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LONG-TERM IMPACTS OF NUTRIENT RECYCLING PROJECTS FROM HUMAN EXCRETA ON FOOD PRODUCTION IN WESTERN KENYA

Master thesis submitted
In partial fulfilment of the requirements
for the degree of

International Master for Natural Resources Management and Ecological Engineering

at
University of Natural Resources and Life Sciences (BOKU), Vienna, Austria and
Czech University of Life Sciences Prague (CULS), Prague, Czech Repulic

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Student number 01340017 24.10.2019

Acknowledgements

I want to thank Günter Langergraber, Priv.-Doz. Dipl.-Ing. Dr. nat. techn., from the Institute of Sanitary Engineering and Water Pollution Control that he put me into contact with Jakob Lederer, MA MSc PhD, of the Technical University of Vienna (TU), who offered the topic of this master´s thesis in cooperation with BOKU. Also, I want to thank him for taking over the main supervision of this thesis and his fast replies to any of my questions. In this context I want to thank Prof. Ing. Svatopluk Matula, PhD, from the Czech University of Life Sciences Prague (CULS) as well, who agreed to be my co-supervisor. For my second co-supervisor Mathew Hernegger, Dipl. – Ing. Dr. nat. techn., I am grateful too. He always helped me out when I asked for it and gave me helpful advice for my stay in Kenya. Here I also want to thank Doris Wimmer, who give me a lot of advice and medications for my stay in Kenya, and Hope Mwanake, who helped me with my questionnaire design.

The most important support came from my supervisors of TU Vienna and Moses Wakala, Eng. I really want to thank Moses for his professional support during my questionnaire survey in Kenya and that he and his family welcomed me so warmly. Through them I had the opportunity to collect many wonderful memories in Kenya. I would not have gotten to Kenya without the big support of Jakob Lederer, MA MSc PhD, who helped me a lot with the organisation of the trip and gave me important inputs for my master ´s thesis, thanks a lot. A very important person for this master´s thesis is Arabel Amann, MSc, my second supervisor at TU Vienna, who supervised me through the whole process of the master´s thesis. I really want to thank her for her detailed and valuable feedback and her great support when I had problems with my data.

The stay in Kenya was financed by the Förderungsstipendium of BOKU. I am very grateful for the financial support.

Table of contents

List of graphs

List of figures

List of tables

Abstract

A promising fertilizer source for farmers of Sub-Saharan Africa can be products of human excreta recycling. One sanitation technology for making the recycling possible is a urine-diverting dry toilet (UDDT). There are several implementation projects of this technology in Africa and many short-term studies and experiments regarding their use and the fertilizing effect of the UDDT products. However, the long-term impact of these human excreta recycling projects on agricultural production in an environment that is not controlled, is unknown. Consequently, this master´s thesis is dealing with the long-term evaluation of nutrient recycling projects and their impact on crop production and food security of smallholder farmers. 94 farmers, who were beneficiaries of an UDDT implementation project between 2006-2010, were interviewed in Western Kenya. The questionnaire survey showed that 50% of the interviewed owners still use the UDDT and 50% do not use it anymore. The main problems were lack of training and missing of a long-term local support network. However, the most common driver for the continuing use of the UDDT is the fertilizer itself. To show the impact of the fertilizer on crop production and food security, a graphical analysis and a Material Flow Analysis (MFA) were conducted. Both methods showed that UDDT products can be an important complement to increase the nutrient input, the agricultural production and in further consequence the food security of a farming household in Western Kenya since the use of inorganic fertilizer is very low in this area. The results could also be valid for other regions in Sub-Saharan Africa.

Kurzfassung

Eine vielversprechende Düngerquelle für die Bauern in Afrika südlich der Sahara sind Nährstoffrecyclingprodukte aus menschlichen Exkreten. Eine Sanitärtechnologie, die dieses Recycling möglich macht, sind sogenannte Trockentrenntoiletten (Urine-Diverting Dry Toilets - UDDTs). In Afrika gibt es für diese Technologie unzählige Implementierungsprojekte und zahlreiche Studien und Experimente, die sich mit den kurzfristigen Folgen dieser Projekte und den Effekten des aus der Trockentrenntoilette gewonnenen Düngers auseinandersetzen. Die Langzeiteffekte von diesen Implementierungsprojekten und die Auswirkungen von der Nutzung des Düngers in einem nicht kontrollierten Umfeld sind nur wenig erforscht. Demnach beschäftigt sich diese Masterarbeit mit der Langzeitevaluierung dieser Projekte und den Auswirkungen des Düngers auf die landwirtschaftliche Produktion und die Ernährungssicherheit von kleinbäuerlichen Haushalten. 94 Bauern, die ein Teil eines UDDT Implementierungsprojektes zwischen 2006-2010 waren, wurden in Westkenia interviewt. Die Auswertung dieser Befragung ergab, dass 50% der Bauern die Toilette noch benutzen und 50% diese nicht mehr nutzen. Als Hauptprobleme wurden der Mangel an Training und das Fehlen eines langfristigen lokalen und professionellen Unterstützungsnetzwerks identifiziert. Der meist genannte Grund für die Weiterbenützung der Toilette sind die Toilettenprodukte selbst. Um den Einfluss des Düngers auf den Ernteertrag und in weiterer Folge auf die Ernährungssicherheit zu zeigen, wurde eine graphische Analyse und eine Materialflussanalyse (MFA) durchgeführt. Beide Analysen zeigten, dass der UDDT Dünger eine wichtige Ergänzung für die kenianischen Kleinbauern sein kann, um den Nährstoffinput zu steigern sowie den Ernteertrag und die Ernährungssicherheit zu erhöhen. Vor allem unter dem Aspekt, dass die Nutzung von Mineraldünger in der Gegend sehr gering ist. Die Ergebnisse könnten auch für andere Regionen in Sub-Sahara Afrika gültig sein.

Abbreviations

CAN	Calcium Ammonium Nitrate
cap	Capita
DAP	Di-Ammonium Phosphate
DM	Dry mass
K	Potassium
MFA	Material Flow Analysis
N	Nitrogen
NPK	Nitrogen-Phosphorus-Potassium fertilizer
O & M	Operation and Maintenance
P	Phosphorus
ppd	Persons per day
SD	Standard deviation
UDDT	Urine-diverting dry toilet
WM	Wet mass
yr	Year

1. Introduction

Due to our worldwide growing population and climate change, issues of declining food security are on the rise. Extreme weather events and a long-term change of temperature and precipitation patterns make especially agriculture-based livelihood systems vulnerable and food insecure (FAO, 2008). The increasing pressure on limited land resources and the overexploitation of arable land, driven partly by a growing population, worsen the food security even more (Population Action International, 2011).

Especially in Sub – Saharan Africa food security is an urgent topic to deal with. On the one hand, the area has currently the highest population growth in the world and on the other hand they have to deal with poor productivity in agriculture, which leads to problems with food security (Tittonell and Giller, 2013; World Bank, 2013).

There are many causes for limited agricultural productivity. One of them is nutrient depletion through consistent harvesting and low agricultural inputs that lead to a higher export of nutrients out of the soil than import into the soil. Consequently, a negative soil nutrient balance can be observed and furthermore, a low soil fertility occurs (Stoorvogel et al., 1993; Tittonell and Giller, 2013).

One solution to this problem is be an integrated soil fertility management (ISFM), where one strategy is the application of modest amounts of mineral fertilizers. However, often farmers, especially smallholder farmers, cannot afford fertilizers (Stoorvogel et al., 1993). A promising alternative could be the use of human excreta, as several studies on Sub – Saharan African agriculture show (e.g. Mnkeni and Austin, 2009; Lederer et al., 2015; Harada et al., 2018)

This fertilizer source could also be promising for the highlands of Western Kenya, where one of the densest rural populations in the world can be found and where nutrient depletion through crop harvesting, leaching and soil erosion is a common problem (Shepherd and Soule, 1998).

Several sanitation projects have been implemented in context with human excreta recycling in Kenya, and some considered urine-diverting dry toilets (UDDT) (von Muench, 2011). Urine-diverting dry toilets collect urine and faeces separately. Urine can be used – directly or after a certain storage time – for fertilization in agriculture. Faeces can also be used after they are stored and dried (Rieck et al., 2013).

The sociocultural acceptance and use of UDDTs in rural Kenya were evaluated in several studies (e.g. Mbalo and Brand, 2012; von Muench, 2011; Pynnönen et al., 2012; Uddin et al., 2012). These studies were mostly done 2 - 5 years after the implementation of UDDTs. Also, some short-term lab-based studies and experiments on trial crops were conducted to prove the possible fertilization effect of products of the UDDT toilet (e.g. Robinson, 2005; Mnkeni and Austin, 2009; Kraft, 2010). However, the long-term impact of human excreta recycling on agricultural production by using UDDT products in an environment that is not controlled like in trial crops, is unknown. In conclusion, long-term evaluations of implementation projects and their impact on food production are missing.

Due to this deficit the main topic of the master’s thesis is the long-term impact of nutrient recycling projects from human excreta on the food production of smallholder farmers in Western Kenya. Nutrient recycling projects in this context is the recycling of human excreta of UDDT implementation projects.

A case study of an UDDT implementation project in Western Kenya should help to analyse the possible impact. Between 2006 – 2010 as part of the Ecological Sanitation Promotion Programme (EPP) 658 UDDTs were constructed for farming households all around rural and peri-urban areas in Kenya. The programme was implemented by GIZ Kenya and financed mainly by the European Union. Focus of the implementation of the UDDTs were among others the Western provinces of Kenya, where the research region is also located (von Muench, 2011).

The fertilization aspect of the UDDTs can be very important for the beneficiaries of the toilet, who are mostly smallholder farmers and have to deal with low productivity due to low input of nutrients. Mineral fertilizers, however, are too expensive. Consequently, human excreta are an alternative source of nutrients and a step to a higher food security for this area (Shepherd and Soule, 1998; von Muench, 2011).

1.1 Objectives

The following research questions will be covered in this thesis:

1. Is there a long-term use of urine-diverting dry toilets and their products as fertilizer in UDDT implementation projects?
2. What are barriers and drivers for the use of the UDDT toilets and excreta?
3. What is the impact of the use of human excreta as fertilizer on crop production and food security of participants of UDDT implementation projects?
4. How sustainable is the use of human excreta from UDDT toilets in agriculture?

The main source for answering the research questions will be a questionnaire survey, where 94 smallholder farmers of the already described EPP project will be interviewed. With the data of the questionnaire survey and an additional literature research the following methods that should support the finding of the answers to the research questions can be developed:

1. A graphical and mathematical analysis of the data of the questionnaire survey to answer the question concerning the long-term use and the barriers and drivers of the use of UDDT toilets and excreta as fertilizer.
2. A graphical analysis and a material flow analysis to show the impact of the use of UDDT products as fertilizer.
3. A short sustainability assessment to evaluate the sustainability of the use of human excreta from UDDT toilets.

1.2 Structure

The detailed description of the used tools in this master’s thesis can be found in the chapter “Material and Methods”. However, prior to that chapter some basic information should help to understand the technology and the context, in which the master’s thesis is embedded.

After the description of the used material and methods, the results of the questionnaire survey are represented in three main parts. The first one deals with the use of the UDDT itself and how the farmers use human excreta as a fertilizer. The second part covers the effect of human excreta on food production and the last one contains a sustainability assessment of the human fertilizer. Finally, the results are discussed and summarized.

2. Fundamentals

2.1 Smallholder farming in Kenya

Around 80% of all farmers in Kenya are smallholder farmers (FAO, 2005). They produce 63 % of the food in the country. These farming households have around 0.5 ha. In average 7 people live in one household, whereby at least two of these seven are younger than 14 years. The farms have an average gross income of 2527 $ per year (Rapsomanikis, 2015). Most smallholder farmers in Kenya use their agricultural products for self-consumption, but if they have an excess production they also sell their products (IFDC, 2012). After the FAO (2005) 25% of the agricultural production of a smallholder farm is sold. Agricultural production includes animal and crop products.

Smallholder farmers in Kenya own a significant part (55%) of the total livestock in the country (Rapsomanikis, 2015). The main livestock are cattle, sheep, goats and poultry (FAO, 2017). In the crop production the most grown crop is maize. Other common crops for smallholder farmers in Kenya are sorghum, millet, cassava, potatoes, beans, bananas and vegetables (Rapsomanikis, 2015). They normally achieve an average maize yield from 0.5 to 1.5 t/ha (IFDC, 2012). This harvest is really low, especially if it is compared to the maize harvest in Austria, where farmers can yield around 10 t/ha of maize (BMNT, 2017). The low harvest of Kenyan smallholder farmers can partly be explained by the low to zero fertilizer input. However, the farms could achieve 3 to 6 t/ha under appropriate agronomic practices and improved technology (IFDC, 2012).

Part of the appropriate agronomic practices is the application of fertilizer. Kenyan smallholder farmers often rely on animal manure as fertilizer, but like Onduru et. al. (2008) found out for the sub-humid and semi-arid area in Kenya the manure management is very variable and often poor. If there is a use of inorganic fertilizer the smallholder farmers mostly apply it on maize (Ariga et al., 2008). The most used fertilizer types for maize are DAP, Monoammonium phosphate, NPK, CAN and UREA (IFDC, 2012). According to a study of Ariga et.al. (2008) smallholder farms apply around 59 kg per acre (148 kg/ha) on their maize crops. However, compared to other studies this number seems quite high. Chianu et al. (2012) assumed that a Kenyan farmer applies in average 29 kg/ha of inorganic fertilizer on their farms. In a study of Kibunja et al. (2017) it is stated that Kenyan farmers apply 50 kg/ha of nutrients on their maize crops. For comparison in Western Europe the fertilizer application for grain maize ranges from 45 to 230 kg/ha (Isherwood, 2010).

2.2 Urine-diverting dry toilets (UDDTs)

2.2.1 Principles of the UDDT

The main principle of an UDDT is that it separates the urine and the faeces at the so-called user interface. It can be a squatting pan or a specially designed toilet seat, where the faeces fall into a drop hole and the urine goes to a urine hole. There are four different types of UDDTs. The differentiation is based on the method of faeces collection. The list below should give an overview of the types of faeces collection and management (Rieck et al., 2013):

1. **UDDT with double dehydration vaults:** Faeces are collected in two vaults, that are used alternately. The faecal matter gets dehydrated trough storage in the vaults.
2. **UDDT with a single vault with interchangeable container:** The faeces are collected and stored in containers. However, the pathogen load cannot be reduced only by storage and mostly requires a post-treatment for removal or use of the faeces.
3. **UDDT with shallow ventilated pits:** The simplest form of UDDT. Faeces are collected in a shallow pit, where they get naturally mineralised and composted. It is not a widely used technology, because it is necessary to move the structure when the pit is full and it can be implemented safely only in areas with a low water table and a minimal threat of flooding.

4. **UDDT with composting vaults:** Faeces are collected in one large, well-ventilated vault or container system. For the composting process a certain moisture content and a carbon-nitrogen ratio is needed. This can be achieved through adding extra organic materials, like kitchen or garden waste (Rieck et al., 2013).

2.2.2 UDDT with double dehydration vaults

The UDDT with double dehydration vaults is described here in more detail because an improved understanding of this technology is relevant for the master's thesis. As mentioned before the faeces are collected in two faeces vaults. The advantage of two drop holes is that the storage and handling of the faeces is easier, because after one faeces vault is filled, the drop hole that is above the other faeces vault can be opened and used. During the usage of the second faeces vault the first one is closed and not used anymore. Through this procedure the faeces can dry assisted by a ventilation pipe (von Muench, 2011; Rieck et al., 2012).

To enhance the drying process mostly ash is added to the faeces after each use. The ash is not only absorbing the water, it also controls the odour, prevents insect infestation and provides a visual barrier. Furthermore, it increases the pH of the faeces. After the second faeces vault is filled, the first one is already dried up and ready for usage (Rieck et al., 2012). For hygienic reasons it is recommended to store the faeces at least around 6 to 12 months. Most pathogens die off during this storage time. The faeces vaults can be emptied with a shovel or something similar and can be used as a fertilizer (WHO, 2006; Rieck et al., 2013).

The urine hole of the squatting pan is connected to a urine vault with a piping system, where the urine is collected or infiltrated. If the urine is collected it can be used directly for fertilization (Rieck et al., 2012), although, a study of Richert et al. (2010) recommends one or two weeks of storage to reduce the risk of possible pathogenic contamination. Jönnson et al. (2004) recommend diluting the urine with water to decrease the risk of application of too much urine so that it has a toxic effect on the crops.

2.3 The effect of the UDDT fertilizer

There are already several papers and reports that analyse the impact of human excrements as a fertilizer on agriculture. The focus of this literature research will be on Sub-Saharan-Africa due to the variance in the composition of excreta between different regions depending on the nutrition of the population (Jönsson et al., 2004). Harada et al. (2018) assessed that farmers, who use the fertilizer, observe a positive effect on the agricultural yield through the application of human excreta. They conducted a study in 227 rural households in Malawi, where UDDTs were constructed between 2007 and 2014. The potential of human excreta as a valuable fertilizer could not only be determined via personal estimations of farmers. For example, a material flow analysis (MFA) for the agricultural land of Busia District in Uganda from Lederer et al. (2015) showed a high potential of human excrements to reduce the soil nutrient deficits in Uganda. The data for this MFA analysis was generated through collection of own data and a detailed literature research.

These outcomes can be supported through lab results and field trials that are showing valuable amounts of nutrients in human excreta. **Table 1** shows examples for lab results, where the nitrogen and phosphorus content of urine and faeces from dry toilets was measured.

Table 1 *Examples for measurements of the N- and P-content of urine taken from dry toilets in Kenya compared to measurements of the N and P content in faeces in a field trial in Eastern Cape Town.*

Nutrient type	Quantity Urine (g/l)	Quantity Faeces (g/kg)
N	2.49* (Kraft, 2010)	18 (Mnkeni and Austin, 2009)
N	1.67* (Robinson, 2005)	
P	0.15 (Kraft, 2010)	3 (Mnkeni and Austin, 2009)
P	0.25 (Robinson, 2005)	

* only the NH3-N was measured

For the urine values it can be assumed that there is a higher total N content, because both studies only analysed the NH_3 ratio of urine. However, the biggest amount of N in urine is available in form of urea. Urea is changed trough urease to NH_3 in the soil. Consequently, urine has a high amount of nitrogen and can be a low-cost alternative for N-rich mineral fertilizer in plant production. Urine also contains a high content of phosphorus and potassium, "[…] but due to its large content of N, its P/N and K/N ratios are lower than in many mineral fertilizers used for vegetable production" (Jönsson et al., 2004).

The improvement of the soil productivity through the application of faeces was assessed in the already mentioned paper of Mnkeni and Austin (2009). They tested the nutrient content in soil after they applied the human manure on a cabbage trial crop in South Africa and compared the yield from trial crops, where they applied goat manure and mineral fertilizer. Results showed that dry human faeces achieved a higher yield than goat manure, but a lower one than mineral fertilizer. The higher effectiveness of faecal matter compared to goat manure can be explained through the higher potassium (K) and phosphate (P) content. However, human manure was a poor source of nitrogen (N).

Similar conclusions can be found in the general guidelines for the use of faeces in crop production from Jönsson et al. (2004). However, in this widely accepted report it is stated that faeces have a lower nutrient amount than urine. **Table 1** shows different results, but here it must be mentioned that in **Table 1** the concentrations are given and Jönsson et al. (2004) assesses the total nutrient quantity that can be collected per person during a day. The results of a study of Harada et al. (2018) can be a further indication, besides the results of **Table 1,** that faeces have a higher impact on the nutrient household of farms than urine. They assessed that 98% of the farmers believed that the yield increased using faeces as fertilizer. Only 44% of the farmers believed in an increase of the harvest with the application of urine.

Nevertheless, Jönsson et al. (2004) concludes, like Mnkeni and Austin (2009), that faeces have a high concentration of P and K. Since P is very important for the development of plants and roots, it is recommended to apply the fertilizer before sowing or planting (Jönsson et al., 2004).

The best time for the application of urine is before the reproductive stage of the crop, after this stage the plant nearly takes no nutrients up. The impact on the yield depends on several factors, like the organic content of the soil. If the organic substance is low then the effect of urine is probably also lower (Jönsson et al., 2004).

A harvest improvement through the fertilization with human excrements, especially of urine, was observed in several field trials conducted all over the world. **Table 2** is showing some examples of these improvements.

***Table 2** Comparison between harvest without fertilization and harvest with fertilization of urine or faeces.*

Type of fertilization	Harvest without fertilization	Harvest with fertilization	Crop	Country	Source
Only urine	875 kg/ha	1500 kg/ha	Amaranth	Mexico	Jönsson et al., 2004 after Clark, 2003
Only urine	17 t/ha	51-54 t/ha[1]	Leeks	Sweden	Jönsson et al., 2004 after Bath, 2003
Only urine	230 g fresh weight	500 g fresh weight	Lettuce[2]	Zimbabwe	Morgan, 2003
Only urine	1680 g fresh weight	6084 g fresh weight	Tomatoes[2]	Zimbabwe	Morgan, 2003
Only faeces	45 t/ha	49-58 t/ha*	Cabbage	South Africa	Mnkeni and Austin, 2009

*Depending on the rate of kg N/ha that is put out through the fertilizer application
[1] Depending on how often urine was applied on crops
[2] Plants were planted in 10-litre cement basins not on fields

Dagerskog et al. (2014) estimate the effect of recycling human excreta on the crop production for Sub-Saharan Africa. They assume that an increase of around 50 kg of cereals per person per year is possible. This increase could cover the energy requirement for a person throughout 71 days.

The possible fertilizer effect of human excreta cannot only raise the harvest, but also has the potential to replace or at least complement mineral fertilizers and consequently, can help farmers to save money. A study of Dagerskog and Bonzi (2010) found that the annual N and P content in urine and faeces from a family of ten persons in Burkina Faso corresponded to a quantity of N and P in 50 kg urea and 50 kg NPK (14-23-14). Consequently, the family could save 80 $ in Burkina Faso. However, the influence of the UDDT fertilizer on the farmers economic situation depends on, for example, the economic status or the size of the farm (Robinson, 2005; Meinzinger et al., 2009).

2.4 Barriers and drivers for usage of UDDT and of the fertilizer

The discussed barriers and drivers for the usage of the UDDT and of its fertilizer focus on the household level in rural areas. For urban areas and big scale projects like schools and other public places, other aspects may be important.

To ensure the use of the UDDT and the fertilizer, proper training for the utilisation and the specific operation and maintenance activities is essential. The system with separate holes for faeces and urine may not always be intuitive for users, who are used to so-called “drop-and-forget” or “flush-and-forget” systems (Rieck et al., 2012).

However, the training is not only important in the planning and construction phase of the toilet, it is also important to have follow-up training sessions for open questions regarding the use of the toilet itself and the application of the fertilizer. In several UDDT implementation projects it was reported that a long-term support could assure the sustainability of the project (Brikke and Bredero, 2003; Mulonga, 2007; von Muench, 2011). One recommendation is to have an information session 1.5 years after the construction. This time span considers the start-up phase of the use of the toilet and a full cycle of faeces recycling. Consequently, confusion regarding the utilisation of the fertilizer can be solved and support for technical issues, that occur after some time, can be offered (von Muench, 2011).

Several projects showed that a local support network plays an important role for a continuing use of the toilet, because it provides not only the technical knowledge, it also has an influence on the community and the ability to mobilise and sensitise the local households regarding sanitary issues. Furthermore, it is essential that the responsibilities within the project team and the local network in all the phases of a project are clear to the owners of the UDDT. Especially, if there are any problems during the construction, the implementation and the utilisation phase (von Muench, 2011; Mbalo and Brand, 2012).

However, not only the support structure is important for the sustainability of an UDDT implementation project, it is also essential to create an ownership of the toilet. This can be achieved for example through contribution of the future owner to the financing of the UDDT and/ or contribution of unskilled labour for construction. Another aspect is the involvement of the users in the choice of sanitation technology and the toilet design. This community participation is not only increasing the feeling of ownership, it also enhances the knowledge about the use and the technology (Brikke and Bredero, 2003; von Muench, 2011).

Social and cultural barriers are quite common when it comes to handling human excreta. An example for such barriers is that it is not allowed to handle the faeces of daughters- or sons-in-law. Nevertheless, these barriers can be overcome through awareness raising, training and public education. These sensitivity actions can also help to resolve negative perceptions of neighbours and potential customers of crop products that are fertilized with human compost (Uddin et al., 2012). If training and other education programs are successful, UDDTs can even rise to prestige objects, like it was reported in several projects (Robinson, 2005; Mulonga, 2007; von Muench, 2011).

If it is not considered in the design of the UDDT, the use of it can be difficult for special users like old people and young children, because for young children the urine basin and the faeces hole may be too big and old people are often not able to squat anymore. With some adaptations these obstacles can be removed. There are, for example, removable child seat adapters or movable constructions to make squatting easier for old people (Mbalo und Brand, 2012; Rieck et al., 2012). Problems can also occur if men are not willing to squat for urinating and urinate in the faeces vault. The solution for this specific problem could be solved with an additional waterless urinal. The misuse of visitors, who are not familiar with the concept of the UDDT, is reported as a common problem in several projects. This leads to mixing of urine and faeces (von Muench, 2011; Pynnönen et al., 2012; Rieck et al., 2013)

One possible driver for accepting the UDDT is the improved health and hygiene situation like Harada et al. (2018), Mbalo and Brand (2012) and Mulonga (2007) are reporting. Especially, the smell and the flies are really important factors here. If the toilet is used correctly the development of strong odours and flies can be prevented, which is a major advantage compared to the commonly used pit latrine (Pynnönen et al., 2012). However, if the toilet is poorly operated, for example if there is too little ash to cover the faeces, bad smell develops. This can lead to the abandonment of the toilet (Drangert, 2004; Pynnönen et al., 2012).

A main success factor for the uptake of an Ecosan technology can be adverse hydrogeological conditions, like rocky ground and high-water tables. These conditions lead to difficulties digging a pit latrine. The fact that the UDDT is a permanent structure, also helps to save space, because there is no need to dig new pits, when the old ones are filled up (Robinson, 2005; Mulonga, 2007; Pynnönen et al., 2012).

The positive uptake of using the UDDT fertilizer is supported through the so-called “seeing is believing” approach. If the owner of the toilet can observe the positive effects of the fertilizer in, for example, already existing projects, they are convinced of its usefulness and can also act as an opinion leader to change the attitude towards the UDDT in the community (Dagerskog and Bonzi, 2010; von Muench, 2011).

In the areas, where the UDDT has a good reputation, local replications are possible. But Uddin et al. (2012) point out the problem that the replication often depends on external financial contributions by donors. Most of the times the construction of an own UDDT is not affordable for low income earners without subsidies. A possible solution to this issue could be to offer cheaper designs and use more locally available materials. Furthermore, alternative financing mechanisms, like microfinancing and local community fundraising initiatives could help to get independent from external financing (Uddin et al., 2012).

However, the low maintenance costs and the additional benefit through the fertilizer can again be a driver for the use and even the replication of an UDDT (Uddin et al., 2012). The effect of the fertilizer is discussed more detailed in the previous chapter. The maintenance effort is quite low if the toilet is operated properly. Unfortunately, the UDDTs are often abandoned due to common and easy to solve problems, like clogging of the urine pipe (Rieck et al., 2013). Proper training and local UDDT experts, who are available for the owners of the toilet, could prevent this abandonment (von Muench, 2011; Mbalo and Brand, 2012).

In conclusion, the main drivers for the use of the UDDT and its fertilizer are a proper training of the beneficiaries, a local and long-term support network, improved health and hygiene conditions, the durability of the structure, the benefit of the fertilizer and the low maintenance costs and efforts. The main barriers are social and cultural concerns, problems with the use for special users, like young children and old people, misuse of visitors and the high construction costs for low income households.

2.5 Study area

The study area is located in Bungoma County (N 00° 35´E 34° 35´) and Kakamega County (N 00° 17´ E 34° 45´) in Western Kenya. Bungoma has a population of around 136 3000 inhabitants and Kakamega has around 164 3000 inhabitants. In both counties around 85 % of the population is living in rural areas (KNBS, 2013).

50.3 % of the inhabitants of Bungoma and 43.7 % of the inhabitants of Kakamega are working in family agricultural holdings. These numbers show that agriculture is an important sector in both counties (Ngugi et al., 2013a, 2013b). The income in this sector is around 172666 Kenyan Shillings (or around 1500€) per year and employee. It is only an estimation of the real average wage earnings for workers in agriculture, forestry and fishing from the national Kenyan bureau of statistics for the year 2018 and for whole Kenya (KNBS, 2019). Unfortunately, there is no information available regarding the income in the agricultural sector for each county. However, the estimated income of KNBS can give a good impression about the earnings of a farmer’s household.

The counties have two rainy seasons. One season brings heavy rains from March to July and the other one brings light rains from October to December. The minimum annual rainfall in Bungoma is 400 mm and the maximum is 1800 mm. In Kakamega the annual rainfall ranges from 1280 mm to 2214 mm. The temperatures in Bungoma depend on the altitude and range from 0 to 32°C. 0°C is the temperature of Mount Elgon, the highest peak of the county. In Kakamega the temperature ranges from 18-29°C (County Government of Bungoma, 2017; County Government of Kakamega, 2017).

The agriculture is mostly rain-fed, that means that the farmers only plant during the rainy seasons. Consequently, there are two harvest seasons throughout the year. The main crops in Bungoma are maize, beans, bananas, potatoes and finger millet. The most common cash crops are sugarcane, cotton, palm oil, coffee and sunflowers. The main crops in Kakamega are sugarcane, maize, beans, cassava, finger millet, sweet potatoes, tomatoes, bananas, tea and sorghum. Although, maize, sugarcane and tea are the most common cash crops. The main livestock in both counties consists of cattle, sheep, goats, pigs and poultry (County Government of Bungoma, 2017; County Government of Kakamega, 2017).

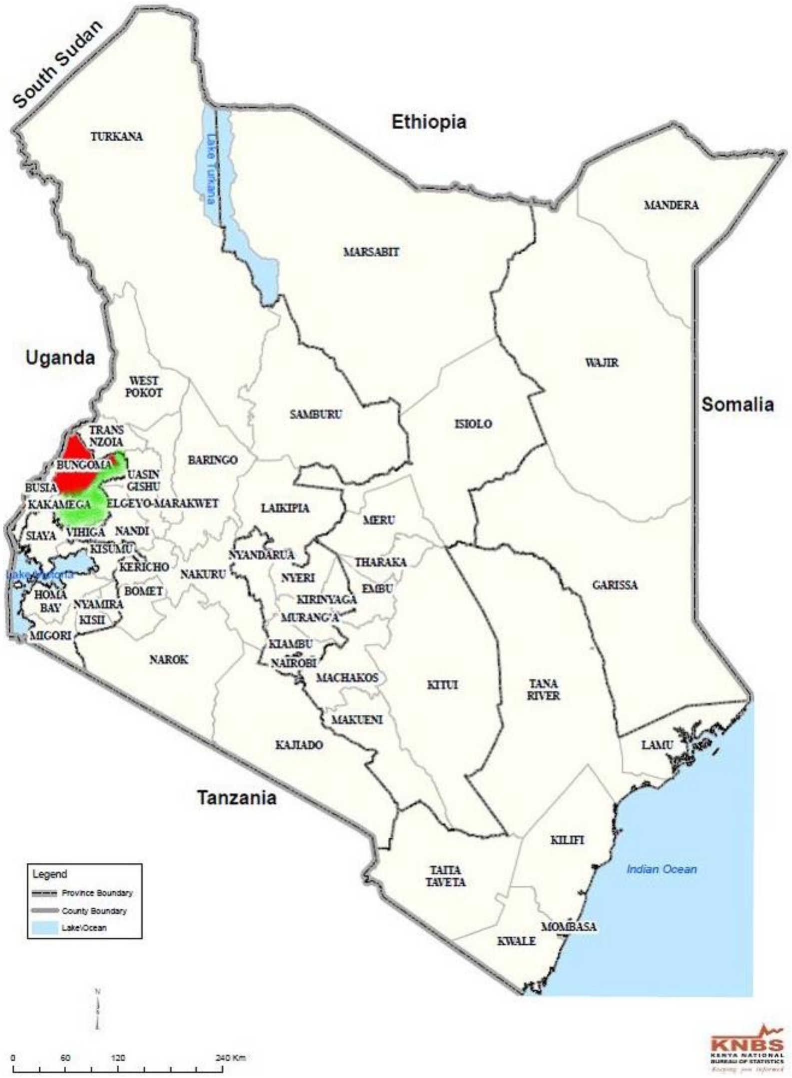


Figure 1 *Map of location of Bungoma County (red) and Kakamega County (green) after County Government of Bungoma, 2017 and County Government of Kakamega, 2017.*

2.6 The sanitation technology of the EPP project

In this chapter the technology of the EPP project is described only shortly, because most of the information can already be found in the literature review in chapter 2.2 “Urine-diverting dry toilets (UDDTs)”.

The sanitation technology that was implemented in the EPP project is a double vault urine diverting-dry toilet (UDDT) for around 20 users (von Muench, 2011). **Figure 2** below show how the UDDT was constructed in the project. The chosen user-interface here is a squatting pan, where it is possible to close the faeces hole, which is not in use, with a lid without a handle, so it is clear which dropping hole is currently used. For the drying process the owners of the toilet are trained to put ashes to the faeces after every use and store it for at least 6 months.

The urine hole of the squatting pan is connected with a flexible hose pipe to the urine vault, where the urine is collected in an empty jerry can, a container that is available in supermarkets and often used for storing cooking oil.

Additionally, a hand washing facility consisting of a 100-litre plastic tank with a tap placed on top of the urine storage vault, was installed. The water for this facility is provided through a rainwater harvesting system from the toilets roof (von Muench, 2011).

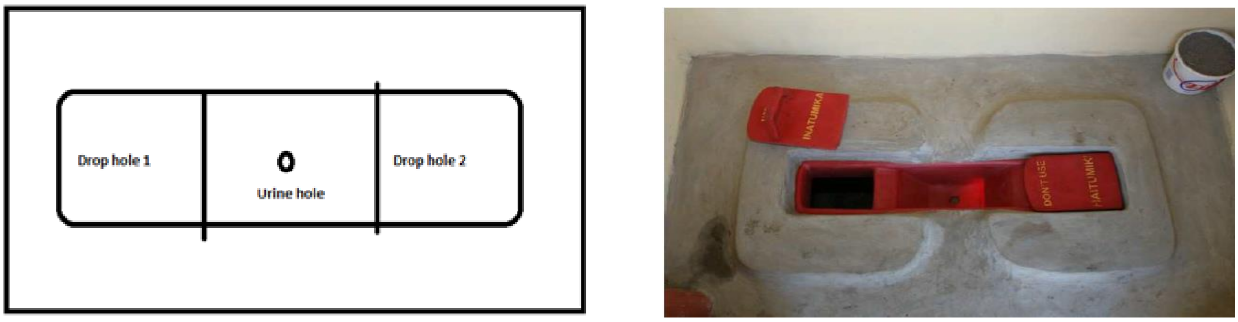


Figure 2 *Picture of squatting pan from GIZ Kenya (2008) like it was installed in the EPP project and scheme of UDDT after Rieck et al., 2012.*

3. Material and methods

3.1 Overview of methods

In this master's thesis there are five types of tools to answer the research questions. These tools are used for different purposes. The list below should give an overview about the organisation of the methods:

- Data collection (Chapter 3.2)
  - Literature review
  - Questionnaire survey
- Data analysis (Chapter 3.3)
  - Graphical Analysis
  - Material Flow Analysis (MFA)
- Data assessment (Chapter 3.4)
  - Sustainability assessment

3.2 Data collection

3.2.1 Literature review

The literature review is a tool that is used throughout the entire process of the master's thesis. In the beginning the focus of the literature research was on the EPP project and the UDDT itself. The research concentrated on the implementation of the EPP project, the function, the advantages and disadvantages of the UDDT and other aspects that might be important for the questionnaire survey. Based on the collected information the questionnaire was designed.

After the questionnaire survey and the basic data analysis, another literature review for a detailed data analysis was conducted. The main topic here was to detect different nutrient values of the three main nutrients (Nitrogen, Phosphorus and Potassium) for urine, faeces, animal manure and inorganic fertilizers. Furthermore, nutrient recommendations regarding the N, P and K input for maize, banana and coffee were searched for. The local focus was Sub-Saharan Africa, especially (Western) Kenya.

During the writing process a constant literature research was needed. The topics were numerous, but the local focus remained the same. Examples for topics are sustainability parameters for UDDT products, the possible fertilization effect of faeces and urine, influences on the quality of the fertilizer, average harvest data for selected crops, etc.

3.2.2 Questionnaire survey

Of the 658 households, who were beneficiaries of the EPP project, 94 farmers in Bungoma and Kakamega were interviewed throughout a month (July 2018). They were selected due to three reasons:

- In western Kenya one of the densest rural populations can be found and the UDDT fertilizer is a promising nutrient source for smallholder farmers of this area, who have to deal with low productivity due to low input of nutrients (Shepherd and Soule, 1998).
- The regional accumulation of UDDT implementations through the EPP project.
- The availability of GPS-data of the farming households, who were the beneficiaries of the project.

The selection of the beneficiaries in the EPP project depended on the characteristics of the area. Rural and peri-urban areas with frequent cholera outbreaks due to seasonal flooding or with generally high numbers of other water related diseases were mainly chosen. One of these areas is the study area, which is a critical cholera hotspot (von Muench, 2011).

The questionnaire itself is separated into seven parts (A-G) (see Appendix “

Questionnaire survey”). However, these parts can be structured into two main sections, one focuses on the UDDT itself and its use (Part B and F) and the second one deals with the UDDT products and the fertilization practices (Part C to E and G).

Part A: The questions of part A determine the basic data of the interviewed farmer including the characteristics of the household (number of people in the household, area of owned farm land and type of farm) and the personal and geographical data. This data is only used for an overview of the interviewed households.

Part B: The first main part is about the UDDT itself and if the beneficiaries still use it or not. These questions help to answer the research questions about the long-term use of the toilet in UDDT implementation projects and the barriers and drivers for the use of it. The most important question for finding out if there is a long-term use of the UDDT is if the farmers still use the toilet or not.
For evaluating the barriers and drivers, the farmers, who do not use the toilet anymore, were asked only about the reason for the non-usage. Through this question it is possible to find out barriers for the usage of the UDDT. Farmers who still use it, were asked several questions. The list below should give an overview for which aspects of the research question the answers are used:

- ***Number of people, who use the UDDT and reasons for non-usage of some family members (if applicable):***
  These questions help to find out if the toilet is used by all family members of the household and if there are barriers for members with special needs, like children and old people. Furthermore, the data can be used for the verification of the quantity of collected faeces and urine, which is important for the research question about the possible impact of the UDDT fertilizer on the agricultural production.
- ***Method of sanitation that was used before the UDDT and if this method is still in use:***
  The former method of sanitation can be a possible driver to use the UDDT and if this method is still in use it has an influence on the quantity of the collected faeces and the urine.
- ***Advantages of the UDDT:***
  The advantages of the UDDT determine the possible drivers for the use of this technology.
- ***Disadvantages of the UDDT:***
  The disadvantages of the UDDT determine the possible barriers for the use of this technology.
- ***Maintenance costs of the UDDT:***
  Here the most important aspect is to find out if the maintenance costs can be a possible barrier for the UDDT use.
- ***Recommendation of the UDDT to other people and knowing of households, who reconstructed the toilet by their own:***
  If the interviewed farmers recommend the UDDT to other people it can be a verification that the toilet is really in use. The knowledge about people in the area, who reconstructed the toilet by their own with local materials, is a good indicator for possible drivers and barriers for replication of the technology.

Part B asks for qualitative information and is presented as graphs and text in the thesis.

Part C: Part C already belongs to the second main part, which is about the UDDT products and if the farmers use them for fertilization or not. If they are used, it was evaluated how the farmers use the products. That means the farmers were asked if they take the whole UDDT fertilizer for

fertilization or only a part of it (only urine or only faeces). This evaluation is important for assessing the impact of the fertilizer on the agricultural production.
If the farmers do not use the fertilizer, they are only asked about the reason for the non-usage and the way of disposal of the human waste. The reasons for non-usage can be used for evaluating possible barriers for the application of the UDDT products in agriculture. The way of disposal is considered in the assessment of the sustainability of the fertilizer, in the aspects of possible emissions through the infiltration of urine into the ground or the burial of faeces. However, the way of disposal can also be a driver, if the farmers can sell it.

Part D and E: These parts assess basic quantitative data about the use of faeces and urine as fertilizer. The data is used mainly for the question concerning the impact of fertilization through UDDT products on the agricultural production. Here the questionnaire includes the questions about the quantity of faeces and urine that are collected through a certain time period and the treatment the farmers apply before they put the UDDT products on their crops. Furthermore, it is asked if the farmers use all the fertilizer and if not where they dispose the rest of it.

Part F: Here only the condition of the toilet was inspected during the survey to evaluate if the information of the farmers about the usage of the toilet is realistic and eventually assess possible (visible) problems that can turn into future barriers for further usage of the UDDT.

Part G: This part is the most important one for the evaluation of the impact of the UDDT fertilizer. The data is recorded in a table and then processed together with the data of part D and E in form of text descriptions, graphical models and a material flow analysis. The detailed approach is described in the following chapter. The farmers, who use the UDDT fertilizer on their crops, were asked the following questions:

- Type and area of crop, where the farmers apply the fertilizer
- If they use urine for each type of crop and the frequency of application together with the time of use (e.g. before planting, before/during harvest, whole year round)
- If they use faeces for each type of crop and the frequency of application together with the time of use (e.g. before planting, before/during harvest, whole year round)
- If they add additional inorganic fertilizer to the crops, where they apply the UDDT fertilizer, and the quantity of it together with the type of inorganic fertilizer
- If they add additional organic fertilizer to the crops, where they apply the UDDT fertilizer and the type of it
- The harvest the farmers achieve from the crops, where they apply the UDDT fertilizer
- If the farmers sell the crop products and how much they earn for these products

The last point is not only asked to answer the impact of the UDDT fertilizer on the farmers crop production and food security, it is also asked because it is an indicator of whether the products are sellable or if there are problems with selling due to negative perceptions of possible customers. This is possibly an important driver/barrier for the use of the UDDT products.

It should be noted that for the assessment of the sustainability of the UDDT fertilizer from all the parts of the questionnaire data was processed. A more detailed description of the processing can be found in chapter three “Data assessment”.

3.3 Data analysis

3.3.1 Introduction

The data analysis should answer the research question concerning the impact of the UDDT fertilizer on crop production and food security of the interviewed farmers. The analysis is split in two parts. The first one includes a graphical analysis, where the harvest and the total nutrient input through different fertilizer combinations of each farmer is compared. These graphs assess the impact of the UDDT products on the crop production. In particular, they should show:

- if an increasing nutrient input leads to an increase in the harvest,

- if the used fertilizer combination influences the harvest and the nutrient input
- and if there is a development of clusters of the same fertilizer combinations.

In conclusion, this analysis is used to check if the data of the questionnaire is plausible.

The second part of the data analysis includes a material flow analysis (MFA), which should help to understand the impact of the UDDT fertilizer on the food security of a farming household. A MFA assesses the flows and stocks of materials within a system that is defined through a local and a time scale (Cencic, 2016). It can be developed for systems in different sizes (e.g. farms, water sheds, districts, countries, globally) and is a common tool used to answer questions of nutrient management (Lederer et. al. , 2015). In this thesis the MFA will be developed on the farm level for maize crops and for the three different main plant nutrients (N, P and K) supported by the programme STAN. The MFA models offer information about the nutrient inputs through different fertilizer combinations and to what extent these inputs can cover the yearly food requirements of a family with 10 members, if they are only covering their nutritional demands with maize. This helps to answer the question how the UDDT fertilizer can contribute to the food security of an average interviewed farming household. It also gives the opportunity to compare different scenarios with various combinations of fertilizer types.

The data that is used for answering both parts of the research question, is based on the questionnaire data and a literature research. For both parts it is necessary to calculate the total nutrient input per ha for each crop, where the farmers reported that they apply the UDDT fertilizer. A literature research is conducted to find out the different nutrient contents of the fertilizers (urine, faeces, animal manure and inorganic fertilizer), which the farmers apply on their crops. For the final calculation the results of this research are multiplied by the quantities of the different fertilizers per hectare assessed in the questionnaire survey. Only for animal manure there are no quantity data. Consequently, these data are based on assumptions from the literature. The approach for the literature review of different nutrient contents, the exact procedure of the nutrient input calculation and the more detailed description of the chosen approach can be found in the next four chapters.

3.3.2 Literature research

A literature research was conducted for the nutrient contents (i.e. N, P and K input) of the different fertilizer types, that were evaluated in the questionnaire survey (see chapter 4.1 “Literature review of nutrient values”). In most of the cases several values were found in the literature. Consequently, the mean of these values was taken for further processing.

For the N and the P input of urine and faeces two types of values are available. On the one hand, there are values only taken from different sources of literature and on the other hand there is one value for each input, that was calculated based on a formula found in the literature. For animal manure an average model farm of a Kenyan smallholder farmer is created based on a literature search and own local observations. After calculating the mean of the nutrient content of manure from the selected animal groups and searching the mean manure production for each animal type, the N, P and K content of animal manure can be calculated.

3.3.3 Processing of the data of the literature research

This chapter explains how the collected values from the literature and the data of the questionnaire survey are processed, and which formulas are used to get the final values that are included in the graphs and partly in the MFA models.

In the first step for every farmer the applied fertilizers of each crop are assessed and then the nutrient content of these fertilizers is calculated based on the following formulas:

- **Nutrient content of urine (g/ha/year)** = Quantity of urine (l/ha/year) * Mean nutrient content (g/l)
- **Nutrient content of faeces (g/ha/year)** = Quantity of faeces (kg dry mass/ha/year) * Mean nutrient content (g/kg dry mass)
- **Nutrient content of animal manure (g/ha/year)** = Mean manure production for a specific animal type (kg dry mass/ha/year) * Mean nutrient content for a specific animal type (g/kg dry mass)
- **Nutrient content for each type of mineral fertilizer (g/ha/year)** = Quantity of each type of mineral fertilizer (kg/ha/year) * Mean nutrient content of each type of mineral fertilizer (g/kg)

For nearly all the types of fertilizer, data was collected through the questionnaire survey. Only for the amount of animal manure there is no data available, because it was not asked in the questionnaire due to the reason that the interviewed farmers had problems to report quantities for this fertilizer type. So, the calculation of the nutrient input for this type of fertilizer is based on a literature research, as it was described in the previous chapter.

The quantities of the UDDT fertilizer for each crop could not be assessed, only the whole quantity that is applied at the farm and the type of crop, where the UDDT products are applied, together with the size could be evaluated. To get the quantity that is applied for each crop on one hectare the procedure used in **Table 3** was conducted:

Table 3 *Analysis procedure for the UDDT fertilizer, explained on the example of application of faeces.*

Crop Type	**Crop Size (ha)**	**Weighting of share of size of crop (%)**	**Quantity of faeces (kg/year)**	**Quantity of faeces per crop (kg/year)**	**Quantity of faeces per crop (kg/year/ha)**
Crop 1	x	$s_1 = x / \Sigma xy$	Q_1	$Q_2 = Q_1 * s_1$	$Q_{end1} = Q_2/x$
Crop 2	y	$s_2 = y / \Sigma xy$	Q_1	$Q_3 = Q_1 * s_2$	$Q_{end2} = Q_3/y$
	Σxy				

The same procedure is used for the calculation of quantities of urine.

For the calculation of the quantity of animal manure for each farm per hectare the nutrient content of the manure is divided through the size of the total land of each farmer due to the assumption that the farmers use animal manure for their complete farm. For the mineral fertilizer it is assumed that the quantity data, that the farmers reported for each crop, is only used for the type and size of crop as it is recorded in the questionnaire survey. That means the quantities per hectare are calculated through the division of each size of each crop, where the mineral fertilizer is added.

In the end all the calculated values per hectare of each farm and crop are added up to get the sum of the N, P and K inputs.

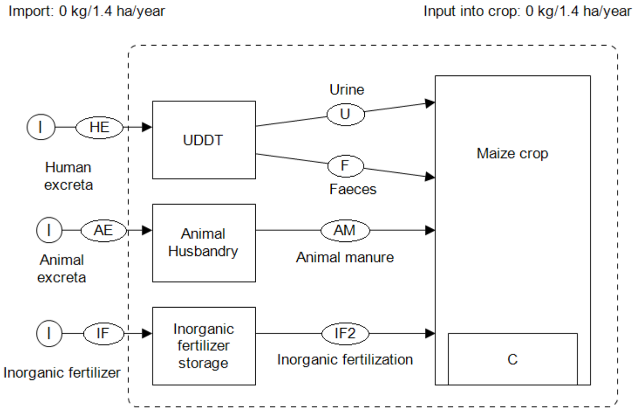
3.3.4 Analysis of the effect of UDDT products on crop production of smallholder farms

The inputs that are calculated above are finally used for the graphical analysis that deals with the effect of the UDDT products on crop production. Several graphs were created for each nutrient input of maize, banana and coffee crops. These crops were chosen because sufficient data was collected through the questionnaire survey. The graphs include the fertilizer combinations that are applied on each crop. Fertilizer combinations in this case mean that for example there are farmers, who applied only urine and faeces on their crops while others used a combination of faeces, animal manure and inorganic fertilizer. Furthermore, the nutrient input in kg/ha/year and the harvest in kg/ha/year is included in the graphical analysis. For the banana and the coffee crops the farmers often reported the size of the crop in numbers of stems and not in hectare. To transfer these values into a unit of area the assumption is made that every banana stem needs around 9 m^2 (Haifa, no date). For coffee in Kenya it is assumed that it is possible to grow 1300 stems of coffee on one hectare of land (Coffee Research Institute, 2019). Furthermore, for bananas the farmers reported their harvest in bunches not in kg. For the transfer it is assumed that one bunch weighs around 17 kg (Wairegi et al., 2009).

Additionally, the applied total nutrient amount for each crop is compared with the recommended nutrient amount. The recommendations for the nutrient inputs for maize, banana and coffee are based on a literature research, whose results are shown in chapter 4.3. Through the calculation of the ratio between these two nutrient input values the limiting nutrient can be defined. The results of this analysis are also shown in a graph, which includes the nutrient input ratio of the limiting nutrient type and the harvest in kg/ha/year. This particular analysis is done to find out how farmers can optimise their fertilizer behaviour regarding their nutrient input.

3.3.5 Analysis of the effect of UDDT products on food security of smallholder farms

The MFA models are developed on farm level for maize crops for the three different main plant nutrients (N, P and K). The crop size is the reference system of the models. This calculated size can cover the yearly food requirements of a family with 10 members. 10 members are chosen because it is the average household size that was assessed during the questionnaire survey. **Graph 1** shows the developed MFA model that is used for the calculation of the different nutrient flows.



Graph 1 *MFA model for calculation of nutrient flows of a smallholder farm with 10 family members for one year*

To calculate the reference crop size the values in chapter 3.3.2 “Processing of the data of the literature research” are further processed. For this processing another literature research must be conducted first. **Table 4** shows the relevant information gathered through this research. The groups in the table are clustering similar data and are only used for a better overview of the collected values. For the calculation of the quantity of plant nutrients and the size of the maize crop that can cover the yearly food requirements of a family with 10 members, the following data is collected: The distribution of boys, girls, women and men in an average family in Bungoma County, the daily energy requirements for each age group, the energy value of maize and the nutrient recommendations for maize with the possible harvest.

***Table 4** Results of a literature research for the calculation of the yearly needed plant nutrient input for covering the nutrient needs of a family of 10.*

Number of group	Variables	Values	Source
1	Average household size	10	Average size of questionnaire survey
	Number of boys in household	3	KNBS, 2015
	Number of girls in household	3	KNBS, 2015
	Number of women in household	2	KNBS, 2015
	Number of men in household	2	KNBS, 2015
2	Daily energy requirement boy (1-18 years old)	2115 kcal/day*cap	FAO, 2001
	Daily energy requirement man (18-60 years old)	3250 kcal/day*cap	FAO, 2001
	Daily energy requirement girl (1-18 years old)	1818 kcal/day*cap	FAO, 2001
	Daily energy requirement woman (18-60 years old)	2683 kcal/day*cap	FAO, 2001
3	Energy value of Maize (E_M)	1.13 kcal/g	USDA, 2018
4	Average possible harvest with recommended fertilization rates (h)	5564 kg/ha/year	See nutrient recommendations in chapter 4.3 “Analysis of the use of UDDT products on crop production of smallholder farms/ Maize”
	Recommended average N input (n)	106 kg/ha/year	See nutrient recommendations in chapter 4.3 “Analysis of the use of UDDT products on crop production of smallholder farms/ Maize”
	Recommended average P input (p)	45 kg/ha/year	See nutrient recommendations in chapter 4.3 “Analysis of the use of UDDT products on crop production of smallholder farms/ Maize”
	Recommended average K input (k)	26 kg/ha/year	See nutrient recommendations in chapter 4.3 “Analysis of the use of UDDT products on crop production of smallholder farms/ Maize””

Table 5 shows how the information from **Table 4** is processed further so that it is possible to calculate the plant nutrient input that is needed to cover the nutrient need of the model household. The values of N, P and K are included in the MFA for having a comparison between the nutrient input that is possible with different fertilizer combinations and the optimal nutrient input.

Consequently, this comparison can give an estimation on how much the UDDT fertilizer can contribute to the food security. The calculated field size is the needed size for planting the maize quantity that covers the food demand of the farming household and at the same time it is the reference system of the MFA.

Table 5 *Calculation of the variables needed for the final calculation of the yearly needed plant nutrient input for covering the nutrient need of a family of 10.*

Variable	Formula	Result
Average daily energy requirement for one household (E_H)	E_H=Σ Daily energy requirements x* Number of x in household	24000 kcal/day*household
Average maize quantity (Q)	$Q=(E_H/E_M)*365$	7753 kg/year
Maize field size (S)	S=(Q/h)	1.4 ha
Optimal N input for S (N)	N=n*S	148 kg/year
Optimal P input for S (P)	P=p*S	63 kg/year
Optimal K input for S (K)	K=k*S	36 kg/year

In the end the quantities of each fertilizer that is included in the different MFA models, are calculated for the reference size of 1.4 ha. The values are based on the quantities that are evaluated in the questionnaire survey and are processed partly like it is described in the chapter 3.3.3 “Processing of the data of the literature research”.

For each nutrient flow (N, P and K) five scenarios, which are listed below, are modelled:

1. **Urine and Faeces Scenario 1:**
   For the first scenario, where only urine and faeces are applied on the crops, the average quantity of urine and faeces that is applied from the farmers on their maize crops, is taken.

2. **Urine and Faeces Scenario 2:**
   For the second scenario, where only urine and faeces are applied on the crops, it is assumed that the assessed average collected human excreta from a household of 10 members is applied only on maize and not like in the first scenario on other crops too. To get the nutrient quantities for one hectare in this scenario, the average yearly quantities of urine or faeces collected in a household with 10 people is divided by the average evaluated crop size of maize. The calculation of the quantities is based on the results of the questionnaire survey. They are then transferred to the reference crop size of 1.4 ha.

3. **Animal manure**
   For this scenario it is assumed that the whole manure is taken for fertilizing the maize crops. Consequently, the values of the literature research of the model farm are included (see
   Table 16-**Table 18**) and not the further processed results.

4. **Urine, Faeces and Animal manure**
   In this scenario the quantities of urine and faeces are taken from point 2 and the quantities for animal manure are the same as in point 3.

5. **Animal manure and inorganic fertilizer**
   In this scenario the values used for animal manure are the same as mentioned in point 3.

For the inorganic fertilizer the assumption that all the fertilizer is used for the maize crops and not for other crops is made again. DAP is chosen as the model fertilizer since it contains nitrogen and phosphorus and is the second most used inorganic fertilizer from the interviewed farmers after CAN. There is no use of potassium containing inorganic fertilizers for maize in the study area. In the model the average DAP quantity from the questionnaire survey transferred to the reference crop size is included.

The two different scenarios for urine and faeces are made, to see if there is a significant difference, if the farmers use the UDDT products only for their maize crops and if they use them for other crops too.

For all the modelled scenarios it is necessary to calculate a standard uncertainty. The calculation is done in two steps:

Standard deviation coefficient=Mean quantity of fertilizer/Standard deviation of mean quantity of fertilizer

Definition of mean quantity for the different fertilizer types:

- Mean quantity for urine and faeces
  = Average yearly quantity that can be collected from one person is calculated and then multiplied with the model household size of 10 people.
- Mean quantity for animal manure
  = Mean nutrient content of different animal types in g/kg DM is taken (Values see **Table 12**-**Table 14**).
- Mean quantity for DAP
  = Mean quantity of DAP in kg/ha/year that is assessed in the questionnaire survey

Standard uncertainty=Mean nutrient content (kg/S/year)*Standard deviation coefficient

For the mean nutrient content in kg/1.4 ha/year the calculated values are used as already described in each scenario above.

3.4 Data assessment

3.4.1 Sustainability assessment

The sustainability assessment helps to assess the collected and the processed data. Furthermore, it is a tool to find out how sustainable the use of the UDDT fertilizer is. However, with the evaluation of some parameters it is also possible to get further data for answering other research questions, especially for the question regarding the possible barriers and drivers for the use of the UDDT fertilizer and for the possible effect of it on crop production and food security of farmers.

The sustainability assessment method is based on assessment concepts of the vision document of Susana (2008) and a paper of Lennartsson (2009). These two sources deal with the evaluation of the sustainability of sanitation systems. Since there are already several sustainability assessments of the UDDT itself, the focus here is on the UDDT fertilizer. Although, it is sometimes necessary to include the toilet system, because the fertilizer is part of this system and cannot be evaluated separately. The data for the assessment is gathered from a literature research and the questionnaire survey, where data from the questionnaire is missing for a proper assessment, information from the literature is used. The final evaluation is based on a grading system, where 1 is the worst score and 4 is the best one. The list below shows the five main parameters with their sub-categories. Each sub-category is rated individually. In the end, a mean of every rate is calculated and is then used as the final score for the main parameter.

1. Health and Hygiene
    1.1. Risk of exposure to pathogens and hazardous substances
2. Environment and natural resources
    2.1. Quality of the UDDT fertilizer
    2.2. Use of natural resources
    2.3. Water use
    2.4. Possible emissions
3. Technology and operation
    3.1. System robustness
    3.2. Odour
    3.3. Complexity of construction and O & M
4. Financial and economic issues
    4.1. Investment costs
    4.2. O & M costs
    4.3. Benefits of the fertilizer
5. Socio – cultural aspects
    5.1. Convenience
    5.2. Contribution to food security
    5.3. System perception (Susana, 2008; Lennartsson et al., 2009)

4. Results

4.1 Literature review of nutrient values

4.1.1 Nutrient values for urine

Table 6, **Table 7** and **Table 8** show the results of the literature research regarding the nutrient content of urine. For nitrogen an average loss coefficient of 7 % is included in the converted value. This coefficient was calculated in a study from Montangero and Belevi (2007) in Vietnam for double vault dry urine diversion latrines. Nitrogen is lost through NH_3-volatilization. In **Table 6** the first two values seem to be much smaller than the following values. However, it does not have a significant effect on the nitrogen and phosphorus input, if one only takes the average of the first two values to calculate the nutrient quantity or the mean of all the researched nutrient values. A statistical sensitivity analysis was conducted to prove this. The output of this analysis can be found in Appendix 1.

The self-calculation of the nitrogen and the phosphorus content of human excrements is based on equations of a report from Richert et al. (2010):

Total N=0.13*Total food protein
Total P= 0.011*(Total food protein + plant food protein)

The total food protein for Kenya is 47 g/cap/day and 31 g/cap/day for the plant food protein (FAOStat, 2013a, 2013b). To differentiate between urine and faeces the assumption is made after Jönsson et al. (2004) that 88 % of the nitrogen and 67 % of the phosphorus is found in urine and 12 % and 33 % in faeces. To calculate the nitrogen value in gram per litre urine the resulting value is divided through 1.2 l urine/cap/day (Shaw, 2010; Cherunya et al., 2015). The value 1.2 l/cap/day is based on a study of Cherunya (2015), where data was collected for the drinking water consumption per person in a rural area of Kenya.

***Table 6** Nutrient Content N for Urine. n.r. = not reported*
An average loss coefficient of 7 % is included in the converted quantities (Montangero and Belevi 2007)

Nutrient	Quantity	Unit	Country	Area	Sample Size	Quantity Conversion (g/l)	Source
NH3-N	2678	mg/l	Kenya	EPP-project	30	2.5	Kraft, 2010
NH3-N	1.67	g/l	Kenya	Rural Kisumu	33	1.6	Robinson, 2005
N	4.48	g/l	Kenya	n.r.	Self - calculation	4.2	See description below
N	5	g/l	Burkina Faso	n.r.	Estimations	4.7	Richert et al., 2010
N	11	g/ppd	Scandinavia	n.r.	Estimations	6.8*	Esrey et al., 2001; Shaw, 2010
MEAN: 3.94 g/l							

*For the conversion of the value into g/l the initial nutrient amount is divided through 1.5 l/cap/day and not 1.2 l/cap/day, because it can be assumed that there is a higher production of urine in Scandinavia than in Kenya (Shaw,2010).

Table 7 *Nutrient Content P for Urine. n.r. = not reported*

Nutrient	Quantity	Unit	Country	Area	Sample Size	Quantity Conversion (g/l)	Source
P	151	mg/l	Kenya	EPP project	30	0.2	Kraft,2010
P	0.25	g/l	Kenya	Rural Kisumu	33	0.3	Robinson, 2005
P	0.48	g/l	Kenya	n.r.	Self-calculation	0.5	See description above
P	0.5	g/l	Burkina Faso	n.r.	Estimations	0.5	Richert et al., 2010
P	1	g/ppd	Scandinavia	n.r.	Estimations	0.7*	Esrey et al., 2001; Shaw, 2010
MEAN: 0.41 g/l							

*For the conversion of the value into g/l the initial nutrient amount is divided through 1.5 l/cap/day and not 1.2 l/cap/day, because it can be assumed that there is a higher production of urine in Scandinavia than in Kenya (Shaw,2010).

Table 8 *Nutrient Content K for Urine. n.r. = not reported*

Nutrient	Quantity	Unit	Country	Area	Sample Size	Quantity Conversion (g/l)	Source
K	1.5	g/l	Burkina Faso	n.r.	Estimations	1.5	Richert et al., 2010
K	2.5	g/ppd	Scandinavia	n.r.	Estimations	1.7*	Esrey et al., 2001; Shaw,2010
MEAN: 1.58 g/l							

*For the conversion of the value into g/l the initial nutrient amount is divided through 1.5 l/cap/day and not 1.2 l/cap/day, because it can be assumed that there is a higher production of urine in Scandinavia than in Kenya (Shaw,2010).

4.1.2 Nutrient values for faeces

Table 9, **Table 10** and **Table 11** show the results of the literature research regarding the nutrient content of faeces.

For the self-calculation of the nutrient content of the faeces the same procedure as already explained in the chapter “Nutrient values for urine” is applied. Only the last step of the calculation was changed.

To calculate the nutrient content of the faeces in g/kg dry mass (DM) the value of 0.039 kg/cap/day (dry matter) is included in the conversion. It is based on a paper by Rose et al. (2015), where the dry weight of low-income countries is reported. Additionally, a WM-content of 30% is considered in the final calculation of the mean since it is not possible to get a fully dried product during the storage process in the UDDT (WHO, 2006; Kraft, 2010).

Table 9 *Nutrient Content N for Faeces.*

Nutrient	**Quantity**	**Unit**	**Country**	**Sample Size**	**Quantity Conversion (g/kg DM)**	**Source**
N	0.3	kg/cap,yr	Uganda	Estimations	21.1*	Jönsson et al., 2004; Rose et.al, 2015
N	18.8	g/kg	Kenya	Self-calculation	18.8	See description above
N	18	g/kg	Eastern cape town province	Trial site	18	Mnkeni and Austin, 2009
MEAN 13.50 g/kg DM[1]						

*For the conversion of the values into g/kg dry mass (DM) the initial nutrient amount is divided through 0.039 kg/cap/day (dry matter) (Rose et al., 2015).

[1] The mean is only 70 % of the original value, because it is assumed that in the UDDT the product has still 30 % wet substance, which does not have the nutrient amounts like they were found in the literature or were calculated.

Table 10 *Nutrient Content P for Faeces.*

Nutrient	**Quantity**	**Unit**	**Country**	**Sample Size**	**Quantity Conversion (g/kg WM)**	**Source**
P	0.1	kg/cap,yr	Uganda	Estimations	7.0*	Jönsson et al., 2004; Rose et.al, 2015
P	7.26	g/kg	Kenya	Self-calculation	7.3	See description above
P	3	g/kg	Eastern cape town province	Trial site	3.0	Mnkeni and Austin, 2009
MEAN 4.03 g/kg DM[1]						

*For the conversion of the values into g/kg dry mass (DM) the initial nutrient amount is divided through 0.039 kg/cap/day (dry matter) (Rose et al., 2015).

[1] The mean is only 70 % of the original value, because it is assumed that in the UDDT the product has still 30 % wet substance, which does not have the nutrient amounts like they were found in the literature or were calculated.

Table 11 *Nutrient Content K for Faeces.*

Nutrient	Quantity	Unit	Country	Sample Size	Quantity Conversion (g/kg WM)	Source
K	0.4	kg/cap,yr	Uganda	Estimations	28.1*	Jönsson et al., 2004; Rose et.al, 2015
K	1	g/ppd	Scandinavia	Estimations	33.2[1]	Esrey et al., 2001; Jönsson et al., 2004
K	44	g/kg	Eastern cape town province	Trial site	44.0	Mnkeni and Austin, 2009
MEAN 24.57 g/kg DM[2]						

*For the conversion of the values into g/kg dry mass (DM) the initial nutrient amount is divided through 0.039 kg/cap/day (dry matter) (Rose et al., 2015).

[1] For the conversion of the value into g/kg DM the initial nutrient amount is divided through 0.03 kg/day (dry mass) (Jönsson et al., 2004).

[2] The mean is only 70 % of the original value, because it is assumed that in the UDDT the product has still 30 % wet substance, which does not have the nutrient amounts like they were found in the literature or were calculated.

4.1.3 Nutrient values for animal manure

In the survey the only information that was asked from the beneficiaries regarding animal manure was if they apply it on each crop or not. Considering this fact, some assumptions are necessary to calculate the nutrient content of animal manure. Based on a literature search and own local observations an average model farm of a Kenyan smallholder farmer was created. After the FAO (2017, 2018) an average Kenyan smallholder farmer has 3 dairy cattle, 5-30 chickens, 2-5 goats, 2-5 sheep. **Table 12**, **Table 13** and **Table 14** show the data used for the calculation of the mean of the nutrient content of the manure from these four animal groups.

Table 12 *Nutrient Content N for Animal manure. n.r.=not reported.*

Nutrient	Quantity	Unit	Country	Sample Size	Animal type	Quantity Conversion (g/kg DM)	Source
N	14	kg/t DM	Kenya (Kisii, Kakamega, Embu)	17	n.r.	14.0	Bosch et al., 1998
N	1.41	% DM	Kenya (Kiambu and Mbeere)	60	Cattle, goats, sheep, pigs, poultry, rabbits	14.1	Onduru et al., 2008
N	9.8	kg/t DM	Sub-Saharan Africa	n.r.	Cattle	9.8	Nziguheba et al., 2016
N	494	mg/kg DM	Central Kenya	281	Cattle	0.5	Lekasi et al., 2003
N	1.12	% DM	Central Kenya	281	Cattle	11.2	Lekasi et al., 2003
N	1.4	% DM	Sub-humid central Kenya	n.r.	Cattle	14.0	Lekasi et al., 2001
N	1.19	% DM	Sub-humid central Kenya	n.r.	Cattle	11.9	Onduru et al., 2008 after Kihanda, 1996
N	15	kg/t DM	Sub-Saharan Africa	n.r.	Goat	15.0	Nziguheba et al., 2016
N	1.89	% DM	Dryland eastern Kenya	n.r.	Goat	18.9	Onduru et al., 2008 after Kihanda et al., 2004
N	12.8	kg/t DM	Sub-Saharan Africa	n.r.	Sheep	12.8	Nziguheba et al., 2016
N	28.8	kg/t DM	Sub-Saharan Africa	n.r.	Poultry	28.8	Nziguheba et al., 2016
MEAN Cattle 10.78 g/kg DM							
MEAN Goat 15.50 g/kg DM							
MEAN Sheep 13.63 g/kg DM							
MEAN Poultry 18.97 g/kg DM							

Table 13 *Nutrient Content P for Animal manure. n.r.=not reported.*

Nutrient	Amount	Unit	Country	Sample Size	Animal type	Conversion (g/kg DM)	Source
P	5	kg/t DM	Kenya (Kisii,Kakamega, Embu)	17	n.r.	5	Bosch et al., 1998
P	0.53	% DM	Kenya (Kiambu and Mbeere)	60	Cattle, goats, sheep, pigs, poultry, rabbits	5.3	Onduru et al., 2008
P	2.2	kg/t DM	Sub-Saharan Africa	n.r.	Cattle	2.2	Nziguheba et al., 2016
P	0.3	% DM	Central Kenya	281	Cattle	3	Lekasi et al., 2003
P	0.6	% DM	Sub-humid central Kenya	n.r.	Cattle	6	Lekasi et al., 2001
P	0.2	% DM	Sub-humid central Kenya	n.r.	Cattle	2	Onduru et al., 2008 after Woorner et al.,1999
P	4	kg/t DM	Sub-Saharan Africa	n.r.	Goat	4	Nziguheba et al., 2016
P	0.47	% DM	Dryland eastern Kenya	n.r.	Goat	4.7	Onduru et al., 2008 after Kihanda et al., 2004
P	4.7	kg/t DM	Sub-Saharan Africa	n.r.	Sheep	4.7	Nziguheba et al., 2016
P	15.8	kg/t DM	Sub-Saharan Africa	n.r.	Poultry	15.8	Nziguheba et al., 2016
MEAN Cattle 5.19 g/kg DM							
MEAN Goat 4.75 g/kg DM							
MEAN Sheep 5.00 g/kg DM							
MEAN Poultry 8.70 g/kg DM							

Table 14 *Nutrient Content K for Animal manure. n.r.=not reported.*

Nutrient	Amount	Unit	Country	Sample Size	Animal type	Conversion (g/kg DM)	Source
K	11	kg/t DM	Kenya (Kisii,Kakamega, Embu)	17	n.r.	11.0	Bosch et al., 1998
K	1.54	% DM	Kenya (Kiambu and Mbeere)	60	Cattle, goats, sheep, pigs, poultry, rabbits	15.4	Onduru et al., 2008
K	2.38	% DM	Central Kenya	281	Cattle	23.8	Lekasi et al., 2003
K	1.3	% DM	Sub-humid central Kenya	n.r.	Cattle	13.0	Lekasi et al., 2001
K	2.38	% DM	Sub-humid central Kenya	n.r.	Cattle	23.8	Onduru et al., 2008 after Woorner et al.,1999
K	1.46	% DM	Sub-humid central Kenya	n.r.	Cattle	14.6	Onduru et al., 2008 after Kihanda, 1996
K	3.72	% DM	Dryland eastern Kenya	n.r.	Goat	37.2	Onduru et al., 2008 after Kihanda et al., 2004
MEAN Cattle 16.95 g/kg DM							
MEAN Goat 21.20 g/kg DM							
MEAN Sheep 13.20 g/kg DM							
MEAN Poultry 13.20 g/kg DM							

For the analysis the mean values must be in g/yr and not in g/kg DM. **Table 15** shows the conversion values. The data was derived from Onduru et al. (2008), who conducted a study with 60 smallholder farmer households in Central and Eastern Kenya.

Table 15 *Animal manure production in kg DM/year after Onduru et al., 2008.*

Animal type	Mean manure production (kg DM/year)
Cattle	1535
Goats and Sheep	212
Poultry	1.5

Table 16, **Table 17** and **Table 18** show the values for each nutrient type that were finally used. As a reminder the formula used for the calculation of the quantity was the following:

Table 16 *Amount of nutrient N for animal manure (g/year).*

Nutrient	Quantity (g/year)	Animal type
N	16554.8	Cattle
N	3278.3	Goat
N	2883.5	Sheep
N	28.5	Chicken
SUM 22744.90 g/year		

Table 17 *Amount of nutrient P for animal manure (g/year).*

Nutrient	Quantity (g/year)	Animal type
P	7960.1	Cattle
P	1004.6	Goat
P	1057.5	Sheep
P	13.1	Chicken
SUM 10035.25 g/year		

Table 18 *Amount of nutrient K for animal manure (g/year).*

Nutrient	Quantity (g/year)	Animal type
K	26018.3	Cattle
K	4483.8	Goat
K	2791.8	Sheep
K	19.8	Chicken
SUM 33313.65 g/year		

4.1.4 Nutrient values for mineral fertilizers

Table 19, **Table 20**, **Table 21** and **Table 22** show the type of nutrient and the mean nutrient contents of each mineral fertilizer based on a literature research.

Table 19 *Nutrient content CAN (g/kg).*

	Nutrient	**Quantity**	**Unit**	**Quantity Conversion (g/kg)**	**Source**
CAN	N	24.2	%	240	Chianu et al., 2012
	N	210	g/kg DM	210	Bosch et al., 1998
	MEAN 225 g/kg				

Table 20 *Nutrient content DAP (g/kg).*

	Nutrient	**Amount**	**Unit**	**Conversion (g/kg)**	**Source**
DAP	N	19.5	%	195	Chianu et al., 2012
	N	180	g/kg dry matter	180	Bosch et al., 1998
	P_2O_5	50	%	218.2*	Chianu et al., 2012
	P	200	g/kg dry matter	200	Bosch et al., 1998
	MEAN N 187.5 g/kg		**MEAN P 209.1 g/kg**		

*For the conversion of P_2O_5 into P the conversion factor of 0.4364 was used.

Table 21 *Nutrient content NPK for coffee (g/kg).*

	Nutrient	**Amount**	**Unit**	**Conversion (g/kg)**	**Source**
NPK	N	17	%	170	Oseko and Dienya, 2015
	P_2O_5	17	%	74.2*	Oseko and Dienya, 2015
	K_2O	17	%	141.1*	Oseko and Dienya, 2015

*For the conversion of P_2O_5 into P the conversion factor of 0.4364 was taken. For the conversion of K_2O into K the conversion factor of 0.8301 was used.

Table 22 *Nutrient content UREA (g/kg).*

	Nutrient	**Amount**	**Unit**	**Conversion (g/kg)**	**Source**
UREA	N	45,5	%	455	Chianu et al., 2012
	N	420	g/kg dry matter	420	Bosch et al., 1998
	MEAN N 437.5 g/kg				

4.2 Questionnaire results

The households that are interviewed are all smallholder farmers, who own on average around 1.9 ha. Most of them are subsistence farmers with some cash crops and livestock. Few of the interviewed farmers have no livestock or no cash crops. 54% of the interviewed farmers were male and 46% were female. Most of the time the interview was conducted with the main beneficiary. In some cases, the interviews were conducted with the spouse, the son, or the daughter. Around 10 people live in an average household.

The sub-chapters 4.2.1 to 4.2.5 are mostly used for answering the question concerning the long-term use of the UDDT in nutrient recycling projects and the barriers and drivers for the usage of the UDDT itself and its fertilizer. The sub-chapters 4.2.6 to 4.2.10 should give an overview of some basic data for assessing the impact of the UDDT fertilizer on crop production and consequently the impact on food security of the farming household. Furthermore, possible influences on the effects of the UDDT fertilizers are reported here.

4.2.1 Usage of the UDDT

Most of the 94 toilets that were visited during the questionnaire survey were constructed in the year 2009, only a few of them were already built in the year 2008. 50% of the interviewed owners still use the UDDT´s while the other 50% do not. The map below shows which interviewed farming households use the UDDT and which households do not. The biggest aggregation of farmers, who still use the toilet can be found in the area where the red arrow is plotted. It is the area, where Moses Wakala lives, one of the main managers of the EPP project.

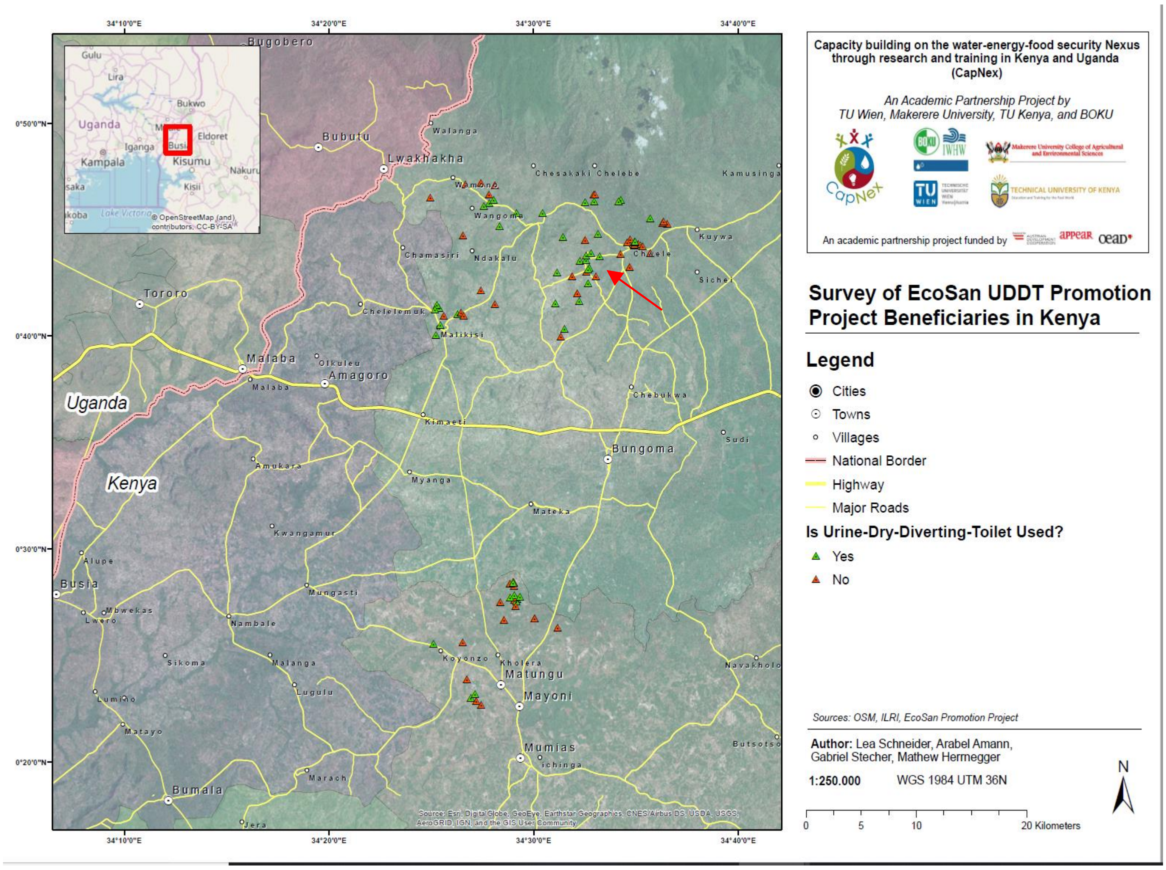


***Figure 3** Map of locations of interviewed farmers and mapping of the use and non-usage of the UDDT. The arrow indicates the area, where Moses Wakala, one of the managers of the EPP project is living.*

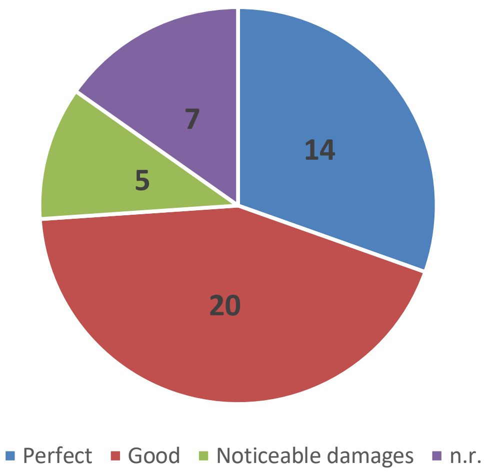
If the toilet is still in use, it is used in average by 8.4 people in one household. In 81% of those households all family members use it. Only in 19% of the households not all members, mostly old people or young children, are not using the UDDT. Older members cannot squat anymore and so the use of the toilet gets difficult. For small children the design of the UDDT can be challenging since they must use two different holes. The owners of the UDDT, where the young children are not allowed to use it, are scared that they may spoil the toilet. Another interesting reason that not all the household members use the toilet was due to cultural reasons. It is a common believe that the mother or father in law should not share the toilet with their son or daughter in law.

All the farmers used a pit latrine before the UDDT. In 30% of the 47 households, which are using the UDDT, the pit latrine is still in use next to the UDDT. In 53% of the households the pit latrine is not existing anymore. For 17% there is no information about the previous method of sanitation, because the households were interviewed in the test phase and the question to this topic was not yet included in the questionnaire. The reason for still using the pit latrine is often that visitors do not know how to use the UDDT and spoil it or they do not want to use it. So, the household provides a pit latrine for them. Another common argument was that there are too many people in the household, so an extra toilet is necessary.

All the users of the toilet would recommend the UDDT and some interviewed farmers asked if there is again such a program because neighbours, friends, etc. also wish to have one. In some cases, even the households shared the toilet with their neighbours, because the toilet in this area had a very good reputation.

Although there were a lot of people who requested an UDDT for their own household, only 21% of the 47 interviewed users of the UDDT knew households or people, who reconstructed the toilet by themselves with local materials and if they knew somebody it was in most of the cases only one household. 79% did not know any household who reconstructed an UDDT.

Graph 2 shows the condition of the toilets of the farmers who still use the UDDT. It was assessed during the questionnaire survey. Most of the toilets are in either a perfect or a good condition, meaning that there are no damages at all or only some small ones. Small damages are most of the time degrading faeces or urine vault doors. Noticeable damages are highly decayed toilet houses or missing of the urine pipe.



***Graph 2** Assessment of the condition of the UDDTs, which are still in use, in numbers of farming households (n=46). n.r.=not reported*

***Figure 4** Picture from UDDT toilet in use, taken during the questionnaire survey.*

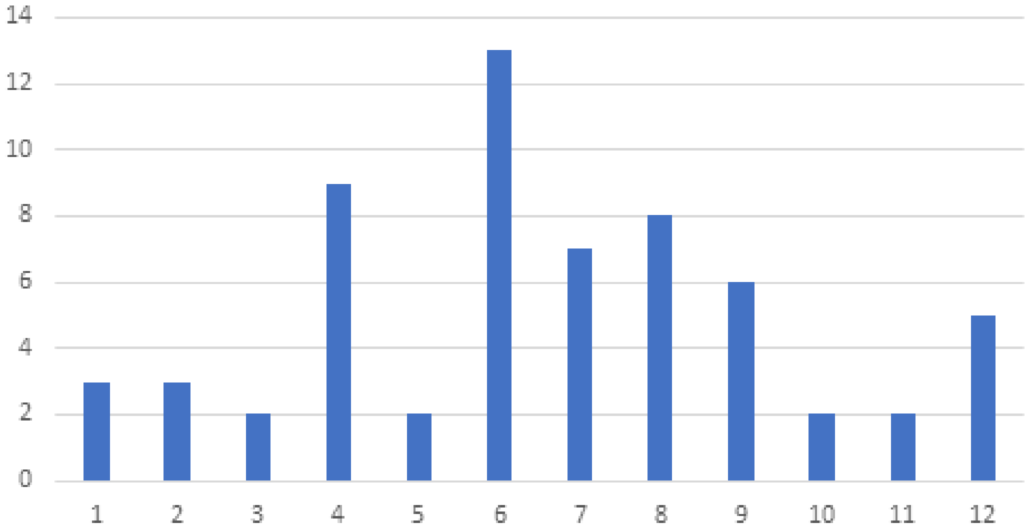
The 47 owners who do not use the UDDT anymore, stated 62 arguments for not using the toilet (**Graph 3**). The argument that was mostly mentioned was problems with the construction. That means in this case the toilets were never completed and the owners waited for some material like the back doors, the venting pipe or the urine pipe, which never came. In nine households the toilet is not used anymore because the owner moved and the property was abandoned or new owners moved there, but the knowledge of how to use the toilet got lost.

Another problem in some areas was that the farmers did not get any proper training for the usage of the UDDT and its fertilizer or were misinformed by the local person in charge or the construction workers. The most reported misinformation was that a chemical treatment for the faeces will be provided.

Seven farmers stopped to use the toilet due to technical problems. Examples for such problems are clogging of the urine pipe or a broken squatting pan. In some of the households the toilet was not there anymore or had significant damages because the UDDT collapsed. At two visited farms they used it recently, but one collapsed during heavy rains while the other one was destroyed because a tree fell on it.

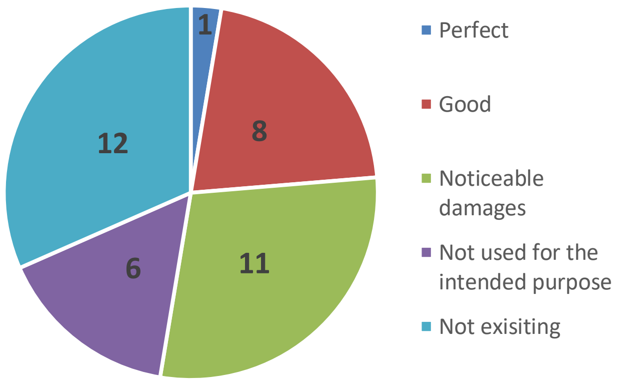
One of the two farmers who reported a bad smell in the toilet did not have enough ash to control the drying and the smell. The other one has a lot of little children in the household, who do not know how to use the toilet and so a bad smell developed.

The owners of the toilets who mentioned cultural reasons for not using the toilet, used the UDDT for some time, till the faeces chambers were filled up and then they stopped it´s operation, because they did not want to handle the human waste. Other reasons are that the toilet was built too near or too far from the house or lack of ownership, because the main beneficiary, who was trained, is currently not living in the household.



Graph 3 *Reasons for no use of the UDDT in numbers of arguments (n=62).*
Technical problem-Urine pipe=1; Other technical problem=2; Wrong usage=3; Owner moved =4; Material got stolen =5; Problems with construction=6; Misinformation=7; Missing training=8; Toilet collapsed=9; Bad smell=10; Cultural reasons=11; Other reasons=12

Graph 4 shows the condition of the toilets of the farmers who do not use the UDDT anymore. It was assessed during the questionnaire survey. Most of the toilets are not existing anymore or have noticeable damages. Noticeable damages in this case are toilets, which are showing signs of high decay or are partly destroyed. Six farmers do not use the UDDT for its intended purpose, that means that they use it as bathroom or storage room.

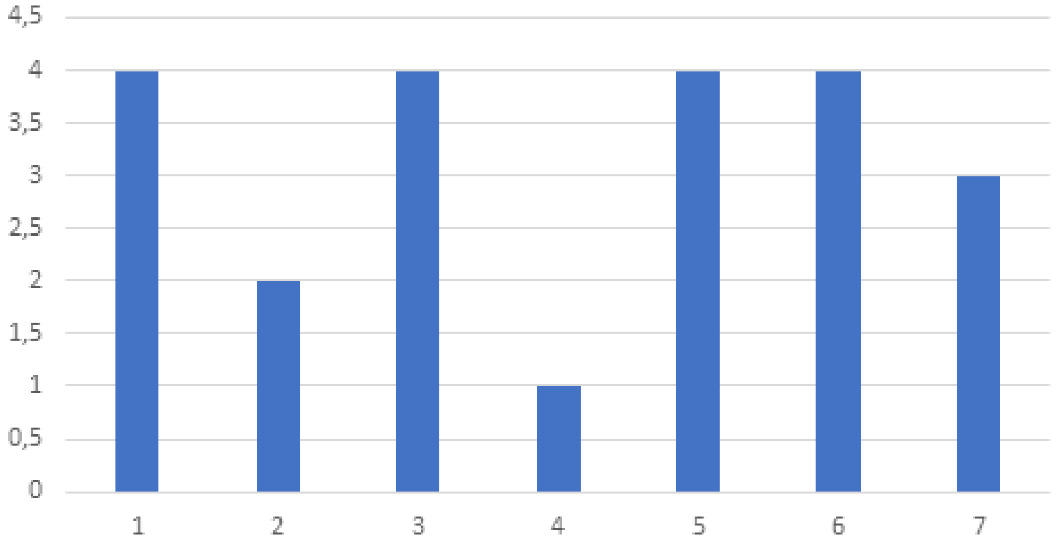


Graph 4 *Assessment of the condition of the UDDTs, which are not in use anymore, in numbers of farming households (n=46). n.r.=not reported*

Figure 5 *Picture from abandoned toilet, taken during the questionnaire survey.*

4.2.2 Non-usage of UDDT fertilizer

There were 22 arguments collected for the non-usage of the fertilizer (**Graph 5**). One of the arguments that were mostly mentioned in the interviews was the cultural aspect of handling human waste. Also, the problem with the urine pipe comes up again. When it is clogged the collection is difficult and the common solution of the farmers is letting the urine leak into the faeces chamber. Another recurring problem is misinformation. For example, one farmer thought that some chemical treatment for the faeces would occur while another one believed that the urine is acidic for the crops. Four farmers still waited to use the faecal matter because the faeces chambers are still not yet filled. These farmers mostly started to use the toilet later than 2009 for several reasons. Other reasons were that the farmer does not have enough time to handle the faecal matter, the jerry cans for collecting the urine get stolen or the toilet was never completed, and the urine and the faeces are mixed together.



Graph 5 *Reasons for no use of fertilizer in numbers of arguments (n=22). Cultural aspect=1; Distance to agricultural land too long =2; Technical problem-urine pipe=3; Other technical problems=4; Lack of information=5; Faeces chamber is not yet filled=6; Other reasons=7*

The farmers who do not use the faecal matter for fertilization still wait to fill up the faeces vaults or bury it in land that is not used in an agricultural way. Other ways of disposal are putting it in the pit latrine or mixing urine and faeces and wait for some time till the material is degraded and then reuse the chamber.

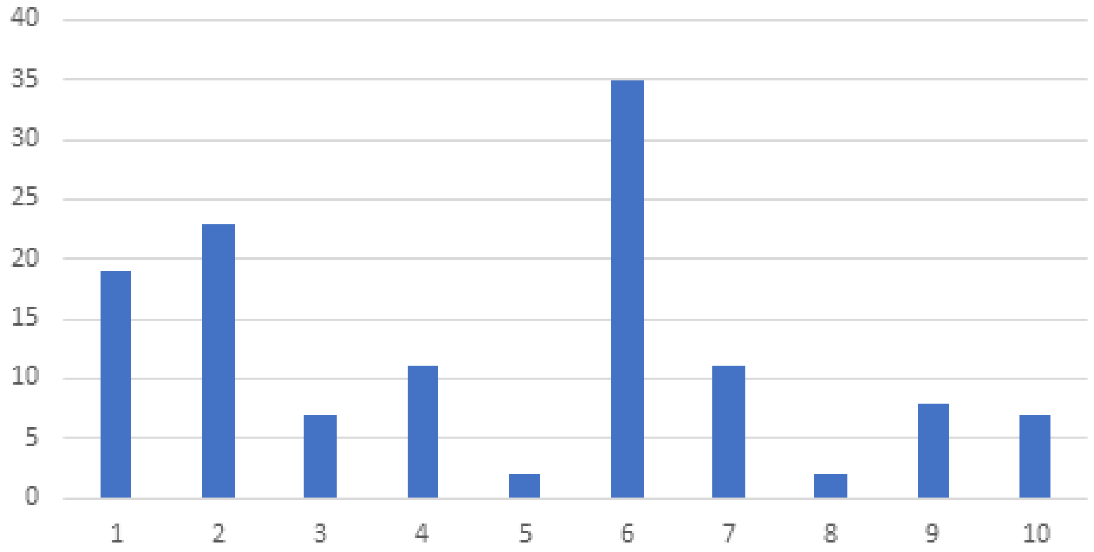
The most common way to disposal the urine when it is not used for fertilization, is to spill it on non-agricultural land. Two farmers have a soak-away pit for disposal. Another way of disposal is to let the urine leak into the faeces chambers.

4.2.3 Advantages of the UDDT

Graph 6 shows the advantages and how often an owner and user of the UDDT mentioned this benefit. In total there were 125 advantages mentioned of the 47 users during the questionnaire survey. The most common argument for the toilet was that it is possible to use the UDDT products for fertilization. Also, the fact that the toilet nearly has no smell is important for a lot of owners.

The durability of the structure was the third most mentioned argument for the toilet. This aspect is especially appreciated in areas which have problems with swamps and collapsing of the pit latrines. Here the UDDT is a good option for avoiding collapses. One farmer emphasised the fact that the toilet is here for more generations and there is no need to always dig new pit latrines, which is particularly difficult with a stony underground. This advantage of non-excavation was also mentioned by nine other farmers. Efficiency was mentioned as often as the non-excavation argument. Efficiency in this context means the cost-efficiency of the UDDT and that the toilet does not need much space since there is no excavation of a pit latrine needed. Other reasons were for example that it is easy to use.

The improved health and hygiene should also be pointed out. Some farmers reported that since they have this toilet, the household members do not get diarrhoea as often as before the UDDT. The aesthetic aspect was mentioned the same number of times (11). Here the toilet owners pointed out that the UDDT is beautiful and they are very proud of it because it makes their home nicer.



***Graph 6** Advantages of the UDDT in numbers of arguments (n = 125).*
Durable and permanent structure=1; Convenience-no smell=2; Convenience-no flies=3; Health and Hygiene (improved sanitation) = 4; Easy operation and maintenance=5; Usage of UDDT products for fertilization=6; Aesthetic aspect=7; Efficiency=8; No excavation needed=9; Other reasons=10.

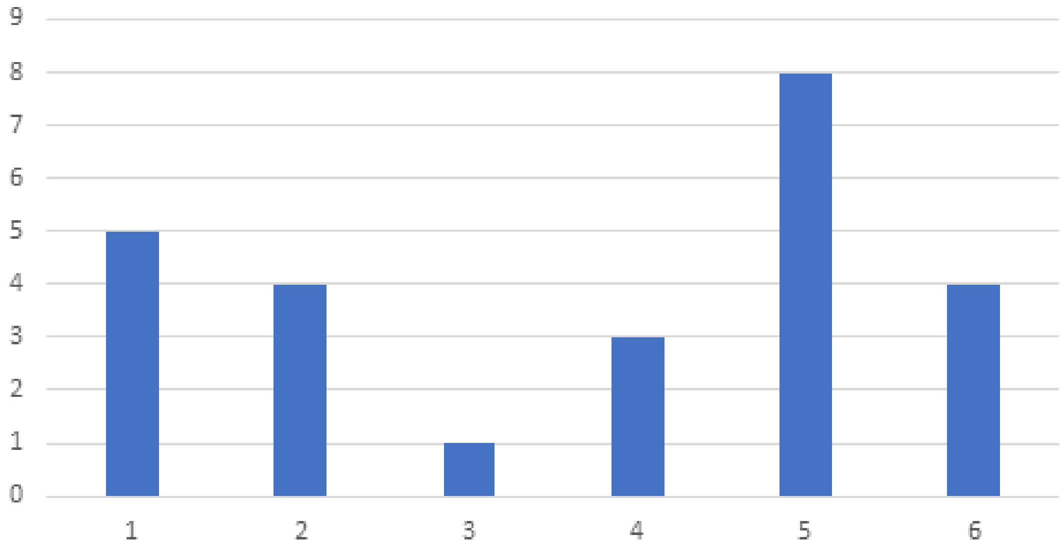
4.2.4 Disadvantages of the UDDT

Graph 7 shows the disadvantages of the UDDT and how often one was mentioned of the 47 owners and users of the UDDT. In total there were 25 disadvantages reported. For 23 users of the toilet there was no disadvantage, these 23 were taken out of the graph above.

One of the biggest problems is that the urine pipe is clogged or broken. Another disadvantage that was reported is that the faeces collection vault doors are degrading and are not in good shape anymore. Consequently, rain water can enter the faeces vault and disturb the drying process.

Next to the technical problems, the wrong use of people who do not know the toilet, (e.g. visitors) was also mentioned as a negative aspect. Furthermore, four farmers reported that they have problems selling their agricultural products, where they apply the fertilizer.

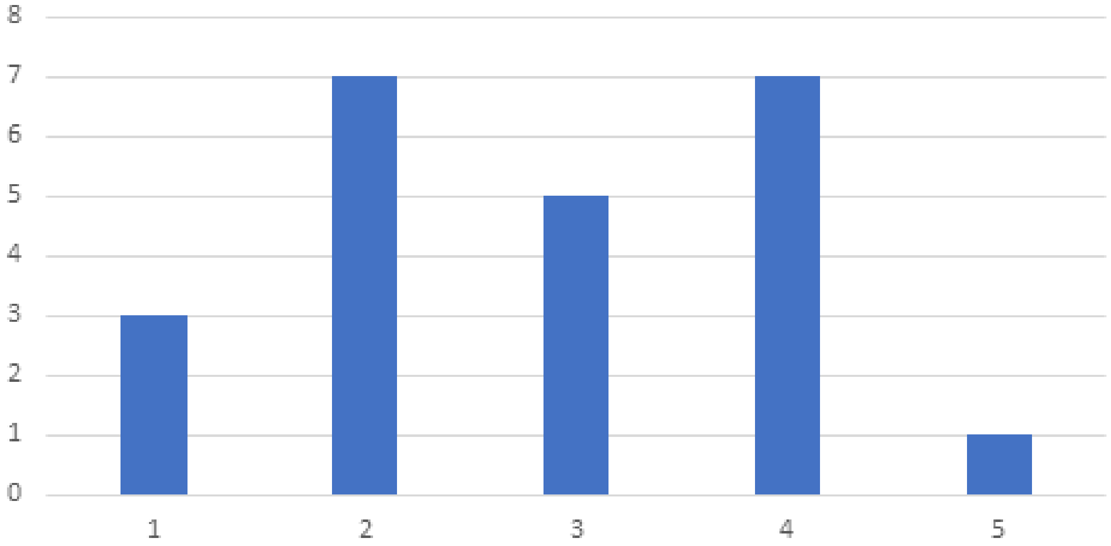
Other disadvantages are for example the time effort to operate the UDDT, that it is not easy to repair it with local materials and that you need a lot of ash to maintain it.



Graph 7 *Disadvantages of the UDDT in numbers of arguments (n=25).*
Technical problem-urine pipe=1; Technical problem-faeces collection vault =2; Other technical problems=3; Wrong use=4; Cultural stigma for using fertilizer=5; Other disadvantages=6

4.2.5 Costs of the UDDT

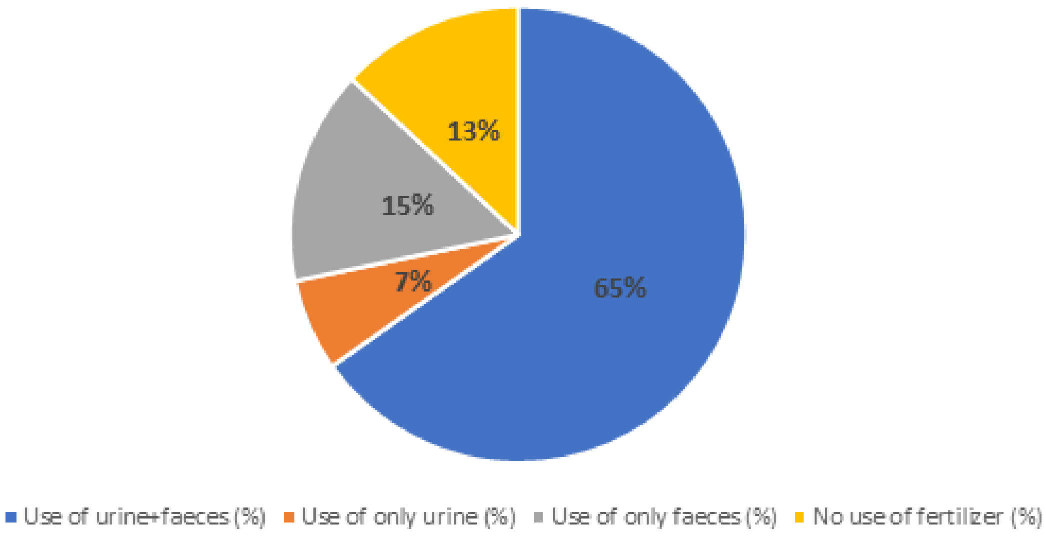
In total there were 23 cost factors mentioned (**Graph 8**). 28 owners who used the toilet, did not have any costs in the last 10 years. This data is not included in the graph above. However, many farmers mentioned that there will be some repairs necessary in the future. If there were some repairs needed, mostly the urine pipe or the faeces vault doors had to be replaced. Five farmers also reported damages on the urine chamber and the connected costs to its repair. The average costs for repairing parts of the toilet were around 651 Kenyan Shillings within 10 years. All the expenses are not recurring costs and were only one-time investments.



Graph 8 *Cost factors in numbers of arguments (n=23).*
Repaint=1; Urine pipe =2; Urine chamber=3; Faeces vault doors=4; Other costs=5

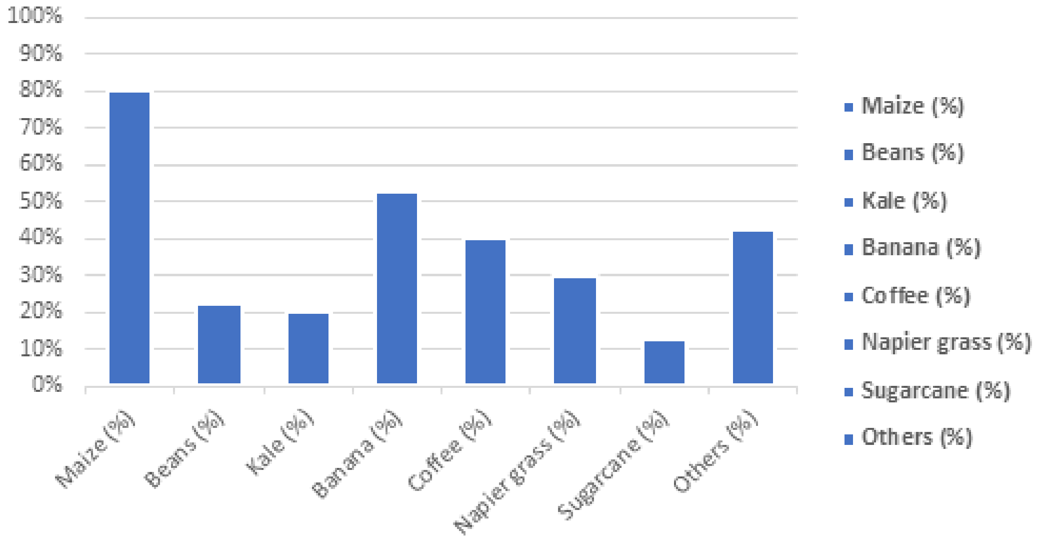
4.2.6 Use of the UDDT fertilizers by the interviewees

Graph 9 gives an overview over the usage of the fertilizer of the UDDT and if the farmers use both products (urine + faeces), only one of the products or if they do not use the fertilizer at all. Most of the 47 users of the UDDT are using the fertilizer, only 13 % do not use it.



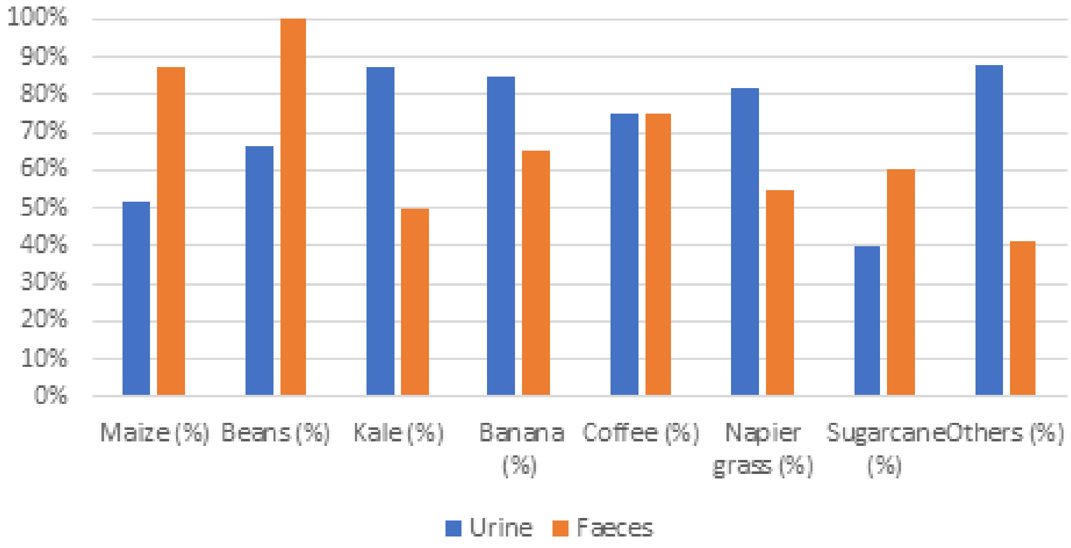
Graph 9 *Use of fertilizer of the Users of the UDDT in percent (n=47).*

Graph 10 shows on which crops the UDDT fertilizer is applied in all possible combinations, including the use of urine and faeces together, the use of only urine and the use of only faeces.. Out of the 40 farmers who use the UDDT fertilizer for their crops, 80% apply it most of the time on maize. Banana and coffee were also mentioned quite often. Other crops are for example tomatoes, avocado, groundnuts, etc. These crops, where summarised because they were only mentioned by a maximum of three farmers.



Graph 10 *Use of UDDT products on crops in general in percent (n = 40 farmers)*

Graph 11 shows the percentage of crops, where urine and faeces are applied together or only one of the two is used. That means for example 52 % of the total maize crops where the farmers put out the UDDT fertilizer, are fertilized with urine, 87 % are fertilized with faeces. The graph does not show the differentiation between the fertilization with only urine, with only faeces or with a combination of both. This more detailed analysis is only made later in the thesis for the three most mentioned crops (maize, banana and coffee).



***Graph 11** Use of UDDT products on crops separated in urine and faeces in percent*
n=Number of crop types used for calculation of ratio. $n_{Maize}=31$, $n_{Beans}=9$, $n_{Kale}=8$, $n_{Banana}=20$, $n_{Coffee}=16$, $n_{Napier\ grass}=11$, $n_{Sugarcane}=5$, $n_{Others}=17$

4.2.7 Use of urine

The 33 farmers who use urine for the fertilization of their crops, use around 460 litres of urine per year. From the questionnaire data it is also possible to derive the quantity of urine that can be collected from every user in the household in one week. It was calculated that around 1.14 l of urine per user was collected (Standard deviation: 1.07). Most of the time it is collected in a 20-litre jerry can throughout the year. They apply the urine on their crops every 3.6 weeks on average. 95% of the farmers use the urine the whole year round and mostly apply it in the morning. Only a few use it before or during planting.

72% of the farmers who use urine for fertilization, dilute it with water before they put it out on their crops. The most common dilution with 52% is a ratio of 1:1. Other dilution ratios are 1:2, 1:4 and 1:5. 28% are not using any dilution.

***Figure 6** Picture from Moses Wakala of urine chamber with jerry cans*

4.2.8 Use of faeces

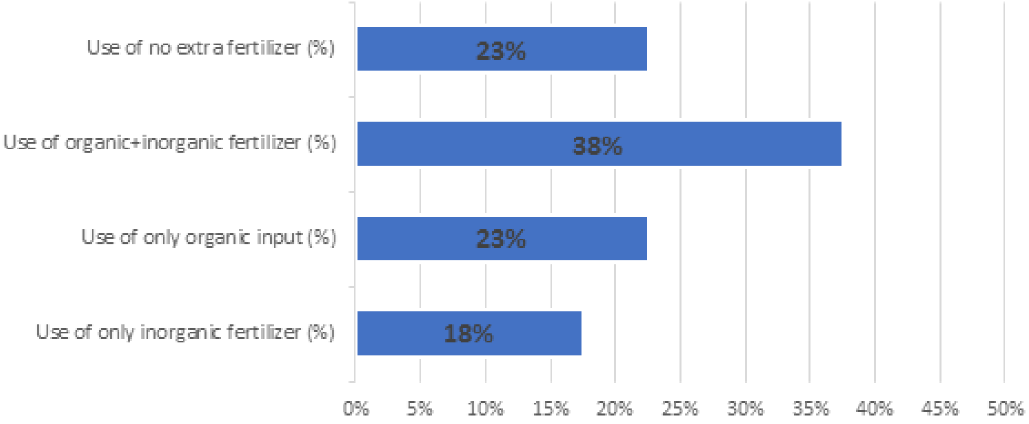
The 37 farmers who use faeces for the fertilization of their crops, collect around 253 kg faeces per year and apply it on their crops every year. From the questionnaire data it is also possible to derive the quantity of faeces that was collected from every user in the household in one year. It was calculated that around 16 kg of faecal matter per user can be produced (Standard deviation: 21.34). The average storage time of the faeces are around 5 months. All the farmers add ashes if they want to use the faeces as fertilizer for their crops. Additionally, the users of the toilet put wiping material into the faeces chamber. Here, normally toilet paper, leaves, or a combination of both are used.

48% of the farmers apply the faecal matter during planting, 27% put it out before planting. The rest of them use the faecal matter the year round or before the harvest. Like urine faeces are usually also applied in the morning.

Figure 7 *Picture of dried faecal matter in faeces chamber, taken during the questionnaire survey.*

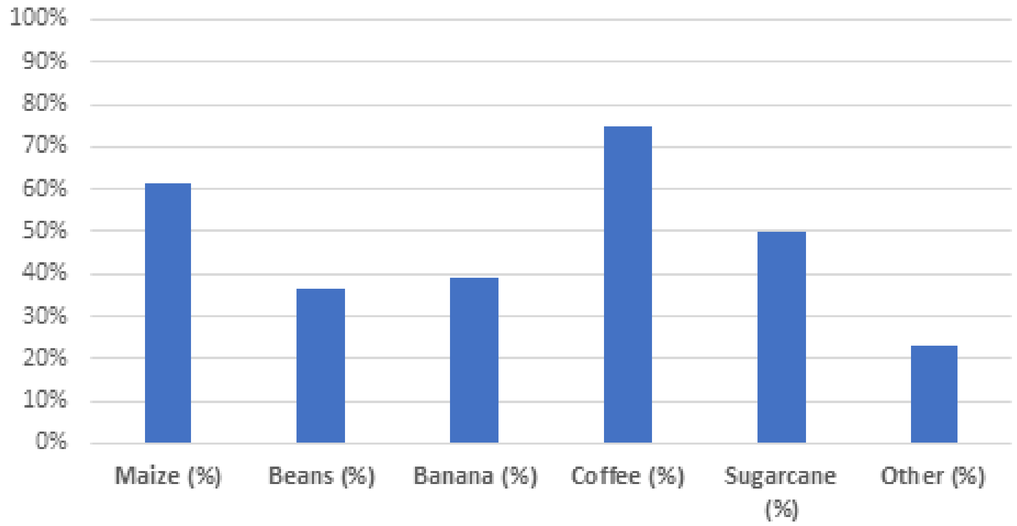
4.2.9 Use of additional fertilizer

31 of the 40 farmers, who use the UDDT fertilizer, add additional fertilizers (**Graph 12**). That means they add not only the UDDT fertilizer to the crops, but also apply animal manure (organic fertilizer) and/or mineral fertilizer. The most applied combination is the application of the UDDT fertilizer combined with extra organic and inorganic inputs. If animal manure is applied on the crops it is mostly applied over all the reported crops.



Graph 12 *Use of additional fertilizer in percent (n=40). x-scale from 0-50 %.*

Graph 13 shows on which type of crops the inorganic fertilizer is applied. The most common crops where additional mineral fertilizer is used are coffee and maize.



Graph 13 *Use of inorganic fertilizer on types of crops in percent.*
n= Number of crop types used for calculation of ratio. $n_{Maize}=39$, $n_{Beans}=11$, $n_{Banana}=23$, $n_{Coffee}=24$, $n_{Sugarcane}=4$, $n_{Other}=13$

Table 23 shows the type of inorganic fertilizer, for which type of crops it is used and the average quantity that is applied on the crops in kg per year and hectare. “UREA” is applied on several crops, but for the calculation of the quantity only one farmer is considered. This farm was the only one which could report all the needed information to calculate the quantity.

In the last column of the table there are literature values from a study of Oseko and Dienya (2015) for comparison with the calculated quantities in this master’s thesis. They assessed the quantity of different types of inorganic fertilizer in tons for several crop types for the year 2013 in Kenya. They also evaluated the area applied with fertilizer per ha. Consequently, it is easy to calculate the quantity of each fertilizer type in kg per year and hectare. The comparison shows significant differences between the evaluated quantities and the ones from the literature. Furthermore, the calculated quantities show high standard deviations. The possible causes for this are analysed more detailed in the chapter “Discussion”.

However, from the number of included data sets that were used to calculate the mean quantity of the inorganic fertilizer, it can be seen that “CAN” and “DAP” are the most applied fertilizers. “CAN” and “UREA” are used to increase the nitrogen content in the crops. “DAP” additionally increases the phosphor content. Consequently, the most added nutrients through inorganic fertilizer are nitrogen and phosphorus.

***Table 23** Type of inorganic fertilizer used for different crops and average quantity applied compared with the literature values. n= number of crops, where a specific type of inorganic fertilizer is applied.*

Type of fertilizer	Type of crops	Mean quantity (kg/ha/yr)	Standard deviation	Literature values (kg/ha/yr)
DAP	Maize, Beans, Banana, Coffee	585.25 (n=12)	734.28	85.58
UREA	Maize, Beans, Banana, Coffee, Sugarcane	247.11 (n=1)	/	8.84
NPK	Coffee	609.71 (n=5)	647.67	210.01
CAN	Maize, Beans, Banana, Coffee, Sugarcane	620.39 (n=14)	693.85	40.26

4.2.10 Field sizes, harvest and crop selling

Table 24 shows the mean size and the average harvest of crops where UDDT fertilizers are applied in tons per year as well as in tons per hectare and year. The literature values in tons per year and hectare are the typical maize and coffee harvest of a Kenyan smallholder farmer. The values for beans and banana are not in particular for smallholder farmers but rather the yearly average harvest from the study area.

The selection of crop types for the table depends on the quantity of data that could be collected through the questionnaire survey for these two parameters. For example **Graph 10** shows that 30 % of the farmers use the UDDT fertilizer for Napier grass, but it is not included in the table below, because the farmers could not give any information about the size and the harvest of this crop type.

The last parameter shows how many farmers also sell the products of the crops where the UDDT fertilizer is applied. The number of the crops that are included in calculation of the different parameters differs between the first two and the last one, as some farmers could not always recall the size and the harvest of their crops. Also, there are more farmers involved in the calculation of the mean of the total harvest in t/year, because now farmers, who could not report the size of the crop, are included.

Table 24 *Average size (ha), average total harvest (t/ha/year and t/year) and ratio of sold products of selected crops, where UDDT fertilizer is applied.*
n= Number of crops included in each calculation of the average size and the average harvest for a specific crop type. $n_{Maize}=22$, $n_{Beans}=7$, $n_{Banana}=14$ ($n_{Banana\ stems}=11$), $n_{Coffee}=13$ ($n_{Coffee\ stems}=9$). *SD=Standard deviation*

Crop	Size (ha)	Total harvest (t/year)	Total harvest (t/ha/year)	Literature harvest values (t/ha/year)	Selling of products (%)
Maize	0.23	2.35 (n=26, SD 3.1)	9.4 (SD 10.92)	1.7 (Tittonell et al., 2008)	72 % (n=32)
Beans	0.24	0.9 (n=7 SD 0.76)	3.4 (SD 2.82)	4.86 (Paul, 2017)	67 % (n=9)
Banana	0.05 (44 stems)	1.87 (n=15 SD 2.39)	40.1 (SD 40.72)	20.18 (Paul, 2017)	71 % (n=21)
Coffee	0.12 (150 stems)	1.54 (n=15 SD 1.68)	16.0 (SD 14.46)	0.38 (ICT Authority, 2014)	94 % (n =16)

4.2.11 Summary of questionnaire results

50% of the interviewed owners still use the UDDT and 50% do not use it anymore. If the toilet is still in use, it is used on average by 8.4 people in one household. All the farmers used a pit latrine before the UDDT. All the users of the toilet would recommend the toilet. Although there were a lot of people who requested an UDDT for their own household, only 21% of the 47 interviewed users of the UDDT knew households or people, who reconstructed the toilet by themselves with local materials. For the non-usage of the UDDT the most mentioned argument was a problem with the construction, which means that the toilets were never completed. Other reasons were for example changing of the property situation, missing information and training and technical problems (e.g. clogging of urine pipe, broken squatting pan). Reasons for the non-usage of the fertilizer are cultural aspects, technical problems and misinformation. The main disposal way of the UDDT products is disposing them on non-agricultural land or storing it in the vault chambers.

The most common advantage for the toilet was that it is possible to use the UDDT products for fertilization. Also, the fact that the toilet is a durable structure and nearly has no smell is important for a lot of owners. Other benefits were for example the improved health and hygiene situation and the aesthetic value of the UDDT. Most of the farmers did not mention any disadvantages. However, one of the biggest problems are technical difficulties like the clogging of the urine pipe or the degrading of the faeces collection vault doors. Next to the technical problems, the wrong use by people, the negative image of the UDDT fertilizer and the amount of ash that is needed for maintenance were pointed out among other arguments as a negative aspect. The average costs for repairing parts of the toilet were around 651 Kenyan Shillings. Mostly the urine pipe or the faeces vault doors had to be replaced. None of the expenses are recurring costs.

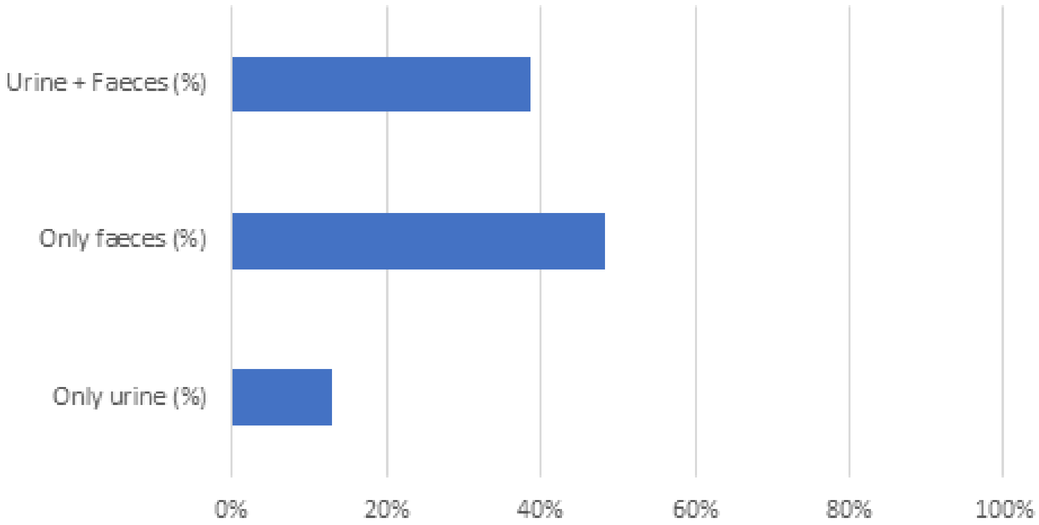
Most of the 47 users of the UDDT are also using the fertilizer, only 13 % do not use it. Most of the users of the fertilizer use urine and faeces. The main crops where the fertilizer is applied on are maize, bananas and coffee. On average, 460 l urine and 253 kg faeces per year are put out on the crops. The urine is applied throughout the whole year around every 3.6 weeks and the faeces are applied once a year after an average storage time of 5 months. The urine is often diluted extra before it is used on the crops. Ash is added to the faeces after every use. 31 of the 40 farmers who use the UDDT fertilizer add additional fertilizers (animal manure and/or inorganic fertilizer). Often the products of the crops, where the fertilizer is applied, are partly sold.

4.3 Analysis of the use of UDDT products on crop production of smallholder farms

To understand the impact of the UDDT fertilizer on the crop production of the farmers a graphical analysis is conducted. The analysis is done for maize, bananas and coffee. The selection process is based on data availability. For the three mentioned crop types sufficient data from farmers who applied the UDDT fertilizer on it was collected through the questionnaire survey. For the banana and the coffee crops the farmers often reported the size of the crop in numbers of stems and not in hectare. To transfer these values into a unit of area, assumptions based on values from the literature were used. Furthermore, for bananas the reported number of harvested bunches had to be converted into kg based again on literature values (see chapter 3.3.4).

4.3.1 Maize

Graph 14 shows that most of the farmers who use the UDDT fertilizer for their maize crops use only faeces (48%). But 40% also apply urine and faeces together on their maize crops.



***Graph 14** Use of UDDT fertilizer on maize crops in percent (n=31).*

Graph 15, **Graph 16** and **Graph 17** show the graphical analysis for the maize crops of the farmers who used the UDDT fertilizer. They show the nutrient input (N, P, K) through the calculated fertilizer inputs in comparison to the harvest that was achieved by the farmer. The green dashed lines show the recommended nutrient input on the x-axis and the harvest that results through this nutrient input on the y-axis. The average maize harvest from a smallholder farm in Kenya is displayed as a dotted red line on the y-axis (Source see **Table 24**).

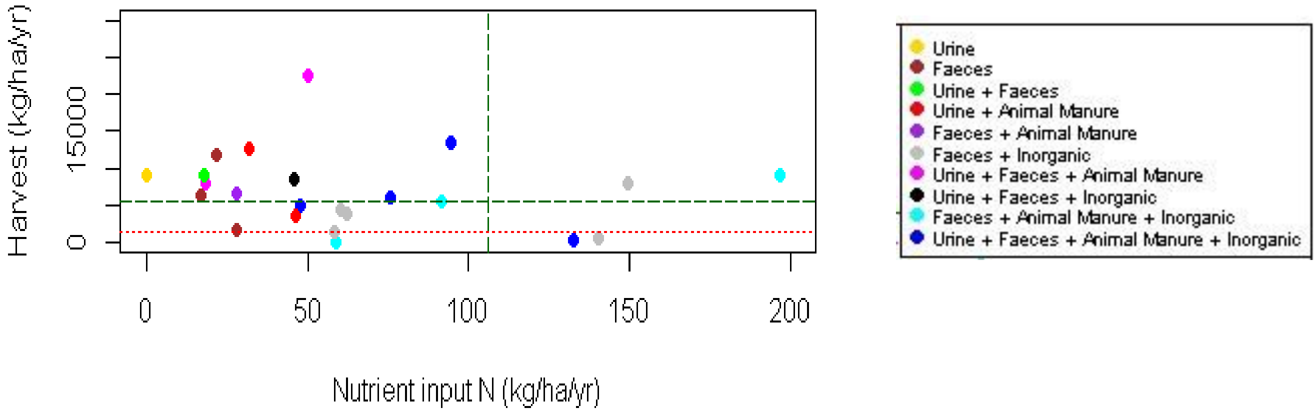
The nutrient recommendation for maize is the mean of collected data from a survey in Ethiopia by Balemi et al. (2017) and a study by Kibunja et al. (2017) in different parts of Kenya. For the potassium input recommendation from Kibunja et al. (2017) there is no data available for the western upper part of Kenya, so the mean of the values from areas where values for K are available, are taken.

Table 25 shows the possible harvest that is achievable with the recommended nutrient input. The mean of the recommended nutrient inputs and the mean of the possible harvest is taken for all following models.

Table 25 *Nutrient recommendations maize. The first three values are from the study by Balemi et al. (2017) and the last ones are from the survey by Kibunja et al. (2017).*

Nutrient	**Recommendation (kg/ha/yr)**	**Possible harvest (kg/ha/yr)**	**Area**
N	125	6913	Ethiopia
P	53	6913	Ethiopia
K	36	6913	Ethiopia
N	86	4985	Kenya Western Upper (>1400 masl)
P	36	3499	Kenya Western Upper (>1400 masl)
K	15	4162	Kenya Western Lower (<1400 masl), Rift Valley Lower (<2300 masl), Eastern Upper (>1200 masl)
Mean N 106 kg/ha/yr			
Mean P 45 kg/ha/yr			
Mean K 26 kg/ha/yr			
Mean Harvest 5564 kg/ha/yr			

Some farmers are excluded in this analysis due to incomplete data. Furthermore, there are four farmers included in the graphs who applied the UDDT fertilizer on maize crops where intercropping together with beans is practiced, and one farmer who does the same only together with bananas. The effect of intercropping is not considered in the following analysis because no data was collected regarding this issue.



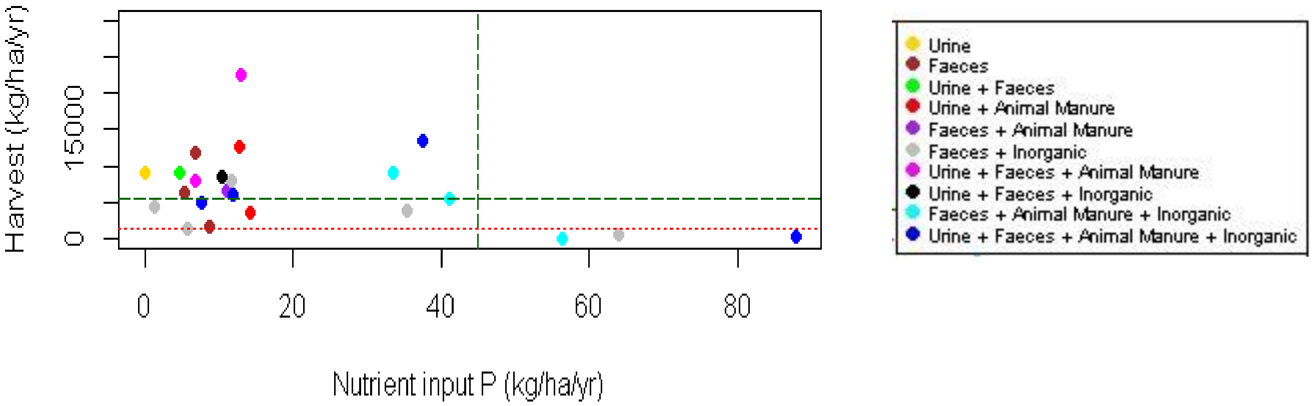
Graph 15 *Analysis of the influence of different fertilization combinations on the nutrient input N (kg/ha/yr) and the harvest of maize (kg/ha/yr). The dashed green line shows the nutrient recommendation for maize on the x-axis and the possible maize harvest on the y-axis. The red dotted line shows the average maize harvest that is achieved at a smallholder farm in Kenya. n = 23*

The graphical analysis shows that the harvest of the 23 farmers ranges around 100 kg/ha/year to 22000 kg/ha/year. However, most values are found in the range of 100 kg/ha/year to 13000 kg/ha/year. That means that several farmers achieved a higher harvest than the possible harvest with a certain nutrient recommendation. Since the average harvest is even lower than the possible one, the reported harvest is often much higher.

The application of only urine has the lowest impact on the nitrogen inputs with 0.32 kg/ha/year. The highest N input (197 kg/ha/year) has been achieved by one farmer who applied faeces, animal manure and inorganic fertilizer. However, most values for the nitrogen input range between 0.32 and 95 kg/ha/year. Consequently, they are lower than the recommended nitrogen input.

If animal manure and/or inorganic fertilizer is additionally applied to the crop, the nutrient input is on average higher than if only the UDDT fertilizer is used. The highest nitrogen input values were achieved by farmers who used the fertilizer combination “Faeces + Animal manure + Inorganic”, “Faeces + Inorganic” and “Urine + Faeces + Animal manure + Inorganic”. The analysis shows that the average highest N input is achieved by the farmers who apply a combination of faecal matter and inorganic fertilizer.

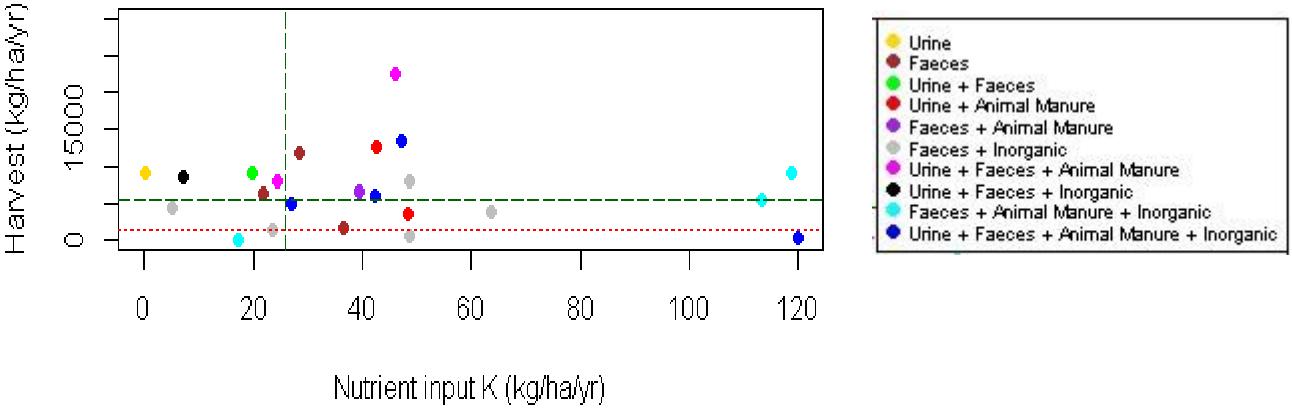
Overall, a trend between the increase in harvest and the increase in nitrogen inputs is observed. However, in some cases the given harvest by the farmers does not correspond well with the calculated input of nitrogen derived from the farmers information. For example, for the three farmers, who apply only faeces on their maize crops, similar nitrogen inputs have been calculated (Range: 4 – 28 N kg/ha/year), but their reported harvest is quite different (Range: 1800 – 11700 kg/ha/year). For the farmers, who applied urine, faeces and animal manure, the observed difference is even larger (Harvest: 8100 kg/ha/year and 22500 kg/ha/year). These differences in the harvest might be indicative that collecting valid harvest and input data from the farmers was not achieved in all cases. There are several reasons why this could be the case which are analysed in the chapter “Discussion”.



Graph 16 *Analysis of the influence of different fertilization combinations on the nutrient input P (kg/ha/yr) and the harvest of maize (kg/ha/yr). The dashed green line shows the nutrient recommendation for maize on the x-axis and the possible maize harvest on the y-axis. The red dotted line shows the average maize harvest that is achieved at a smallholder farm in Kenya. n = 23*

Graph 16 is similar to **Graph 15**, but now the graphical analysis is conducted for phosphorus. Consequently, the analysis is similar and the harvest stays the same. However, now the calculated nutrient input ranges between 0.03 – 88 kg P/ha/year. However, most of the values range between 0.03 – 14 kg P/ha/year. The highest phosphorus input is observed at one farm, which fertilizes with faeces, urine, animal manure and inorganic fertilizer (88 kg/ha/year) and on one farm, which applies the fertilizer combination of faeces and inorganic fertilizer (64 kg/ha/year). In general, the farmers who are using faeces, animal manure and inorganic fertilizer, have the highest P inputs (Range: 34 – 56 kg/ha/year).

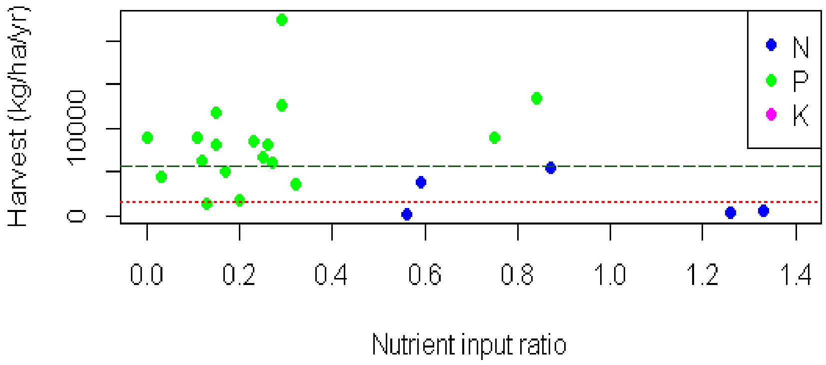
Here the trend between the increase in harvest and the increase in P inputs is even weaker than in **Graph 17**. It is especially interesting that the farmers who have the highest P inputs, also have one of the lowest harvests. For example, the farmer who applies all the possible fertilizers has a nutrient input of 88 kg/ha/year and only achieves a harvest of 250 kg/ha/year. Furthermore, in some cases quite different harvest ranges within similar P inputs are observed. This aspect is already analysed for nitrogen in more detail. Consequently, the analysis for phosphorus indicates, like the N analysis does, that not all of the collected harvest and input data from the farmers are completely plausible.



Graph 17 *Analysis of the influence of different fertilization combinations on the nutrient input K (kg/ha/yr) and the harvest of maize (kg/ha/yr). The dashed green line shows the nutrient recommendation for maize on the x-axis and the possible maize harvest on the y-axis. The red dotted line shows the average maize harvest that is achieved at a smallholder farm in Kenya. n = 23*

Graph 17 also shows similar patterns as already described in the last two analyses. Now the nutrient input ranges between 0.13 – 120 kg/ha/year. Most of the values are found between 0.13 – 49 kg/ha/year potassium input. The highest potassium input is observed at one farm, which uses all the possible fertilizers. However, on average the points of the fertilizer group “Faeces + Animal manure + Inorganic” show the highest nutrient outcomes (113 and 119 kg/ha/year), even if there is one exception with 17 kg/ha/year within the group.

The difference between the K analysis and the N and P analyses is that it is not entirely clear that the potassium input is increasing with the addition of animal manure and inorganic fertilizer. The explanation for this observation is that none of the farmers use an inorganic fertilizer containing potassium for maize. However, the actual K input of farmers often lies above the recommended nutrient input.



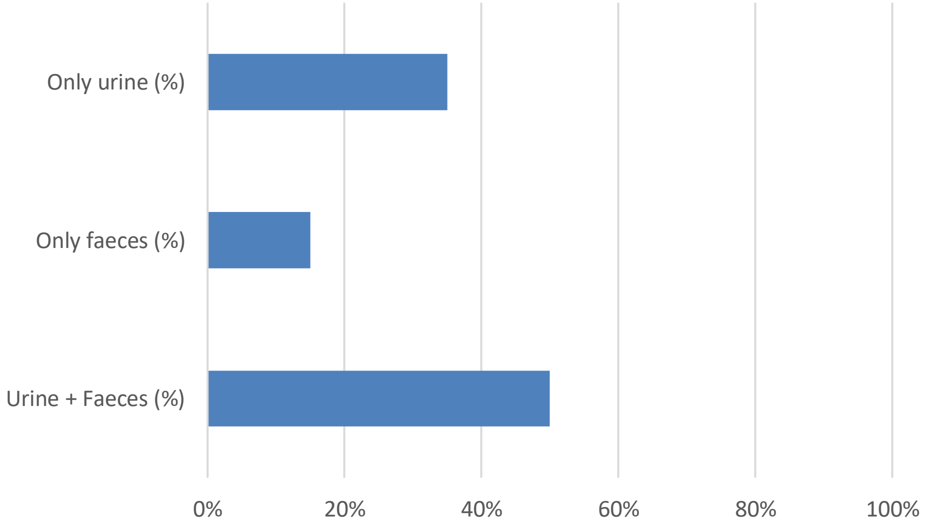
***Graph 18** Analysis of the limiting nutrient input of maize based on the nutrient input ratio in comparison with the maize harvest (kg/ha/yr). The dashed green line shows the possible maize harvest with a certain nutrient recommendation. The red dotted line shows the average maize harvest that is achieved at a smallholder farm in Kenya. n=23*

Graph 18 shows the harvest in kg/ha/year in comparison to the nutrient input ratio of the limiting nutrient type for maize crops, where the UDDT fertilizer in all the possible combinations is applied on.

The analysis of the given data shows that phosphorus is usually the limiting nutrient type while nitrogen is the limiting nutrient at only five farms. The ratio also shows that most of the time there is a lower nutrient input in comparison to the recommended nutrient input. Despite of this fact, the harvest is still often higher than the possible harvest with a certain nutrient input recommendation.

4.3.2 Banana

Graph 19 shows that most of the farmers, who use the UDDT fertilizer for their banana crops, use urine and faeces together (50 %). However, 35 % also only apply urine on their crops.



***Graph 19** Use of UDDT fertilizer on banana crops in percent (n=20).*

Graph 20,**Graph 21** and **Graph 22** show the graphical analysis for the banana crops of the farmers who use the UDDT fertilizer. It includes the nutrient input (N, P, K) through a certain fertilizer combination and the harvest that could be achieved through the fertilization. The green dashed lines show the recommended nutrient input on the x-axis and the harvest that results through this nutrient input on the y-axis. The average harvest in the area, specifically in Bungoma, is displayed as a dotted red line on the y-axis (Source see **Table 24**).

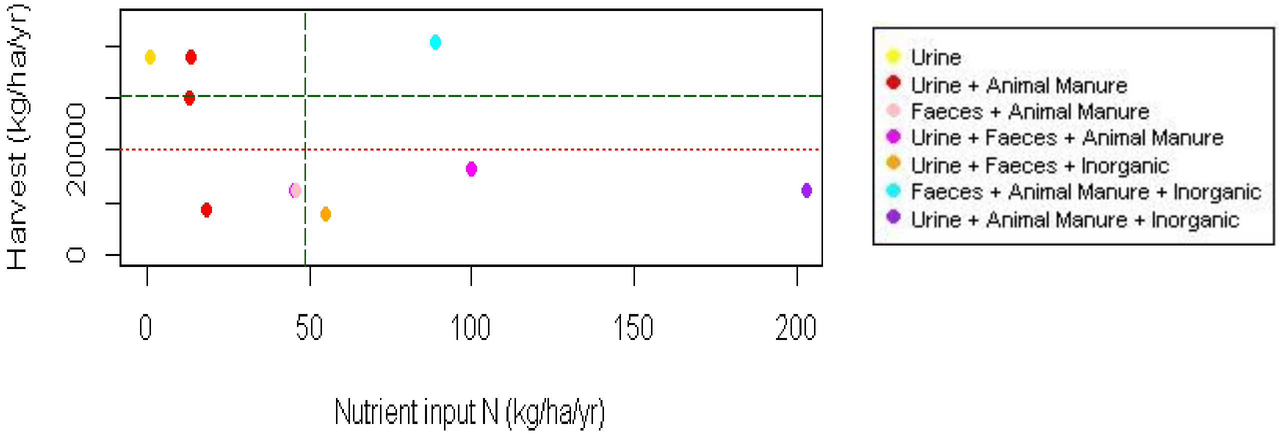
The nutrient recommendation for bananas is taken from a survey by Kibunja et al. (2017) in different parts of Kenya. There are only nutrient recommendations for the eastern upper part of Kenya.

Table 26 shows the possible harvest that is achievable with the recommended nutrient input.

Table 26 *Nutrient recommendation Banana (Kibunja et al., 2017).*

Nutrient	**Recommendation (kg/ha/yr)**	**Possible harvest (kg/ha/yr)**	**Area**
N	49	39422	Kenya Eastern Upper (>1200 masl)
P	25	23031	Kenya Eastern Upper (>1200 masl)
K	59	29298	Kenya Eastern Upper (>1200 masl)

Due to their significantly higher harvest compared to the other farmers, 2 farmers are completely excluded in the graphical analysis below. Also, some farmers are excluded in these models due to incomplete data. However, there is one farmer included in the model who applied the UDDT fertilizer on his banana crop, where intercropping together with maize is practiced. The effect of intercropping is not considered in the following models, because no data was collected regarding this issue.



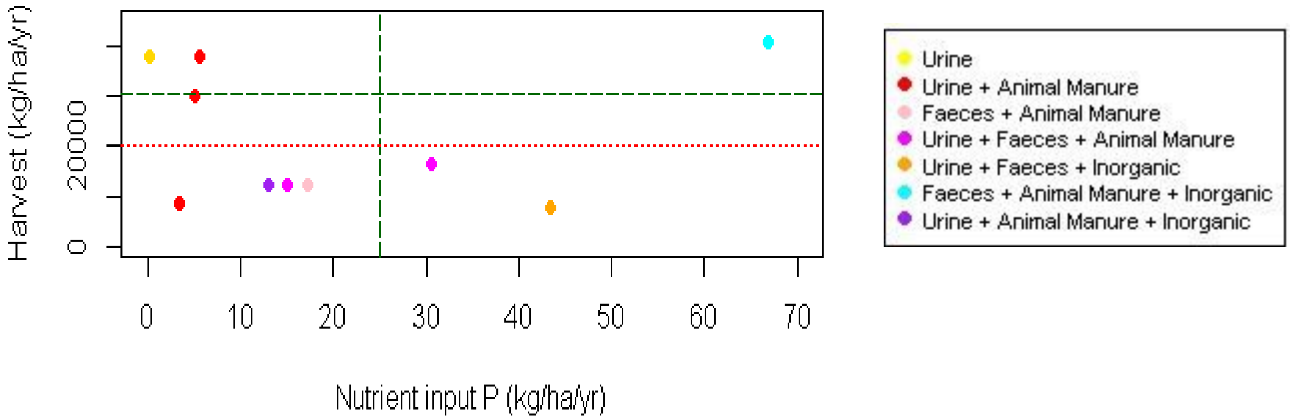
Graph 20 *Analysis of the influence of different fertilization combinations on the nutrient input N (kg/ha/yr) and the harvest of bananas (kg/ha/yr). The dashed green line shows the nutrient recommendation for bananas on the x-axis and the possible banana harvest on the y-axis. The red dotted line shows the average banana harvest that is achieved in Bungoma. n = 10*

Graph 20 shows that the harvest of the included 10 farmers ranges from around 8014 kg/ha/year to 40800 kg/ha/year. However, more than half of the values where a harvest is reported are found in the range of 8014 kg/ha/year to 16000 kg/ha/year. These values are below the average harvest that can be achieved in Bungoma.

Yet, there are four farmers, who have a harvest that is not only above the average banana harvest in Bungoma, it is also above the possible harvest with a certain nutrient recommendation. However, the N input of these farmers is mostly below the nutrient recommendation and they have similar inputs as the other farmers in the graph (Range: 1.2 - 55 kg/ha/year).

These four farmers are also disturbing the trend that shows an increasing harvest with an increasing nutrient input. For example, for the farm which only applies urine on the banana crops, the lowest nitrogen input of all banana farms was calculated with 1.2 kg/ha/year, but the farmer reported a harvest which is one of the highest of all banana farms (37777 kg/ha/year). The highest N input (203 kg/ha/year) can be observed at one farm which applies urine, animal manure and inorganic fertilizer, but this farmer reported a harvest that is even lower than the average banana harvest in Bungoma (Reported harvest: 13000 kg/ha/year).

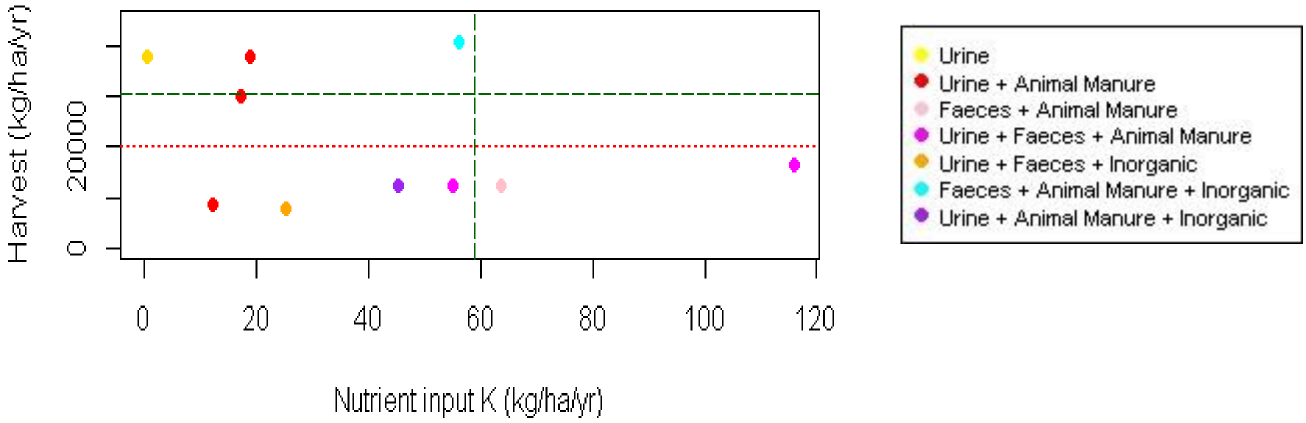
This observation and the one from above can be an indication that collecting valid harvest and input data from the farmers was not achieved in all cases. There are several reasons why this is the case and they are analysed in the chapter "Discussion"



***Graph 21** Analysis of the influence of different fertilization combinations on the nutrient input P (kg/ha/yr) and the harvest of bananas (kg/ha/yr). The dashed green line shows the nutrient recommendation for bananas on the x-axis and the possible banana harvest on the y-axis. The red dotted line shows the average banana harvest that is achieved in Bungoma. n = 10*

Graph 21 is similar to **Graph 20**, but now the graphical analysis is conducted for phosphorus. Consequently, the analysis is similar and the harvest stays the same. However, now the nutrient input ranges between 0.12 – 67 kg/ha/year.Most of the values are found between 0.12 – 17 kg/ha/year phosphorus input. The highest phosphorus input is observed in the graph at a farm which is using the fertilizer combination of faeces, animal manure and inorganic fertilizer (69 kg/ha/year). The lowest impact on the phosphorus content was calculated again for the application of only urine (0.12 kg/ha/year).

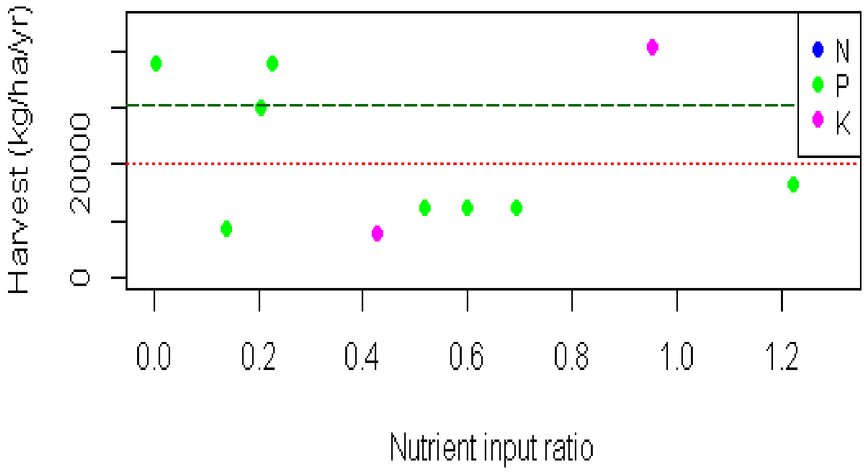
The same observations regarding the plausibility of the collected data can be made as in the analysis of nitrogen.



***Graph 22** Analysis of the influence of different fertilization combinations on the nutrient input K (kg/ha/yr) and the harvest of bananas (kg/ha/yr). The dashed green line shows the nutrient recommendation for bananas on the x-axis and the possible banana harvest on the y-axis. The red dotted line shows the average banana harvest that is achieved in Bungoma. n = 10*

Also, **Graph 22** shows similar patterns as already described for the last two models. Now the nutrient input ranges between 0.47 – 116 kg/ha/year. However, most of the values are found between 0.47 – 64 K kg/ha/year. The highest potassium input was calculated for the farm which is using the fertilizer combination of urine, faeces and animal manure.

Here the most significant difference compared to the other models is that the farms which are fertilizing with inorganic fertilizer, are now lying in the average calculated nutrient input range. The highest calculated K input is not achieved with the fertilizer combinations containing inorganic fertilizer but rather with fertilizer combinations including animal manure and the UDDT products. The explanation for this outcome is that none of the farmers use an inorganic fertilizer containing potassium. A further consequence of this is that there are less farmers whose nutrient input is above the nutrient recommendation.



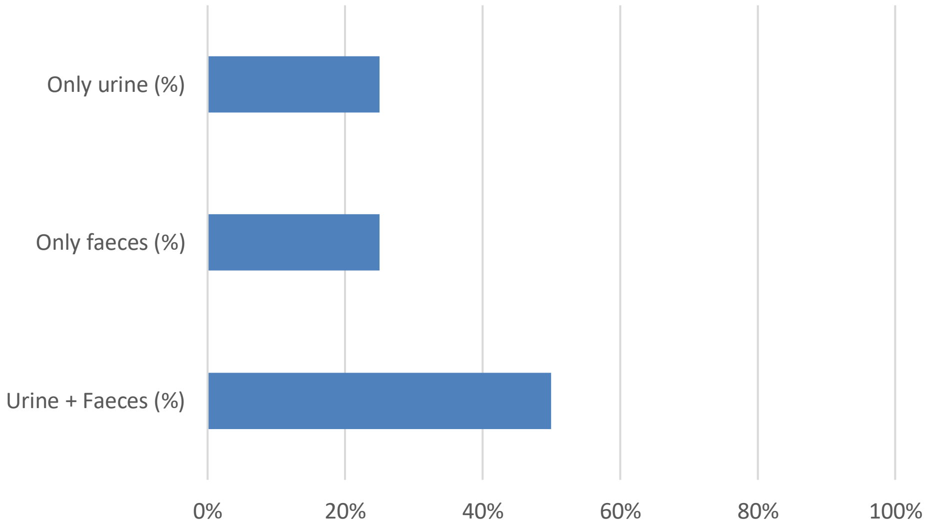
***Graph 23** Analysis of the limiting nutrient input of bananas based on the nutrient input ratio in comparison with the banana harvest (kg/ha/yr). The dashed green line shows the possible banana harvest with a certain nutrient recommendation. The red dotted line shows the average banana harvest that is achieved in Bungoma. n=10*

Graph 23 shows the harvest in kg/ha/year in comparison with the nutrient input ratio of the limiting nutrient type for banana crops, where the UDDT fertilizer in all the possible combinations is applied on.

The analysis shows that phosphorus is most of the times the limiting nutrient type While potassium is the limiting nutrient type at only two farms. The ratio also shows that there is a lower nutrient input in comparison to the recommended nutrient input with one exception. Consequently, the harvest is in most cases smaller than the possible harvest that can be reached with the recommended nutrient input. Furthermore, most of the farmers have a lower harvest than the average harvest in Bungoma. It can also be seen that a higher nutrient input ratio does not automatically result in a higher harvest. However, most of the points form a trend that shows an increasing nutrient input ratio that increases the harvest. There are only four points which are not fitting to this trend.

4.3.3 Coffee

Graph 24 shows that most of the farmers who use the UDDT fertilizer for their coffee crops, use urine and faeces together (50%). The same number of farmers apply only urine or only faeces on their crops (25 %).



***Graph 24** Use of UDDT fertilizer on coffee crops in percent (n=16).*

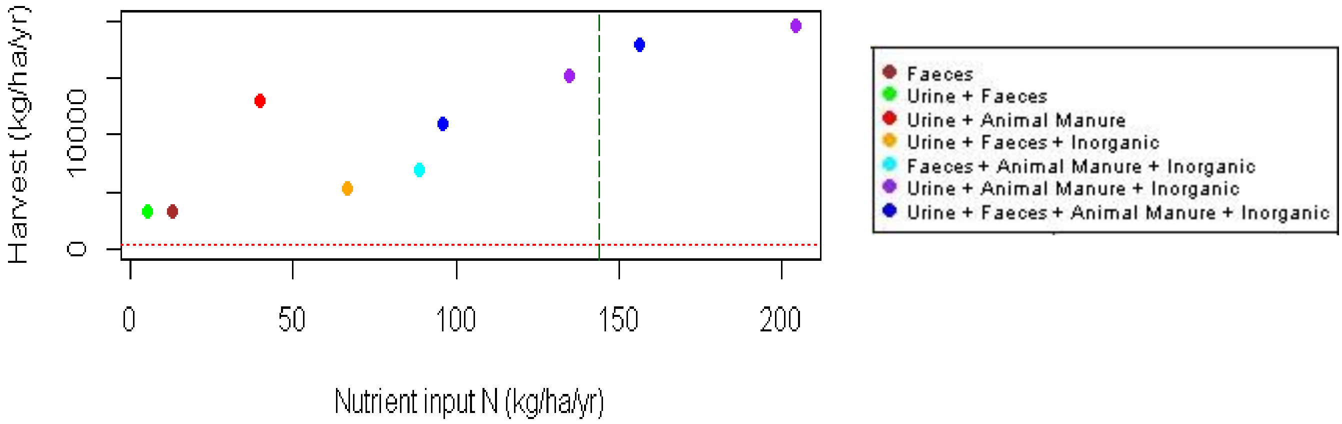
Graph 25, **Graph 26** and **Graph 27** show the graphical analysis for the coffee crops of the farmers, who use the UDDT fertilizer. It includes the nutrient input (N, P, K) through a certain fertilizer combination and the harvest that could be achieved through the fertilization. The green dashed line shows the recommended nutrient input and the red dotted line shows the average harvest for a smallholder farmer in Kenya (Source see **Table 24)**.

The nutrient recommendation for coffee is the mean of collected data from a study of Bekunda et al. (2002) in the north-eastern highlands of Tanzania. Bekunda et. al. (2002) claims that these values are slightly higher compared to the Kenyan ones. Unfortunately, the values that were used for comparison could not be found during research, but it can be assumed that the values in **Table 27** are appropriate for this analysis. Furthermore, Bekunda et. al. (2002) did not publish the harvest that can be achieved with these recommendations, as can be seen in the third column of **Table 27** (n.r.).

Table 27 *Nutrient recommendation Coffee (Bekunda et al., 2002). n.r. = Not reported*

Nutrient	Recommendation (kg/ha)	Possible harvest (kg/ha)	Area
N	144	n.r.	Usambara Highlands, Tanzania
P	15	n.r.	Usambara Highlands, Tanzania
K	60	n.r.	Usambara Highlands, Tanzania

Some farmers are excluded in these models due to incomplete data.

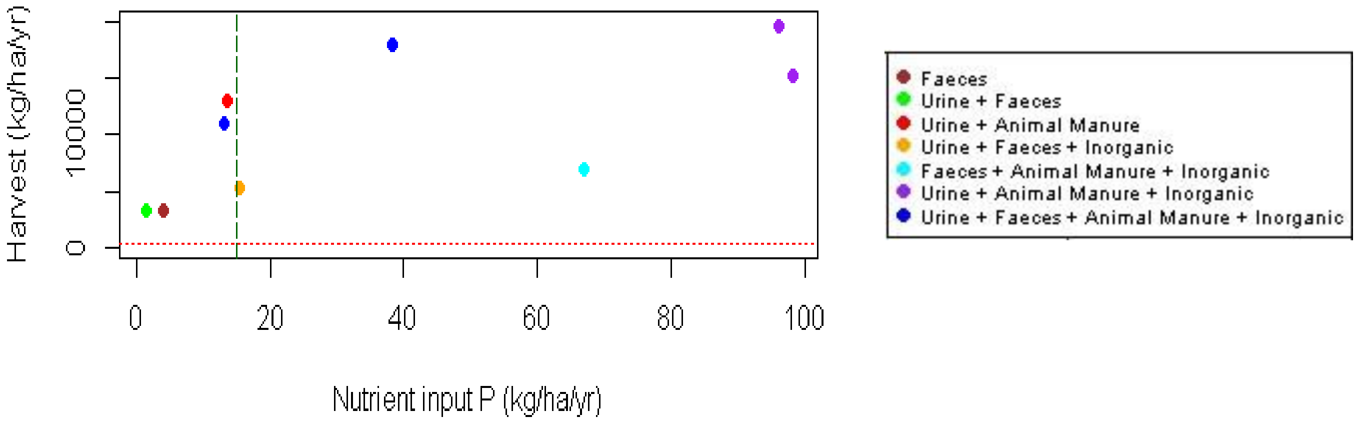


Graph 25 *Analysis of the influence of different fertilization combinations on the nutrient input N (kg/ha/yr) and the harvest of coffee (kg/ha/yr). The dashed green line shows the nutrient recommendation for coffee. The red dotted line shows the average coffee harvest that is achieved by a smallholder farmer in Kenya. n = 9*

Graph 25 shows that the harvest of the nine included farmers ranges from around 3335 kg/ha/year to 19500 kg/ha/year. However, most values are found in the range of 3335 kg/ha/year to 13000 kg/ha/year. That means that all farmers who could report a harvest are above the average coffee harvest that is achieved by a smallholder farmer in Kenya. The causes for the evaluation of mostly much higher coffee harvests than the average harvest are discussed more detailed in the chapter "Discussion".

However, most of the N input of the interviewed coffee farms is below the nitrogen recommendation, which was found in the literature. The lowest impact on the nitrogen content can be observed at a farm which applies urine and faeces (5 kg/ha/year). The highest N input (294 kg/ha/year) has been achieved by one farmer who applied urine, faeces and inorganic fertilizer. However, most values in the graph for the nitrogen input range between 5 and 96 kg/ha/year.

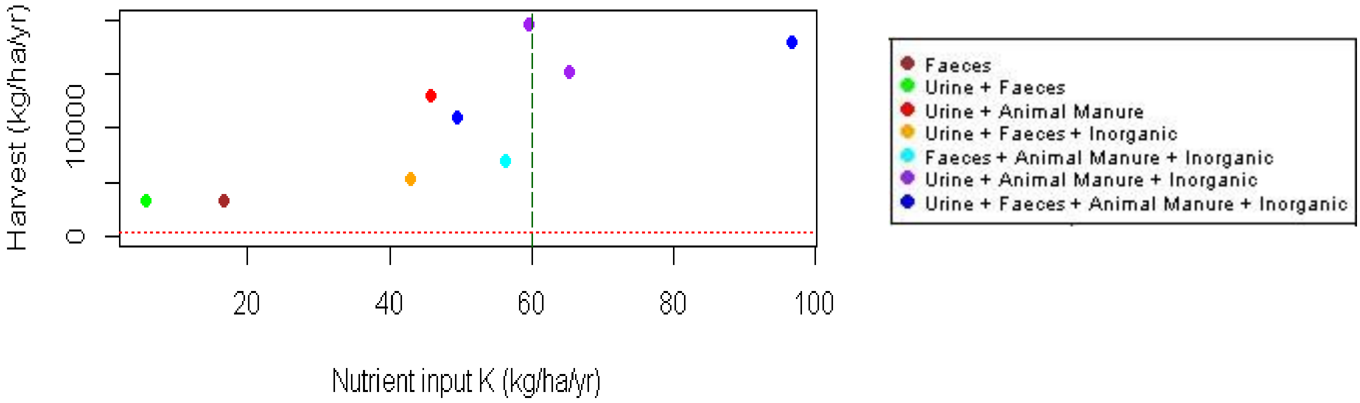
Furthermore, it can be observed that an increasing nitrogen input leads to an increasing harvest.



Graph 26 *Analysis of the influence of different fertilization combinations on the nutrient input P (kg/ha/yr) and the harvest of coffee (kg/ha/yr). The dashed green line shows the nutrient recommendation for coffee. The red dotted line shows the average coffee harvest that is achieved by a smallholder farmer in Kenya. n = 9*

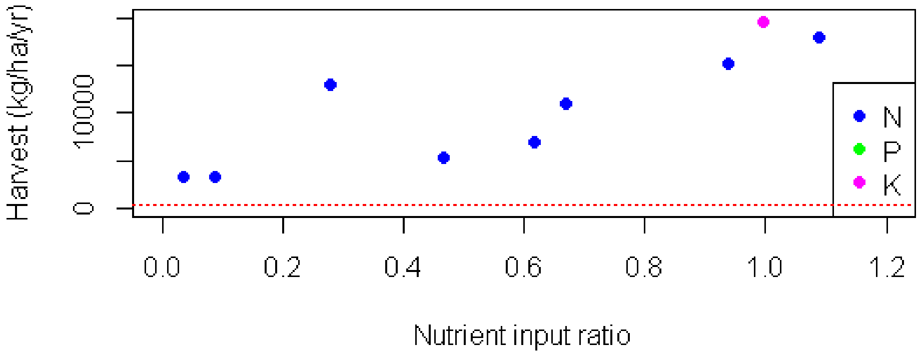
Graph 26 is similar to **Graph 25**, but now the graphical analysis is conducted for phosphorus. Consequently, the analysis is similar and the harvest stays the same. However, now the P input ranges between 0.99 – 98 kg/ha/year. Most values can be found between 0.99 – 15 The highest phosphorus input can be observed at two farms which use the fertilizer combination of urine, animal manure and inorganic fertilizer. The graph shows that for the application of urine and faeces the lowest impact on the phosphorus content was assessed.

The trend of an increasing nutrient input and an increasing harvest is observed again, but it is not as strong as in the N analysis. Furthermore, it is interesting that now several farmers are above or near the nutrient recommendation border. These farmers are mostly using P-rich inorganic fertilizers for their coffee crops (DAP or NPK).



Graph 27 *Analysis of the influence of different fertilization combinations on the nutrient input K (kg/ha/yr) and the harvest of coffee (kg/ha/yr). The dashed green line shows the nutrient recommendation for coffee. The red dotted line shows the average coffee harvest that is achieved by a smallholder farmer in Kenya. n = 9*

Also, **Graph 27** shows similar patterns as already described for the last two analyses. Now the nutrient input ranges between 4 – 97 kg/ha/year. However, most of the values are found between 4 – 65 kg/ha/year potassium input. The highest potassium input is observed on a farm which uses the fertilizer combination of urine, faeces, animal manure and inorganic fertilizer. Most farmers have a lower K input than recommended in the literature.



Graph 28 *Analysis of the limiting nutrient input of coffee based on the nutrient input ratio in comparison with the coffee harvest (kg/ha/yr). The red dotted line shows the average coffee harvest that is achieved by a smallholder farmer in Kenya. n=9*

Graph 28 shows the harvest in kg/ha/year in comparison with the nutrient input ratio of the limiting nutrient type for coffee crops, where the UDDT fertilizer in all the possible combinations is applied on.

The analysis shows that nitrogen is usually the limiting nutrient type, while potassium is the limiting nutrient type at only one farm. The ratio also shows that there is mostly a lower nutrient input in comparison to the recommended nutrient input. Furthermore, a trend between the increasing nutrient input ratio and an increasing harvest is observed. There is only one point which does not fit to the trend.

4.3.4 Summary of Analysis of the use of UDDT products on crop production of smallholder farms

The most common way for farmers to apply the UDDT fertilizer on their crops is a combination of urine and faeces. **Table 28** shows the harvest ranges that are observed most of the times in the analysis.

Table 28 *Harvest ranges for maize, banana and coffee that can be found in the graphical analysis.*

Crop type	Harvest ranges (kg/ha/year)
Maize	100 - 13000
Banana	8014 – 16000
Coffee	3335 - 13000

The nutrient inputs of each nutrient type and for all three crops are quite the same, when the ranges are used for comparison that are found most of the time in the analysis. For example, the nitrogen input for maize and coffee has a similar range (0.32 - 96 kg/ha/year). Only for the N fertilization of banana crops the upper value deviates from the N input range of maize and coffee with 55 N kg/ha/year. For the P and K input the ranges are even more similar than for the N ranges. For phosphorus the range starts from 0.03 kg/ha/year and goes to 17 kg/ha/year and for K the lowest value is 0.13 kg/ha/year and the highest 65 kg/ha/year. The lowest nutrient inputs are observed mostly if only urine is applied, only for coffee the combination of urine and faeces has a lower impact on the nutrient content. The highest calculated nutrient inputs are achieved with the application of different fertilizer combinations, but inorganic fertilizer and/or animal manure are always included.

In all graphs a trend is observed that shows that the harvest increases with an increasing nutrient input. For coffee this trend is the strongest. However, it is not always the case that higher nutrient input increases the harvest. The most extreme example for this observation is the banana crop, where the lowest nutrient input achieves one of the highest harvests and the harvest for the highest nutrient input is even below the average harvest that can be achieved in the study area. It indicates that collecting valid harvest and input data from the farmers was not achieved in all cases. There are several reasons why this is the case and they are analysed in the chapter “Discussion”.

The comparison of the nutrient recommendations and the harvest that can be achieved with the recommended nutrient input shows for the maize and the coffee graphs that the nutrient inputs of the interviewed farmers are mostly below the nutrient recommendations, but the harvests are often above the possible harvest. Similar observations can be made when the data is compared to the average harvest of Kenyan smallholder farmers. For the banana graphs this phenomenon cannot be observed. Here the nutrient inputs and the harvests are mostly lower than the recommendations and the possible and average harvest that can be found in the literature. Furthermore, the comparison of the nutrient recommendation and the nutrient inputs of the interviewed farms helped to find out the limiting nutrient type. For maize and banana it is phosphorus and for coffee nitrogen.

4.4 Analysis of use of the UDDT products on food security of smallholder farms

For the analysis of how UDDT fertilizers contribute to the food security of an average interviewed farming household, MFA models are developed. In different scenarios it is shown which N, P and K input can be achieved with different fertilizer combinations on an average maize field of 1.4 ha. With this size it is possible to cover the yearly nutrient need of a farming household of 10 people in Western Kenya (see chapter 3.3.5). To visualize the contribution of fertilizers to the food security of an average household, the results of the MFA are compared to the nutrient input, that is needed to cover the food demand of the model household (see **Table 29**, **Table 30** and **Table 31**). Consequently, it is possible to compare the different fertilizing strategies with this method.

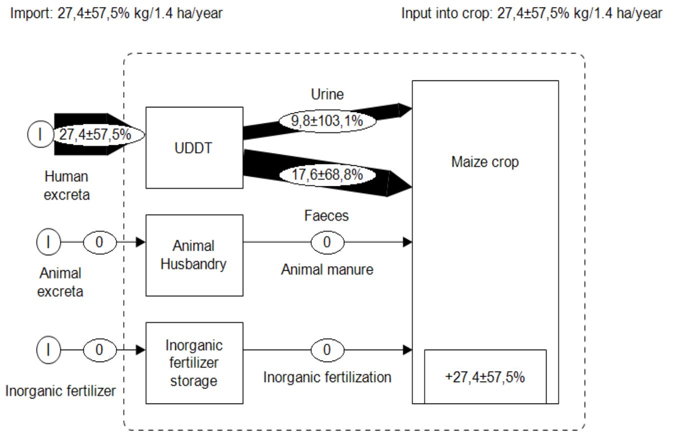
The following scenarios are modelled for each nutrient flow (N, P and K). The detailed description of the scenarios can be found in chapter 3.3.5:

- Urine and Faeces Scenario 1
- Urine and Faeces Scenario 2
- Animal manure
- Urine, Faeces and Animal manure
- Animal manure and inorganic fertilizer

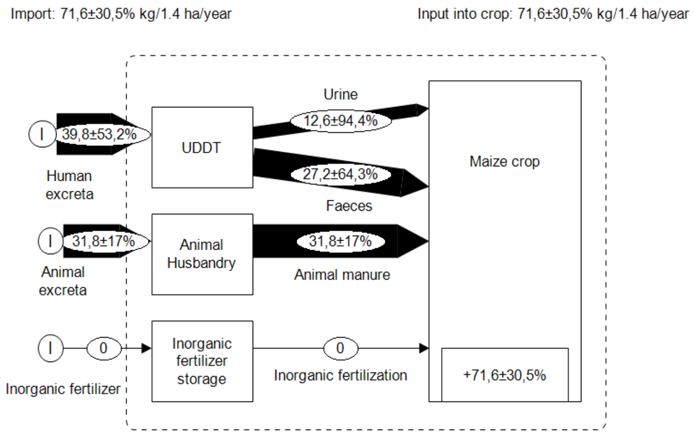
There are two different scenarios for the fertilizer combination of urine and faeces. For the first one the basis for calculating the nutrient input was the average quantity of faeces and urine that is applied from the farmers on their maize crops. For the second one it is assumed that the assessed average collected human excreta from a household of 10 members is applied only on maize and not like in the first scenario on other crops too. In the fourth scenario the calculated nutrient quantities for urine and faeces are taken from the second scenario of urine and faeces. For the inorganic fertilizer DAP is chosen as the model fertilizer.

4.4.1 Nitrogen

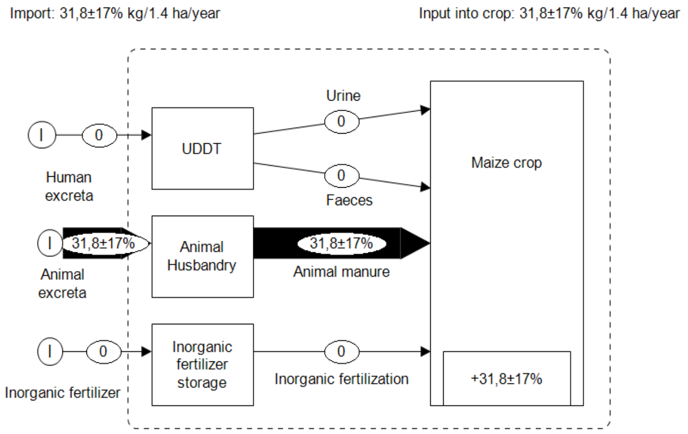
Graph 31, **Graph 30**, **Graph 32**, **Graph 29** and **Graph 33** all show the scenarios for the N input in kg/ 1.4 ha/ year.



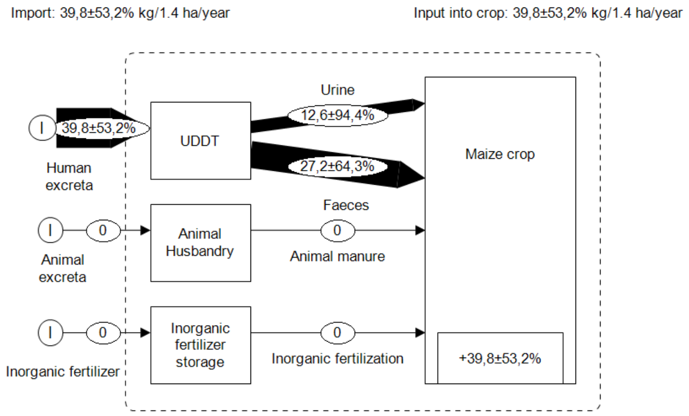
Graph 31 *MFA for N and fertilization with urine and faeces (Scenario 1) on farm level in kg/1.4 ha/yr.**



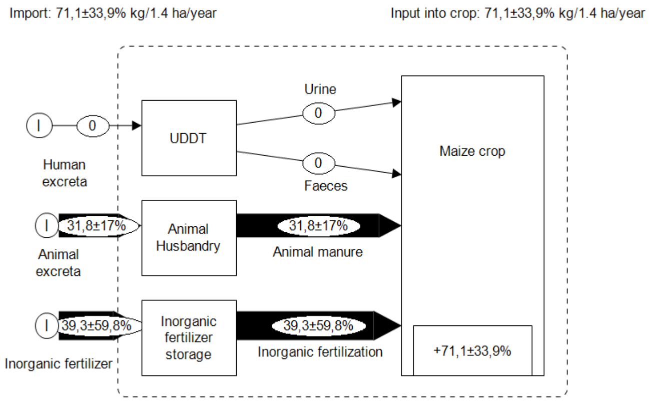
Graph 30 *MFA for N and fertilization with urine and faeces (Scenario 2) on farm level in kg/1.4 ha/yr.**



Graph 32 *MFA for N and fertilization with animal manure on farm level in kg/1.4 ha/yr.**



Graph 29 *MFA for N and fertilization with animal manure, urine and faeces (Scenario 2) on farm level in kg/1.4 ha/yr.**



Graph 33 *MFA for N and fertilization with animal manure and inorganic fertilizer on farm level in kg/1.4 ha/yr.**

*The numbers in percent are the calculated and modelled standard deviations.

***Table 29** Ratio between the optimal N input (148 kg/1.4 ha/yr) and the N input achieved with different fertilizer combinations.*

Scenario	Sum of nutrient input (kg/1.4 ha/yr)	Ratio	Graph
Urine + Faeces (Scenario 1)	27.4	18%	**Graph 31**
Urine + Faeces (Scenario 2)	39.8	27%	**Graph 30**
Animal Manure	31.8	21%	**Graph 32**
Animal Manure + Urine + Faeces	71.6	48%	**Graph 29**
Animal Manure + Inorganic fertilizer	71.1	48%	**Graph 33**

The graphs and also **Table 29** show that the highest N input is achieved with the fertilizer combination of urine, faeces and animal manure and animal manure and inorganic fertilizer. These two combinations have nearly the same N input. However, both scenarios can only cover half of the optimal N input (148 kg/1.4 ha/year) that is needed for a sufficient nutrient supply of a household of 10 people.

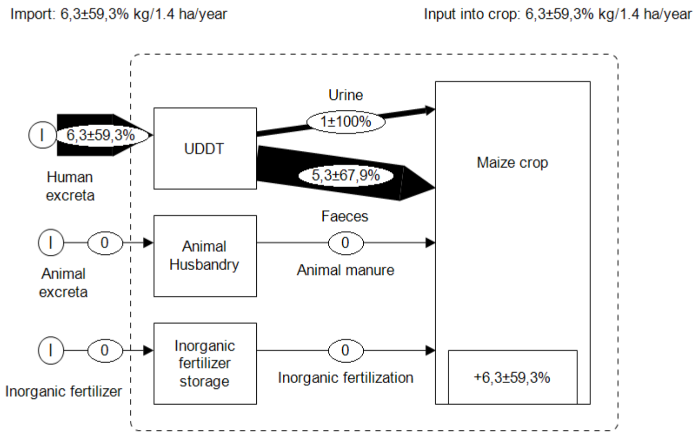
The first fertilizing scenario with urine and faeces has the smallest contribution to food security. However, the N input of this scenario and the input of the fertilization with animal manure only shows a difference of 3% between the calculated ratios in **Table 29**. Analysing the difference between the two scenarios of fertilization with urine and faeces, the result for the N input is that the first scenario can cover 69% of the N input of the second scenario (100%).

If each single flow is analysed the highest N input can be achieved with the inorganic fertilizer, if applied according to the average given amounts by farmers. However, the difference between the single flows seem insignificant. Only the fertilization with urine shows a significant lower N input compared to the other flows, especially towards animal manure and the inorganic fertilizer. Nevertheless, it must be pointed out here that urine fertilization has the highest standard deviations from all flows. Also, the faeces and the inorganic fertilizer show quite high deviations. The possible reasons for these deviations are analysed in the chapter “Discussion”.

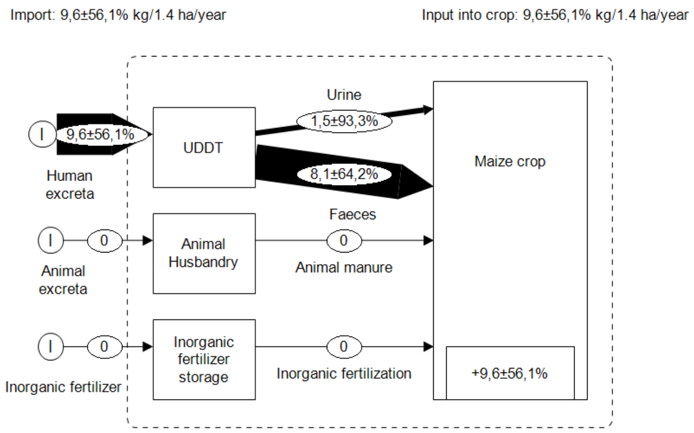
Another interesting aspect here is that if the N input through the second scenario of urine and faeces is compared with the N input through the inorganic fertilizer, the UDDT products achieve a slightly higher N input than the inorganic fertilizer.

4.4.2 Phosphorus

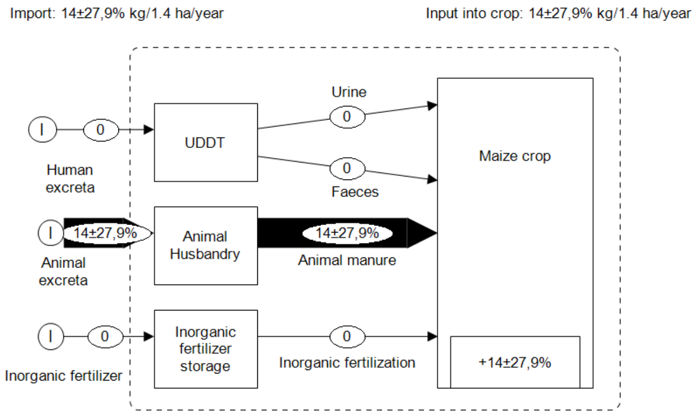
Graph 37, **Graph 36**, **Graph 35**, **Graph 34** and **Graph 38** show all the scenarios for the P input in kg/ 1.4 ha/ year.



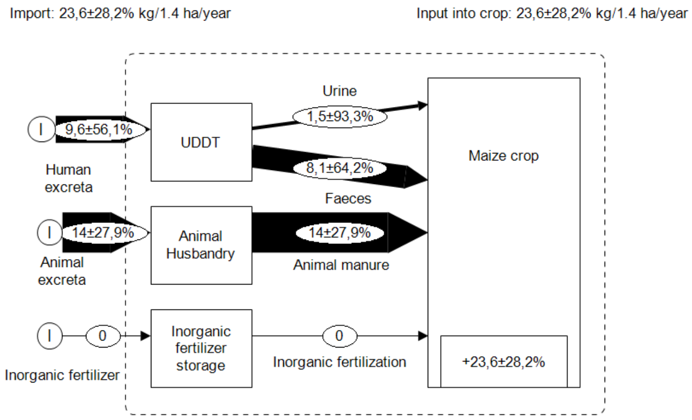
Graph 37 *MFA for P and fertilization with urine and faeces (Scenario 1) on farm level in kg/1.4 ha/yr.**



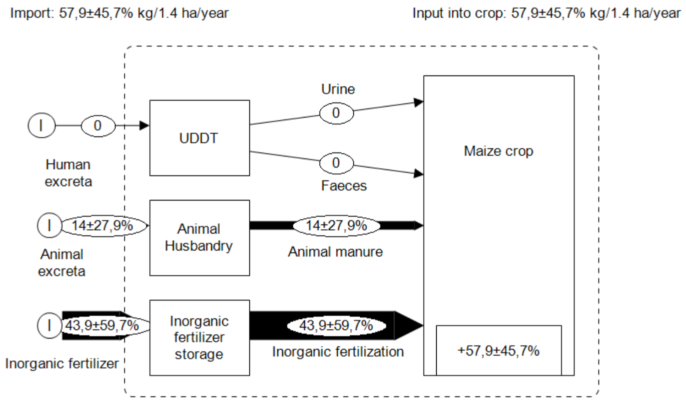
Graph 36 *MFA for P and fertilization with urine and faeces (Scenario 2) on farm level in kg/1.4 ha/yr.**



Graph 35 *MFA for P and fertilization with animal manure on farm level in kg/1.4 ha/yr.**



Graph 34 *MFA for P and fertilization with animal manure, urine and faeces (Scenario 2) on farm level in kg/1.4 ha/yr.**



Graph 38 *MFA for P and fertilization with animal manure and inorganic fertilizer on farm level in kg/1.4 ha/yr.**

*The numbers in percent are the calculated and modelled standard deviations.

***Table 30** Ratio between the optimal P input (63 kg/1.4 ha/yr) and the P input achieved with different fertilizer combinations.*

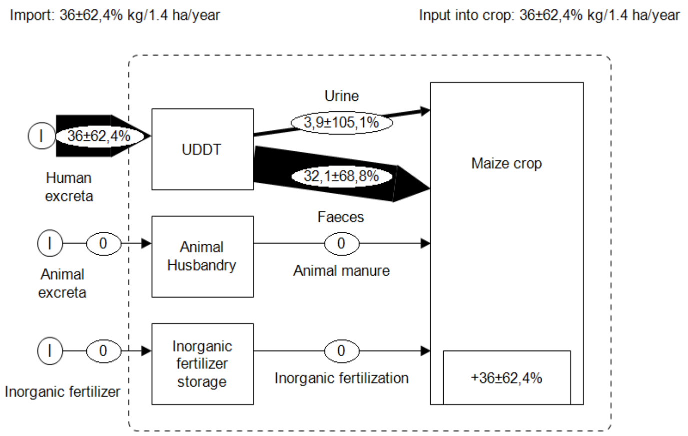
Scenario	Sum of nutrient input (kg/1.4 ha/yr)	Ratio	Graph
Urine + Faeces (Scenario 1)	6.3	10%	**Graph 37**
Urine + Faeces (Scenario 2)	9.6	15%	**Graph 36**
Animal Manure	14.0	22%	**Graph 35**
Animal Manure + Urine + Faeces	23.6	37%	**Graph 34**
Animal Manure + Inorganic fertilizer	57.9	92%	**Graph 38**

The graphs and **Table 30** show that the highest P input is achieved with the fertilizer combination of animal manure and inorganic fertilizer. This scenario can nearly cover the optimal P input if the fertilizers are applied in doses of an average interviewed farmer (63 kg/1.4 ha/year). In contrast to the N models, the P model for animal manure and inorganic fertilizer shows a significantly higher input than the other models. The reason for this is the much higher P content of the inorganic fertilizer compared to the other fertilizer types.

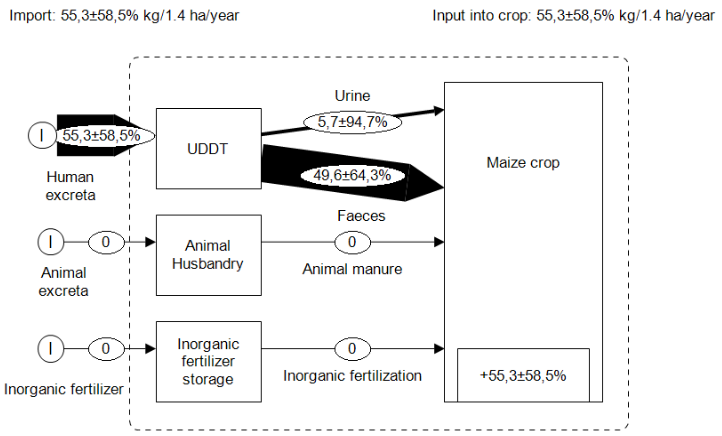
Animal manure and both scenarios where it is included achieve the second-best P inputs, although, the P input through the fertilization with only animal manure is not significantly higher than the input through urine and faeces (Scenario 2). Afterall, the lowest P inputs still have the fertilizer combinations with just urine and faeces. This can be explained through the low P contribution through urine. However, here it must be pointed out again that the urine fertilization has the highest standard deviations from all flows. Also, the faeces and the inorganic fertilizer show quite high deviations. If the difference between the two scenarios of fertilization with urine and faeces is analysed, the result for the P input is that the first scenario can cover 66% of the P input of the second scenario (100%).

4.4.3 Potassium

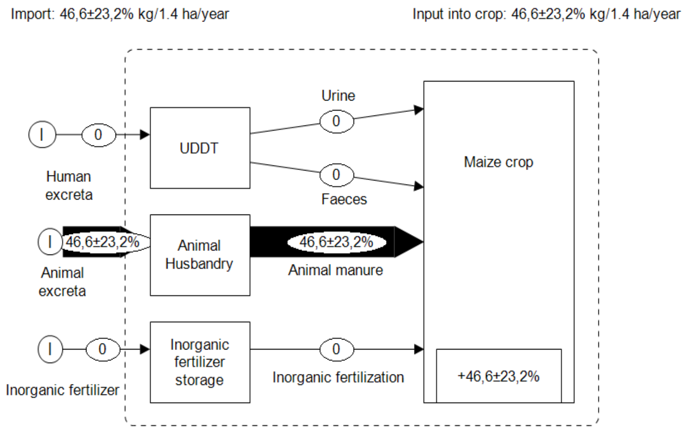
Graph 42, **Graph 41**, **Graph 40**, **Graph 39** and **Graph 43** show all the scenarios for the K input in kg/ 1.4 ha/ year.



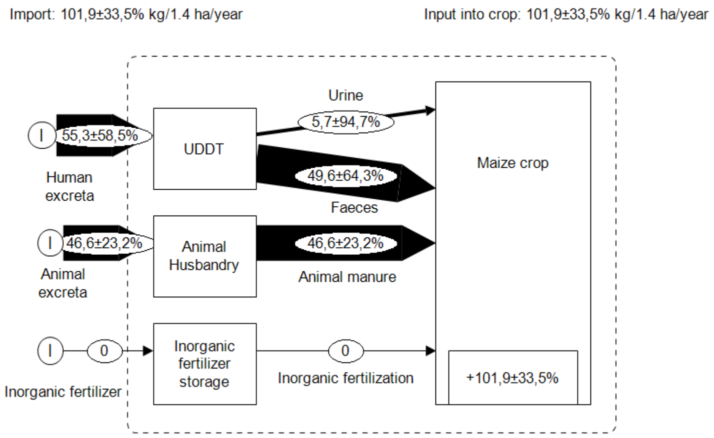
Graph 42 *MFA for K and fertilization with urine and faeces (Scenario 1) on farm level in kg/1.4 ha/yr.**



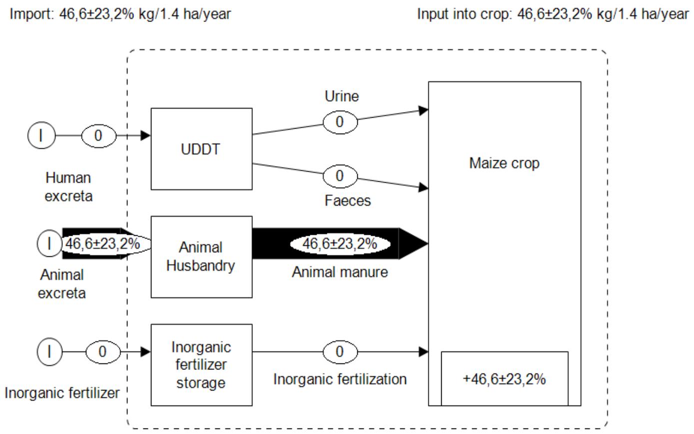
Graph 41 *MFA for K and fertilization with urine and faeces (Scenario 2) on farm level in kg/1.4 ha/yr.**



Graph 40 *MFA for K and fertilization with animal manure on farm level in kg/1.4 ha/yr.**



Graph 39 *MFA for K and fertilization with animal manure, urine and faeces (Scenario 2) on farm level in kg/1.4 ha/yr.**



Graph 43 *MFA for K and fertilization with animal manure and inorganic fertilizer on farm level in kg/1.4 ha/yr.**

*The numbers in percent are the calculated and modelled standard deviations.

Table 31 *Ratio between the optimal K input (36 kg/1.4 ha/yr) and the K input achieved with different fertilizer combinations.*

Scenario	**Sum of nutrient input (kg/1.4 ha/yr)**	**Ratio**	**Graph**
Urine + Faeces (Scenario 1)	36.0	99%	**Graph 42**
Urine + Faeces (Scenario 2)	55.3	152%	**Graph 41**
Animal Manure	46.6	128%	**Graph 40**
Animal Manure + Urine + Faeces	101.9	280%	**Graph 39**
Animal Manure + Inorganic fertilizer	46.6	128%	**Graph 43**

The graphs and **Table 31** show that the highest K input is achieved with the fertilizer combination of animal manure, faeces and urine. The reason for this is the high amount of K input through animal manure and faeces, whereby the faecal matter achieves a slightly higher input than animal manure. The inorganic fertilizer has no impact here since the interviewed farmers did not use inorganic fertilizers containing K for their maize crops.

In contrast to the N and P model, nearly all the scenarios are significantly higher than the optimal K input (36 kg/1.4 ha/year). Only the first scenario with urine and faeces achieves the optimal fertilizing amount of K. The low K input through urine offers an explanation for this. However, here the urine fertilization has the highest standard deviations from all flows. Also, the faeces again show quite high deviations. If the difference between the two scenarios of fertilization with urine and faeces is analysed, the result for the K input is that the first scenario can cover 65% of the K input of the second scenario (100%).

4.4.4 Summary of Analysis of the effect of UDDT products on food security of smallholder farms

The analysis of how much the UDDT products can contribute to the nutrient input and in further consequence to the food security of a farming household is quite different for each nutrient type. In the second scenario, where only urine and faeces are used, it can nearly cover one-third of the optimal N input. On the P input the fertilization with the UDDT products has a quite low impact. The K models of the two scenarios, where only urine and faeces are fertilized, show a completely opposite effect. Here the first scenario can nearly cover the optimal input rate and the second one has an even higher input compared to the optimal rate. If the two scenarios are compared to each other, the nutrient input of the first scenario can cover on average 67% of the nutrient input of the second scenario (100%).

The highest nutrient inputs can be achieved with the fertilizer combination of urine, faeces and animal manure and animal manure and inorganic fertilizer. However, it is interesting that if the fertilization with only the UDDT products (Scenario 2) is compared to the inorganic fertilizer, the comparison for N shows that the UDDT fertilizer even has a slightly higher input than the inorganic fertilizer. For P the inorganic fertilizer can achieve much higher inputs, together with the application of animal manure it can even cover the optimal input rate. However, the UDDT fertilizer has a significantly higher impact on the K input than the inorganic fertilizer since the used inorganic fertilizer (DAP) does not contain any potassium. If the nutrient input through animal manure and the second scenario of the fertilization with urine and faeces is compared then it seems that there is no significant difference for all nutrient types.

If urine and faeces are separately compared with each other and with the other flows, the smallest input in all scenarios has urine. However, the standard deviation of urine is always the highest. Additionally, faeces and inorganic fertilizer have quite high standard deviations.

4.5 Sustainability assessment of UDDT fertilizer

The sustainability assessment finally evaluates the collected and the processed data. The main purpose of this is to find out how sustainable the use of the UDDT fertilizer is. However, with the evaluation of some parameters it is also possible to get further data to answer other research questions, especially for the question regarding the possible barriers and drivers of the use of the UDDT fertilizer and for the possible effect of it on crop production and food security of farmers. The following parameters are graded based on a system where 1 is the worst score and 4 is the best one.

4.5.1 Health and Hygiene

The most important aspect for this point is the risk of exposure to pathogens and hazardous substances on the household level (Lennartsson et al., 2009). The dry faeces are safe to use after an appropriate storage time.However, some rules for the agricultural application should be considered (Rieck et al., 2013):

- The faeces should be buried into the soil and should not be distributed on the surface (Schönning and Stenström, 2004)
- It is the safest when the UDDT fertilizer is applied to fruit trees and crops that are further processed, like coffee. The application to vegetables or root crops should be avoided (Rieck et al., 2013)

Kraft (2010) conducted a sampling survey over three months for five households from the EPP project and found out that the faecal matter is safe to use if the use of the UDDT is correct, which means that the material is dried enough and was stored for an appropriate time (around 6 months). If this is not the case, there is an insufficient pathogen die-off.

The health risk for urine is low. The biggest risk is the faecal cross-contamination, which happens when faecal matter is falling into the urine collection vault. Consequently, for the use of urine the right use of the UDDT is also important. The safest way to reuse the urine for fertilization is applying it on fruit and timber trees (Rieck et al., 2013).

Since the health risk of the UDDT fertilizer is quite low, but the right use of the UDDT is crucial for a hygienic safe product, the point “Health and Hygiene” is rated with a two.

4.5.2 Environment and natural resources

This parameter includes the following points:

- Quality of the UDDT fertilizer
- Use of natural resources
- Water use
- Possible emissions

Here, the quality of the fertilizer especially involves the nutrient content of urine and treated faecal matter. **Table 29**, **Table 30** and **Table 31** in chapter 4.4 “Analysis of the effect of UDDT products on food security of smallholder farms” show the nutrient inputs that can be achieved with the UDDT products. In these tables it is possible to see that the fertilization of a maize crop with urine and faeces can contribute a little to the optimal N and P input rate. The calculation of the optimal input rate is based on nutrient recommendations for Sub-Saharan Africa and is adjusted to a crop size from which a farming household of 10 people can cover their food requirements. For K the input rate can be covered totally through the fertilization with the UDDT products. It even occurs that a higher input than the recommended K input is achieved. However, it should be mentioned here that the used data is based on the questionnaire survey and it is possible to achieve higher nutrient inputs through the UDDT products if the farmers optimise the use of the UDDT. It can be optimised for example if the toilet is used by every household member and there is no additional use of a pit latrine. Consequently, more urine for fertilization can be collected. Another option would be to use more jerry cans for collecting urine, so that none of the urine gets lost due to spillage

However, if the nutrient input of the UDDT fertilization is compared to an inorganic fertilizer (in this case DAP) then it can achieve similar nitrogen inputs, but significantly less phosphorus inputs than DAP (see MFA models in chapter “4.4 Analysis of the effect of UDDT products on food security of smallholder farms”). For potassium a comparison is not possible since DAP does not contain K.

Besides of the main plant nutrient, urine also contains various micronutrients and faecal matter contains organic carbon that can have a positive effect on the fertility of land (Dagerskog et al., 2014). These aspects of fertilization can help to save and protect natural resources since the UDDT fertilizer has a high potential to save mineral fertilizers (Robinson, 2005; Meinzinger et al., 2009 and **Table 32** in chapter “4.5.4 Financial and economic issues”). However, the fertilization with human excreta should be seen more as a complement rather than a replacement of existing fertilizers. To increase the fertility in degraded soils it is important to use a mixture of fertilizers like human excreta, animal manure and mineral fertilizer (Dagerskog et al., 2014). Especially if it is considered that animal manure has 1 to 2 times as much nitrogen as human excreta (Dagerskog et al., 2014 after Drangert, 2010). Consequently, the quality of fertilizer and the use of natural resources will be rated with a three.

There is no water needed for the operation and maintenance of the UDDT, so the rating for this aspect will be four. Possible emissions of faecal matter are nutrients, COD and bacteria that could infiltrate to drinking water aquifers (Guness et al., 2005). However, through the dehydration of the faecal matter in the double vault UDDT the pathogen loads can be reduced and consequently, the contamination of the groundwater too (Endale et al., 2012). The infiltration of urine may influence the nitrate concentrations in the groundwater. However, this aspect is neglectable (Rieck et al., 2013). This is supported by a field study of Guenss et al. (2005), where a high nitrogen content in the top layer of the soil could be found after they buried UDDT products three weeks before. Therefore, nitrogen and other nutrients can be reachable for even shallow-rooted plants. Consequently, it can be concluded that the nutrients of buried UDDT products are taken up in the soil and do not leach into the groundwater, where a risk of possible contamination exists. The only possible negative impact here can occur if the UDDT product is not completely sanitized through the storage and the microbial contaminations also move to the top layers of the soil. However, it can be assumed that the emissions of the UDDT fertilizer are insignificant considering the environmental perspective and so the rating here is also a four.

4.5.3 Technology and operation

This parameter includes the following points:

- System robustness
- Odour
- Complexity of construction and Operation & Maintenance (O&M)

For the technology and operation, the whole UDDT system must be considered. The system robustness includes the vulnerability towards power cuts, water shortages, floods, etc. and the flexibility and adaptability of technical elements (Rieck et al., 2013). The vulnerability of UDDT is low, because iit does not depend on power or water supply (Tilley et al., 2014). Additionally, the UDDT is quite resistant against floods and does not collapse as the pit latrine, like several farmers reported in the questionnaire survey. For the fertilizer there are two risks. One of them is that water enters the faeces chamber due to degrading doors and prevents the faecal matter from drying properly (Kraft, 2010). The doors can be repaired with local material. The other one is that it is not possible to collect urine because of a clogged urine pipe. However, with simple tools, like bottle cleaners, the pipe can be cleaned. In the worst-case scenario a new pipe can be found in every local hardware shop. Considering these aspects, the system robustness can be rated with a three. Also, the odour can be rated the same way, because if the UDDT is used in a correct way, no unpleasant odours should develop (Rieck et al., 2013)

After a report of the Tilley et al. (2014) the UDDT is simple to design and built. The O & M of dried faecal matter of a double-vault UDDT is quite easy due to long storage durations which makes it possible that the faecal matter only has to be emptied yearly with a shovel (Rieck et al., 2013). The handling of the faeces can get more complex when the drying process is disturbed through precipitation that enters the faeces chamber or urine that flows into the faeces chamber due to wrong use. Also, the urine is quite easy to handle, only the jerry can has to be emptied regularly. Consequently, the complexity of the construction of the UDDT and the O & M of its fertilizer is low and so the parameter will be rated with a three.

4.5.4 Financial and economic issues

This parameter includes the following points:

- Investment costs
- Operation & Maintenance (O&M) costs
- Benefits of the fertilizer

For this point the whole UDDT system has to be considered again. The toilets of the EPP project were not built in the cheapest way, because the EPP team thought that through an appealing design it could promote the concept of this toilet in the area. Nevertheless, the toilet could be built cheaper with an easier design and with locally available material. The investment costs for the owners were quite low, because they got subsidies for the construction, only 20% had to be contributed by the household itself. The investment costs parameter will be rated with a two, because if the costs for the construction of an UDDT are compared with the digging of a pit latrine, the initial expenses are quite high. (von Muench, 2011).

For the operation only ash is needed, which is available in the household from cooking activities. The questionnaire survey showed that there are additional average costs of 651 Kenyan Shillings for maintaining the toilet throughout 10 years. Compared with an average income of around 173000 Kenyan Shillings per year of an agricultural employee in Kenya, the O&M costs are very low (KNBS, 2019). The farmers can even afford any repairs with their monthly income. However, during the questionnaire survey sometimes it was observed that important repairs are not done, like repairing the doors of the faeces vaults to avoid the entering of raining water or changing of a damaged urine pipe, but that is probably not due to financial reasons. It is more likely that the knowledge how to repair these small damages with local materials is missing. Consequently, the rating of the O&M parameter will be a four.

The project´s case study assumes that after 12 years the UDDT is generating profit. The calculation is based on the use of the fertilizer for mango and banana production. Since the toilet is designed for 20 years, the profit still can be derived for another eight years (von Muench, 2011). The benefit of the fertilizer is derived from the increased harvest. This positive effect of faeces and urine on the yield was proven in several studies (e.g. Jönsson et al., 2004; Mnkeni and Austin, 2009; Semalulu et al., 2011). Also, in the questionnaire survey an improved harvest was observed. For example, for maize an average harvest of around 9 tons per year and hectare could be evaluated. That is much more than a study of IFDC (2012) for Kenya assumed. According to this survey a smallholder farmer can normally achieve an average maize yield from 0.5 to 1.5 t/ha. However, with appropriate agronomic practice and improved technologies 3-6 tons per hectare can be harvested. However, it should be noted here that the data of the evaluated harvest from the questionnaire shows some problems due to the various ways to report the size of land in the questionnaire survey. This problem is discussed more detailed in the chapter “Discussion”.

Additional economic benefits can be derived from saving mineral fertilizer. Dagerskog and Bonzi (2010) found that the annual N and P, that can be collected from a family with 10 people in Burkina Faso, is roughly the same as the quantity of the N and P content of 50 kg of urea and 50 kg of NPK (14-23-14), which costs about 80 $. **Table 32** shows how they calculated the results in their study.

Table 32 *Method of calculation of the nutrient quantity (N and P) of UDDT fertilizer that can be produced from 10 people in a year and the calculation of the equivalent amount of inorganic fertilizer after Dagerskog and Bonzi (2010).*

Fertilizer	N (kg)	P (kg)
Urine et faeces from 10 person in one year	28	4.5
50 kg of urea and 50 kg of NPK (14-23-14)	30	4.9

Based on the method of this study the financial value of the UDDT fertilizer from the toilets evaluated in the questionnaire survey can be calculated. **Table 33** shows the calculated nutrient quantity for a household of 10 people based on the average collected urine and faeces amount from the questionnaire survey. In the third column the quantity of DAP is given. It is the amount of inorganic fertilizer that is needed to get a nutrient quantity equivalent to the one which can be achieved with the UDDT fertilizer. DAP was chosen due to the same reasons that were already mentioned in the MFA model. It is the second most applied fertilizer after CAN and contains N and P. The calculation of the nutrient amount in DAP is based on the literature research in the chapter “3.3.2 Literature research”. Finally, the financial value of the UDDT fertilizer is calculated. That means for example for N that 80 kg DAP worth 52.6 US $ can be saved through the fertilization with urine and faeces. The calculation of the savings are based on the evaluation of the price from AfricaFertilizer.org (2019). According to this organisation the price for DAP was 658 $/t in July 2019.

Table 33 *Comparison between the nutrient quantity (N and P) of the UDDT fertilizer that can be produced by a household of 10 people and the equivalent DAP quantity that can be saved through the UDDT fertilization plus the possible financial savings in US $.*

Nutrient type	Urine + Faeces nutrient quantity of 10 persons	DAP equivalent quantity	Savings
N	15.7 kg/yr	80 kg (=15 kg N)	52.6 $
P	4.9 kg/yr	20 kg (=4.2 kg P)	13.2 $

Nearly 50% of the interviewed farmers reported that they use no inorganic fertilizer at all on some crops (see **Graph 12**). This seems reasonable since **Table 33** shows that-especially for N-the UDDT fertilizer can help to save an essential part of inorganic fertilization. However, the benefit of saving mineral fertilizers depends on the farmers economics, such as the economic status or the size of the farm (Robinson, 2005; Meinzinger et al., 2009). Considering all this information the benefit of the fertilizer from an economic point of view can be rated with a four.

4.5.5 Socio – cultural aspects

This parameter includes the following points:

- Convenience
- Contribution to food security
- System perception

The convenience includes the operation and maintenance activities that are needed for having a proper UDDT product. The O & M of the dried faecal matter of a double-vault UDDT is quite easy due to long storage durations which make it possible that the faecal matter only has to be emptied yearly. However, the emptying procedure with the shovel can be repellent for some users (Rieck et al., 2013). Problems that are reported or observed during the questionnaire survey are that water enters the faeces chamber due to degraded or not completely tight faeces chamber doors. Only few farmers repaired them with locally available materials. Another problem is that urine enters the faeces chamber due to the wrong use of people, who do not know this type of toilet.

Also, there has to be enough ashes available for the drying process of the faeces. Some farmers reported that it is sometimes a problem to collect enough ash for maintenance. The jerry can of the urine has to be emptied regularly, if this is forgotten urine will get lost. Considering that the user needs to think about several aspects to have a hygienic unproblematic fertilizer the aspect “Convenience” will be rated with a two.

The possible positive impact on food security was already assessed with the MFA nutrient analysis and is also thematised in the chapters 4.5.2 “Environment and natural resources” and 4.5.4 “Financial and economic issues”, where the benefit of the fertilizer is discussed. The results show that not only the income of the farmer can increase through the increased yield due to higher nutrient input, but also the food security of the household can be enhanced to an extent. Especially if there is nearly no external nutrient input to the crops due to low fertilizer use before the UDDT (IFDC, 2012). Including all the relevant information from the chapters before and since the effect of the UDDT fertilizer on food security depends on how much the farmer fertilized before, this parameter will be rated with a three.

The perception of the use of the fertilizer shows a broad range of opinions. The questionnaire survey showed that on the one side the users of the fertilizer cherish it. One farmer even collected human waste from other toilets to increase the amount of UDDT fertilizer. Furthermore, in areas, where neighbours or guests see the positive impact of the toilet and the fertilizer, the demand for an own UDDT toilet is high. On the other side the farmers who refuse to use the fertilizer for their crops, indicated that they do not want to handle with human waste due to cultural reasons. Four farmers even reported that they have problems to sell their products if the customers know that the farmer applied the UDDT fertilizer. However, there were more positive responses to the fertilizer than negative ones. So, the parameter “System perception” will be rated with a three.

4.5.6 Summary of sustainability assessment

Table 34 is a summary of the rating of the described parameters above. The rating of the five main parameters is the rounded up mean of the sub-criteria.

Table 34 *Sustainability assessment summary of rating. 1 = very low, 2 = low, 3 = high, 4= very high*

PARAMETERS	RATING
Health and Hygiene	**2**
Risk of exposure to pathogens and hazardous substances	2
Environment and natural resources	**4**
Quality of the UDDT fertilizer	3
Use of natural resources	3
Water use	4
Possible emissions	4
Technology and operation	**3**
System robustness	3
Odour	3
Complexity of construction and O & M	3
Financial and economic issues	**3**
Investment costs	2
O & M costs	4
Benefits of the fertilizer	4
Socio-cultural aspects	**3**
Convenience	2
Contribution to food security	3
System perception	3

5. Discussion

The qualitative part of the master thesis, mainly dealing with the UDDT itself, helped to answer the research question concerning the drivers and barriers of the use of the UDDT and its fertilizer. Furthermore, the analysis of this part showed similar outputs like several other studies and reports about this sanitation technology. For example, in the questionnaire survey it was observed that there are many people who want an own UDDT toilet, but only 21% of the 47 interviewed users of the UDDT knew households who reconstructed the toilet by themselves with local materials. This phenomenon can be explained by the relatively expensive design of the UDDT. Hence it seems that for low income earners who are interested in having such a toilet for their own household, it is not affordable. Furthermore, the EPP project was financed through subsidies and there are no other external financing options, like microfinancing or community fundraising initiatives available in the area. Possible solutions for increasing local replications could be cheaper designs, use of more locally available materials and alternative financing mechanisms besides of subsidies (von Muench, 2011; Uddin et al., 2012).

Furthermore, a long-term local support network would increase the replications, because often the knowledge for building the UDDT with local materials is missing. However, the local support network is also crucial for the long-term use of the toilet, as the map in the “Usage of the UDDT” (**Figure 3**) shows. Technical knowledge about the UDDT and regional opinion leaders, who mobilise and sensitise people regarding sanitary issues, play an important role for continued usage of the toilet. This could prevent the abandonment of the toilet for several reasons (von Muench, 2011; Mbalo and Brand, 2012). For example, in the questionnaire survey one of the reasons of non-usage was that technical problems occurred, like clogging of the urine pipe or a broken squatting pan. These common and easy to solve problems could be prevented through the availability of local experts on UDDTs (von Muench, 2011; Rieck et al., 2013).

Some farmers never started to use the toilet due to improper training and misinformation by local people in charge or the construction workers. This shows that it is essential to have training sessions throughout all the phases of the project, including the planning, the construction and the utilisation phase. Due to financial and time reasons the EPP project had no follow-up training after the construction phase (Mulonga, 2007; von Muench, 2011; Harada et al., 2018). Furthermore, it is important that the responsibilities within the project team and the local network in all the phases of a project are clear to the owners of the UDDT, especially if there are any problems or confusions about the UDDT, the UDDT fertilizer and its usage (von Muench, 2011; Mbalo and Brand, 2012).

Another reason for the abandonment of the UDDT that was reported in the questionnaire survey is the lack of ownership. The EPP project included the owners of the UDDT through the contribution of own financial capital and unskilled labour for construction. It is not possible to conclude based on the results of the questionnaire survey if this was a reason that farmers continue to use the UDDT. However, practical experience in several ecological sanitation projects shows that the involvement of future owners increases the use of the UDDT (von Muench, 2011; Uddin et al., 2012). A new, long-term problem that could be assessed through the questionnaire survey is that the toilet was given up because the person who was trained, is currently not living in the household or the property situation changed and the knowledge got lost with the new owner.

One of the biggest problems that occurred to owners of the UDDT who still use the toilet, are of technical nature. The most reported ones were clogging of the urine pipe and degrading faeces collection vault doors. Both problems are quite common for the UDDT technology (Rieck et al., 2013). The reason for the clogging in the EPP project is that users put accidental ash or toilet paper in the urine section or defecate there. Another point is the poor material selection for the urine pipe itself. Due to its flexibility, sharp bends can develop and cause blocking. Standard straight PVC pipes that are found in local hardware shops, could prevent the constant clogging. The problem with degrading faeces vault doors is also due to the material decision. They are made from flat iron sheets with a wooden frame. Exchanging the doors with metal, concrete or other more resistant material, can prevent the degrading process (von Muench, 2011).

Another disadvantage that was mentioned quite often was the wrong use by people who do not know the toilet, such as visitors. It's a quite common problem that is reported in several projects (von Muench, 2011; Pynnönen et al., 2012; Rieck et al., 2013). But not only the usage for untrained people is problematic. It can also be a challenge for small children due to the design with the two holes. This problem leads to non-usage of the toilet by young children in the family. Additionally, old people in the household sometimes do not use the toilet because they have difficulties to squat. In a study of Starovoitova (2012) it is emphasized that it is essential-for the sustainability of a sanitary project-that all needs of all household members in the context of age and disability should be considered in the toilets design. The two groups of special users mentioned above were not specially considered in the design of the UDDT in the EPP project. Training and some easy adaptations, like a movable construction to help old people to squat, could increase the probability of usage of all family members (Mbalo und Brand, 2012; Rieck et al., 2013).

The most mentioned driver in the questionnaire survey for using the UDDT is the possibility to use its products for fertilization. Also, in a study of the long-term acceptability of UDDTs in rural Malawi, Harada et al. (2018) found out that the belief that human excreta have a positive effect on the agricultural yield is one of the main reasons to use the UDDT.

Another important advantage for the farmers who were interviewed, was that there is nearly no smell developing. Drangert (2004) emphasizes the importance of odourless operation in his report about norms and attitudes towards Ecosan and other sanitation systems. If strong odours develop it even can lead to abandonment of the toilet. Two interviewed farmers reported exactly this as the reason for the non-usage of the UDDT. Strongly related to this argument is the health and hygiene aspect. Some owners of the UDDT observed an improved health and hygiene situation in the family since the toilet is in use. This driver is also reported in some reports and studies (e.g. Mulonga, 2007; Mbalo and Brand, 2012).

However, a more important factor for the usage is the durability of the toilet structure. That was especially mentioned by farmers in the study area who have problems with digging a pit latrine due to rocky grounds or live in a swampy area and have to deal with collapsing of the pit latrines. These adverse hydrogeological conditions can be the main success factor for the uptake of an Ecosan technology (Robinson, 2005; Mulonga, 2007; Pynnönen et al., 2012; Uddin et al., 2012). Furthermore, in combination with the durability of the UDDT it was mentioned that it is not necessary anymore to dig a new pit latrine every time when it is full. This advantage was also reported in a study of Pynnönen et al. (2012), who evaluated among other topics the key success factor of UDDTs in schools in rural Kenya.

The quantitative analysis of the questionnaire survey gave mostly some information for answering the question regarding the impact of the UDDT fertilizer on the crop production and the food security of users of this technology. Here not only the collected quantities of urine and faeces are relevant, but also the possible impacts on the quality and the fertilization effect of different treatment types and times of use are interesting.

The analysis of the use of urine as fertilizer shows that the interviewed farmers use on average around 460 l urine per year. If it is assumed that every person produces around 1.2 l of urine in one day and that the toilet is used by 8.4 people per household the yearly quantity of urine should be around 3679 l (Cherunya et al., 2015). Although most farmers use the urine the whole year for fertilization it seems that not the whole potential of the toilet is used. However, there can be several reasons why there is such a high discrepancy between the evaluated value and the calculated potential. At first it has to be considered that not all the people, who use the toilet are at home constantly and use only this toilet, especially during the day. Rieck et al. (2012) accounted this fact with reducing the daily amount of urine by one-third.

Furthermore, there will be some losses due to forgetting to empty the jerry can. This assumption seems reasonable if the daily quantity for 8.4 people (9.84 l) is calculated with reducing it by one-third (6.56 l) and the fact that most of the households use a 20-litre jerry can for the collection of urine. Together with the information that the farmers apply the urine all 4 weeks it adds up to the collection of around 26 litres, so more than the jerry can is able to collect. Also, 30% of the 47 households who use the UDDT, still have a pit latrine where urine is getting lost. Additionally, young children and men of the household probably still urinate openly and use no toilet at all (von Muench, 2011).

Farmers reported in the questionnaire survey that they are able to collect 253 kg of human manure per year on average. If the assumption is made that the weight of faeces with a water content of 30% is around 0.05 kg/cap/day in low-income countries, it can be calculated that 8.4 people produce around 153 kg faeces yearly (WHO, 2006; Kraft, 2010; Rose et al., 2015). That in this case the evaluated value is higher than the calculated one can be explained partly with the fact that the mathematically generated quantity does not include the weight of wiping materials. Furthermore, the quantity information in the questionnaire survey is only a rough assumption and was reported mostly in how many wheel barrows of manure the farmers get out of the faeces chamber.

Most farmers apply the urine the whole year round. However, it only has an effect until the plant enters the reproductive stage. After this it nearly does not take up any nutrients. The recommended time to put out the faecal fertilizer is before sowing or planting, because it can be an important source for phosphorus and this is essential for the development of plants and roots (Jönsson et al., 2004). 75% of the interviewed farmers applied the faeces during and before planting, so it can be assumed that most of them can benefit of the nutrient input in the best way regarding the time of use.

The influence of the application time on the nutrient content is neglectable. Possible nitrogen losses of urine in form of ammonia due to evapotranspiration can be avoided if the urine is buried in the soil (Schönning, 2001). The daytime of application is probably only important for convenience since most of the field work is done in the morning. Most interviewed farmers apply the fertilizer during this time.

The dilution of urine increases the volume and thus increases the labour and equipment needed, because there is more urine to spread. However, the advantage is that the risk of the application of too much urine so that it gets toxic to the crops can be decreased (Jönsson et al., 2004). With the dilution, it is possible that the quantity of urine that is applied per hectare crop is decreasing and consequently, the applied nutrient content changes. However, this assumed effect could not be assessed in this master’s thesis. Kassa et al. (2018) found out through trial crops that the fertilization with 500 ml of urine is the optimum for growing maize and with a further increase of the urine quantity the dry biomass, the height, the length of the leaf and the leaf number of maize is not changing significantly. However, Semalulu et al. (2011) found out that the number of cobs is increasing with the increase of the urine concentration. They started with a dilution of 5 litres of water with 0.5 litres of urine (10% urine) and achieved a cob number of 43. After they applied water that was diluted with 20% and 30% urine the cob number increased to 58 and 72 cobs. Afterall, the effect of dilution seems irrelevant for the results of the data analysis (i.e. graphical analysis and MFA models) in this master’s thesis, especially since 52% of the farmers in the questionnaire survey used a 1:1 dilution.

The effect of wiping material on the faecal nutrient content is also not included in the analysis, because it has probably no significant influence on it, if it is considered that the quantity of wiping material is negligiblly small compared to the quantity of the faecal matter. The wiping material mainly changes the required storage volume for the dehydration vaults. But the quantitative data of human manure that was evaluated in the questionnaire already includes the weight added with toilet paper or leaves. The wiping material easily decomposes, so there is no problem for the agricultural application. The toilet paper can even act as an additional absorbent medium, enhancing the dehydration process (Rieck et al., 2013). However, the added ash can influence the nutrient content. The ash is not only absorbing the water, it also increases the pH of the faeces as well as the nutrient content, because plant ash is rich in P, K and calcium (von Muench, 2011; Rieck et al., 2013; Jönsson et al., 2004). This possible influence on the added nutrient input is not considered in this master’s thesis.

However, a problem, that was reported from some farmers was that they did not have enough ash to control the drying process and the smell. One farmer even stopped to use the UDDT due to this reason. This fact could be problematic in the future, if the farmers do not cook as much with firewood anymore, which is where they get the ashes from. 85% of the population of Bungoma and 87% of the population of Kakamega still cooked with firewood in 2013, however this fact could change with the development of these areas (Ngugi et al., 2013a, 2013b). Although, Moses Wakala stated that they were taught different ways for covering the faeces, such as sand and dry soil, during the implementation phase of the EPP project. These methods could be forgotten already by a lot of the beneficiaries of the UDDT due to the long time that already passed since the construction of the toilet.

The UDDT fertilizer was mostly applied on maize, banana and coffee. From a hygienic point of view the application on these crop types isno problem. Rieck et al. (2013) recommended applying the fertilizer on fruit trees and crops that are processed further. The application on vegetable or root crops, especially regarding faecal manure, should be avoided. The analysis of the questionnaire survey shows that the fertilizer is also put out on kale and beans. This could possiblly have a negative impact on the hygienic situation of the farmers household. However, none of the farmers reported an observation of adverse effects on the hygiene during the questionnaire.

The qualitative analysis of the reasons why farmers did not used the fertilizer, if they used the UDDT itself, showed that often cultural barriers are the cause. That this is quite a common barrier is also shown in a study by Uddin et al. (2012). Nevertheless, these barriers can be overcome through awareness raising, training and public education. These sensitivity actions can also help to overcome the negative perception of neighbours and potential customers of agricultural products fertilized with the UDDT fertilizer. The doubts of potential consumers towards these products was reported from four farmers during the questionnaire survey and that these doubts lead to problems of selling the agricultural products. However, most farmers sell their products, where they apply the UDDT fertilizer, without problems, as the table in the chapter 4.2.10 “Field sizes, harvest and crop selling” shows.

The analysis of the nutrient input through the graphical analysis and the MFA models (see chapter 4.3 and 4.4) showed that farmers who apply urine and/or faeces together with animal manure and inorganic fertilizer have the highest nutrient inputs. Dagerskog et al. (2014) recommend using a combination of animal manure, inorganic fertilizer and human excreta to increase the soil fertility in degraded soils. Consequently, especially in Sub-Saharan Africa the UDDT fertilizer is seen as an important complement that is needed to increase the agricultural production since the use of inorganic fertilizers in this area is very low in the global context and the manure management in Kenya is very variable and often poor (Onduru et al., 2008; Dagerskog et al., 2014).

This importance also becomes clear in the results of the MFA models. If the farmers optimise their fertilizing behaviour (see MFA model urine and faeces scenario 2), then nitrogen inputs similar to the inputs of DAP can be achieved. For potassium the nutrient inputs for a family of 10 people can even be covered with the non-optimised fertilizing behaviour. Only for phosphorus DAP shows a significantly higher P content than the UDDT products. The optimised UDDT fertilization cannot only achieve similar nutrient inputs as inorganic fertilizer, but also has similar inputs compared to animal manure.

However, **Table 29, Table 30** and **Table 31**, where the results of the different MFA scenarios are summed up, show-especially for N and P-that the fertilization with only urine and faeces does not offer such high contributions to the optimal nutrient input and in further consequence to the food security of a household of 10 people. Nevertheless, indirect influences on the food security, such as the increased income through the increased harvest of the household, which uses the UDDT fertilizer and the savings that can be made from the lower consumption of inorganic fertilizer, are not considered in the MFA models (see **Table 32** and **Table 33**). The correlation between food security and income is an important aspect as FAO et al. (2019) states. A loss of income decreases food security.

Furthermore, while analysing the results of the MFA it must be considered that the validity of the data of the models is restricted since only one type of inorganic fertilizer is included and the analysis is based on a model household size and model crop. Consequently, for farming households who use different inorganic fertilizers or/and have less people and land, the contribution to food security can change. Especially when the model household size that was evaluated in the questionnaire survey is compared to literature results, it can be expected that the average farming household is smaller than assumed. For example, Rapsomanikis (2015) determines that on average seven people live in a household of a smallholder farmer in Kenya.

Additionally, it seems that the nutrient contents of urine are too low when compared to the nutrient contents of faecal matter. According to Jönsson et al. (2004), 88% of N and 67% of P is in the urine and only 12% N and 33% P can be found in the faecal matter. However, in this widely accepted report it is stated that faeces have a lower nutrient amount than urine. The literature research in this master's thesis shows higher nutrient values for faeces than for urine (see chapter 3.3.2 "Literature research"), but here it must be mentioned that the concentrations of the UDDT products were calculated during the literature research and Jönsson et al. (2004) assesses the total nutrient quantity that can be collected per person during a day. Consequently, it can be assumed, as already discussed above, that the interviewed farmers collect the urine not in an efficient way and the collecting behaviour can still be optimised.

In a paper by Dagerskog et al. (2014, after Drangert, 2010) it is stated that animal manure has 1-2 times as much nitrogen as human excreta. However, in the MFA models of N the human excreta of the second scenario achieve a higher input than animal manure. The explanation for the difference of outcomes is that on the one hand it seems like the interviewed farmers overestimate the collected quantity of faeces. This aspect is also already discussed above. On the other hand, the input data used for animal manure is only based on a model farm and not on evaluated data (see chapter 3.3.2 "Literature research").

Furthermore, the nutrient inputs of the UDDT products in the MFA models show high standard deviations, especially for urine. This can again be explained through the assessed quantities. Reasons for the deviations of quantities were already discussed above. Other explanations can be that households who have many guests will collect more UDDT products than other farmers. Furthermore, the generated quantity depends on the family structure since children produce less urine and faeces (Rose et al., 2015).

But there were not only issues with the reported quantity of urine and faeces. Additionally, the data regarding the quantity of inorganic fertilizer must also be seen critically due to difficulties during the questionnaire survey. Some farmers reported the total quantity of inorganic fertilizer and not the quantity they apply on each crop type. Consequently, the quantity of inorganic fertilizer per hectare on the analysed crops could be lower than calculated. It can be assumed that this is also the case since the results of the master's thesis are significantly higher in comparison to values derived from the literature (see **Table 23**).

A similar problem can be found within the harvest quantities per hectare. Here some farmers reported the total harvest of each crop type, but only indicated the area where they apply the UDDT fertilizers, although in total they have for example a bigger maize crop. This fact probably has an influence on the results regarding the graphical analysis for finding out what effect the UDDT fertilizer has on crop production of the interviewed farmers. Here it was observed that for maize and coffee the nutrient inputs of the interviewed farmers are mostly below the nutrient recommendation, but the harvest is often above the possible and the average harvest. However, for the banana crops more than half of the farmers fertilize below the nutrient inputs and consequently achieve a harvest below the nutrient recommendations and the average harvest. Yet there are some farmers who achieve a much higher harvest than the possible and average one. This has an influence on the calculation of the average banana harvest, which is two times higher as the average harvest (see **Table 24**). For maize and coffee the calculated average harvest in **Table 24** is even more than two times higher as the average harvest.

This phenomenon cannot only be explained through the difficulties during the questionnaire, the processing of the questionnaire data also has an influence. For banana and coffee several assumptions had to be made since most farmers reported the size of their crops in number of stems. Consequently, the size in hectares could only be estimated based on a literature research.

Another reason for the deviations of the values of the questionnaire survey from the literature values is that they are not entirely comparable. For example, for maize and coffee the studies for the comparison of the calculated average harvest with the literature harvest make an assumption for all smallholder farmers throughout Kenya. Thus, they include different soil conditions. The literature regarding the recommended nutrient input for maize from Balemi et al. (2017) involves the average of the recommendations from whole Ethiopia. Therefore, here again various local conditions are included. The recommendations for maize and banana from Kibunja et al. (2017) consider the aspect of regional differences between the parts of Kenya, but the values are based on the economically optimum rate of financially constrained fertilizer and are determined with the costs of mineral fertilizers and a quantity assumption for each crop type. Furthermore, for bananas the study only has recommendations for eastern upper Kenya, where different local conditions occur compared to the western part of Kenya (Kibunja et al., 2017). For coffee it was only possible to find recommendations from Tanzania, that means that there are some deviations from the Kenyan recommendations (Bekunda et al., 2002).

However, as expected, in all graphs of chapter 4.3 a trend can be observed that shows that the harvest increases with an increasing nutrient input.This is not always the case though, and there are some exceptions in most of the analyses. Local soil and precipitation conditions which are not included in the graphical analysis are an influencing factor on the harvest(Tittonell et al., 2008). Jönsson et al. (2004) state that the impact on the yield depends on several factors, such as the organic content of the soil and that for example the effect of urine as a fertilizer has a lower effect if the organic substance is low.

Furthermore, not all aspects of the UDDT fertilizer that could have a positive effect on the harvest, are considered in the analysis of the master's thesis. For example, that faecal matter also has a high concentration of organic matter and can through its application improve the soil structure, the water-holding capacity and the buffering capacity. Another aspect that is not included in the survey is the effect on the pH of the soil through urine and the added ashes (Jönnson et al., 2004; Mnkeni and Austin, 2009).

Even if the graphical analysis shows that the data is not completely plausible, the nutrient input rates that were observed, are lying mostly in a range that can be compared with other studies from western Kenya. For example, Tittonell et al. (2005) found out that the nitrogen input through inorganic and organic fertilization ranges between 0 - 116 kg/ha with an average of 28 kg/ha in a study with 15 smallholder farmers. For the phosphorus input they found a range from 0 - 58 kg/ha with an average of 16 kg/ha and for potassium they could assess values from 0 – 118 kg/ha with an average of 24 kg/ha. The graphical analysis in this thesis showed that most evaluated farms achieve N inputs between 0.32 and 96 kg/ha/year, a P input between 0.03 and 17 kg/ha/year and a K input between 0.13 and 65 kg/ha/year. In the study of Titonell et al. (2005) three farms are included, which had no nutrient input at all. Additional to the three farms, three more farms did not have any potassium inputs. Compared to the outcomes of the master's thesis, it can be concluded that without the UDDT fertilizer, some of the interviewed farmers would not have any nutrient input at all since there are some farmers, who use only this fertilizer as nutrient source for their crops.

6. Conclusion and outlook

The questionnaire survey showed that 50 % of the participants of the EPP project still use the UDDT and 50 % do not use it anymore. 87 % of the UDDT users used the fertilizer of the toilet. The most important driver to use the UDDT is the use of the fertilizer itself and the feeling of the farmers that the fertilizer has a positive impact on their harvest. Furthermore, a local support network with people who have not only the technical knowledge, but also have an influence on the community, and a training throughout all the phases of the project are important factors. The odourless operation and the improved health and hygiene in comparison to the pit latrine are also main drivers. Finally, the durability of the toilet structure is relevant, especially the aspect of avoiding the regular excavation that is necessary for the pit latrine, is appreciated here. In areas, where adverse hydrogeological conditions prevail and the pit latrine collapses, the durability is one of the most important drivers.

Possible barriers to use the UDDT and its fertilizer are technical problems, knowledge loss through changes of owners, the wrong use through guests and the low quantity of ash that limits the control of smell. For some household members, especially for old people and young children, the design can also be an obstacle. One of the main barriers to use excreta as fertilizer are cultural and social barriers. An expensive design can hinder the replication of the UDDT, because people think it is not possible to build such a toilet with an easier design and local materials. Here, subsidies also have a negative effect due to the dependency that develops and the belief that it is only possible to get an UDDT with this financial support.

The sustainability criteria for the use of human excreta are quite similar to the barriers and drivers. Important criteria are for example the odourless operation, the quality and the benefit of the UDDT fertilizer, the system robustness, the system perception and the investment costs.

The graphical analysis and the MFA models show that the application of the UDDT fertilizer increases the nutrient input and can be an important fertilizer source, especially for farmers, who would not have any input if they did not have the UDDT. The graphical analysis shows-with some exceptions- that the harvest improves with an increased input of nutrients. However, other aspects, like the soil condition, probably also have a significant influence on the achievable harvest.

The highest nutrient inputs are achieved by farmers who applied a combination of UDDT fertilizers, animal manure and/or inorganic fertilizer. Furthermore, the conducted MFA shows that through the application of urine and faeces only a part of the required nutrient inputs for providing sufficient food for a household of 10 people, can be covered. Consequently, the UDDT fertilizer should be seen more as a complement than a replacement of other fertilizers. Nevertheless, the contribution of the UDDT products to the food security should not be underestimated since there is a possibility of increasing the income of a household through an improved harvest or the lower consumption of inorganic fertilizer. Through a higher income a higher food security is possible.

Unfortunately, it was not possible in this study to find out if there is a pattern regarding the harvest and the nutrient input through a specific fertilizer combination. Here a statistical analysis could help to evaluate the significance of the nutrient input through different fertilizers on the harvest. However, there is not enough data available to conduct such an analysis here. Furthermore, through the improvement of the data collection and a detailed assessment of the quantity of all types of fertilizer the farmers apply on each crop, the validity of the analysis towards the nutrient input would increase.

To get a more relevant result regarding the long-term effect of the UDDT fertilizer on the harvest, the collection of additional data from crops of the same area where the UDDT fertilizer is not applied, will be necessary. Further research should focus on the influence of local soil conditions on the harvest and a lab assessment of the soil where farmers apply the UDDT fertilizer for a longer time period.

Also, lab measurements of the nutrient contents of the UDDT products would help to increase the quality of the used data for the nutrient input analysis. A further aspect for increasing the data quality would be the assessment of the family structure. The information about how many children, women and men are in one household would help to understand the differences between the collected quantities of urine and faeces between each farmer and in further consequence would at least partly explain the high standard deviations in the MFA models.

7. Summary and conclusions

A promising fertilizer source for farmers of Sub-Saharan Africa can be products of human excreta recycling. One sanitation technology to make the recycling possible are urine-diverting dry toilets (UDDTs). There are several implementation projects of this technology in Africa and many short-term studies concerning their social-cultural acceptance and their use were conducted in the past. Additionally, several experiments on trial crops and in the lab were conducted to prove the possible fertilization effect of the UDDT fertilizer. However, the long-term impact of human excreta recycling on agricultural production by using UDDT products in an environment that is not as controlled as trial crops, is unknown. Long-term evaluations of implementation projects and their impact on food production are missing. Due to this deficit the main topic of this master's thesis was the long-term impact of nutrient recycling projects from human excreta on the food production of smallholder farmers.

A case study of an UDDT implementation project that was conducted between 2006-2010 as part of the Ecological Sanitation Promotion Programme (EPP) in Western Kenya helped to analyse the possible impact. 94 farmers, who were beneficiaries of this project, were interviewed during July 2018. A graphical and mathematical analysis of this questionnaire survey answered the following research questions:

1. Is there a long-term use of urine-diverting dry toilets and their products as fertilizer in UDDT implementation projects?
2. What are barriers and drivers for the use of the UDDT toilets and excreta?
3. What is the impact of the use of human excreta as fertilizer on the crop production and the food security of the participants of UDDT implementation projects?
4. How sustainable is the use of human excreta from UDDT toilets in agriculture?

With the analysis of the questionnaire survey, it was possible to mainly answer the questions concerning the long-term use and the barriers and drivers of UDDTs. Other tools had to be developed for analysing the impact of the use of UDDT products and for assessing the UDDTs sustainability. Combining the data of the questionnaire survey and results of a literature research, it was possible to create a graphical analysis and a material flow analysis (MFA), which show the impact of the UDDT fertilizer. Furthermore, a sustainability assessment was conducted, that helped to answer the last research question.

The analysis of the questionnaire survey showed that 50% of the interviewed owners still use the UDDT and 50% do not use it anymore. If the toilet is still in use, it is used on average by 8.4 people per household. All the farmers used a pit latrine before the UDDT. All the users of the UDDT would recommend it. Although there were a lot of people who requested an UDDT for their own household, only 21% of the 47 interviewed users of the UDDT knew households or people who reconstructed the toilet by themselves with local materials. This can be explained by the relatively expensive design of the UDDT toilet and the missing of external financing options, like microfinancing or community fundraising initiatives.

For the non-usage of the UDDT the most mentioned barrier was problems with the construction, meaning that in this case the toilets were never completed. Other reasons were for example:

- Change of the property situation
- Lack of information and training
- Technical problems (e.g. clogging of urine pipe, broken squatting pan)

Reasons for the non–usage of the fertilizer were:

- Cultural aspects
- Technical problems
- Misinformation

Training and a long-term local support network can help to overcome most of the mentioned barriers.

The most common advantage and driver for the toilet was that it is possible to use the UDDT products for fertilization. Further advantages were:

- The durability of the structure
- Low smell development
- Improvement of the health and hygiene situation
- Aesthetic value of the UDDT

Most of the farmers did not mention any disadvantages. However, one of the biggest problems are technical problems like the clogging of the urine pipe or the degrading of the faeces collection vault doors. Other mentioned problems next to the technical ones were:

- Wrong use by people
- Negative image of the UDDT fertilizer
- Amount of ash that is needed for maintenance

The average costs for repairing parts of the toilet were around 651 Kenyan Shillings within 10 years. Mostly the urine pipe or the faeces vault doors had to be replaced. Since none of the expenses are recurring costs the operation and maintenance costs can be seen as very low for an average smallholder farming household.

Most of the 47 users of the UDDT are using the fertilizer, only 13 % do not use it. Most of the users of the fertilizer use urine and faeces. The main crops where the fertilizer is applied on, are maize, bananas and coffee. In average 460 l urine and 253 kg faeces are collected from farmers during a year. The urine is applied throughout the whole year around every 3.6 weeks and the faeces are applied once a year after an average storage time of 5 months. The urine is often diluted extra before it is brought to the crops. Ash is added to the faeces after every use. 31 of the 40 farmers who use the UDDT fertilizer, add additional fertilizers (animal manure and/ or inorganic fertilizer). Often, the products of the crops where the fertilizer is applied, are partly sold.

The graphical analysis includes each interviewed farm who uses the UDDT fertilizer on maize, banana or coffee. For each crop three graphs were created assessing the N, P and K inputs that are achieved with a certain fertilizer combination. The inputs are compared with the average harvest. The analysis showed that the harvest increases with an increasing nutrient input. However, there are some exceptions.

Furthermore, it was possible to check the plausibility of the data with the graphical analysis. The results were compared on the one hand with nutrient recommendations and their achievable harvest. On the other hand, they were compared with the average harvest for smallholder farmers in Kenya. This comparison and the exceptions of the trend of the increasing nutrient input and the harvest showed that the data is not completely plausible.

Additionally, the comparison of the nutrient recommendation and the nutrient inputs of the interviewed farms helped to find out the limiting nutrient type. For maize and banana it is phosphorus and for coffee it is nitrogen. A possible reason for the different limiting nutrient type is that different inorganic fertilizers are used for the crops.

The highest nutrient inputs can be achieved with the fertilizer combinations, where animal manure and/or inorganic fertilizer is additionally applied. Thus, the UDDT fertilizer should only be seen as a complement and not a replacement of other fertilizers. This finding is also supported by the MFA models, where the contribution of different fertilizer combinations to the food security of a household of 10 people is modelled.

Furthermore, the analysis of the MFA models showed that the contribution to the food security of a farming household of each fertilizer combination is quite different for each nutrient if average application amounts are considered. This conclusion is based on a comparison of an optimal nutrient input that is covering the nutrient needs of 10 people and the nutrient input that resulted from modelling various scenarios including different fertilizer combinations. The fertilization with only urine and faeces can cover around one-third of the optimal nitrogen input. It has a quite low impact on the phosphorus input. The potassium models show the completely opposite effect. Here, the optimal input rate can be covered or can even be exceeded with the use of the UDDT fertilizer.

If fertilization with products from UDDTs is compared to the observed average use of inorganic fertilizer, in this case with DAP, the results of the MFA showed that the UDDT products have similar nitrogen inputs as the inorganic fertilizer, but for phosphorus they achieve significantly lower inputs. For potassium no comparison can made since DAP does not contain any of it. If the nutrient input through animal manure and the fertilization with urine and faeces is compared it seems that there is no significant difference. This is valid for all nutrient types. However, the graphical analysis and the MFA models showed that the collection of urine can still be optimised and that the quantity assumptions of faeces are probably too high.

All in all, the nutrient input analysis showed that the UDDT fertilizer can be an important complement that is needed to increase the agricultural production since the use of inorganic fertilizer is very low in Sub-Saharan Africa. In further consequence the food security of households can increase through the usage of the UDDT products. Especially, if a possible increase in income is considered through an improved harvest and a lower consumption of inorganic fertilizer.

The last research question dealing with the sustainability of UDDT fertilizer was answered using a sustainability assessment. The results of the questionnaire survey, the nutrient input analysis and an additional literature research were structured and evaluated under certain sustainability aspects. The evaluation showed that all in all this type of fertilization can be regarded as sustainable.

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9. Appendix

9.1 Statistical sensitivity analysis of N and P input of urine

The statistical analysis is based on a Wilcoxon rank sum test in R. In Appendix 1 the p-values are shown for the analysis of the difference between the mean of the sum of nutrient input, where only the average of the N or P values of urine from Robinson (2005) and Kraft (2010) are included and the mean of the sum of nutrient input, where all the values of the literature research are included.

Appendix 1 p-values for the sensitivity analysis of N and P values of urine.

Nutrient type	p-value
N	0.82
P	0.82

9.2 Questionnaire survey

Questionnaire Identification Number __/__/__/__/__/__/__/__/__/

Part A: Respondent’s Identification/Background

County ____________________________

Sub-County ______________________________

Location________________________________

Respondent´s Sex: Female Male

Respondent’s Name: ________________________

Relationship with the farm owner_________(see code 1)

Contact mobile phone No of the respondent________________

Interviewer’s Name __________________________________ Date of Interview_____________

GPS coordinates of residence:

NORTH: EAST:

Type of household

1. How many people live in the household? ____________Persons
2. What is the total area of owned farm land (acres)? __________Acres
3. Type of farm (Yes/No):

Subsistence	
Cash Crop	
Livestock farming	

PART B: The UDDT

1. In which year was the UDDT installed in your household? _____________

2. Are you currently using the UDDT?

☐ Yes

☐ No

☐ Yes, but not for the intended purpose

If the answer for question 2 is NO:

3. Why you don´t use the UDDT?

☐ It is too expensive to maintain

☐ It takes too much time to maintain it

☐ It takes too much time to clean it

☐ There are too many flies

☐ It smells bad

☐ It has no user-friendly design

☐ It is not hygienic enough

☐ Because there are technical problems (Specify:________________________________)

☐ Other reasons: ____

If the answer for question 2 is YES:

4. How many people use the UDDT (including interviewer)? __________Persons

(Max. of 20 people should use it)

5. Are all members of the household using the UDDT?

☐ Yes

☐ No

If no, why? ____

6. Which method of sanitation did you used before the UDDT?

☐ Pit latrine

☐ Open defecation

☐ Other methods:____

7. Are you still using the previous method of sanitation?

☐ Yes

☐ No

8. Where do you see the advantages of UDDT (in comparison to previous method of sanitation)?

Technical factor:

☐ Durable and permanent structure

☐ Waterless operation

Personal or individual factor:

☐ Convenience (no flies, no smell)

☐ Privacy

☐ Health and hygiene (improved sanitation)

Management factor:

☐ Availability of training and technical expertise

☐ Easy to operate and maintain

☐ Financial factors

☐ Usage of UDDT products for fertilization

Other reasons: ____

9. Where do you see the disadvantages of UDDT?

☐ No disadvantages

☐ The technical problems coming with the UDDT (e.g. urine pipe blockage, leakage of rainwater into faeces collection vault, ______________________________________)

☐ The time effort for the operation activities (e.g. daily activities like checking of the volume of excreta, provision of cover material, …. OR other routine operation tasks like cleaning urine piping system, emptying vaults and containers, ….)

☐ The time effort for the maintenance activities (e.g. removing obstructions from the urine piping, keeping vault doors intact, …)

☐ The time effort for the cleaning

☐ The waiting time for the drying of the faeces and filling up of the jerry cans with urine
☐ There are too many flies
☐ The smell
☐ The design regarding the user interface
☐ The design regarding the appearance
☐ Wrong use of people who are not familiar with the toilet
☐ Other: ____

10. What are your maintenance costs of the UDDT and how high are they?

☐ No costs
☐ Repaint
☐ New urine pipes
☐ New water taps for hand wash facility due to breakage
☐ New rainwater harvesting tanks for the hand wash facility due to theft
☐ New faeces vault door due to termites or other degrading and decomposing processes
☐ New ventilation pipes
☐ Payment for removal of UDDT products
☐ Other costs: ____
____

Costs: ________________ Kenyan Shilling

11. Would you recommend the toilets to others?

☐ Yes
☐ No

12. Do you know people in your area who reconstructed the UDDT from local materials after they saw yours and the effects of it? If yes, how many people did that?

☐ I don´t know any people in the area who reconstructed the UDDT
☐ I know people in the area who reconstructed the UDDT

Numbers of people/ households: ______________

PART C: The UDDT products

13. Do you use any of the products from the UDDT as fertilizer and if YES which?

Products	Collection	Use
Only urine		
Only faeces		
Faeces and urine (separated)		
Mixed urine + faeces		

<u>If there is no use of the UDDT products at all (see question 13):</u>

14. Why you don´t use the products of the UDDT for fertilization?

☐ Because I don´t have any storage room for the UDDT products

☐ Because there are problems with emptying the chamber with the dried faeces once it is full

☐ Because the distance between the UDDT and the agricultural area are too long

☐ Because I don´t think it is safe

☐ Because my neighbours look down upon the practice of reusing human excreta (cultural reasons)

☐ Because there are technical problems (Specify:______________________________)

☐ Because I didn´t know that I can use the UDDT products as fertilizer

☐ Other reasons: ____

15. Where do you put the faeces instead? (also have to be answered if there is no use of faeces – see question number 13)

☐ We bury it in the ground (but not on an agricultural land)

☐ We sell it

☐ We trade it for other products

☐ We pay someone to put it away

☐ We throw it away (with other household garbage)

☐ We store them in the faeces vault

☐ Other usage: ____

16. Where do you put the urine instead? (also have to be answered if there is no use of the urine- see question number 13)

☐ It goes to a soak-away pit or to an infiltration trench (to the ground)

☐ We intentionally evaporate it from a flat surface

☐ We bury it in the ground (but not on an agricultural land)/ We spill it

☐ We sell it

☐ We trade it for other products

☐ We pay someone to put the products away

☐ Other usage: ____

If there is a use of the UDDT products (see question 12):

PART D: Faeces as fertilizer

17. How often must you remove the faeces from the chamber? ____

18. How many kg/bags of faeces are you collecting monthly /yearly?

____

19. How much of the faeces do you use for fertilization? ____________ % (Robinson)

20. If less than 100%, what do you do with the rest? (Robinson)

☐ We burn it

☐ We sell it

☐ We trade it for other products

☐ We pay someone to put it away

☐ We throw it away (with other household garbage)

☐ Other usage: ____

21. How do you treat the faeces before you use it as fertilizer?

☐ No treatment

☐ Storage + drying (for _____ months)

☐ Addition of wood ashes

☐ Addition of other materials like dry soil, saw dust

☐ Addition of toilet paper or other wiping materials (leaves or other material-

☐ specify: ___________________.)

☐ External composting

☐ Drying through solar sanitation or heat treatment

☐ Chemical treatment with urea

☐ Other treatment: ____

PART E: Urine as fertilizer

22. How often must you remove the urine from the collection container (jerry cans)? ____

23. How much of the urine do you use for fertilization? ____________ %

24. If less than 100%, what do you do with the rest? (Robinson)

☐ It goes to a soak-away pit or to an infiltration trench (to the ground)
☐ We intentionally evaporate it from a flat surface
☐ We sell it
☐ We trade it for other products
☐ We pay someone to put the products away
☐ Other usage: ____

25. How do you treat the urine before you use it as fertilizers?
☐ No treatment
☐ Storage (for _____ days/weeks/months)
☐ Dilution (Ratio: 1: __________)
☐ Addition of flushing water (If yes, how much________________________________)
☐ Addition of other material:____
☐ Other treatment: ____

PART F (optional):

Information that can be observed by the interviewer in the household (optional):

In what condition is the toilet (if you can see it)?
☐ Perfect condition (no damages at all)
☐ Good condition (only small damages)
____
☐ Noticeable damages (e.g. the toilet house seem decayed)
____
☐ Toilet not used for its intended purpose
Other purpose:
____
☐ Toilet not existing
Reason:____

Parcel *Nr.	Crop(s) grown (Crop codes C1)	Crop/Parcel area (A)	Use of urine (Yes/No)	Frequency of use	Time of use (Codes C2)	Use of faeces (Yes/No)	Frequency of use	Time of use (Codes C2)	Type of inorganic fertilizer used (Codes C3)	Quantity of fertilizer (kg/*yr*)	Type of other organic inputs (Codes C4)	Total harvest (kg/bags/ time)	Selling of products (yes/no)	Average selling price (Ksh)

10. Curriculum Vitae

Personal Data

Name:	Lea Schneider
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Citizenship:	Austria

Education and work experience

2000 - 2004	Volksschule, Draschestraße 96, 1230 Wien
2004 - 2012	Bg/Brg 10 Pichelmayergasse 1, 1100 Wien Graduation with Matura
August 2012 - February 2013	Volunteer work with Grenzenlos & ICDE India, Mysore
March 2013 - July 2013	Assistant at SEPURA Systems GmbH Radio systems for security-critical applications
October 2013 - April 2017	Bachelor University of Natural Resources and Life Sciences, Vienna Environment and Bioresources Management
August – September 2015	Internship in the winery of DI Edtih Reithofer in Rossatz 76, 3602 Rossatz
December 2016 – today	Work for ESG + as Research Assistant for assessment of the sustainability of investments
October 2017 – today	Master University of Natural Resources and Life Sciences, Vienna Natural Resource Management & Ecological Engineering with focus on Water Engineering
October 2018 - July 2019	Erasmus+ Czech University of Life Sciences Prague Natural Resource Management & Ecological Engineering with focus on Water Engineering

Voluntary work

Amnesty International	Head of youth group, Participant in student network
Red cross	Tutoring for German and support of an Afghan family
[sic!]	Students innovation centre Voluntary work in a student's association for start-ups and projects on the University of Natural Resources and Life Sciences, Vienna
ClimateLaunchpad 2016	Organisation of the Austrian ClimateLaunchpad („The world's largest cleantech business idea competition")
Social Impact Award 2017	Marketing- and event manager from December 2016 - May 2017

11. Affirmation

I certify, that the master’s thesis was written by me, not using sources and tools other than quoted and without use of any other illegitimate support.

Furthermore, I confirm that I have not submitted this master’s thesis either nationally or internationally in any form.

Vienna, 24.10.2019, Lea Schneider, BSc.,