structure increases significantly while the water-holding capacity increases due to the decrease in water irrigation requirements. Finally, mango peels can be used for biogas: the peels can produce 0.21m of biogas per kilogram of total solids. The mango peels can be used in ponds at the rate of 34kg/100m² area. This can feed carp and yield 8.35kg/100m² of carp with a good colour and flavour[230].

Figure 10: Mango
Source: National Cancer Institute

5.5 Papaya

Papaya is generally grown in the southern hemisphere. It is a tree-like plant, with a single stem growing from 5 to 19 metres, with spirally leaves around the top of the trunk. Papaya is ripe when it has a soft structure. It is rich in nutrients and contains provitamin A carotenoids, vitamins C and B, dietary fibre, and minerals. The fruit can be eaten cooked when unripe and is used in curries, salads and stews[231].

Bioslurry application can have significant effects on papaya yield. Bioslurry of poultry litter increases the sweetness of the fruit as compared to chemical fertilisers[232]. Using the general rate of 10 tons/ha in irrigated areas and 5 tons/ha in dry farming compost on the fruit plants is suggested[233].

5.6 Watermelon

Watermelon is a healthy fruit, rich in vitamin C and water. It consists of 6% sugar and 92% water. Sometimes the fruit is cooked and used as a vegetable. The juice can also be used to make wine[234].

Bioslurry application can be very useful in increasing the yield of watermelon[235]. Using the general rate of 10 tons/ha in irrigated areas and 5 tons/ha in dry farming compost onto the fruit plants is suggested[236].

223 Wikipedia, 2013.
224 SNV, 2011, c, p. 33.
225 Wikipedia, 2013.
226 Liedl, Bombardiere and Chatfield, 2006.
227 Wikipedia, 2013.
228 Gurung 1997.
229 Beyene, 2011.
230 Karki, 2001.
231 Wikipedia, 2013.
232 Islam, 2006.
233 SNV, 2011, c.
234 Wikipedia, 2013.
235 Gurung, 1997.
236 SNV, 2011, c.

6 PULSES

6.1 Beans

Beans are a common name for different species: e.g. fava beans, red beans, lentils, peas, and soybeans. They are high in fibre, protein, complex carbohydrates, folate and iron. They can also help to lower blood cholesterol[237].

Figure 11: Castor plant

Source: USDA

237 *Wikipedia, 2013.*

6.1.1 Castor bean

Castor is a fruit or bean from the 'miracle tree'. Generally castor is used as oil for bioenergy, food additives and flavouring, medical use, chemical use and more. The seed contains ricin, a toxin, but it also contains between 40 and 60% oil, rich in triglycerides (mainly ricinolein)[238].
Castor yields can be increased by at least 3% when bioslurry is applied as compost[239]. Applying between 10 and 20 t/ha of bioslurry onto the crop is suggested.

6.1.2 Gram

Gram is also known as the Mung bean and is the seed of Vigna radiata native to India and currently mainly grown in China, Thailand, the Philippines, Indonesia, Burma, Bangladesh and India as well as south-eastern Europe and the United States[240].

Bioslurry has a number of advantages for green gram: increased, stronger and more uniform budding; better root development; greener leaves and stronger stems; crops which are more resistant to diseases, pests and cold and have a higher survival rate[241]. Gram can increase its crop yields by around 15% compared to untreated plots[242]. With the application of 10 t/ha of slurry, black gram yields can increase by up to 68%. The slurry also increases rhizobium nodules. Table 1 and 2 show that biogas slurry at 10 t/ha enriched with gypsum 250 kg/ha gave an additional grain yield of 1.80 t/ha compared to the control crop. Additionally, the gypsum-enriched bioslurry had a clear edge compared to slurry alone. It must also be noted that the residual effect of farmyard manure was comparatively better than that of bioslurry. But most importantly, the research shows that gypsum-enriched bioslurry in combination with 75% recommended NPK obtained the maximum grain yields in black gram. 'Seed coating with bio-digested slurry and di-ammonium phosphate recorded the additional grain yield of 0.47 and 0.59 t/ha' over the uncoated in black gram and green gram, respectively'[243]. Additionally, seed soaked in slurry can improve

238 *Wikipedia, 2013.*
239 *Gurung, 1997.*
240 *Wikipedia, 2013.*
241 *Karki, 2001.*
242 *Gurung, 1997.*
243 *Gurung, 1997, p. 60.*

germination rates and support the development of better plants, which are greener and less susceptible to disease[244]. With slurry application of 0.47 ton/ha on black gram, the germination rate can be improved as well thanks to this development of better and greener plants, less susceptible to disease. Gnanamani and Kasturi Bai[245] found that the application of 40 t/ha of slurry alone, 40 t/ha + NPK and 40 t/ha + N all significantly increases the yield. 1.85 g/pot was obtained with slurry at 40 t/ha. 'The combined application produced the maximum gram production of 2.2 g/pot in 40 t/ha + NPK treatment'[246]. Black gram is therefore ideal for harvesting the residual nutrients of paddy cultivation. Due to the results above, applying bioslurry at the rate of 40 t/ha in combination with NPK at a rate of 180:90 and 40kg/ha as well as gypsum is suggested whenever possible[247].

6.1.3 Guar

Guar is an annual cluster bean, mostly found in India and Pakistan[248]. Guar yields can increase when treated with slurry together with Nitrogen[249]. Apply between 10 and 20 t/ha of slurry and adding Nitrogen when necessary is suggested.

6.1.4 Peas

Peas are a green bean vegetable and are found in pods. Peas are usually grown in cooler seasons. Like other bean species, they are high in fibre, protein, vitamins, minerals and lutein. The yield of peas can increase when bioslurry is used as a fertiliser[250]. Applying between 10 and 20 t/ha of bioslurry to the crop is suggested.

Table 17: Direct and residual effect of bioslurry on black gram

Treatments details	Tiller number/hill	Black gram Pod number/plant	Gram yield kg/ha
Wet bio-digester slurry @ 10 t/ha	6.83	9.21	422
Dried bio-digested slurry @ 10 t/ha	7.08	8.94	383
Wet bio-digested slurry @ 10 t/ha with gypsum 50kg/ha (1: 0.025)	7.58	9.12	402
Farmyard manure @ 10 t/ha	6.58	10.22	463
Farmyard manure @ 10 t/ha with gypsum 50kg/ha (1: 0.025)	7.26	10.1	431
Gypsum 50kg/ha	6.33	7.83	294
Control	6.17	7.70	292
CD (P=0.05)	0.22	1.24	51

Source: Gurung (1997, p. 41).

Table 18: Effect of plain and enriched slurry on black gram cropping system

Treatment details	Tiller number/ hill	Black gram Pod number/plant	Gram yield kg/ha
Control	8.36	22.33	586
IOO:50:50kg NPK/ha	10.37	32.68	988
Biogas slurry @ 10 t/ha	9.16	26.64	762
Biogas slurry + 100:50:50:kg NPK/ha	1200	37.42	1196
Biogas slurry 75:37.5:37.5kg NPK/ha	11.66	36.86	1175
Biogas slurry + 50:25:25kg NPK/ha	11.36	35.94	1170
Gypsum-enriched biogas slurry + 100:50:50 kg NPK/ha	13.63	42.92	1283
Gypsum-enriched biogas slurry + 75:37.5:37.5 kg NPK/ha	13.94	43.68	1295
Gypsum-enriched biogas slurry + 50:25:25 kg NPK/ha	1.87	42.06	1279
Gypsum-enriched biogas slurry @ 10 kg/ha	9.56	228.16	787
100:50:50kg NPK/ha + 500kg gypsum/ha	10.48	32.91	1011
CD (P = 0.05)	0.84	2.52	30.86

Source: Gurung (1997, p. 42).

244 Gurung, 1997, p. 60.
245 Gnanamani and Kasturi Bai, 1991.
246 Gnanamani and Kasturi Bai, 1991, p. 217.
247 Gurung, 1997; Gurung 1998.
248 Wikipedia, 2013.
249 Dahiya and Vasudevan, 1985, p. 71.
250 Gurung, 1997.

6.1.5 *Pigeon pea*

The pigeon pea is another member of the bean family. The pigeon pea is widely grown in tropical and semi-tropical regions. It is a perennial variety and can last three to five years. It contains protein, fibre, carbohydrates, Vitamin A, calcium, magnesium, phosphorous, potassium, and zinc[251]. Pigeon pea yields can increase significantly when treated with bioslurry. Applying between 10 and 20 t/ha of bioslurry to the crop is suggested.

6.1.6 *Soybeans*

The soybean is a fat-free bean. Due to its high and complete protein, it contains the nutritional equivalent of meat, eggs and casein. Some products made of soybeans are soy milk, tofu, tempeh, and soy sauce. Soy can also reduce the risk of colon cancer[252].

Soybeans can be treated with slurry and may show increased yields, more than FYM. Indeed, around 75% of the N need of soybeans can be met through slurry in clay soils in the Bhopal region. The use of superphosphate, rhizobium, and phosphor bacteria gave additional grain yield of 0.64 and 0.91 t/ha in clay loam, sandy clay loam, and sandy loam soils[253]. Research by Singh[254] concludes that the combination of fertiliser and slurry increases the yield of soybeans significantly. However, it depends on the crops, soil and agro-climatic conditions as to whether 20 to 100 fertiliser doses can be replaced by bioslurry. However, using bioslurry of 10 t/ha as an organic fertiliser is suggested, solely due to the negative effects of chemical fertilisers on the environment.

6.1.7 *Tabe bean*

According to Ding et al[255], bioslurry treatment on the tabe bean increases the yield and improves the bean's nutritional qualities. Applying between 10 and 20 t/ha of bioslurry to the crop is suggested.

6.2 Groundnut

The groundnut is native to West Africa and ripens underground, like a peanut. The nut can be eaten fresh or boiled after drying[256]. '*The application of biogas slurry of 10 t/ha in [...] groundnut [...] gave better yields than FYM*'[257]. The same rate increased the yields by 24% over the control plot[258]. The range of yield increase of groundnut treated with bioslurry was between 20 and 33% and the pod number per plant ranged from 60 to 70, compared to 45 to 55 in the control plot[259]. Using 10 t/ha of bioslurry for groundnut cultivation is suggested.

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251 Shahabz, 2011.
252 Wikipedia, 2013
253 Gurung, 1997.
254 In: Shahabz, 2011.
255 In: Shahabz, 2001.
256 Wikipedia, 2013.
257 Gurung, 1997, p. VIII.
258 Gurung, 1998, p. 33.
259 Gurung, 1997; Shahabz, 2011.

7 OTHER CROPS

7.1 Cotton

Cotton is a soft and fluffy stable fibre growing as a boll around the seeds of the cotton plant. The fibre consists of almost pure cellulose. The plant is native to tropical and subtropical regions of the Americas, Africa, and India. The crop does not necessarily need much irrigation or rainfall, but since much of the cotton worldwide is now grown in northern countries, the crop has a great effect on water scarcity and drought in such regions[260].

When bioslurry is applied to cotton, it can give significantly higher yields compared to FYM[261]. Other research and data show comparative results. The use of anaerobic digestion slurry of human waste, pig waste and rice straw also increases cotton yield[262]. Spraying the slurry, or combining it with small amounts of pesticide, can effectively control red spider and aphids effects on cotton[263]. The average yield increase is around 24% compared to the control plot[264]. Spraying wet bioslurry on cotton with an application rate of 154.5kg/ha is suggested.

7.2 Chat

Next to coffee, chat is a major cash crop in Ethiopia. '*Chat is a mild stimulant harvested from a shrub (Catha edulis), the fresh leaves of which are chewed, and popular in the arid regions of Ethiopia, Kenya, Djibouti, and Somalia*'[265]. Chat is a major source of revenue for rural households as it provides a faster return on investment than coffee does.

From the survey answers provided by farmer G. Bihonegne of Ethiopia[266], it can be said that the tree and a loamy soil can be treated with bioslurry at a rate of 50kg per big tree and 25kg per small tree. This can be done by making a ring around the roots of the tree while mixing the slurry with the soil and then covering it with mulch. The treatment can be applied twice a year: at the start of the drying season and then again six months later. The quality of the leaves improves and the trees become more resistant to frost, insects and diseases such as powdery mildew. In the meantime the yields increase, while money is saved as chemical fertilisers are not used and water irrigation requirements are lower. Finally, the soil benefits as well since the fertility increases, as does the structure and water-holding capacity.

260 Wikipedia, 2013.
261 Gurung, 1997, p. 26.
262 Gurung, 1997.
263 Gurung, 1997; Shahabz, 2011.
264 Gurung, 1998, p. 33.
265 Reynolds, 2013.
266 Survey results, 2013.

7.3 Coffee

Coffee beans are well-known and are used intensively around the world to prepare coffee beverages. Coffee is also referred to as 'brown gold', referring to the fact that coffee is the second-most-used resource in the world, after oil.

Slurry can have significant positive effects on coffee beans. Indeed, small-scale coffee producers from Honduras reported that when using slurry, it can reduce the impact of coffee rust diseases on the trees. Coffee rust is a fungus which attacks tree leaves and causes them to fall off the trees. It results in reduced foliage and lowers coffee production. Due to the high nutritional values of slurry, it increases the resistance of this disease and therefore increases the yield productions of the plants[267]. With slurry, the beans crops mature earlier and an increase in growth rate has been seen in test crops. The weight, colour, shape and aroma are all increased and/or improved. Additionally, the irrigation requirement is low since crops treated with bioslurry

Box 8: Coffee in Uganda with slurry

Nasiri Mukasa grows coffee beans while using slurry as a compost for the crop with a loamy soil type. He uses liquid and composted slurry during the two rainy seasons in Uganda (March – May and August – November). He uses one jerrycan (20 litres) per plant twice a year, around the roots. The bean yields are then increased by around 50%. In addition the crops show a resistance to disease, especially Coffee Wilt Disease (CWD), and there was additional control of insect pests like small black ants and mealybugs.

Sources: Survey results, 2013

267 Gonzale or Ponce, 2013.

hold more water than non-treated crops. Finally, the coffee weevil (a pest) is absent when slurry is used. The additional income for a household can be increased by around €100 to €250 with the use of slurry. This is due to savings on chemical fertilisers, increased crop yields and pest and disease control. Using 10 to 20 t/ha or 20 litres per plant is suggested in order to make a significant impact on the plant's yields and resistance to diseases. When the slurry is liquid, it can be added directly to the roots of the plant using a bucket. This can be carried out once a year, after the coffee beans are harvested.

7.4 Deccan hemp

Deccan hemp, or kenaf, is a fibre plant native to southern Asia. The stems are around 1 to 2cm in diameter. The fruit contains different seeds and the crop is used for its fibre, as an oil and as paper[268]. The yield of Deccan hemp can increase by around 50% with bioslurry application[269]. Using 10 to 20 t/ha is therefore suggested in order to have a significant effect on the plant's yield.

7.5 Elephant grass, Rhodes grass and vetch

Elephant grass is a species native to African grasslands and is low in water and nutrient requirements, allowing it to make use of otherwise uncultivated lands. It is primarily used for grazing but has also been incorporated into pest management strategies. Roads grass is the most common grass in the world, generally growing alongside roads. Vetch is a flowering plant in the legume family and it is native to Europe, North America, South America, Asia and Africa. The closest relatives are lentil and true peas[270].

From the survey[271], it was concluded that the crops benefit from the application of liquid bioslurry on a loamy soil with a bucket, applying it between the rows around the root of the plant after the crop is cut. This increases the soil fertility and yields of the crop.

Elephant grass after cutting and bioslurry

Improved breed of cattle fed with grasses

Figure 12: Grasses and slurry

Source: Farmer T. Mekonene, Ethiopia, survey results, 2013

7.6 Mustard

Mustards are a plant species. They are generally used as a spice but can also be used as oil, and the leaves are edible.

268 *Wikipedia, 2013.*
269 *Gurung, 2001.*
270 *Wikipedia, 2013.*
271 *Farmer T. Mekonene, survey results, 2013.*

Although, according to Dahyia and Vasudevan[272], higher yields of mustard can be obtained when whole N is supplied through chemical fertilisers, the yield of mustard can increase by at least 35% when bioslurry is used. As shown in the table below, the slurry can be applied with different fertilisers as well. However, when only slurry is applied, the yield can also increase by 45%[273]. Other figures state that the increase is not as high as this, and ranges from 11 to 23%. In any case, the yield does increase so the application of bioslurry is worthwhile when cultivating mustard. Using 10 to 20 t/ha is suggested.

Table 19: Effects of various fertilisers on mustard

Treatments details	Percentage increase Mustard
Control	----
Farmyard manure	25.80
Slurry	45,75
Slurry + single superphosphate	49.75
Slurry + rock phosphate	35.24
Slurry + potash	-----
FYM + phosphate	33.98

Source: Gurung, 2001, p. 29

7.7 Red Pepper

Red pepper is a hot, spicy plant which is used to spice up different dishes. There are many varieties of peppers and the applications are manifold. Not much is known about the yield increase of red pepper when slurry is applied, but research suggests it has a minor effect[274].

The survey executed by Hivos shows that farmer S. Hungnaw from Ethiopia[275] uses bioslurry together with chemical fertilisers to increase the yields and performance of the crop. He used liquid slurry and applied it manually between the rows with a bucket. He applied half of the dose (5.5 t/ha) after two weeks of planting and the other half during the flowering stage. Crop performance with bioslurry was good. The yield increased and the pepper sizes were large with an attractive colour. In addition the crops did not wilt when the rain stopped early, and the roots resisted wilting diseases.

7.8 Tea

Tea is a well-known species which is used worldwide.
When treated with slurry, tea improves in quality and the yields increase by 11%. This is a net saving of around €148 per hectare per harvest[276]. Using 10 to 20 t/ha for tea yield increase is suggested.

272 *Dahyia and Vasudevan, 1985.*
273 *Gurung, 2001.*
274 *Shahabz, 2011.*
275 *Survey results, 2013.*
276 *SNV, 2011, c, p. 31.*

7.9 Tobacco

Tobacco is a product processed from the leaves of the tobacco plant. It can be consumed, used as a pesticide and added to some medicines. It is commonly used as a drug for smoking, chewing or sniffing[277].

The yield of tobacco can increase by 13%[278] with bioslurry use. With liquid slurry based on pig dung, at a one to one basis (1:1 water/slurry) 400 litres can be applied three times per life cycle at the roots of the plant. This can increase the plant's performance by 133%. With composted slurry, applying the slurry to the roots of the plants twice is suggested, using 15m³ per hectare. This can increase the performance of the plant by 106%. Within a 75m² plot, the planting can be repeated three times with five rows of 15cm long at a one metre distance apart and with 20 plants with a 0.75cm separation[279].

7.10 Sugar cane

Sugar cane is grown in the tropical regions of South Asia and is widely used all over the globe. It belongs to a grass family and is quite economically viable for farmers. It can be consumed in different forms (liquid, hard sugar, and additive) and can be used for ethanol production. It is therefore a versatile plant and is important to many cultures and economies[280].

Sugar cane yield can increase to an extent with bioslurry application[281]. Farmer A. Dessie from Ethiopia[282] used composted bioslurry on the crop at the rate of 8 t/ha on a loamy soil once a year or until the sugar cane was cut. Crop performance was good and it grew fast, with deep-green-coloured leaves, while the cane was thick, long, and juicy. It was harvested within nine to ten months, whereas non-treated plots take more than a year to be ready for harvest. Money was saved on chemical fertilisers and the soil fertility increased. The additional crops were sold, increasing the farmer's income and improving his livelihood. Sugar cane yields can increase by up to 175% with the application of 10 t/ha of dried slurry. In the tables below you can find the nutrient composition, yield parameters and nutrient uptake of sugar cane plant and ratoon when treated with different organic amendments. Bioslurry can produce similar yields compared to recommended NPK treatments[283]. Furthermore, '*The treatment with BGS yielded 71.9 t/ha, which was higher than with FYM (70.9)*'[284].

The slurry was applied at the rate of 10 t/ha. The same rate is therefore suggested here.

Table 20: Nutrient composition of organic amendments on dry-weight basis

Organic amendments	Nutrient composition (%)			
	Organic C	N	P	K
Vermicompost	40	1.60	0.60	0.80
FYM	46	0.85	0.20	0.55
Biogas slurry	55	0.87	0.65	0.70
SPMC	40	1.60	1.00	1.20
Sesbania aculaeta	45	1.99	0.21	1.20

Source: Singh et al, 2007, p. 368

277 Wikipedia, 2013.
278 Gurung, 2001.
279 Silvestre, A. and Martí-Herrero, 2010.
280 Wikipedia, 2013.
281 Gurung, 2001.
282 Survey results, 2013.
283 Singh et al, 2007.
284 De Groot and Bogdanski, 2013, p. 9.

Table 21: Yield parameters and yield of sugar cane plant and ratoon crops treated with organic amendments

Treatment	Millable cane (thousand/ha)		Cane length (cm)		Cane thickness (cm)		Cane yield (t ha-1)	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
Control	77.4	70.0	184.1	173.0	2.2	2.0	53.0	46.30
NPK at 150 – 60 – 60kg/ha	95.2	98.5	221.0	216.5	2.4	2.4	76.1	78.10
Vermicompost at 10 t/ha	95.4	98.6	223.8	207.8	2.4	2.2	76.7	77.72
FYM at 10 t/ ha	94.2	97.0	220.6	204.5	2.2	2.2	70.9	70.70
Biogas slurry at 10 t/ha	94.9	96.2	218.0	206.1	2.2	2.2	71.9	70.44
SPMC at 10 t/ ha	95.6	101.0	224.7	210.6	2.4	2.3	75.3	78.16
Intercropped Sesbania green manuring	83.4	97.6	219.3	214.0	2.5	2.2	65.0	72.52
CD (P=0.05)	1.97	5.36	10.30	11.40	0.20	0.11	6.20	9.55

Source: Singh et al, 2007, p. 374

Table 22: Nutrient uptake by sugar cane plant and ratoon crops treated with various organic amendments

Treatments	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)			
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
Control	147.0	119.7	22.9	12.0	114.6	104.3
NPK at 150 – 60 – 60kg/ha	306.8	278.5	32.9	30.6	221.9	228.5
Vermicompost at 10 t/ha	212.6	271.5	41.4	31.5	226.5	228.8
FYM at 10 t/ha	184.0	213.3	33.2	30.5	201.9	205.0
Biogas slurry at 10 t/ha	199.5	229.1	31.1	30.4	202.1	188.6
SPMC at 10 t/ha	227.7	284.6	40.6	30.6	203.3	216.2
Intercropped Sesbania green manuring	196.7	225.9	25.7	28.6	189.7	184.0
CD (P=0.05)	10.10	12.14	2.40	2.50	12.00	13.10

CD critical difference between two treatments

Source: Singh et al, 2007, p. 374

7.11 Sunflower

Sunflower is an annual plant commonly grown around the world. Sunflower seeds are edible, and the seeds are also used for oils. It is even used as a biofuel. The stems contain fibre which can be used for paper production[285].

With bioslurry, sunflower crop yields can increase by around 25% in comparison to untreated crops[286]. '*In sunflower, the use of biogas slurry alone in various doses and the combination of the same doses with N at 60kg/ha gave lower yields than the treatment with N at 120kg/ha. However, even the lowest dose of (5 t/ha) gave yield that is 36.84% higher than the control*'[287] (see table below). Due to the negative effects of N on the environment, we suggest using only 15 t/ha of bioslurry.

Table 23: Effect of biogas slurry with and without mineral fertiliser on sunflower yield

Treatments	Computed yield kg/ha	% Increase over control
Control	1773.33	---
N @ 120kg/ha	3233.33	82.33
Slurry @ 5 t/ha	2426.67	36.84
Slurry @ 10 t/ha	2206.67	25.00
Slurry @ 15 t/ha	2573.33	45.11
Slurry @ 5 t/ha + N@ 60kg/ha	2796.67	52.63
Slurry @ 10 t/ha + N @ 60kg/ha	2226.57	25.55
Slurry @ 15 t/ha + N @ 60kg/ha	2646.67	49.24

Source: Gurung (2001, p. 27)

285 Wikipedia, 2013.
286 Gurung, 2001; Shahabz, 2011; Gurung, 1998.
287 Gurung, 2001, p. 27.

8 ANIMAL FEED

8.1 Introduction

As an experiment, slurry has been used to feed cattle, pigs, poultry, earthworms and fish and to grow algae. The results are encouraging and bioslurry can make a great substitute for regular animal feed. Vitamin B12 increases with the anaerobic digestion of slurry[288]. Some of the ammoniac nitrogen in the slurry is used for growing bacterial biomass for its conversion into new amino-acids[289]. It must be noted that the feeding of bioslurry to livestock must be done alongside regular feed, and it is not the intention that bioslurry be the sole feed given to animals unless there is no other food available.

8.2 Worm growing

Worm growing can be stimulated with bioslurry and the worms can be used as feed for chicken, fish and pigs. The worms can be harvested one to two weeks after the bioslurry pit is filled[290].

8.3 Algae and fish

The slurry can be used as a fertiliser in water to allow algae to grow and it can be used in dried form to feed fish[291]. The net fish yield of ponds fed only with slurry and chicken manure can be up to 3.5 times that of non-treated ponds. The fish survival rate was 100% in the slurry-treated ponds, compared to 93% in those treated with raw cow dung fodder. In Vietnam, the use of slurry as a fodder for fish nurseries saved 67% of fish food costs – around €375 per hectare per harvest. In addition, bioslurry feed for adult fish not only saves 40% of fish food costs, but also eliminates head floating and increases the yield by 12% (counting around €1000 per hectare per harvest)[292]. The fish culture with bioslurry saves purchasing inorganic fertilisers and feeds (60% of operating costs). In addition, it is environmentally friendly since it does not require oxygen for decomposition, unlike raw animal manure. Use of raw animal manure in fish ponds creates a greater demand for oxygen than the water environment can produce. This can lead to the death of fish by suffocation[293], [294].

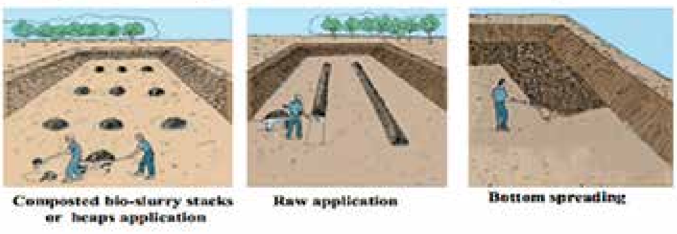
Bioslurry is used for fish rearing in various ways: for the growth of planktons (phytoplanktons) and for fish growing and breeding[295]. In order for the pond to be operational for fish culture and bioslurry feeding, the pond must be dried for at least one week. Thereafter, it must be disinfected with lime and then manure can be applied following an interval of at least 15 days from the disinfection. The manure is applied to the floor before the pond is filled with water. This must be done at least ten to fifteen days before the pond is stocked with fish. Additional water can be added until the water looks transparent. The bioslurry can be sprayed onto the surface or discharged directly into the pond water. Adding five to seven fish per m² is recommended. 100kg of lime and three to four kilograms of urea per 1000m² can also be added, while bioslurry can replace urea at a rate of 100 to 200kg DM/1000m², [296].

The bioslurry can now be mixed with fish fodder and added directly to the pond to feed the fish. The application rates are at around 0.3 to 0.4 litres per m² of surface or 300 to 400 litres per 1000m² or 3000 to 4000 litres/ha. Composted slurry has an application rate of 100 to 150kg per 1000m2 per week, which increases the growth of the fish from 15 up to 30%. In addition, the slurry provides readily-available nutrients for the fish which are easily soluble and dispersible in water. The bioslurry kills aerobic pathogenic fungi and parasitic eggs which are harmful to the fish[297].

A study by Vu, Tran and Dang[298] states that some farmers were convinced that fish in ponds fertilised with pig manure grew faster than fish fed with fertilisers. A study by Kaur et al in 1987 showed that the growth rates of carp can increase significantly when ponds are fertilised with slurry. The study also showed that no fish died due to fertilisation of the fish ponds[299].

288 SNV, 2011, c.
289 Ejigu, 2010; Gurung, 1998; SNV, 2011, c.
290 Ssendangire, 2013.
291 Lansing et al., 2010; Ejigu, 2010, p. 54.
292 SNV, 2011, c.
293 Ssendangire, W. (August, 2013). Personal communication. Comments on Bioslurry manual.
294 Ssendangire, 2013.
295 Organic matter from bioslurry is converted into large quantities of inorganic compounds which are assimilated directly or indirectly by water organisms acting as food fish growth and breeding.
296 Ssendangire, 2013.
297 Ssendangire, 2013.
298 Kaur et al, 2007.
299 De Groot and Bogdanski, 2013, p. 11.

Figure 13 Newly constructed or drained fish ponds



Source: Ssendangire, 2013, p. 14

8.4 Duckweed ponds

Duckweed is unique in the sense that its protein content can be manipulated according to the nitrogen content of the water in which it grows. Being a protein source, duckweed could potentially be used as a food for humans and animals. Duckweed cleans up the waste of artificial fertilisers by removing organic and inorganic nitrogen from decomposition of organic matter, therefore also fighting eutrophication[300]. In a study on producing duckweed in ponds, slurry was used as a fertiliser. The study showed that with the same input of nitrogen, plant nutrients from slurry supported higher concentrations of crude protein in duckweed than nutrients from raw manure. Bioslurry therefore facilitates the integration of duckweed ponds with biodigesters. The study showed that '*Crude protein content of duckweed was higher (P=0.001) and root length shorter (P=0.001) when the ponds were fertilised with effluent rather than manure [..]*'[301],[302]. The use of a range of 20 to 30 mg/litre a day is suggested in order to achieve the optimum level of nitrogen in the pond water[303].

8.5 Animal feed

'*Feeding of animal wastes results in reducing feed cost and a lower price of animal products; it contributes to self-sufficiency in protein, phosphorus and other expensive nutrients in feed rations […]. In theory, using BGS {slurry} for animal feed follows the same logic, yet studies on this particular topic are scarce*'[304]. However, we have some information which is relevant for this manual in relation to pig and sheep feed.

8.5.1 Pig feed

The use of bioslurry for pig feed saves around €9 to €11 in food costs per pig feeding cycle of two months. The bioslurry can be used in rotation to feed pigs. It contributes to a weight increase of around 8 to 10% in pigs of around 20kg and over, and the percentages are higher in undernourished pigs. The increase in feed intake increases by 8 to 30% and the health of the pigs improves significantly. The application rates are as follows: add one to two litres of liquid bioslurry per kilogram of feed. However, be aware that pigs of 20kg and above can eat with the slurry, while small piglets may get diarrhoea from it. The application rate should be increased in proportion to the daily feeding as the pigs grow[305].

8.5.2 Sheep feed

The study by Saxena and Ranjhan[306] states that oven-dried and sun-dried digested slurry is edible when mixed with wheat bran, and can be fed to sheep according to a maintenance ration of up to 30% wheat bran replacement with slurry without any adverse effects. In addition, oat hay and fresh water were given. The nutrients uptake and balance of Nitrogen, Calcium and Phosphorus in sheep remained the same compared to the control group (fed with wheat bran) and therefore the authors suggest that oven- and sun-dried slurry together form a good and nutritious feed for sheep. Additionally, the values and intake of digestible crude protein and total digestible nutrients of sheep were comparable to the control group[307]. '*[…] fermentative processes in the biogas plant enhance the protein content of dung from 8% to about 15% in the digested slurry*'[308]. In the event of food scarcity, slurry can help with feeding animals and maintaining their body weights for a period of 21 days. This can be of interest for regions dealing with chronic feed shortages, for example in dry or flooded areas. However, slurry is low in energy content. In conclusion, slurry can be a superior material to feed animals compared to the dung from which it is produced, since digestion upgrades even poor-quality dung[309].

300 Chau, 1998b.
301 Chau, 1998b, p. 5.
302 Note that root length of duckweed is related with protein content and thus is a good indicator of the protein status of the plant. See Chau, 1998b, p. 7.
303 Chau, 1998b, p. 7.
304 De Groot and Bogdanski, 2013, p. 12.

305 Gurung 1998; SNV, 2011; Ssendangire, 2013.
306 Saxena and Ranjhan, 1983.
307 Saxena and Ranjhan, 1983.
308 Saxena, Nath and Srivastava, 1989, p. 74.
309 Saxena, Nath and Srivastava, 1989.

LIST OF ACRONYMS

Al: Aluminium
BBW: Banana Bacterial Wilt
Ca: Calcium
CH4: Methane
CO_2: Carbon dioxide
C/N: Carbon / Nitrogen ratio
Cu: Copper
CWD: Coffee Wilt Disease
DLS: Diluted liquid slurry
DM: Dry matter
DPS: Diluted poultry slurry
DS: Digested slurry
Fe: Iron
FYM: Farmyard manure
GDP: Gross Domestic Product
GE: Green entrepreneurship
GHG: Greenhouse gas
Hivos: Humanistic Institute for Development Corporation
IPCC: Intergovernmental Panel for Climate Change
ISD: Institute for Sustainable Development (Ethiopia).
K: Potassium
KGE: Kitchen Garbage Effluent
K_2O: Potassium oxide
LPG: Liquefied Petroleum Gas
Mg: magnesium
Mn: Manganese
Mo: Molybdenum
N: Nitrogen
NO: Nitrogen monoxide
N_2O: Nitrous oxide
NO_3 : Nitrate
NUE: Nitrogen Use Efficiency
O: Oxygen
P: Phosphorus
Pb: Lead
pH: a measurement of acidity or basicity
P_2O_5 : Phosphorus pentoxide (superphosphate)
ROI: Return On Investment
SNV: Netherlands Development Institute
Zn: Zinc

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