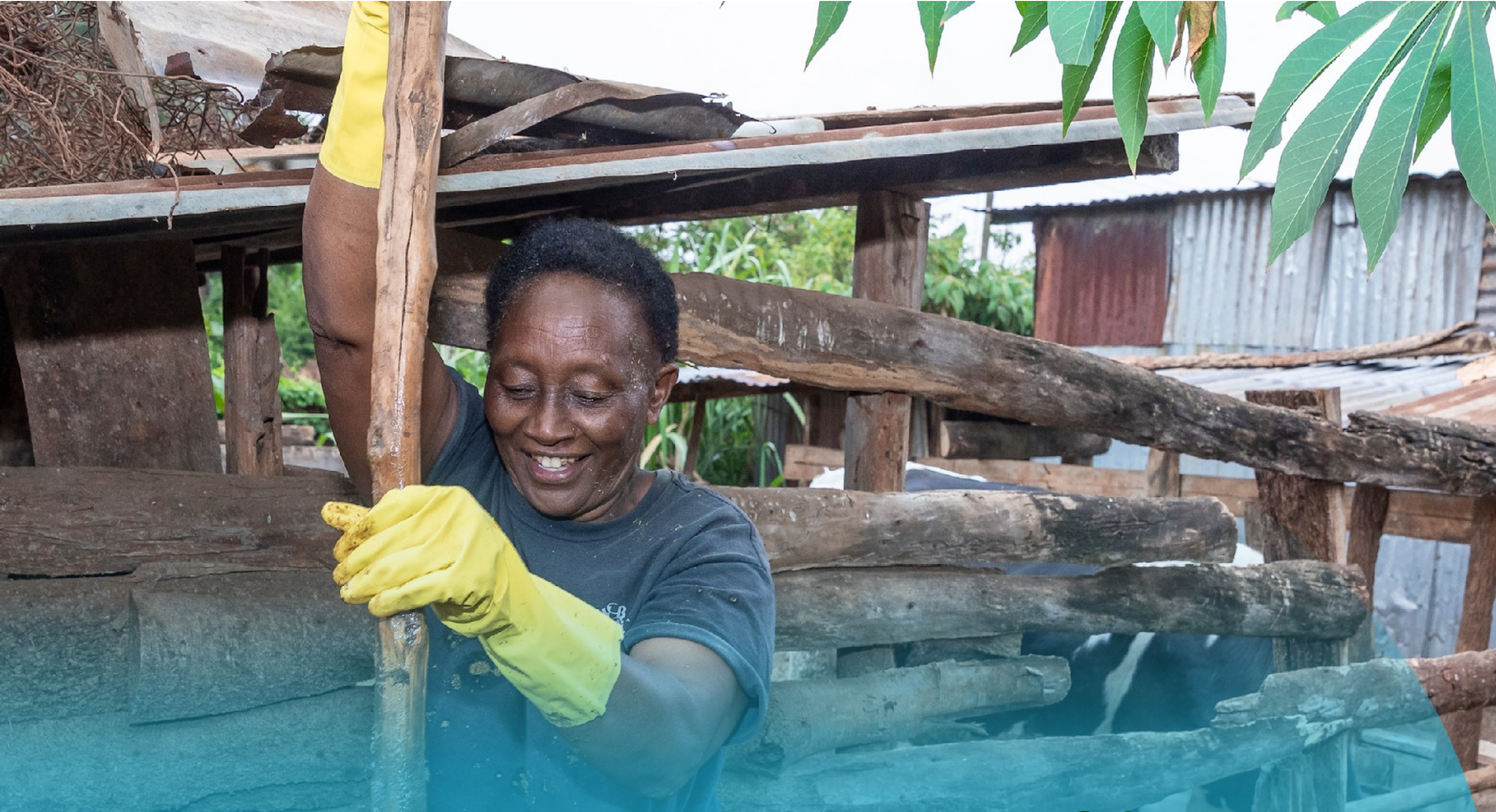

Literature review of best practices regarding bio-slurry and bio-slurry enriched compost (BEC) application

African Biodigester Component

Organic Fertiliser Valorisation Implementer

SEE – Clean Cooking

Co-financed by:
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Acronyms

ABC	African Biodigester Component
ABPL	Africa Bioenergy Programs Limited
BEC	Bio-slurry Enriched Compost
BSUL	Biogas Solutions Uganda Limited
NP	National Partner
OFVI	Organic Fertiliser Valorisation Implementer
OM	Organic Matter
PNB-BF	Programme National de Biodigesteurs du Burkina Faso
SNV	SNV Netherlands Development Organisation

Terminology

Bio-slurry - the product from bio-digesters, generated through anaerobic digestion of organic materials (often animal manure)
Compost - consists of composted biomass, this may or may not include bio-slurry. Under ABC, only Bio-slurry Enriched Compost (BEC) will be considered
Bio-slurry Enriched Compost (BEC) - compost that has been generated using (amongst other inputs) bio-slurry
Farm-yard Manure (FYM) - decomposed mixture of dung, urine, straw and litter and fodder residues. It is a form of solid manure
Organic fertiliser - any bio-based fertiliser which may include both bio-slurry and compost, but also other organic fertilisers such as biochar and bokashi.
Other biomass used in agriculture such as mulching with woodchips, straw etc is not included here as organic fertiliser, this is only indirect organic fertiliser once decay of this biomass starts.
End user - person applying the bio-slurry and/or compost (BEC) on his or her own land

Summary

The OVFI project aims to demonstrate that bio-slurry valorisation is a key component in biodigester business development as biodigesters can play an important role in the transformation toward sustainable agriculture and poverty alleviation in smallholder households in Africa. The OFVI project aims to do that by creating new business cases for biodigester owners including, next to the biogas that is generated, the added value and sales of bio-slurry and Bio-slurry Enriched-Compost (shortened to BEC) applications.

The main objective of this literature research is to assess the potential nutrient and fertiliser value of bio-slurry and BEC under prevailing conditions in the target countries.

Existing literature was identified in online databases using various search engines. A selection of was categorised by geographical region bio-slurry and BEC data availability. Thirty-one publications representing the work area of the OFVI project were selected for further analysis. Coverage of the target countries is very uneven. Nine studies present results for Kenya, nine for Uganda, five for Burkina Faso, two for Mali and two for Niger. Some cover multiple countries. Three studies provide results outside of the African continent.

Data from the most prominent studies are summarised. Special attention is given to the composition and fertiliser value and yield effects on crops. A distinction is made between short- and long-term effects. Short term effects refer to the provision of nutrients needed for crop growth. Long term effects include effects on soil structure (soil organic matter, water holding capacity, CEC) and soil life (bacteria and fungi). This study only included short term effects; long term effects are discussed in other OFVI activities.

A detailed overview of the contents of the main studies is presented. Most studies provide data on bio-slurry application. The feedstock is mostly manure (60% of the studies). Four studies present data on bio-slurry or BEC made from agricultural residues and another four on household waste. Two thirds of the studies present data on nutrient composition, but only five studies describe the fertiliser value. A majority of the studies (60%) provide data on crop production, often maize or vegetables. One third provided data on crop yield; eleven studies provide a description of the soil. Safety issues of bio-slurry handling and application were discussed in five studies. Finally, six studies addressed the gender aspects.

Formal data on yield effects of crops in Africa are scare. Cut flower yields were reported to increase by 60% after application of vermicompost and bio-slurry in Ethiopia. Data presented for Kenya and Uganda suggest maize yield can be raised by 59% to 220%. Yield improvement was also reported for cabbage (70%) and coffee (66%), while eggplant yields in Uganda were increased by 77% after bio-slurry application.

Large variation in crop varieties, cultivation practices, soils, and application levels of bio-slurry and BEC make it very difficult to provide balanced yield assessments in the target countries. In order to overcome this problem, a table with generalized yield effects for major crop groups (cereals, grasses, vegetables, and other crops) is presented. Results suggest bio-slurry application leads to an average yield improvement by 30% (cereals,

vegetables), 25% (grasses), and 40% (coffee) comparing to unfertilized plots. In many cases, bio-slurry application was found to be (almost) as effective as mineral fertilizers. A slight reduction of yields was reported for cereals, grasses, and vegetables. For coffee, bio-slurry is reported to be superior to mineral fertilizers, but this figure is based on one study only.

Short term yield effects for application of BEC could not be assessed due to lack of suitable data. A first analysis suggests short term yield impacts for cereals and coffee may be superior to those of bio-slurry (and mineral fertilizers). No difference was found for vegetables.

Long term yield effects were not quantified. Following van der Wurff et al. (2016), chemical fertilizers perform extremely well for short term nutrient availability; they are expected to, however, a negative effect on soil life. Fresh bio-slurry is slightly less favourable for nutrient availability but has a positive effect on soil structure and soil life. BEC seems to combine positive effects of bio-slurry and ordinary compost, improving short- and long-term nutrient availability while stimulating soil composition and soil life.

The report briefly discusses social benefits of biodigesters. A decline in disease pressure (from manure) is positive, as is reduction of time needed for wood collection or costs of fossil gas. This may, however, be countered by time demands for managing the biodigester, field application of bio-slurry and (especially) production of BEC. Most of this workload is borne by women who generally provide most of unpaid household labour. There is risk, therefore, that bio-slurry and especially BEC can increase the workload of women already face a challenging burden in terms of labour.

Although bio-slurry has been promoted for its ability to function as a cheaper and more environmentally friendly alternative to chemical fertilisers, there are still many farmers who are unfamiliar with its potential risks. No toxic or harmful effects on soils or crops have been reported, and the concentration of toxic heavy metals is very low compared to synthetic fertilisers (Kumar et al., 2015). Actual risks depend on the content of potentially toxic metals, pathogens, and viruses, retention time and temperature of the digestion process.

Also, spraying bio-slurry directly on the crop’s leaves to increase yields brinks risks, as anaerobic digestion does not necessarily kill all pathogens, parasites, and viruses. This is especially relevant for application on fresh food crops.

1 Introduction

While so far bio-digester applications in Africa are mainly used for their energy output (bio-slurry being considered – mostly – a by-product) African soils are threatened by overexploitation and increased weather uncertainty. With declining carbon content in soils and the immediate need for climate-smart agriculture, organic fertilisers are more important than ever. Application of bio-slurry, either direct or via the production BEC, can help transform agricultural production systems, making them more robust and resilient.

A new RVO programme, African Biodigester Component (ABC), has been developed to promote and develop biodigester production and utilisation in the continent. The Organic Fertiliser Valorisation Implementer (OVFI) project has been developed to define and promote the unique value of bio-slurry as a valuable source of nutrients and organic matter.

The OFVI project is implemented by a consortium of three organisations: Biomass Research, DIBcoop and SNV Netherlands Development Organisation. Activities are implemented in close cooperation with National Partners (NPs) who have a rich experience in this field: Africa Bioenergy Programs Limited (ABPL) in Kenya, Biogas Solutions Uganda Limited (BSUL) in Uganda, and Programme National de Biodigesters (PNB-BF) in Burkina Faso. For Mali and Niger, SNV (national offices) will assume this role until a suitable national implementer has been identified.

OVFI aims to demonstrate that bio-slurry valorisation is a key component in any biodigester business development, showing how biodigesters play an important role in the transformation towards regenerative agriculture. Activities to be undertaken in the project include a review of the fertiliser value of bio-slurry and BEC under the context of low-input smallholder farming in East and West Africa. Further, the project will focus on market development, policy improvement, stakeholder involvement, product quality, safety of application and gender impacts.

Biodigesters have mainly been promoted for the production of biogas (a mixture of CH4 and CO2) through anaerobic digestion of organic matter (OM) in an oxygen-deprived environment. Much less attention has been paid to bio-slurry (Schoeber et al., 2020), a valuable by-product also referred to as digestate or in wet systems as digester effluent (Vögeli et al., 2014). Many are unaware of the benefits of bio-slurry and thus simply discharge it into nearby water bodies, creating a risk of eutrophication and contamination of drinking water (Vögeli et al., 2014). Therefore, there is a great potential in improving the livelihoods of many farmers around the world by addressing the valorisation of bio-slurry. This project aims to do that within a Sub-Sahara African context.

Application of organic matter to soils has many advantages (Gilbert et al., 2020):

- Increase of soil organic matter content
- Increase of cation exchange capacity (CEC; this increases nutrient buffering)
- Improvement of water retention
- Improvement of soil temperature regulation and above-ground microclimate
- Increase of biological activity (soil cohesion, water infiltration and nutrient availability)
- Increaseof soil pH (reducing acidity and stimulating nutrient availability).

Cattle manure is predominately used as feedstock by smallholder farmers (Kinyua et al., 2016). The feedstock used for the digesters commonly reflects the availability of local organic sources. The feedstock could be animal manure, human faeces, crop residues and kitchen waste. Both the levels of biogas and the quality of the bio-slurry differ depending on the nutrient contents of the feedstock (Smith et al., 2014; Schoeber et al., 2020). Within the developing world, it is commonly livestock manure that is most often used as feedstock for digesters (Kinyua et al., 2016). Livestock manures differ regarding N, P and K content and therefore affect the nutrient content of the bio-slurry differently. While cows utilize a significant part of the carbohydrates available in their feed for energy, the manure from swine has the highest concentration of N (Kinyua et al., 2016).

Bio-slurry application varies as it can be used to fertilise crops directly or it can be added – along with other organic materials – to the compost (Warnars & Oppenoorth, 2014; Laban et al., 2017). Bio-slurry is used in three forms:

- Liquid bio-slurry
- Dry bio-slurry. The liquid bio-slurry is dried, preferably under a shelter.
- Bio-slurry enriched compost (BEC). The bio-slurry is used as an ingredient in the composting process.

Solid and liquid forms differ in structure and nutrient composition (Warnars & Oppenoorth, 2014). Bio-slurry feedstocks often are low in dry matter and generally, water is added to generate a favorable composition for digestion. Furrther, part of the solids are removed during digestion (Vögeli et al., 2014). It can contain a high percentage of N compared to the dry form (Nyang'au et al., 2016) and is most effective when it is applied to the fields shortly before the start of the vegetation period (Vögeli et al., 2014). However, it also represents challenges as it is more complex in storage, handling and transportation compared to a solid material such as compost (Vögeli et al., 2014).

Bio-slurry (whether in liquid form or as BEC) is a suitable organic fertiliser due to its high contents of nutrients and organic matter (Schoeber et al., 2020) with both micro- and macronutrients such as nitrogen, potassium, phosphorus, calcium, magnesium, and iron being present (Schoeber et al., 2020).

A way to address the challenges of handling, storage and transportation of liquid bio-slurry is to transform it into BEC. To achieve this, organic dry materials can be added to the bio-slurry pit (Fulford, 2015). If the added material has a high absorption capacity, then nitrogen losses, through volatilization, can be reduced (Schoeber et al., 2020). The plant nutrients in BEC are more readily available than those in traditional compost (Warnars & Oppenoorth, 2014). Furthermore, the exposure of the bio-slurry to high temperatures during the composting process results in a more sanitary product (Vögeli et al., 2014).

The process will likewise lead to a higher quantity of compost on the farms, as about one part of the bio-slurry can be sufficient to compost around three to four parts of dry plant materials, thereby leading to an overall increase in the on-farm production of nutrient-rich compost (Warnars & Oppenoorth, 2014). As the dry material will absorb parts of the bio-slurry, the compost will become moister and more pulverised, and the decomposition of the added material will be accelerated due to microbes in the bio-slurry (Schoeber et al., 2020).

The business case for biodigester owners includes, next to the biogas that is generated, the added value of bio-slurry and Bio-slurry Enriched-Compost (BEC) applications as well as sales of bio-slurry and/or BEC. Hence, it is important that an assessment is done of the potential nutrient and fertiliser value, while ensuring safe application. There is, however, a limited number of studies that address the added value of the use of bio-slurry or BEC on farming under smallholder conditions.

When bio-slurry is applied to soil, it generally functions as a sponge – with the consistency of hummus – and thereby helps preserve moisture and nutrients in the soil (Fulford, 2015). Because of this, bio-slurry application not only improves soil nutrient content but also its water holding capacity and soil structure (Warnars & Oppenoorth, 2014). The bio-slurry application can thereby be especially beneficial in certain Sub-Saharan regions, as it will help make some depleted soils healthier and more fertile by strengthening their physical, chemical, and biological soil properties (Schoeber et al., 2020). However, as bio-slurry is relatively low in carbon – due to the anaerobic process – it can cause quick mineralisation of soil organic matter and thereby a loss of organic matter (Sánchez & González, 2005).

Farmyard Manure, BEC and bio-slurry are valuable sources of nitrogen, phosphorus, potassium and micronutrients, and their application generally is beneficial to the soil and the crop. A recent report by FAO and ITPS (2021) gives an overview of benefits and drawbacks to the practice of application of manure, bio-slurry, and compost (Annex II). In many cases, however, effects of different fertilizer types cannot be easily compared. In the OFVI project, impacts of bio-slurry and BEC application are compared to alternative fertilization strategies using long term (10 year) modelling. Methodology and results are presented elsewhere (report for Inception 6).

It is estimated that about 50% of phosphorus in bio-slurry is readily accessible for plants (Vögeli et al., 2014) and that between 10% and 33% of total nitrogen is converted to ammonium, increasing its availability (Bonten et al., 2014; Schoeber et al., 2020). Table 1 presents data on composition of bio-slurry. It usually contains little solids, has a favorable pH, generally above 7, and may contain 3 to 14% of nitrogen in the solid phase. One to two thirds of the nitrogen is ammonium, which is readily available for crops. Phosphorus and potassium contents are 0.2 to 0.4% of dry matter. Bio-slurry made from cattle manure may be lower in nutrients but have a higher pH. Pig manure bio-slurry is relatively rich in nitrogen and phosphorus. Nutrient composition in target countries in Africa is expected to be lower.

Table 1: Typical composition of various types of bio-slurry (data refer to Europe)

Parameter	Unit	General	Bio-slurry from cattle manure	Bio-slurry from pig manure
Total Solids	%	1.5 - 45.7	7.0	9.0 – 10.0
Volatile Solids	%	38.6 - 75.4	5.6	
Total N	% DM	3.1 - 14.0	4.80	8.3-8.7
Total N	% of FM	0.12 - 1.5	0.34	0.79 – 0.83
Total $NH4^+$	% Total N	35 - 81		0.4 – 0.72
Total P	% DM	0.2 - 3.5	0.78	2.4-2.6
Total P	% FM	0.04 - 0.26	0.05	0.23 – 0.25
Total K	% DM	1.9 - 4.3	3.91	3.7-3.9
Total K	% FM	0.12 - 1.15	0.27	0.35 – 0.37
pH	-	7.3 - 9.0	8.22	0.68 – 0.8

Source: calculated from Nkoa et al. (2014), van Eeckhoute et al. (2012)

Depending on the biodigester, some 25-30% of the organic matter is converted into biogas (Muhmood et al., 2014; Mofokeng et al., 2020) while approximately 70-75% of the total solids content of the OM becomes bio-slurry (Warnars & Oppenoorth, 2014). The composition of the resulting bio-slurry depends on various factors such as the digester type, the feedstock used, temperature in the digester – due to substrate utilisation and microbial growth rates being affected by temperature -, and the retention time of the bio-slurry within the digester (Kinyua et al., 2016; Nyang'au et al., 2016).

During digestion, manure loses 1% to 5% of its dry matter; losses in organic matter loss vary between 5% and 15%. The amount of total nitrogen does not change but concentration of available nitrogen (ammonium) is increased. Concentrations of phosphorus, potassium and other nutrients do not change much but the amount of water-soluble phosphorus declines. One of the most important effects of digestion is it's pH which is raised during the digestion process (Moeller and Mueller, 2012; Schoeber et al., 2020; Bonten et al., 2014).

Bio-slurry is black or brown having no identifiable substances. The amount of bio-slurry that is generated is almost equal to the feedstock and water input (Warnars & Oppenoorth, 2014). Typically, with sufficient organic input, the composition of the bio-slurry exists of approximately 93% water and 7% dry matter, constituting 4.5% OM and 2.5% inorganic matter (Warnars & Oppenoorth, 2014).

Some studies examine the effects of bio-slurry on soil nutrients and chemical properties along with crop yields (Nasir et al., 2012; Haque, 2013; Hossain et al., 2013; Muhmood et al., 2014; Rahman et al., 2011; Shahbaz et al., 2014; Shaheb et al., 2015; Shaheb et al., 2017; Mofokeng et al., 2020). However, variation between their scope and approach is large, sometimes leading to contrasting results.

The main objective of this activity is to collect and review data on successful bio-slurry and BEC use in the project area. The structure of the report is as follows. First, the methodology that is followed is described in Chapter 2. Results are presented in Chapter 3, followed by a Discussion (Chapter 4). Some conclusions are presented in Chapter 5.

2 Methodology

The literature review database was established through an extensive desk survey and a subsequent analysis of gathered sources.

2.1 Data collection

Literature collection started by examining existing literature within databases of the project partners and with the search for external sources. For the external sources, online databases and search engines such as Academia, Google Scholar, JSTORE, ResearchGate, ScienceDirect and Wiley Online Library were all utilised along with different university libraries for dissertations. The search further included conference proceedings along with social media (Twitter, LinkedIn, YouTube, and Instagram). The search was not narrowed to a single discipline but covered a variety of different fields such as agronomy, economy, social sciences, and health science.

The search was conducted in English for Kenya and Uganda and in English and French for Burkina Faso, Mali and Niger. To narrow the search results, key search terms were determined such as biodigester, digester, bio-slurry, bio-slurry, slurry, effluent, compost, organic fertiliser, fertiliser, bioenergy, biomass, Africa, East Africa, Uganda, Kenya, Sub-Saharan Africa, Mali, Niger, and Burkina Faso. The search words were employed with Boolean operators to specify the search and included "AND", "OR", "-", "~" and quotation marks. Examples include "Biodigester AND Uganda" and "bio-slurry OR bio-slurry". The literature collection yielded a total of more than publications.

When relevant papers that had recently been published were identified, the usage of backward snowballing was implemented: the citations within the relevant paper were used for inspiration to find other suitable publications. The method of forward snowballing was implemented, using Google Scholar to identify publications that cited relevant papers. The Google Scholar function of "Search within citing articles" ensured that the most relevant publications were identified using the afore mentioned Boolean operators.

2.2 Analysis

The selected publications were entered in an Excel spreadsheet and categorised by geographical region and with respect to which data were provided on bio-slurry and/or compost use. Relevance for the project was expressed in a score ranging from 1 to 4 (Annex II). A colour scheme was used to highlight the most relevant publications (score of 3-4). A few dozen of highly relevant publications were found that cover the target countries. Further, five publications were found referring to other parts of Africa while some publications with origins outside of Africa were also included, yielding thirty publications with a relevance score of either 3 or 4.

Publications were classified identifying study type, crop coverage, data on crop yield, cropping system, compost type, feedstock, biodigester type, markets, gender, and safety. The most important information for the different elements were documented in an database, enabling a comparative analysis (e.g., on what crops bio-slurry was most applied within the selected studies). Summaries were written for each of the publications along with remarks that highlighted useful elements stakeholders to quickly overview the contents of each publication. The literature database provides an overview of relevant publications on bio-slurry and/or compost use in target countries, offering additional information on specific topics of relevance to the project.

In this report, a distinction is made between short and long term effects. The former refer to the provision of nutrients that are needed for crop growth. Long term effects include impact on soil structure (soil organic matter, water holding capacity, CEC) and soil life (bacteriae and fungi). This study restricts itself to short term effects; long term effects are discussed elsewhere.

3 Results

Thirty-one publications with a relevance score (Annex I) for the project of 3 or 4 were selected. Table 2 shows the share of publications that deal with various category of interest. From the studies that have been selected, nine present results for Kenya, nine for Uganda, five for Burkina Faso, two for Mali and two for Niger. Some cover multiple countries. Three studies provide results outside of the African continent.

Table 2: Type of information presented in the selected studies

Region	Product	Feedstock	Composition	Crop type	Soil data	Yield	Safety	Gender	Remarks
Kenya	All	4	7	3	3	2	4	2	Total 9
Uganda	All	5	6	7	4	5	2	1	Total 9
Burkina Faso	All	1	2	3	1	2	0	0	Total 4
Mali	All	1	1	1	1	1	0	1	Total 2
Niger	All	1	1	1	1	1	0	2	Total 2
Other Africa	All	4	5	4	1	2	3	1	Total 5
All studies	Bio-slurry	26 87%	19 63%	18 60%	9 36%	12 40%	9 30%	6 20%	Total 26 studies
All studies	Compost	22 73%	5 17%	18 60%	11 37%	12 40%	9 30%	6 20%	Total 22 studies
All studies	All	21 70%	22 73%	18 60%	11 37%	12 40%	9 30%	6 20%	Total 31 studies

A detailed overview of the contents of the main studies is presented in Table 3. Most studies provide data on bio-slurry application; 22 studies present information on compost of which four refer to BEC. The feedstock is mostly manure (18 studies or 60%). Four studies present data on agricultural residues and another four on household waste. Two thirds (73%) of the studies present data on nutrient composition. Only five studies refer to the fertiliser value. Eighteen of the studies (60%) provide data on crop production, where maize was the most represented crop with eight studies. Only twelve studies provided data on yield. Soil descriptions were presented in 11 studies. Safety issues of bio-slurry handling and application were described in 9 studies. Finally, six studies addressed the gender aspects.

From the selected studies, a further selection has been made to the most prominent scientific studies which have been summarised in Table 4. Special attention was given to the composition and fertiliser value of the bio-slurry with the application and yield effect on different types of crops. In those 5 papers, the gender aspect is very little discussed which is also reflected in Table 2 with only 6/31 studies addressing gender. Laban et al. (2017) refer to the fact that women are the majority of the agricultural workforce (in Uganda) which forms a problem as the application of bio-slurry is challenging for women.

The main findings of the selected studies reveal an increase in cut flower yields by 60% after application of vermicompost and bio-slurry in Ethiopia (Nyakeyo et al.; 2021). Data presented for Kenya (Rewe et al., 2021) and Uganda (Komakech et al., 2015; Laban et al. 2017) suggest maize yield can be raised by 59% to an astonishing 220%. Considerable yield effects are also reported for cabbage (70%) and coffee (66%; data by Laban et al. (2017), while eggplant yields in Uganda increased by 77% after bio-slurry application (Nanyanzi et al.; 2018)

Table 3: Detailed overview of the contents of the main studies

Source	Country or region				Bio-slurry, BEC			Feedstock			Nutrients		Crops		Yield	Soil type	Safety	Gend
	Kenya, Uganda	Burkina Faso, Mali, Niger	other Africa	global studies	bio-slurry	BEC	other compost	manure	agric. residue	household waste	Nutrient concen-tration	fertiliser value	maize, cereals	oth				
Hamlin, 2012	X				X			X									X	X
Kirawa, 2020	X				X			X		X	X						X	
Kirawa et al., 2020	X				X			X		X	X						X	
Nyakeyo et al., 2021	X				X		X			X	X	X		X	X	X		
Nyang'au et al., 2016	X				X		X	X			X	X						
Nzila et al., 2015	X				X				X		X							
Postma & Zhang, 2016	X				X		X	X			X		X	X		X		
Rewe et al., 2021	X				X		X	X			X		X		X	X		
Wamwea, 2017	X				X			X									X	X
Asiimwe, 2015	X				X		X							X				X
Komakech et al., 2015	X				X		X	X			X	X	X		X	X		
Laban et al., 2017	X				X	X	X	X			X		X	X	X	X	X	X
Lutaaya, 2013	X				X			X						X				
Nanyanzi et al., 2018	X				X		X	X			X	X		X	X	X		
Nyanzi, 2011	X				X		X											
Pius, 2021	X				X		X	X	X		X				X			

Tumuhimbise, 2021	X				X		X				X			X	X	X		
Warnars & Oppenoorth, 2014	X				X		X				X			X			X	
Kinyua et al., 2016	X		X	X	X		X	X			X			X	X		X	X
Kouya-Takala et al., 2019	X				X		X	X		X	X			X	X		X	
Mofokeng et al., 2020	X				X	X		X			X		X					
Schoeber et al., 2020	X				X	X		X			X			X			X	
Smith et al., 2014	X				X		X				X					X		
Aso, 2021				X	X		X		X		X			X			X	
Reuland et al., 2022				X	X		X	X	X		X					X		
PNB, 2016		X									X							
MRAH, 2014		X									X		X	X	X			
Ouedraogo, 2014		X			X	X	X						X	X	X			
Soalla-Kiagbe, 2019		X			X									X				
Abdou et al., 2017		X	X								X					X		
Sortmann and Sones, 2017		X	X			X	X	X										X
Stewart et al, 2020		x	X				X				X	X	X	X	X	X		X

Table 4: Summary results of some promising studies

Source	background	composition and fertiliser value	soil and crop type	application and yield effects	gender and safety	remarks
Nyakeyo et al., 2021	Trial with vermicompost (V) and bio-slurry (B), compared to untreated (U) control in Kenya during two seasons (S1, S2).	B: Ntirogen concentration 0.25% (S1) & 0.18% (S2). Phosphorus concentration 4.57 % (S1) & 5.96% (S2) Calcium concentration 3.97% (S1) & 3.78% (S2) Density 1.04 & 1.02 (g cm^{-3})	Statice (cut flower) on vitric mollic andosols soil	B applied at 7.8 ton/ha, or untreated control. Combined B & V had a larger impact on plant growth (+60%) than either alone. V made from 40% kitchen waste mixed with garden soil showed highest plant growth increase (compared to V with same amount of weeds or mowed grass).	Not included	B is high in potassium: 79 and 72 mg kg^{-1} (S1 and S2 respectively) More information given on B, V composition
Rewe et al., 2021	Experimental study on the effect of bio-slurry (B) from flexi and dome biodigesters on maize growth, yield and grain quality in Kenya	Nitrogen: same Phosphorus: fixed is higher Calcium: same pH: fixed is higher	Maize (Duma 43 varieties) on well drained acidic humic nitisols	Application rate 8,889L/ha. Dome B increased N, OC and maize grain yield by 9.4% and 6.3%, while exchangeable P and K and most of the grain nutrient content were higher in Flexi treated soils. Therefore, B from either biodigester type can be used in enhancing soil conditions, growth, yield and quality of maize.	Not included	Comparison of fixed domes and Flexi biogas digesters. Data of 2020 (long rains) used here; data for 2019 (short rains) also available
Komakech et al., 2015	Field experiment with vermi-compost (V), bio-slurry (B) and stored cattle manure (M) compared to unfertilised control in Uganda	Available Nitrogen concentration (g/kg DM): B (S1) 1.5 and (S2) 1.4. Stored M (S1) 18.5 and (S2) 19.6 V (S1) 21.4 and (S2) 12.7.	Maize hybrid variety Longe 5, on ferrasol with sandy loam texture	Maize growth and yield did not vary between fertiliser types, but improved significantly compared to unfertilized fields. Most effective organic fertilisers: V (+300% yield) in the first season and B (+220% yield) in the second season.	Not included	Two seasons (S1) & (S2)
Laban et al., 2017	Experiment with different forms of bio-slurry (B)(composted bio-slurry, liquid bio-slurry and dried bio-slurry) in Uganda	Compost bio-slurry (BEC): Nitrogen concentration 1.26% Phosphorus concentration 0.658 ppm Calcium concentration 0.701 ppm	Maize, cabbage & coffee, soil type unknown	Compost bio-slurry compared to unfertilized control: Cabbage: 10 t/ha, + 70% Maize: 10 t/ha, +59% Coffee: 10 t/ha, +65.6%	Women are the majority of agricultural workforce but B application poses challenge for women.	Experiments conducted over two seasons.

Source	background	composition and fertiliser value	soil and crop type	application and yield effects	gender and safety	remarks
Nanyanzi et al., 2018	Determine optimal rates of bio-slurry (B) and poultry manure (PM) application in Uganda	Not included	African eggplant (Solanum aethiopicum Shum), soil type unknown	Predicted optimum rate on yield of African eggplant compared to unfertilized control: PM: 24 t/ha, +85% B: 21 t/ha, +77%.	Not included	Experiment lasted two seasons.

4 Discussion

This chapter discusses the outcomes of the literature review. As Table 3 provides a very incomplete insight in the added value of bio-slurry and BEC application, yield effects will also be assessed in a more generic way.

4.1 Yield effects

Bio-slurry can be used in different ways to achieve agronomic benefits. It is rich in nutrients and often applied as soil amendment (Kinyua et al., 2016). It has the potential to be an important type of organic fertiliser. Applied in a semi-liquid form (Mofokeng et al., 2020) it improves soil fertility, soil structure, and crop productivity (Nasir et al., 2012; de Groot & Bogdanski, 2013; Haque 2013; Hossain et al., 2013; Muhmood et al., 2014; Rahman et al., 2011; Shahbaz et al., 2014; Warnars & Oppenoorth, 2014; Shaheb et al., 2015; Shaheb et al., 2017), as well as improving the nutritious value of the food produced on that soil (Wood, 2018).

The application of bio-slurry as fertiliser to cereal crops has been reported to increase production by 10% to 30% compared to ordinary manure (Gurung, 1998). Other studies compared bio-slurry effects to those of unfertilized plots or plots receiving mineral fertilizers. Maize yields in Uganda increased with 8% (compared to use of mineral fertilizers) to 38% (compared to unfertilized plots) (Laban et al.; 2017). Spring wheat yields were up with 31% in Ethiopia (Häfner et al., 2022). Yield effects for vegetables varied between 14% and 91%.

Crops that benefit most from bio-slurry and BEC are vegetables, root crops, potatoes, fruit trees, maize, and rice (Warnars & Oppenoorth, 2014). When compared to chemical fertilisers, bio-slurry shows a slower decomposition rate (Warnars & Oppenoorth, 2014). This results in nutrients being steadily released throughout the growing season, thereby creating a better environment for nutrient uptake for the plants (Smith et al., 2014).

Large variation in crop varieties, cultivation practices, soils, and application levels of bio-slurry and BEC make it very difficult to provide balanced yield assessments in the target countries. In order to overcome this problem, a table with generalized yield effects for major crop groups (cereals, grasses, vegetables, and other crops) is presented (Table 5). Results suggest bio-slurry application leads to an average yield improvement by 30% (cereals, vegetables), 25% (grasses), and 40% (coffee) comparing to unfertilized plots. In many cases, bio-slurry application was (almost) as effective as mineral fertilizers. A slight reduction of yields (1%-5%) was reported for cereals, grasses and vegetables. For coffee, bio-slurry is reported to be superior to mineral fertilizers but this figure is based on one study only.

Table 5: Generalized short term yield effects of bio-slurry application

	Cereals	Grasses	Vegetables	Coffee	Plantain
Compared to unfertilized plots	31%	27%	31%	44%	No data
Compared to plots receiving mineral fertilizers	-4%	-1%	-3%	17%	No data

Source: this study

Short term yield effects for application of BEC could not be assessed due to lack of suitable data. A first analysis suggests short term yield impacts for cereals and coffee may be superior to those of bio-slurry (and mineral fertilizers). No difference was found for vegetables.

4.2 Long-term impact

Long term yield effects were not quantified. Following van der Wurff et al. (2016), chemical fertilizers perform extremely well for short term nutrient availability. They are expected, however, to have a negative effect on soil life (Table 6). Fresh bio-slurry is slightly less favourable for nutrient availability but has a positive effect on soil structure and soil life. BEC seems to combine positive effects of bio-slurry and ordinary compost, improving short- and long-term nutrient availability while stimulating soil composition and soil life.

Table 6: Long term effects of different types of fertilisers

Effect	Chemical fertilizer	Manure	Bio-slurry fresh	Bio-slurry dried	Compost	BEC fresh
Immediate – chemical	Highly positive	Slightly positive	Positive	Slightly positive	Slightly positive	Positive
Long term - chemical	Negative	Slightly positive	Slightly positive	Slightly positive	Slightly positive	Slightly positive
Long term - physical	Moderate negative	Positive	Slightly positive	Slightly positive	Highly positive	Highly positive
Long term - biological	Negative	Positive	Positive	Positive	Highly positive	Highly positive

Source: adapted from van der Wurff et al. (2016)

4.3 Gender

Women constitute 43% of the agricultural workforce in developing countries, ranging from 20% in Latin America to 50% in Eastern Asia and Sub-Saharan Africa. On the other hand, the persisting gender gap in access to and control of resources remains an important concern which has not only kept women in a vicious circle of low productivity but also has thrown up questions about inclusive and sustainable growth of the sector. A report by the FAO 2011 shows that if women had access to the same productive resources as men, women could boost yield by 20-30%, raising the overall agricultural output in developing countries by two and a half to four per cent. This gain in production could lessen the number of hungry people in the world by 12-17 per cent, besides increasing women's income (FAO, 2011).

Women's involvement in agriculture is diverse and complex. Unlike their male counterpart, women are involved in a wide range of activities in agriculture as well as at home. However, the spectrum of women's participation in agriculture is changing with the changing profile of agriculture and the development of the non-farm sector (Patil & Babus, 2018). The introduction of digesters and the selling of compost is such an example.

Social benefits that come with tubular digesters are discussed in the review by Kinyua et al. (2016). A decreased incidence of disease and decreased time demands for women are positive outcomes of implementation of tubular digesters. Due to social and cultural roles, women provide unpaid household labour by providing energy in activities such as firewood collection (Kinyua et al., 2016).

With the installation of anaerobic digestion systems, one third of the women spent the extra time participating in community and social activities. Biogas saved the women up to three hours each day, time that otherwise may have been spent on searching for firewood (Gautam et al. 2009). However, when it comes to compost and it's application Laban et al. (2017) show that in Uganda women represent the majority of the agricultural workforce. This means bio-slurry and BEC can increase the workload of women which may be challenging given their workload which generally already is high.

Other gender aspects related to bio-slurry and BEC can include:

1. Benefits partly have a longer-term character, yet women's access to land can sometimes be limited merely one or a few seasons, thus limiting their benefits
2. Long-term benefits could play a role getting access to (additional) access to finance which already is challenged for women
3. Biofertilizer is more bulky than chemical fertiliser; women are more challenged in getting to access on-farm transport
4. Potential gender trade-offs in biodigester investments; while cooking benefits generally are for women, men may claim the use of bio-slurry and BEC.

4.4 Safety

Although bio-slurry has been promoted for its ability to function as a cheaper and more environmentally friendly alternative to chemical fertilisers in the developing world, there are still many farmers who are unfamiliar with its potential risks (Warnars & Oppenoorth, 2014). Studies on bio-slurry have reported no toxic or harmful effects on both soil and crops (de Groot & Bogdanski 2013; Shaheb et al., 2017) and the concentration of toxic heavy metals is very low compared to synthetic fertilisers (Kumar et al., 2015). However, just as with the nutritional value, the content of potentially toxic metals, pathogens, and viruses depends on the feedstock, retention time and temperature of the biodigester.

When used as foliar fertiliser (or pest management), the bio-slurry is sprayed directly on leaves. Although this application can increase yields, it does come with certain risks, as anaerobic digestion does not necessarily kill all pathogens, parasites, and viruses. This can form a health risk connected with applying bio-slurry based on manure origin directly onto food crops (Warnars & Oppenoorth, 2014). This risk further increases if for the bio-slurry, human faeces, have been used as a feedstock (Warnars & Oppenoorth, 2014). This project does not focus on bio-slurry originating from human faeces.

5 Conclusion

The main objective of this activity was to collect and analyse data on successful bio-slurry and BEC application in order to assess their potential value after application as organic fertilizers in existing cropping systems. A total of relevant 151 studies were found of which 31 were selected for further analysis. Data provided in these studies are, however, incomplete and do not provide a solid basis for a detailed quantitative assessment of bio-slurry and BEC impacts on crop yield.

A generalized assessment involving studies from various parts of the world suggests a yield improvement by 25% (grasses) to 30% (cereals, vegetables) and 40% (coffee) comparing to underutilised plots. In many cases, bio-slurry application appears to be almost as effective as chemical fertilizers in terms of short-term impact. Bio-slurry may be superior to mineral fertilizers for perennial crops including coffee. An assessment of short term BEC yield effects was not possible due to lack of data. Long term effects of organic fertilizers are more positive than those of chemical fertilizers which tend to reduce soil structure and particularly soil life.

These results suggest bio-slurry and BEC are potentially strong organic fertilizers with high relevance to replace or complement chemical fertilizers in many cases. Long term effects, to be determined, elsewhere, are expected to be superior to those of chemical fertilizers which makes them a crucial element of attempts to maintain or improve soil structure, soil life and soil production capacity. In many cases, however, effects of different fertilizer types cannot be easily compared. In the OFVI project, impacts of bio-slurry and BEC application are compared to alternative fertilization strategies using long term (10 year) modelling. Methodology and results are presented elsewhere (report for Inception 6).

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Annex 1: Selected publications

Table A.1: Overview of the source of each publication with a relevance score of 3-4

Author(s)	source	score
Kenya		
Hamlin, 2012	Independent Study Project	2
Kirawa, 2020	Dissertation	4
Kirawa et al., 2020	Journal of Engineering in Agriculture and the Environment	5
Nyakeyo et al., 2021	African Journal of Agricultural Research	5
Nyang'au et al., 2016	International Journal of Extensive Research	5
Nzila et al., 2015	Journal of Emerging Trends in Engineering and Applied Sciences	5
Postma & Zhang, 2016	NMI report	2
Rewe et al., 2021	International Journal of Plant & Soil Science	5
Wamwea, 2017	Dissertation	4
Uganda		
Asiimwe, 2015	Dissertation	4
Komakech et al., 2015	Journal of Agricultural Science	5
Laban et al., 2017	SNV/NARO end of project report	2
Lutaaya, 2013	Dissertation	4
Nanyanzi et al., 2018	Journal of Agricultural Science	5
Nyanzi, 2011	Abstract of paper from international congress	N/A
Pius, 2021	Dissertation	4
Tumuhimbise, 2021	Dissertation	4
Warnars & Oppenoorth, 2014	Book	3
Sub-Saharan Africa		
Kinyua et al., 2016	Renewable and Sustainable Energy Reviews	5
Kouya-Takala et al., 2019	International Journal of Renewable Energy Source	5
Mofokeng et al., 2020	South African Journal of Plant and Soil	5
Schoeber et al., 2020	Organic Agriculture	5

Smith et al., 2014	Biomass and Bioenergy	5
World		
Aso, 2021	Book chapter	3
Reuland et al., 2022	Agronomy	5

Annex 2: Fertilizer benefits and drawbacks

Table A.2: Benefits of application of manure, bio-slurry, compost and chemical fertilisers

	Manure	Bio-slurry	Compost	Chemical fertiliser
Soil erosion	Application of cow and poultry manure improves soil structure and avoids soil erosion	Bio-slurry application increases soil aggregate stability and may reduce wind erosion.	Better soil structure of more stable soil aggregates which is more resistant	
Nutrient imbalance and cycles	The addition of poultry and cow manure increase the total and available N, P, and K for enhanced microbial activity; the concentration of P increases and the adsorption by soil decreases	The liquid fraction of bio-slurry supplies large amounts of plant available N, P and K	Provides nutrients and increases nutrient holding capacity and enhances biological cycling through a better soil structure	Strong increase in immdiate or short term nutrient availability in specific required ratios
Soil salinization and alkalinizatio n	In saline soils, manure additions decreased soil salinity compared to control soils; however, in non-saline soils, the addition of poultry manure can increase the total soluble solids and particularly Na^+, K^+, $Mg^{2+,}$ SO_4^{2}, and Cl^-			
Soil contamina-tion and pollution	Addition of cow manure in soils contaminated with heavy metals (HM) can reduce their mobility and availability			
Soil acidification	The soil pH soil is slightly modified by adding organic amendments such as cow and chicken manure. Results showed an ambiguous response: slightly acidification or alkalization of the soil.	pH of bio-slurry generally is rather high, helping to combat acidification. In exceptional cases, bio-slurry can be slightly acidic.	Enhancing soil buffer properties and improving cation exchange capacity	

	Manure	Bio-slurry	Compost	Chemical fertiliser
Soil biodiversity loss	The addition of cow manure promotes fungal and bacterial diversity and microbial community structure	Few studies reported a positive, although short-lived, effect of bio-slurry on soil microbial diversity	Compost provides bacteria, fungi and carbon which allow an improved soil fauna and microbiology Good quality compost has a phytosanitary effect	
Soil compaction	Addition of chicken and cow manure for more than a year decreases soil compaction, increasing porosity and field capacity			
Soil water managemen t			Improved soil structure increases meso pores and water-holding capacity. Surface-applied compost keeps the soil surface moist	

Source: adjusted from FAO and ITPS (2021)

Table A.2: Drawbacks of application of manure, bios-slurry, compost and chemical fertilisers

	manure	bio-slurry	compost	chemical fertiliser
Soil erosion				May have a negative impact on soil structure, potentially affecting its stability
Nutrient imbalance and cycles	The excess in the manure addition may generate nutrient imbalance and risk of toxicity for nutrients excess			
Soil salinization and alkalinization	Some manure types, such as poultry or pig manure, may cause an excess of soluble salts and sodium	The salt concentration is sometimes high compared to animal manure due to easily degradable additives that give more energy, and acid and bases used in the processes.		

	manure	bio-slurry	compost	chemical fertiliser
Soil contamination/ pollution	Manures may contain heavy metals, and their long-term application may result in accumulation which could be a potential threat to human health.	The energy from oil rich wastes is often high in comparison to animal manure. A rather large amount of environmental rules and control by government is necessary in the Netherlands to protect against the use of energy-rich waste containing pollutants. Also in other countries there are various types of control, for example a certification in Germany, in necessary for soil protection.	Depending on the source of the composting ingredients (e.g. municipal waste), there can be a significant input of heavy metals, pesticides or organic pollutants. Likewise, the quality of the compost (degree of maturation) determines the mobility of heavy metal mobility.	May contribute to contamination of heavy metals
Soil acidification				Some important types have a strong impact on soil pH, leading to acidification in the long run
Soil biodiversity loss			Inadequately prepared compost (e.g. no heat phase in thermophilic compost) has negative phytosanitary effects and may degrade soil microbiology.	Have a negative effect on soil life
Soil compaction				May have a negative impact on soil structure

	manure	bio-slurry	compost	chemical fertiliser
Soil water management	The excess of manure, especially the uncontrolled application of liquid pig manure (pig slurry) or in general of liquid manures with low C/N ratios can be the cause of N pollution in groundwaters, may promote the runoff and lixiviation of nutrients and in general encourage eutrophication of aquifers and water bodies.			

Source: FAO and ITPS, 2021