Analysing manure and urine management practises of cattle farmers in Western Kenya

An Assessment for the NUANCES-FARMSIM HEAPSIM model

MSc Thesis Plant Production Systems

Lea Norena Ilgeroth
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Contact office.pp@wur.nl for access to data, models and scripts used for the analysis

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Abstract

Climate change and population growth put Sub-Saharan Africa (SSA) more than ever under pressure to increase its production and meet the demand for food products. Agricultural system modelling plays an increasingly important role in the development of sustainable land management options needed to realise a sustainable production increase. The aim of this research is to i) assess management of manure and other organic matter flows between the animal component and the fields and compare these with the flows as assumed in HEAPSIM, ii) suggest improvements by reviewing the underlying model assumptions based on observations in the field and first explorations in NUANCES-FARMSIM and iii) assess the contributions of the co-learning cycles to improved manure management by collecting and analysing data on current manure practises. A survey has been used to collect detailed data on manure management practises of 50 farmers in Western Kenya and to identify practises possibly overlooked in the current NUANCES-FARMSIM. The survey was accompanied by observations on the farms and quantitative manure measurements. Resource flow maps of manure and urine N have been established based on this data in order to identify relevant missing flows in the farm systems. The results of the analysis indicate that especially two flows have been overlooked. Firstly, the collection of urine and application of it to the fields was observed. 68% of farmers had a urine collection facility in their stall. Collection periods ranged from every 24 or 48 hours to weekly or monthly collection. Urine was mainly applied as a liquid fertilizer to napier grass (*Pennisetum purpureum*), but also to banana gardens, leafy vegetables and maize. The resource flow maps disclosed that farmers in this study recycled up to 31% of urinary N and that in an intensive use of a zero grazing unit up to 47% of urinary N could be recycled through urine collection. Secondly the application of fresh manure to the fields was identified as a relevant flow. Up to 43% of all collected manure was applied by farmers directly to the fields. Based on the established resource flow maps, if fresh manure is applied directly to the field up to 28% more manure N can be recycled compared to applying composted manure. First explorations on the effects of including urine nutrient flows in NUANCES-FARMSIM have been done. This showed that urine collection can be integrated in the model and have effect on the napier yield. Overall, it can be concluded that integration of urine collection to the NUANCES HEAPSIM model is advised. Also, the integration of direct fresh manure application should be considered.

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Chapter 1 Introduction and Background

1.1 Introduction

Under the pressure of growing population agricultural productivity in Sub-Saharan Africa (SSA) is more than ever under pressure to increase its production to meet the demands of up to 4 billion people in 2100 (Andriesse et al., 2007; United Nations). Smallholder farmers as prime domestic food suppliers play a major role in achieving this increase due to substantial contributions they make towards sustainable food and nutrition security (CFS, 2013). Smallholder farming systems are highly heterogeneous and complex, therefore models and tools are needed to capture and analyse the present management options (Giller et al., 2011; van Wijk et al., 2009). One such approach is the NUANCES-FARMSIM framework, which targets to analyse farm-level trade-offs and possible synergies through a farm system model to identify best-fit technologies. This work contributes to this framework by improving the manure management component.

1.2 Modelling smallholder farming systems

Due to current pressure of climate change and growing population pressure, agricultural system modelling plays an increasingly important roles in the development of sustainable land management options (van Wijk et al., 2014). This is also since large-scale field and farm experiments require large amounts of resources and may still not provide sufficient information in space and time to identify appropriate and effective management practices (van Wijk et al., 2009). With the shift in focus in the last decades also smallholder systems in Africa, Asia and Latin-America have gained increasing attention from agricultural modelling sciences.

Holistic and systemic approaches are needed in order to respond to the high diversity and complexity of African farming systems (Giller et al., 2011; van Wijk et al., 2009). Simulation models have been identified as valuable in analysing the relationships and dynamics between soil, climate and nutrient factors (Whitbread et al., 2010). Further models are very useful in understanding the interactions of system components as well as trade-offs in decision making and resource allocation (Descheemaeker et al., 2016). Models and tools are ever more needed to analyse possible development pathways of smallholder farming systems and specifically to capture the effects and consequences of decision-making on the use of resources (van Wijk et al., 2014).

However, modelling sciences have also been criticised for not being sufficiently context specific and for not engaging with end-users to practically inform land management decisions on farm level (Whitbread et al., 2010). Participatory modelling, in which farmers and researchers work together to assess options for farm management decisions have gained recent attention. Embedding participatory research tools into farming systems analysis aids researchers in understanding the specific contexts and values of farmers in order to identify targeted opportunities for development.

1.3 Soil fertility management in African smallholder systems

Among others one of the greatest constraints in smallholder farming systems is poor soil fertility and the associated nutrient limitations for crop growth. Nitrogen (N) is among the most needed, but also most significantly limited nutrients in many agricultural systems since it is greatly removed with crop harvest and easily lost through e.g. volatilisation or leaching. Carbon (C) further plays an important role as well in maintaining soil organic matter (SOM) and thus soil structure and soil life (Vanlauwe & Giller, 2006).

Organic and inorganic fertilizers are available options for improving soil fertility. However, any of the two alone seems not sufficient in regenerating poorly fertile fields (Bedada et al., 2014; Place et al., 2003; Waithaka et al., 2007). Multiple field experiments in African smallholder settings showed that if highly degraded soils have become unresponsive to inorganic fertilizer substantial investments of organic fertilizers are necessary in order to restore these soils to a productive stage (Tittonell & Giller, 2013). Especially in smallholder contexts where inorganic fertilizer use is often not available or too costly, manure is often the main nutrient input to sustain yields and the only carbon input to replace crops and crop residues removed from the fields (Tittonell, 2008; Waithaka et al., 2007).

Yet also organic fertilizers pose several challenges as agents to sustain soil fertility. Manure availability is restricted by scarcity of land to produce fodder materials and grasses. Livestock density in SSA further indicates that satisfying soil needs through merely manure is not a feasible approach in most areas (Tittonell & Giller, 2013). To overcome these limits the combination of mineral and organic inputs is increasingly acknowledged as the most promising approach (Bedada et al., 2014; Place et al., 2003; Vanlauwe, 2002; Waithaka et al., 2007). Inorganic fertilizers supplies needed plant nutrients, while organic inputs and manure support a good level of soil organic matter, good soil structure and micro-nutrients (Vanlauwe et al., 2010; Vanlauwe & Giller, 2006). In this practise organic manure plays a vital role specifically in enabling the efficient utilization of mineral nutrient fertilizers (De Ridder & Van Keulen, 1990; Giller et al., 2002), and thus a greater response of mineral fertilizer to fields (Zingore et al., 2008) .

In order to optimise the use of available manure, a basket of options is available to improve manure application. Examples range from spot application of manure in planting holes to dribbling of manure in planting furrows. These practises increase the efficiency of nutrient capture, which supports an increase in yields (Mafongoya et al., 2006; Munguri et al., 1996). Not all manure application practises however facilitate an efficient use of manure. Farmers in East Africa allocate manure and chemical fertilizer to fields around their home rather than those fields further away. A problematic strategy resulting in gradients of soil fertility and serious soil degradation in the more distant fields over time (Tittonell et al., 2005a; Zingore et al., 2007). Also poor manure collection and storage strategies lead often to high nitrogen losses by volatalisation and leaching and thus reduce nitrogen content and manure quality before application (Castellanos-Navarrete et al., 2015). This illustrates the importance of place specific manure management practises and identification of the most efficient place based options.

1.4 Dairy systems and manure management in Kenya

In Kenya 60 % of the farmers in the highlands practise mixed crop – dairy farming (Udo et al., 2011). Popularity of dairy cattle in Kenya is largely due to the value of milk in the local diet and the supportive agro-ecological conditions allowing good forage production (B.O. Bebe, 2002; Udo et al., 2011). Further cattle are also valued as a source of capital and for social status as well as for manure production (Rufino et al., 2007). Most farmers have the traditional Zebu (Bos indicus) breed, some wealthier farmers have started to adopt also cross- and pure-breeds, such as Jersey, Ayrshire and Friesian (Bos taurus) (Castellanos-Navarrete et al., 2015). Due to dominance of family inheritance, splitting of farms between heirs and resulting decrease in farm sizes increases the pressure on farming systems and raises concerns on the sustainability of dominating farming practises. This land pressure and the need for intensification have led to a shift from free-grazing to semi-grazing and zero grazing systems where cattle are either kept in the stable permanently or during the night (Rufino et al., 2006).

The dominant manure storage systems consist of heaps, piles, pits were manure is often mixed with other organic materials such as crop residues, tree pruning, litter or kitchen ashes (Tittonell et al., 2010). The manure is stored over variable time (usually between 3-6 months) for decomposition after which it is applied to the fields (Tittonell, 2008).

However, manure management also faces numerous challenges in the Kenyan smallholder context as mentioned above. The largest carbon (C) and nitrogen (N) volatilisation and leaching losses from manure occur within 7–10 days after excretion (Martins & Dewes, 1992; Murwira, 1995; Thomsen, 2000). Regular collection several times in a week reduces these losses most. Considerable losses also occur after collection during manure storage. Hence, the most important indicators for losses are the type of animal housing and the frequency of manure removal from the stall.

Simple measures can have considerable effect on C and N recovery in the farming systems in western Kenya. Example of this are the use of roofed stalls, the construction of hard (concrete) floors and the use of bedding materials like straw to absorb ammonia excreted by faeces and urine (Rufino et al., 2007; Tittonell, 2008). The introduction of a polythene film, as cover reduced N losses in a simulation from 50% to 20% and mass losses from 55% to 30% (Rufino et al., 2007). Interventions to improve cattle feeding and manure management seem necessary for increasing the returns of organic resources to soils. Consequently, this would also contribute to an improved efficiency of any external nutrients added (Castellanos-Navarrete et al., 2015).

1.5 NUANCES-FARMSIM

The NUANCES (Nutrient Use in Animal and Cropping systems – Efficiencies and Scales) framework was developed in the past two decades, starting with the work of Giller et al. (2006). It aims to evaluate farm performance and impacts of changing practises and technologies on farm scale, which aids in recognising opportunities for sustainable interventions (Giller et al., 2011), tailored to the specific farming situations, farm characteristics and specific niches within farms (Marinus et al., 2017). Various system-analytical methods are embedded in the framework, specifically a combination of farm typologies, data mining, experiments and modelling tools. The NUANCES approach allows also describing and analysing external drivers and some of the mechanisms that result in resource (in)-efficiencies. Generally, the NUANCES framework makes use of two parts, the NUANCES-FARMSIM model as a tool (figure 1) and the DEED cycle (figure 2) as an important framework. Both parts will be explained separately below.

The NUANCES-FARMSIM model is a crop-livestock model at farm level. It simulates the complex interactions at farm level showing the effects of farm management decisions taking short-term yields and longer term (10-15 years) trends in productivity and soil fertility into account (van Wijk et al., 2009). The model represents a farm livelihood system as a set of interacting components.

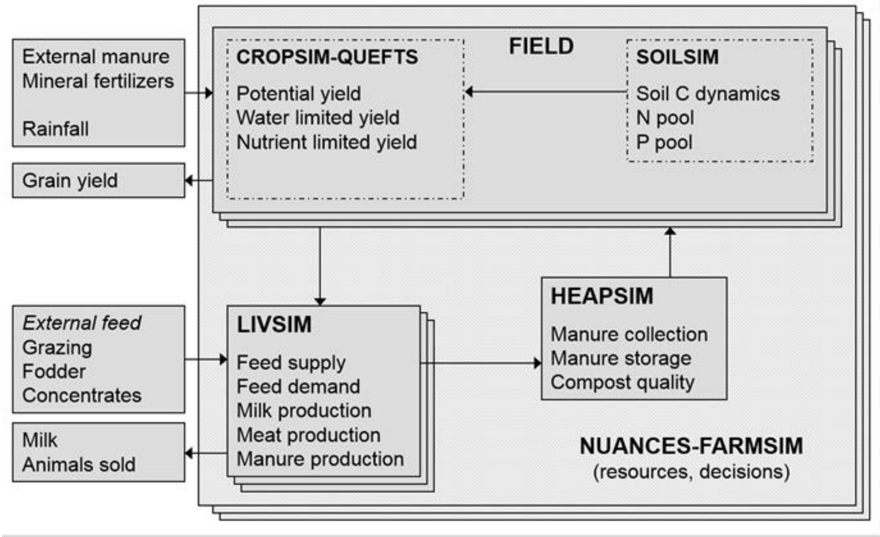


Figure 1 NUANCES-FARMSIM model

The resource flows are managed in the model and determined by decision rules specified by the user (Marinus et al., 2017). The sub-models incorporate processes and interactions in a descriptive way frequently with the use of summary functions, due to the limitations of data availability for modelling of smallholder systems (van Wijk et al., 2009). Experimental data and calibrated process-based models were used to generate functional relationships and thus generating the summary functions, which capture the most important interactions and feedbacks between different system components (Marinus et al., 2017).

The DEED cycle was first described by Giller et al. (2008) and later integrated in the NUANCES Framework (Giller et al., 2011).

The DEED cycle includes 4 steps:

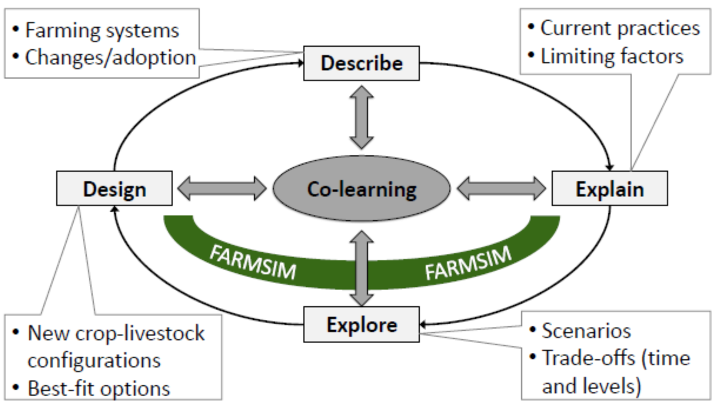


Figure 2 DEED cycle as used in using NUANCES-FARMSIM as a tool in co-learning (Marinus, 2018)

1. Describe the current production systems and their constraints; 2. Explain the consequences of current farmers' decisions on resource allocation; 3. Explore options for agro-technological improvement for a range of possible future scenarios; 4. Design, together with the farmers, new management systems that contribute to the sustainable intensification of smallholder agriculture. (Descheemaeker et al., 2016; Giller et al., 2008)

When designing the DEED cycle the complexity of African farming systems and the need for targeting interventions to specific conditions of farm types and existing niches was recognized. With the intention of enhancing policy fit and achieve improvements in productivity and rural development, it is inevitable to understand also complex constraints faced by farmers at various levels of the farming systems. In order to achieve these goals it is necessary to design research such that findings can be transferred to and exchanged with governments, extension services as well as international development organizations. (Giller et al., 2011)

1.6 HEAPSIM

HEAPSIM is a sub-model of NUANCES-FARMSIM. It aims to simulate the dynamics of nutrient flows through the processes of manure management (Rufino et al., 2007). It is the sub-model on which this study focuses.

The aim of this sub-model is to identify the functional relationships that describe the effects of different manure management practises on the efficiency of nutrient transfer within the NUANCES-FARMSIM model taking into account varying qualities of manure affect the quality on the compost applied and the response of the soil for crop production (Rufino et al., 2007). Thus, it contributes to understand the effect of manure management on the efficiency of mass and nutrient retention within smallholder farming systems in the long-term.

The first version of the model was described by Rufino et al. (2007) and is based on the approach advocated by Rufino et al. (2006) to analyse mass and nutrient flows at farm level and determine management consequences on resource use efficiencies and inefficiencies. Rufino et al. (2006) structured African farming systems into four subsystems through which nutrient transfer takes place: 1. Livestock, 2. Manure collection & handling, 3. Manure storage and 4. Soil and crop conversion (application).

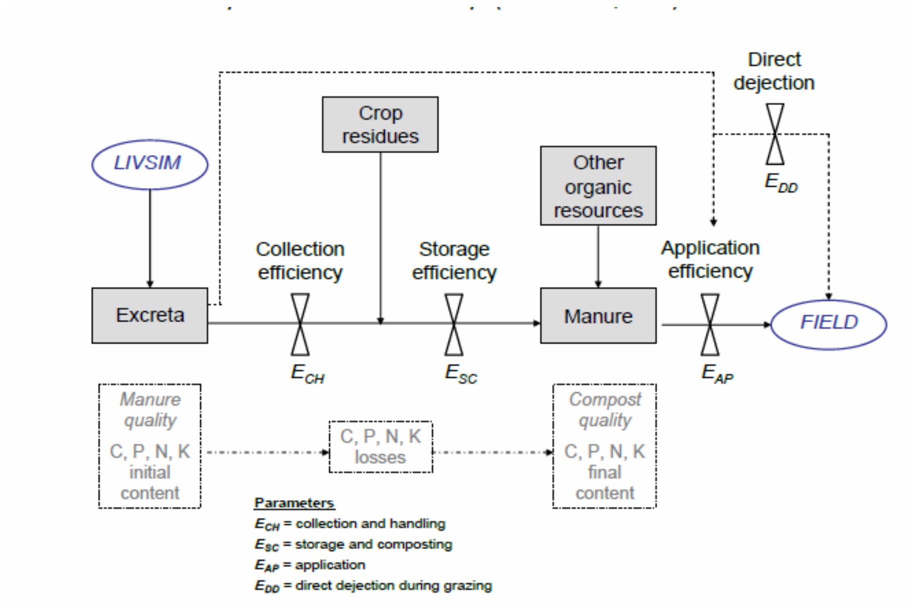


Figure 3 HEAPSIM model (Rufino et al., 2007)

The key parameters for the model that have been determined in the conceptualisation are the collection, storage, application and direct dejection efficiency as depicted in Figure 3.

For the farming systems under study, it was found that the relevant management aspects influencing the outcomes at farm system level were organic matter management, resource allocation and fertiliser and labour availability (van Wijk et al., 2009). Therefore, manure management and the accuracy of the HEAPSIM model have high importance for the NUANCES-FARMSIM framework.

1.7 Current NUANCES-FARMSIM project

Currently the NUANCES-FARMSIM approach is applied in a PhD-study of the MAIZE research program of CGIAR (Consultative Group for International Agricultural Research) in collaboration between Wageningen University and the International Institute for Tropical Agriculture (IITA) in Western Kenya. Every season a co-learning cycle, based on the example of the DEED cycle is organised with participating farmers. Aim of this PhD-study is to assess the effect of the co-learning cycles, using results of NUANCES-FARMSIM amongst other tools, on decision making and farm management. The PhD-study includes 50 farming households in two counties of western Kenya, Vihiga and Busia. For this purpose all farmers receive a voucher of US$100 for maize, groundnut, common bean, soybean and/or dairy inputs (Marinus; et al., 2016). 50% of these farmers are taking part in the DEED co-learning workshops (Treatment group) and the other 50% do not take part in the workshops and serve as control group. At the time of this study the 5th co-learning cycle has ended. In each co-learning cycle workshops are organised to work together with the farmers. In relation to manure management, the focus has been on increasing C and nutrient cycling through increased collection, incorporation of crop residue and plastic sheets as heap cover. The long-term aim of the work in Kenya is to assess if the NUANCES-FARMSIM framework is a suitable co-learning tool to explore best-fit options, regarding aspects such as long-term vs. short-term benefits/ exploration of land allocation options (i.e. maize (*zea mays*) vs. soybean (*Glycine max*) vs. napier grass (*Pennisetum purpureum*)) and increasing production levels and sustainability of farming systems (Marinus; et al., 2016).

As part of the NUANCES-FARMSIM project, a detailed characterization survey (DFC) has been designed to collect detailed data from farmers taking part in the NUANCES-FARMSIM research. It follows the approach described in Tittonell (2008) and Giller et al. (2011). The data collection has been done as part of the project in 2016, with the objective to characterise the farming systems of the participating farmers before the start of the co-learning cycles. The DFC includes 5 parts on the following topics: general information, household composition, income and poverty indicators, livestock and crops on the farm. Besides, the survey covers soil samples, farm and field sketch as well as GPS coordinates of the individual fields. Following the DFC, data has been taken twice yearly in the short and long rains through monitoring surveys as part of the PhD study.

This thesis research has been carried out as part of above described PhD study and in close collaboration with the researchers at the WUR and project staff in Kenya. The DFC serves for this research as a background. Some of the data from the DFC as well as the monitoring surveys were used for temporal comparison in this research.

1.8 Research objectives

1.8.1 Hypotheses and research aim

Currently, much of the conceptualisation of the HEAPSIM component is based on Rufino et al. (2007). Following the work, there has been little review of the sub-model. Therefore, three aspects have been identified that will be addressed in this report. Firstly, there is the need to look at literature to review the assumptions and approaches of the model. Secondly, little review has been done on changes of relevant local practises. An update on local management practises is therefore needed. Besides this, the workshops in the co-learning cycles might have influenced the relevance of some manure management practises of farmers. Potential changes need to be identified and it is necessary that these are accounted for in the HEAPSIM sub model.

The aim of this research is to i) assess management of manure and other organic matter flows between the animal component and the fields and compare these with the flows as assumed in HEAPSIM, ii) suggest improvements by reviewing the underlying model assumptions based on observations in the field and first explorations in NUANCES-FARMSIM and iii) assess the contributions of the co-learning cycles to improved manure management by collecting and analysing data on current manure practises.

1.8.2 Research questions

Above stated aim will be addressed by answering the following research questions and sub-questions:

RQ 1 To what extend does the HEAPSIM model align with farmers practice regarding manure management and storage in Western Kenya?

RQ 1.1 Which observations in the target area give indication to update assumptions in the HEAPSIM model?

RQ 1.2 How does adaptation of the HEAPSIM model affect short term (yields) and long term (soil fertility) model outcomes of NUANCES-FARMSIM?

RQ 2: To which extend did the co-learning cycles included in the NUANCES-FARMSIM project lead to improved manure management?

RQ 2.1 How have practises of farmers changed between the start of the co-learning cycles and after it, in terms of manure and manure management?

Chapter 2 Materials and Methods

2.1 Study area

This research was carried out in the two locations of the PhD research, Vihiga county and Busia county. These locations were chosen based on agro-ecological potential and the differences in population densities and thus farm sizes.

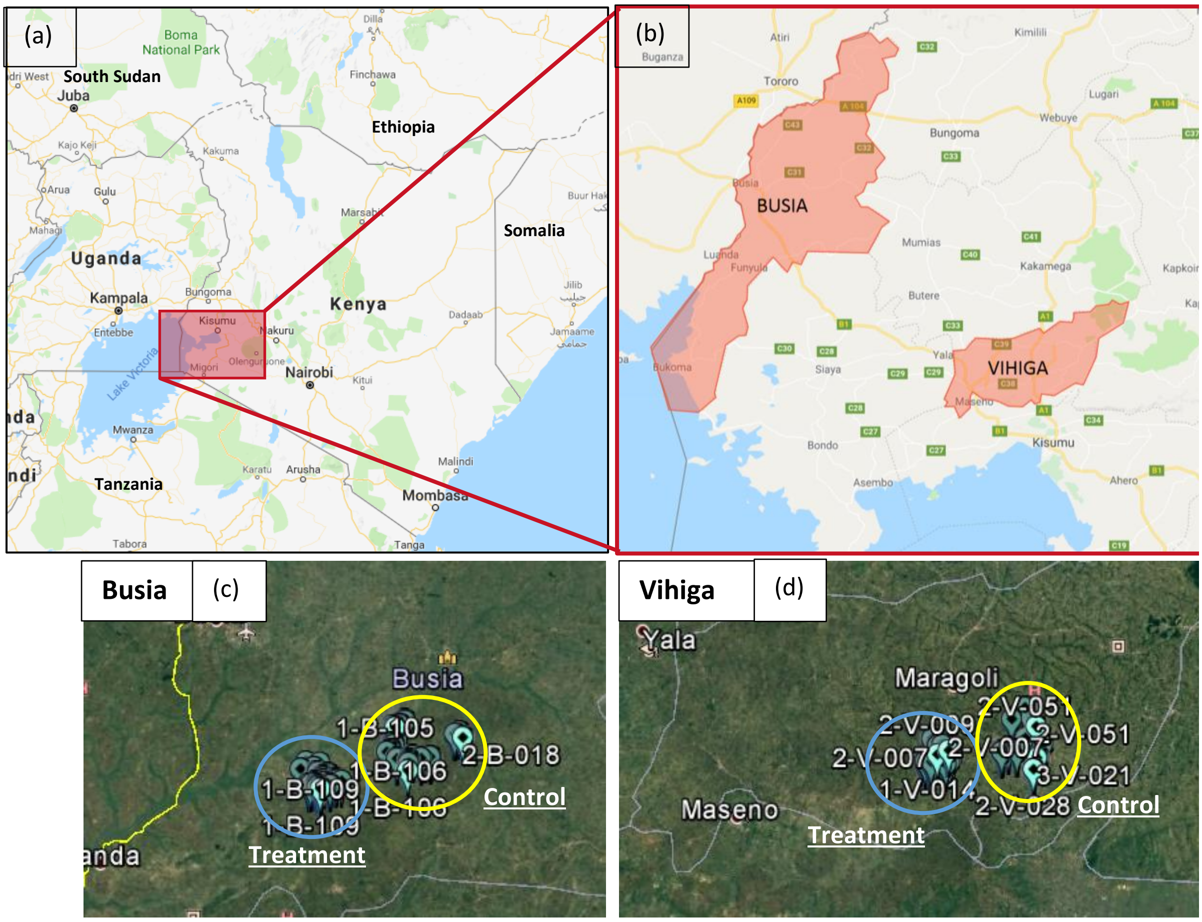


Figure 4 Map of Kenya (a) and Western Kenya (b) indicating Busia (c) and Vihiga county (d) and the farmers in the treatment (blue circle) and control (yellow circle) groups.

Vihiga county is located in the highlands of western Kenya. The dominant soil types include deep reddish Nitisols, Ferralsols and Acrisols (Tittonell et al., 2005a; Tittonell et al., 2005b). The rainfall pattern is bi-modal, totalling 1850 mm year^{-1}, and permitting two cropping seasons (Tittonell et al., 2009) which results in a relatively good agricultural potential (Marinus et al., 2017). Temperatures range between 14° C to 34° C (Aywa et al., 2013). The population density in the region is high (i.e. 800–1100 people km^{-2}) and most of the land is used by smallholder farmers, farming on very small pieces of land (i.e. an average of 0.5 ha), which puts high pressure on the land (Kiptot et al., 2007).

Busia county is located in western Kenya on the Ugandan boarder. The soil fertility is low. On the farms of the NUANCES-FARMSIM project clayey or loamy soils have been found. The temperatures are ranging between 16°C to 28°C, a mean annual rainfall of 1500mm year^{-1} is observed (Wambugu et al., 2012) and seasons greatly equal those in Vihiga. Land sizes are bigger compare to those in Vihiga district, on average in the NUANCES-FARMSIM project a median cultivation area of 0.7 ha.

Crop-livestock (maize-cattle) systems are dominant among farms in both counties. Generally, the productivity of the cattle is low. However, these production systems can highly vary from 1-2 l/day for local cattle to over 15 l/day for improved breeds in zero-grazing systems. The land is allocated mostly to food crops (maize and beans), a few cash crops and fodder crops. The soils in Vihiga and Busia are deficient in major nutrients such as nitrogen and phosphorus and farmers in the area apply no or limited fertilizers frequently (Okalebo et al., 2006; Tittonell et al., 2005a; Tittonell et al., 2005b). Table 1 compares the major characteristics of Busia and Vihiga.

Table 1 Characteristics of Busia and Vihiga county

	Vihiga	**Busia**
Soils	Medium to good soil fertility, Nitisols, Ferralsols, Acrisols	low fertility, Acrisols with sandy surface horizons
Climate	1850 mm year^{-1} 14° C to 34° C	1500mm year^{-1} 16° C to 28° C
Farm sizes, median and maximum in NUANCES-FARMSIM research (ha)	0.4, 1.2	0.7, 2
Languages	Kiluo, Kiluhya, Kiswahili	Kiluhya, Kiswahili

2.1.1 Farm typology and household selection

In the NUANCES-FARMSIM project a Farm typology is used to categorise the 50 farm households in Vihiga and Busia taking part in the research. Three farm types are distinguished which correspond to the differences in production objectives, investment opportunities and manure availability of the farm households. Farm type 1 has no mature cattle, but may have chicken or goats, which provide some manure; farm type 2 owns only local cattle and at least one mature cow; farm type 3 owns at least one mature improved breed cow.

In order to analyse the herd composition of the farms the Tropical Livestock Units (TLU) was used, which converts livestock numbers into a common unit. The approach of the PhD research is followed. 1 TLU represents an animal of 250 kg. In order to account for the different age groups of the cattle in the survey, an age correction factor is used (Njuki et al., 2011). Table 2 provides an overview of this.

Table 2 TLU factor (Njuki et al., 2011)

Cattle age	TLU
<6 mo;	0.4
>6mo & < 3y/ no 1st calving;	0.8
adult	1

2.2 Data collection

The data collection consisted mainly of three activities. First a survey was done among the farmers of the PhD research in the study area, secondly the collection of manure measurements on the same farms and thirdly observations on the farms.

2.2.1 Survey

2.2.1.1 Manure management survey - 2018

This survey was done with two main objectives in mind. Firstly, to assess if there are additional nutrient flows that are currently not captured in HEAPSIM/FARMSIM, but which are of (significant) importance. Secondly, to follow-up on what was done in 2016 and to compare if changes occurred that could be related to the co-learning cycles. The topics in the survey are shown in Table 3. Therefore, in addition to the questions included in the DFC, in this research more exhaustive data has been collected on manure management practises. As part of this it was in the interest of this research to find out the underlying reasons of farmers choices on aspects of manure management. For that reason, both closed and open-ended questions have been included in the survey.

The data collection took place from 10th May to 10th June 2018. The lengths of the survey ranged between 40 minutes to 2.5 hours, depending on farm type. Surveying Farm type 1 (no cattle; only small animals) took less time than surveying farm types 2 and 3 and some farmers had more diverse management (requiring more observations) than others. The surveys have been conducted in English were possible. Two local translators assisted if the farmers only spoke the local languages. Sometimes the survey was done partly in English and partly in the local languages by the aid of the local translators.

Table 3 Overview of survey topics. Aspects only covered in the 2018 survey are in italic, other topics have been covered in both surveys. The full survey is given in Appendix 1.

Topic	Research questions/topics
A. General information	Household ID, date, county, control/treatment, age, position in household, contact,
B. Household rooster	Household composition
C. Livestock	Number of small ruminants, Number of cattle owned, Cattle feeding (dry/wet), seasonal difference, *months of dry and wet season, crop residue fed, reason for practice, changes in practice, feed refusal amounts and use, seasonal difference,*
D. Manure management Part 1: Housing	Night housing proportion, *stalling facilities,* day keeping proportions – *24h memory, reason for practice and changes in practice, bedding materials, reason for practise and changes, slurry/urine collection,*
D. Manure management Part 2: Manure collection and storage	-Collection in the stall (percent, *frequency, local unit, amount of unit, frequency), uncollected manure,* manure collection grazing (percent, *frequency, local unit, amount of unit, frequency), seasonal differences, Manure application (Direct, other purposes, local transport unit, % applied in which way), reason for practise and changes, manure allocated to fields, seasonal differences*, manure storage types, *reason and changes of practise, empty of storage, other materials in storage, reason for practice and changes, turning of heap, reason for practice and changes, time invested in activities and shortage of time*
E. Challenges and changes	*Open questions on main challenges and changes in manure management.*
F. Questions for non-cattle owners	*Use of manure or compost in fields, sources of manure and compost (source, type, amount),challenges in getting manure, reason for practice and changes in practice*

Dry and wet season differences are an important factor for farm management in SSA, including Kenya. Therefore, relevant data, has been collected distinguished for both dry and wet seasons. Specifically, this was relevant for data on feed management and feed amounts, manure amounts, locations and fractions of a 24-hour day and locations cattle are kept in a particular time. All interviewed farmers were asked about the specific months of dry and wet season experienced on their farm. This information allowed to integrate this important farm management factor and to account for the variation in the data analysis.

2.2.2 Manure and urine measurements

Among a small survey as part of the PhD research, farmers in the two locations have shown to use locally specific units for transporting manure, e.g. a bucket, basin, jerry can or wheelbarrow. Yet, high variation was found in this small survey. Therefore, in this study the local units have been measured across all farmers. Based on the farmer's information from the individual interview, the local units used by the farmer have been measured (kg) to quantify the manure amounts (Figure 5). For these measurements, one local unit filled with manure was measured with a digital weighing scale. Units have been measured where possible for different collection places (in the night stall, day stall and compound).

According to farmers´ information collected in the survey on the proportion of the manure they collect, the local unit they use, the amount of this unit they collect, the frequency of collection and collection places, a detailed quantification of the amounts of manure collected per farm was established.

Figure 5 Manure measurements

In this study faeces is always referred to as manure, urine is separate and referred to as urine. Where farmers indicated in the survey to collect also urine in the stall, this was also measured as above described with a hand-held weighing scale if possible. Since the data collection took place during the rainy season one of the limitations in the measurement was the contamination of urine with rainwater where urine was stored outside. This diluted the urine and thus making it difficult to estimate the exact N-content. Especially since no samples were taken for N analysis.

Manure measures on some collection places where not possible for some locations on farms, because manure was not collected there on that day. Then estimates have been made either based on measures of another location on that particular farm when possible or based on the local units established by the measures from the other farmers. Due to limited time and resources available, data on manure nutrient contents have not been collected. Therefore, values from literature were used to calculate the nutrient amounts excreted by cattle per farm.

2.2.3 Observations

Together with the farmers, processes on each of the farms have be observed and recorded, with special emphasis on aspects of manure management, handling and cattle housing, since these are important parameter to determine quality of manure management. Housing is here understood as both keeping of cattle in stalls and other structures, as well as keeping of cattle in semi-open or open spaces like fenced areas or the compound. This follows the use of the term by Hall and Sansoucy (1981).

The main aim of the observations was to identify relevant practises or resource flows that have not been captured in the survey. Observations if possible have been documented visually by the aid of pictures as well as written in the survey. On each farm, farmers were asked for their oral consent prior to taking the pictures. The collection of pictures has been mainly done to allow documentation of the diversity of situations found in the farms, besides it enabled later comparison between farms and cross-checking of information collected in the survey.

In each farm the following pictures have been taken if the facilities were present:

- Cattle housing at night (inside, outside),
- Day stall, e.g. zero grazing units
- compound
- manure storage,
- urine collection facility

2.3 Data analysis

Data documentation was done in Microsoft Excel. The data analysis of the interview data was conducted with R software version 3.5.2. The focus has been on descriptive statistics. Due to the sample sizes other statistical analysis was not relevant.

2.3.1 Resource flow maps

The conducted surveys show the prevalence of certain management decisions among the farmers in the study. The aim of the resource flow maps is to better understand the resource efficiencies of here observed management decisions on the nutrient flows of the individual farms. N is the nutrient most likely to be lost and very important in the farm. Therefore, N-resource flow maps of the average farm types (Busia/Vihiga, type 2,3) have been made based on the survey results. In addition, two specific cases have been explored with the resource flow maps. The two chosen cases have been identified as relevant practices in the observations in the field and the results of the survey. The two cases compare the relevant, identified practise with an opposite situation. Namely the two cases are the collection of substantial amount of urine (and manure) through housing in zero grazing unit vs. the loss of most urine due to lack of a urine collection facility (case 1) as well as the application of all manure to a heap/pit vs. the application of all manure to the fields direct (case 2). The maps help to assess whether all relevant flows are included in NUANCES-FARMSIM or whether important flows are missing. The approach in establishing these N-resource flows is explained below here. Firstly, the manure flows and secondly the urine flows are explained.

2.3.1.1 Manure Calculations

I. Manure excreted:

From the collected data on manure management the total amount of collected manure (kg) was calculated as follows:

$$Total\ collected\ manure\ (kg) = \Big(Yearly\ number\ of\ days\ manure\ is\ collected * weight\ of\ local\ manure\ unit\ (kg) * number\ of\ this\ local\ unit\ in\ location\ i\ in\ dry\ season * \left(\frac{nr\ of\ months\ in\ dryseason}{12}\right)\Big) + \Big(Yearly\ number\ of\ days\ manure\ is\ collected * weight\ of\ local\ manure\ unit\ (kg) * number\ of\ this\ local\ unit\ in\ location\ i\ in\ wet\ season * \left(\frac{nr\ of\ months\ in\ wet\ season}{12}\right)\Big)$$

Based on this result, the amount of excreted manure (kg) was calculated. During the interviews the fraction of collected manure was reported by the farmers.

$$Total\ excreted\ manure\ (kg) = Total\ collected\ manure(kg)\ \times\ (100 \div average\ collection\ fraction\ )$$

Based on this the amount of N contained in the manure was determined. Rufino et al. (2007) made manure experiments from which the figures were used for the nutrient content of the manure. For the manure excreted in the stall figures from the roofed/uncovered part of Rufino's work were used and for manure excreted in compound/grazing field/communal the figures for unroofed/uncovered were used. Table 4 shows the Manure N contents used.

Table 4 Manure N contents used based on Rufino et. al (2007)

	Total N (%)	DM (%)
Manure excreted in stall	2.43	24
Manure excreted in compound	2.63	25

II. Determine the time of housing at various locations

Various manure collection locations have been identified through the survey. For the graphical display of the flow maps and simplification reasons some types have been combined here in the calculations of the flow maps. Namely housing in the families main building (the kitchen), the day and night stall and the zero grazing unit have been all combined as "Stalls", all communal areas, like roadside grazing, grazing fields and others have been combined in "communal area" and all grazing areas on the farmers own compound have also been combined as "Own grazing areas". In other parts of this work, all collection locations have been treated individually, data has been collected and analysed for each location. Only for the flow maps, the data has been combined from the beginning of the calculation.

From the collected data the fraction of the day cattle is housed at various locations has been calculated as follows:

$$Fraction\ of\ staying\ at\ location\ i = (\sum time\ at\ location\ i\ \ wet\ season\ (hours) \div 24 \times (months\ wet\ season \div 12)) + (\sum time\ at\ location\ i\ \ dry\ season\ (hours) \div 24\ \times (months\ dry\ season \div 12))$$

III. Determine the losses:

The amount of losses before the manure collection:

From the interviews it is known how frequent the manure is collected (subchapter 3.2.1), based on this the exposure time can be determined (Appendix 9). Hiddink (1987) found that during a 6 days period 20% of N is lost from a zero-grazing unit with concrete floor. It is assumed here that losses are relatively higher in open condition with sand or mud floors, like the compound or communal grazing areas. Further McGinn and Sommer (2007) and Ryden (1986) have shown that initial losses in the first few hours are considerably higher than losses after 12-48 h, therefore losses in the first 1-2 days are estimated to be highest compared to the subsequent days.

Based on these literature sources and the reported values, the following losses have been estimated for this step (Table 5):

Table 5 Manure N losses (in %) through volatilisation and leaching and number of days before manure collection for different locations and days manure is exposed to open

Days exposed and location i	**Loss rate**
1-2 days Stall	14%-17%
1-4 days in compound	16%-20%
1-7 days in communal area	16%-25%

Therefore, N losses (kg N) have been calculated as follows:

$$losses\ before\ collection\ i\ (kg\ N) = excreted\ manure\ \ i\ (kg\ N)\ \times (lossrate \div 100)$$

Secondly losses (kg N) due to uncollected manure per location were determined.

The fraction of collected manure per location was known from the farmers interviews. Based on this information, the total amount of manure excreted and the losses before collection, the amount of uncollected manure has been calculated as follows:

$$uncollected\ manure\ i\ (kg\ N) = (excreted\ manure\ i\ (kg\ N) - losses\ before\ collection\ i\ (kg\ N)\ ) * (uncollected\ fraction\ i\ \div 100)$$

IV. Determine collected manure

The amount of collected manure (kg N) is understood here as the sum of all collected manure before any further use.

$$Collected\ manure\ (kg\ N) = \sum manure\ excreted\ i\ (kg\ N) - losses\ before\ collection\ i\ (kg\ N) - uncollected\ manure\ i\ (kg\ N)$$

V. Manure allocation

Following this, manure (kg N) removed for off-farm purposes have been set.

From the interviews the amount of manure (%) used for off-farm purposes was known. It was deducted from the manure amount (kg N) available for application on the farm.

$$manure\ removed\ to\ neigbours\ (kg\ N) = collected\ manure\ (kg\ N) * fraction\ removed$$

$$Manure\ removed\ for\ smearing\ the\ house\ (kg\ N) = collected\ manure\ (kg\ N) * fraction\ removed$$

VI. Direct fresh manure application

Afterwards, fresh manure (kg N) allocated to the fields of the farm direct were deducted. The fraction has been determined through the interviews.

$$Manure\ applied\ direct\ (kg\ N) = collected\ manure\ (kg\ N) * fraction\ applied\ direct$$

VII. Stored manure

Also, the fraction of manure stored (kg N) and losses in the manure heap or pit (kg N) have been determined. From the interviews it was known which fraction of manure (kg) was stored on the heap/pit. Manure applied to the heap/pit was assumed to be stored for 6 months. Tittonell et al. (2009) found that after 6 months of storage in a pit, mass fractions of the manure reduced by 60% N, 32% P and 75% of K. Losses (kg N) that occur in the heap/pit were calculated as follows:

$$Manure\ stored\ in\ heap\ or\ pit\ (kg\ N) = collected\ manure\ (kg\ N) * fraction\ stored\ in\ heap\ or\ pit$$

$$Fraction\ stored\ in\ heap\ or\ pit + fraction\ applied\ direct + fraction\ removed\ for\ smearing\ the\ house + fraction\ uremoved\ for\ neigbours = 1$$

$$Losses\ in\ manure\ storage\ (kg\ N) = Manure\ stored\ in\ heap/pit\ (kg\ N) \times 0.6$$

2.3.1.2 Urine Calculations

I. Excreted urine

From the urine measures the amount of urine collected in the stall was calculated as follows:

$$Total\ collected\ urine\ (kg) = \Big(Yearly\ number\ of\ days\ urine\ is\ collected * weight\ of\ local\ urine\ unit\ (kg) * number\ of\ this\ local\ unit\ in\ stall\ in\ dry\ season * \Big(\frac{nr\ of\ months\ in\ dryseason}{12}\Big)\Big) + \Big(Yearly\ number\ of\ days\ urine\ is\ collected * weight\ \ of\ local\ urine\ unit\ (kg) * number\ of\ this\ local\ unit\ in\ stall\ in\ wet\ season * \Big(\frac{nr\ of\ months\ in\ wet\ season}{12}\Big)\Big)$$

Based on this calculation the total excreted urine in stall (kg) was calculated. From the weight excreted in the stall the total amount of urine (kg) was extrapolated as follows:

$$Urine\ excreted\ in\ the\ stall = \left(collected\ urine\ \times \left(\frac{100}{fraction\ of\ urine\ collected}\right)\right) \times fraction\ of\ time\ spend\ in\ stall$$

II. Determine N content

Based on the work from (J.K. Lekasi a, 2003) and Rufino et al. (2006), 10g N kg^{-1} urine was estimated. The amount of N was calculated as follows:

$$Urinary\ N\ excreted\ in\ stall\ (kg\ N)\ =\ urine\ excreted\ in\ stall\ (kg) \times 0.01$$

III. Determine the urinary N losses

For type 2 collection takes place on average every 6 days, therefore based on Rufino et al. (2006) a loss fraction of 0.5 was assumed. For type 3 on average urine is collected every 4 days, so 0.35 was assumed as the loss fraction. The following formula was used for the calculation:

$$Loss\ fraction\ in\ stall\ (kg\ N)\ =\ urine\ excreted\ in\ stall\ (kg\ N)\ \times loss\ fraction$$

IV. Recovered urine

Based on the amount of totally excreted urine (kg N) and the amount of losses (kg N), the recovered urine (kg N) was determined as follows:

$$Recovered\ urine\ (kg\ N) =\ Total\ excreted\ urine\ (kg\ N)\ - (loss\ fraction\ in\ stall\ (kg\ N)$$

2.3.2 Modelling using HEAPSIM and NUANCES-FARMSIM

The aim of the modelling part is to explore how the integration in the NUANCES-FARMSIM model could be realised for those observations identified as important in the survey and identified as significant flows through the resource flow maps. Based on the results, urine application to napier grass was chosen as an example for this exploration.

2.3.2.1 Description of typical urine management farms

The findings of the survey described above were used to identify relevant characteristic differences on the farms, which effect the urine management. These observed characteristic differences (housing characteristics) have been used to create 4 different typical urine management farms. Typical urine management farm 1 and 2 represent housing characteristics observed dominantly in farm type 2, the typical management farms 3 and 4 represent housing characteristics observed rather in farm type 3. The urine collection fraction has been determined based as well on the characteristic differences (housing characteristics). An overview of this is presented in table 6 below. Besides these characteristic differences, comparison of the model outcome and keep differences limited to the significant aspects, several aspects have been kept the same for all the typical urine management farms. In this first exploration urine was only applied to napier grass, since this was one of the dominant practises observed in the surveys. Model runs of this typical management farms were made in NUANCES-FARMSIM.

Table 6 Overview of characteristic differences of the four reference farms for modelling (Housing, housing characteristics, fraction of collectable manure and urine collection)

Typical urine management farm	Farm type	Housing	Housing characteristics	Urine collection fraction
1	2	No housing	-	0
2	2	Night housing, day grazing	Half iron roof, sand floor	0.57
3	3	Night housing, day grazing	Iron roof, cement floor	0.64
4	3	Zero grazing unit	Iron roof, cement floor	0.90

In order to identify the urine collection fraction, the interviewed farms that fit the selected characteristics of the 4 typical urine management farms were selected from the collected survey data. Namely these were those farmers with no housing, those with night stall and day grazing and either cement or sand floor and those with zero grazing units on their farm. From these selected farms farm a weighted sum of the collected % of urine during a 24h day (e.g. stall/compound/ communal land) was calculated for each typical management (Table 7). The housing characteristics were translated into a management factor to account for the varying losses in urine prior to collection.

Table 7 Fraction of collected manure and urine

Typical urine management farm	% of collected urine	Management factor	Urine collection fraction
1	0	0	0
2	0.63	0.90	0.57
3	0.67	0.95	0.64
4	0.90	1.00	0.90

The table below shows some of the major parameters that have been kept the same on all the typical management farms. This also includes the fields and crops, soil data and climate data, which have been parameterised in the model. They are described in Appendix 2.

Table 8 Additional characteristics of the reference farms used in this study for the parameterisation of the NUANCES-FARMSIM model

Aspect	Parameter
Number of cows	3
Breed	Friesian x Zebu
Manure storage type	Pit
Crop residues fed from total stover produced (%)	65%
Fields and sizes (ha)	Field 1: Maize 0,35 ha, Field 2: Maize 0,35 ha, Field 3: Maize 0,35 ha, Field 4: Napier 0,05 ha

Chapter 3 Results from farmer survey

This chapter addresses research question 1.1, "Which observations in the target area give indication to update assumptions in the HEAPSIM model?" and presents all results of the farmer surveys. It includes 2 parts. First the results of the cattle owning farmers (type 2 and type 3) and secondly the analysis of the answers of non-cattle owning farmers. Further this subchapter also addresses research question 2.1, "How have practises of farmers changed between the start of the co-learning cycles and after it, in terms of manure and manure management?", by making use of the data collected in the DFC 2016 in order to compare it with the data from cattle owning farmers obtained in this research to show some developments.

3.1 Cattle management

3.1.1 Herd composition

Farmers in Busia had more livestock (a higher TLU) compared to farmers in Vihiga (Table 9). Moreover, class 3 farmers have some local cattle besides their dairy cattle. The herd composition can be seen in Appendix 3 for the 2016 data from the NUANCES-FARMSIM research.

Table 9 Mean TLU, TLU of female cattle and TLU of local and dairy cattle per farm for type 2 and 3 farmers in Vihiga and Busia

Location	Farmer type	Total TLU per farm		TLU female		TLU local cattle		TLU dairy cattle		n=
		Mean	St.dev	Mean	St.dev	Mean	St.dev	Mean	St.dev	
Busia	2	3.85	2.19	2.38	1.38	3.80	2.18	0.05	0.14	8
Busia	3	3.78	2.95	2.95	1.95	1.07	1.88	2.72	1.85	12
Vihiga	2	1.74	0.99	1.49	0.90	1.69	1.03	0.06	0.15	7
Vihiga	3	3.03	1.47	2.27	1.73	0.95	1.36	2.08	1.17	12

Looking into the herd development between 2016 and 2018 (figure 6), the comparison of the data per household showed that 11 households maintained the same TLU value, 13 households decreased their herd size and 24 household increased their herd size. In Vihiga farmers that reduced and increased their herd size are almost equal among both treatment and control group. In Busia, the farmers that increased their herd size are much more than those that decreased the value. Treatment groups did not increase their herd size more compare to the control groups, rather location appears to create a difference. A detailed data table can be seen in Appendix 4.

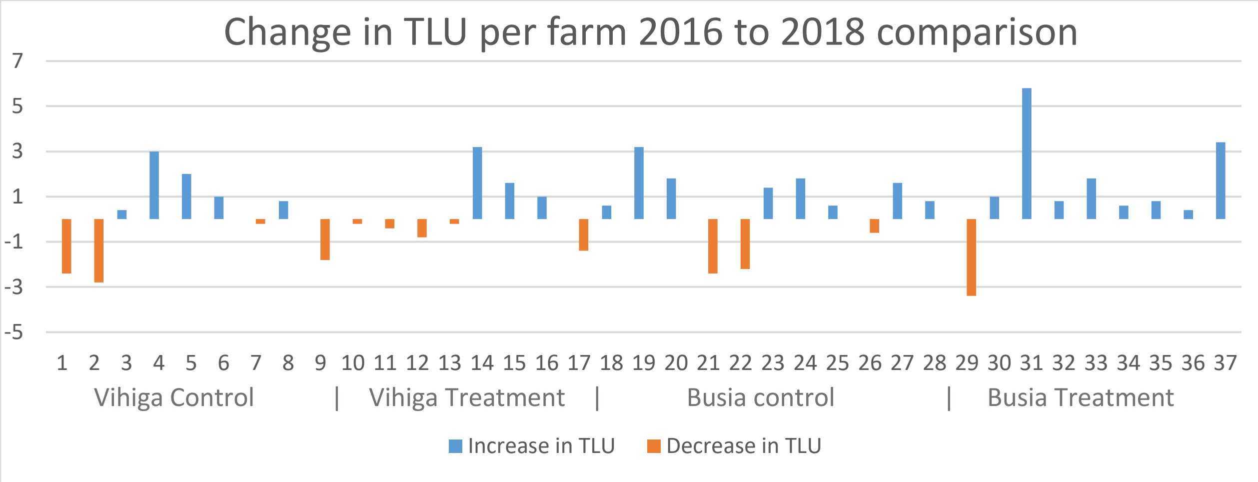


Figure 6 Change in TLU 2016 to 2018 , this graph shows all farms that have changed the TLU from 2016 to 2018. Farms where the TLU stayed equal are not depicted.

3.1.2 Cattle housing and grazing - Management and facilities

3.1.2.1 Housing systems and night housing

For the housing at night, three different systems were observed. The animals are housed in the family's main house (mostly the kitchen), in a stall or outside if no housing is available. Table 10 shows the prevalence among the farmers.

Table 10 Presence of stall, main house/kitchen and no housing as night housing systems (in % and absolute amount) by farmer type 2 and 3. The data for Vihiga and Busia have been cumulated, since no difference was shown between the locations. N= indicates the number of farmers in type 2 and 3. For farmers with two housing systems, both have been counted with 0.5.

Housing at night	Farmer type 2 (n=15)		Farmer type 3 (n=24)	
	count	percentage	count	percentage
Stall	3	20	11[a]	46
Main house/kitchen	7	47	9	38
No housing	5	33	3[b]	13

[a] (10 farmers full stall housing, 2 farmers part stall housing)
[b] (2 farmers with no other housing, 2 farmers with partly outside housing)

In Farmer type 2 (n=15) 47% (=7) of farmers kept their animals in the main house, mostly in the room serving as the kitchen. As shown in figure 7 below, most of these households split some part of their kitchen and constructed wooden fences to house the animals overnight. Picture 4 and 6 show examples of this housing system. In farmer type 3 (n=24) 38% (n=9) of farmers used the kitchen in the night. The main reason farmers mentioned for keeping the animals in the kitchen or main house was the fear of theft of the cattle during the night. Especially in Vihiga that was mentioned often. Even some farmers with a zero grazing unit housed their animals in the main house to protect them. Despite this, 46% (n=11) of type 3 farmers kept the cattle in a night stall. In Picture 3 and 5 of figure 7 examples of this housing system are shown.

Figure 7 Different stalls types present in the study area : Picture 1 shows a simple zero grazing unit; picture 2 shows a day stall; picture 3 and 5 show a night stall; picture 4 and picture 6 show a kitchen space for night stalling.

Besides this some farmers had no housing present in their homestead, thus 33% (n=5) and 13% (n=3) of type 2 and type 3 farmers respectively kept their animals outside during the night. In this system the cattle are tight to a stake in the homestead. All farmers with outside night housing were in Busia. In Vihiga no outside night housing was practised. The fear of theft explains why it is not very common especially among type 3 farmers. These various systems in which farmers kept their cattle showed a major difference in management between type 2 and type 3 farmers, because type 3 farmers reported much less outside housing and much higher number of stalls for housing.

3.1.2.2 Roofing and Flooring

In terms of roofing, the use of iron sheets was the dominating system. Besides those farmers housing their cattle outside during the night all farmers had their houses covered with iron sheets. A common roofing system in the stalls that was observed is the partial roofing. In Figure 8 the pictures 2 and 3 show these systems. Here only the presence of an iron roof was counted in the analysis, but not the fraction of roof coverage.

Table 11 Characteristics of cattle houses: The table only included the 10 and 22 farmers with housing in stall/house as indicated in above table 9; farmers with no housing have been excluded in this table. 0.5 indicates that for some farmers two different facilities were present and then for each facility 0.5 was counted.

Housing Characteristics	Farmer type 2 (n=10)		Farmer type 3 (n=22)	
	count	percentage	count	percentage
Presence of iron roof	10	100	22	100
Presence of cement floor	1	10	10.5	48
Presence of sand/mud floor	9	90	11.5	52
Presence of urine collection facility	8	80	18.5	84

Figure 8 Roofing examples of cattle housing , picture 1 shows a main house with iron roof, picture 2 and 3 show zero grazing units with half roofs and picture 4 shows a stable with complete roof cover.

In terms of flooring, both concrete floors as well as mud/sand floors were present. Figure 9 shows that some differences were observed in the quality of flooring. In type 2 90% of farmers with housing (n=9) had a mud/sand floor; only 1 farmer had a cement floor. Among the type 3 farmers 48% (n=10.5) of farmers had a cement floor in part of their housing system and 52% (n=11.5) of the farmers had a mud/sand floor. Table 11 above shows that among the type 3 farmers, five farmers had both floor types. This is either when only a part of the floor was cemented, or when farmers had two stalls with different floors. In these cases, both was counted with 0.5.

Figure 9 Flooring examples of cattle housing observed in the study area : Picture 1 and 3 show mud floors (mixed with stones in Picture 1); Picture 2 and 4 show cemented floors

3.1.2.3 Urine collection

In some of the houses and stalls urine collection facilities were present. These facilities mainly included an uncovered drainage line in the floor, leading into a hole or bucket outside the building. Figure 10 on the next page shows the different facilities observed. Among the cattle owning farmers interviewed 68% of farmers had a urine collection facility (Table 11). In farmer type 2 53% (n=8) of farmers had a collection facility, representing 80% of farmers with roofed housing. In farmer type 3 77% (n=18.5; one farmer had two stalls, but only one with urine facility) of farmers had a collection facility (84% of farmers with roofed housing). Figure 11 shows that the quality of the facility differed greatly from a mud hole were the urine flows in (Picture 2) or plastic buckets in the ground (Picture 6) to cemented covered basins in the ground (Picture 3+5) to name only the most common once observed.

For farmers that kept their animals inside the house during the night an important reason mentioned for having such a drainage line was to prevent the urine to enter the kitchen area. Farmers maintained varying collection periods, ranging from every 24 (n=7) or 48 hours to weekly (n=5) or monthly (n=3) collection. Mostly the collected urine was directly applied as a liquid fertilizer to napier grass (n=11), but also to banana gardens (n=5), leafy vegetables (n=5) and maize (n=7). The main advantage mentioned by farmers is a good growth of the plants. Especially napier grass was reported to show a vigorous growth with deep green leaves. Also, reduction in insect infestations in the banana plants and roots was observed.

Yet, farmers also faced various challenges with urine collection and application. While urine reduced infestation in banana plants in some farms, other farmers rather feared it attracts parasites that attack some plants. Besides simple facilities made the collection difficult, leading to bad smell and skin rushes. Labour was only mentioned once as a challenge.

Another practise to preserve urinary N is the use of bedding materials, but in this survey the practise was not observed to be common, only 10% of cattle owning farmers (*n=3*) occasionally reported to use it. Yet, 54% of the type 3 farmers and 40% of the type 2 farmers heard of the use of bedding material before. The unavailability of the material, quick dirtying of the stall and the existence of a good stall floor were mentioned main reasons not to use bedding. Many farmers showed to lack knowledge on bedding; the terms and concept was misunderstood and the wish for more information was stressed.

Figure 10 Examples of the diversity of urine collection facilities observed in the study area : Urine collection in Picture 3, 4 and 5 show best practises, picture 1, 2 and 6 show less ideal examples

3.1.2.4 Day time housing

In the daytime most farmers kept the cattle at least some hours grazing in the compound (see table 12). The compound is the grass area around the house of the homestead. Cattle are mostly tethered to a wooden peg. Further grazing in fields on own land, on communal areas and on roadside was reported. Farmers mentioned four reason for keeping the cattle outside during the daytime and not in their zero-grazing unit or day stall. Firstly, exposure to sunlight supports their health and relaxes the animal, moving is believed to relax the muscles. This was mentioned particularly in the Vihiga treatment group. Secondly grazing cattle provides additional feeding and watering opportunities, which reduced farmers´ workload. Therefore, often farmers grazed local cattle outside and keep dairy cattle in stalls where it is safer. Thirdly, dry season also affected housing management. Availability of grasses was more limited, so that some farmers supply collected fodder and others utilize grazing areas further away. Lastly, housing strategy was explained by availability of facilities. The dairy cattle and the local cattle are aimed to be kept separate, in order to avoid diseases spread to dairy cows and to allow different feeding regimes. Therefore, the limited stall space was used for dairy cattle, so male and local cattle stay in the compound.

Table 12 Cattle housing in stall in wet and dry season (in % with its St. dev) for farmer type 2 and 3 in Busia and Vihiga from the DFC 2016 data set. n= shows the total amount of farmers per category in the DFC 2016 data.

Location 2016	Farmer type 2016	Mean % spend in stall in wet season		Mean % spend in stall in dry season		*n=*
		%	St. dev	%	St. dev	
Busia	2	63	48	13	25	7
Busia	3	100	1	97	8	9
Vihiga	2	15	19	31	41	7
Vihiga	3	57	46	50	45	11

3.1.3 Crop residues

Farmers also utilized crop residues like maize stover from their fields to feed their cattle. This was mostly done in dry season when other feed sources are scarce (Appendix 5 shows further data on the feeding per season). The use of stover as feed competed with leaving it in the field to add soil organic matter. Therefore, here the fraction of stover fed to the cattle was determined.

On average in Busia 55% and 84% of crop residue was used as feed for cattle in type 2 and 3 farms respectively, in Vihiga 50 and 78% of residues was fed to cattle by type 2 and 3 farmers respectively (Table 13). It shows that type 3 farmers fed more crop residues to their cattle compared with type 2 farmers. Besides, farmers in Busia fed on average more residues to their cows than farmers in Vihiga.

Table 13 Maize residue from farmers field fed to the cattle (in %) and feed refusal (in % of total feed) by farmer type 2 and 3 in Vihiga and Busia

Location	Farmer Type	Residue fed		*n=*
		%	sd	
Busia.2	2	55	33	8
Busia.3	3	84	31	12
Vihiga.2	2	50	11	7
Vihiga.3	3	78	23	12

3.2 Manure management

3.2.1 Manure collection

3.2.1.1 Collection places

Table 13 below shows if cattle are housed at a certain location, how much time in a 24h day they have then spend at that location. The count indicates that most important locations are the compound and the night place. For this analysis all locations where cattle are housed during the night hours, e.g. in the kitchen, the night stall or outside were combined as night place. It can also be seen in the table 14 below that the number of farmers using the communal area was rather low.

In addition, the table indicates the fraction of manure that was collected at the various locations based on the total excreted amount of one day and the times spend on that location. It is assumed that over a 24 h period equal manure is excreted every hour. The largest amount is lost at the communal grazing area, where only 5% is collected. High losses also occur in the grazing fields, which are fields on the own land of the farmers; here only 13% was collected. Grazing at the roadside and neighbouring farms was not dominant and cattle show not to spend much time in these locations, however if they did then no manure is collected there.

Table 14 Management per manure collection locations , time cattle spend per location (h), manure collection fraction per location (%) and time between excretion and collection (days)

Location	Time spend at location In h	Collected manure from excreted one at that location %	Time between excretion and collection In days	*n=*
communal grazing area	1	5	1.0	3
Compound	3	82	1.9	42
day stall	3	90	1.9	8
grazing field	2	13	7.8	8
neighbours farm	1	0	-	2
night place	6	93	1.1	37
roadside grazing	1	0	-	8
zero grazing unit	8	74	0.6	7

3.2.1.2 Manure units

Figure 11 below shows the median amount of kg measured across farms per container. Most common units and their weights (median) by usage frequency were bucket (22 kg), basin (20 kg), wheelbarrow (39 kg) and cut jerry can (28 kg) and small bucket (35 kg). The boxplot below shows the spread of the measures per collection unit and gives an indication that measures for almost all collection units show a high variation. The data table can be found in Appendix 6.

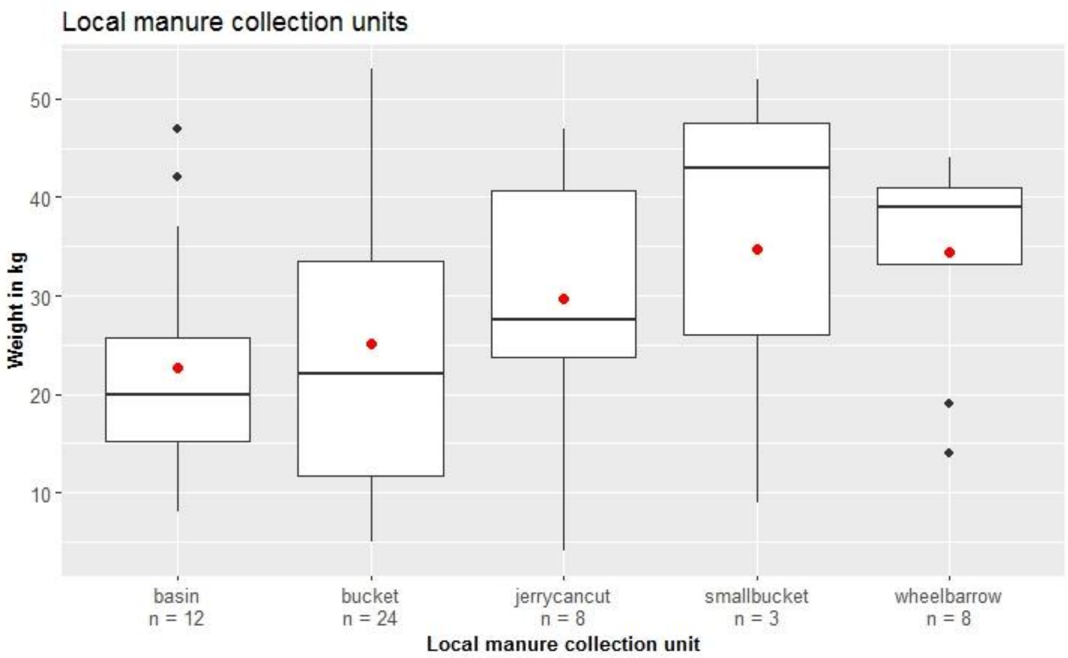


Figure 11Median local manure collection units with their fresh weights (kg) measured after collection; bucket (22kg), basin (20kg), wheelbarrow (39kg), cut jerry can (28kg) and small bucket (35 kg). The red dots show the means.

3.2.1.3 Urine units

The graph below (Figure 12) shows the median of local collection units for urine, which have been established in the same way as described above for the manure units.

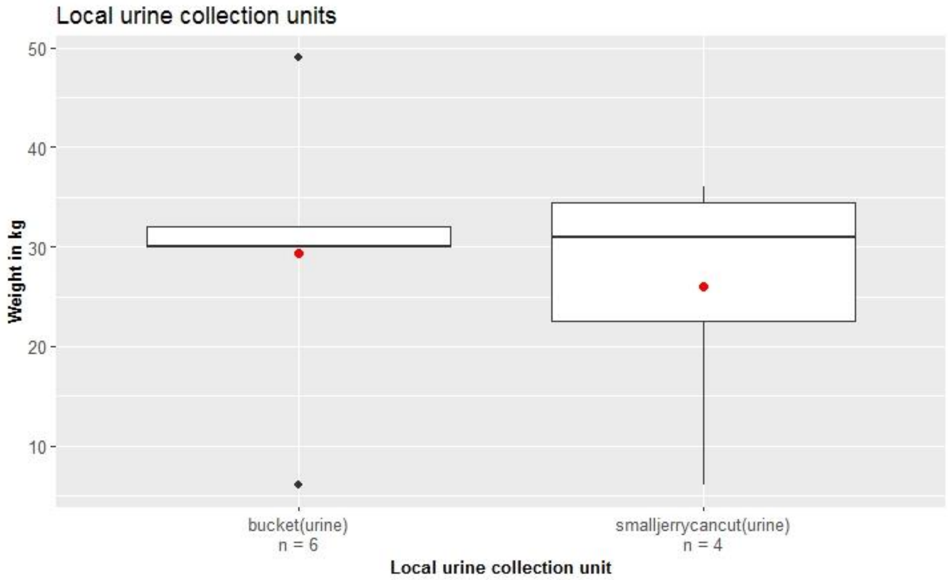


Figure 12 Median local urine collection units with their fresh weight (kg) measured after collection; jerry can (31kg) and bucket (30 kg) were mostly used. The red dots show the means.

Most commonly, a bucket (30 kg) or a cut jerry can (31 kg) was used to collect the urine. Sometimes this was the same as the one inside the urine collection hole, but mostly an additional bucket or jerry can was used for urine collection by hand.

3.2.1.4 Manure amounts

The amount of manure collected per homestead on yearly and daily level by location and farmer type is shown in table 15. In Busia both type 2 and 3 farmers produced more manure compared to the farmers in Vihiga, but per cattle more was produced in Vihiga. Among farmers in Vihiga 9530 kg and 15409 kg manure were collected on average per year in type 2 and 3 respectively and 15 and 14 kg per TLU on a daily level. Among type 2 and 3 cattle in Busia 15434 kg and 16339 kg respectively were collected. This relates to daily collection amounts ranging from 11 to 12 kg per day per TLU.

Table 15 Manure collection amounts (fresh weight) yearly and daily per farm (kg) and per TLU (kg TLU^{-1}) for type 2 and 3 farmers in Busia and Vihiga

Location	Farmer type	TLU	Yearly manure amount kg	Yearly manure amount kg TLU-1	Daily manure amount kg	Daily manure amount kg TLU-1	*n=*
Busia	2	4	15434	4009	42	11	8
Busia	3	4	16339	4319	45	12	12
Vihiga	2	2	9530	5468	26	15	7
Vihiga	3	3	15409	5080	42	14	12

Table 16 Urine collection amount yearly and daily per farm (kg) and per TLU (kg TLU^{-1}) for type 2 and 3 farmers in Busia and Vihiga

Location	Farmer type	TLU	Yearly urine amount kg	Yearly urine amount kg TLU^{-1}	Daily urine amount kg	Daily urine amount kg TLU^{-1}	*n=*
Busia	2	4	2008	521	6	1	8
Busia	3	4	6167	1630	17	4	12
Vihiga	2	2	500	287	1	1	7
Vihiga	3	3	1950	643	5	2	12

In relation to the urine collection firstly it can be seen in table 16 that there was a high variability in the total and daily amounts. In Busia between 1 and 4 kg urine were collected per day and TLU^{-1} in type 2 and 3. On farm level this sums to yearly amounts of 2008 kg and 6167 kg urine.

Table 17 shows that comparing collection fractions (%) of manure, it can be seen that for night housing many farmers (29) have indicated to collect a similar fraction in 2016 and 2018, 10 farmers have reported a higher fraction in 2018 and 7 farmers have reported a lower fraction. In relation to the fraction of manure collected when animals are grazing, 13 farmers indicated the same amount, 20 farmers a higher amount and 10 farmers a lower amount.

Table 17 Changes in manure collection fraction in night stall and day grazing between 2016 and 2018 , percentage of change and count of number of farmers with equal, higher and lower collection fraction are shown

	Night						Grazing					
	Total		Treatment		Control		Total		Treatment		Control	
	%	*n=*	%	*n=*	%	*n=*	%	*n=*	%	*n=*	%	*n=*
equal	0	26	0	11	0	15	0	13	0	7	0	6
higher/more	80	10	76	5	83	5	74	20	66	8	80	12
lower/less	-31	7	-18	3	-40	4	-34	10	-29	4	-38	6

3.2.2 Manure allocation

Collected manure was either applied directly as fresh manure to the fields or it was stored in a heap or pit. In the decision for direct application of the manure or storing of manure in a heap/pit some farmers had a clear preference for either one of the two, others chose a middle way of combining the two. Figure 13 shows that the amount of manure allocated to the heap/pit was much higher in Busia (85%/80%) than in Vihiga (57%/52%) for both type 2 and 3 respectively. Stored manure was mainly used during planting time and applied in planting holes. This corresponds with 13118 kg and 13071 kg of fresh manure that was stored on average per year in a heap/pit in Busia type 2 and 3 respectively. In Vihiga 5432 kg and 8012 kg was stored yearly on average in type 2 and 3. The data table can be seen in Appendix 7.

Three main reasons for manure storage in heaps/pits were mentioned by farmers in the survey. First, decomposition of manure together with organic materials support higher nutrient content by the added organic material to be present in the compost. The second reason was that the volume of compost in storage was larger, since other organic materials were added. Larger amounts could be applied to larger areas. Thirdly it was mentioned that storing the manure kills some of the unwanted worms and bacteria, which are present in the fresh manure. Some farmers saw disadvantages of storing manure because stored composted manure attracts neighbours to ask for a share of this compost, which is then lost for the farm. Even theft of stored compost was reported.

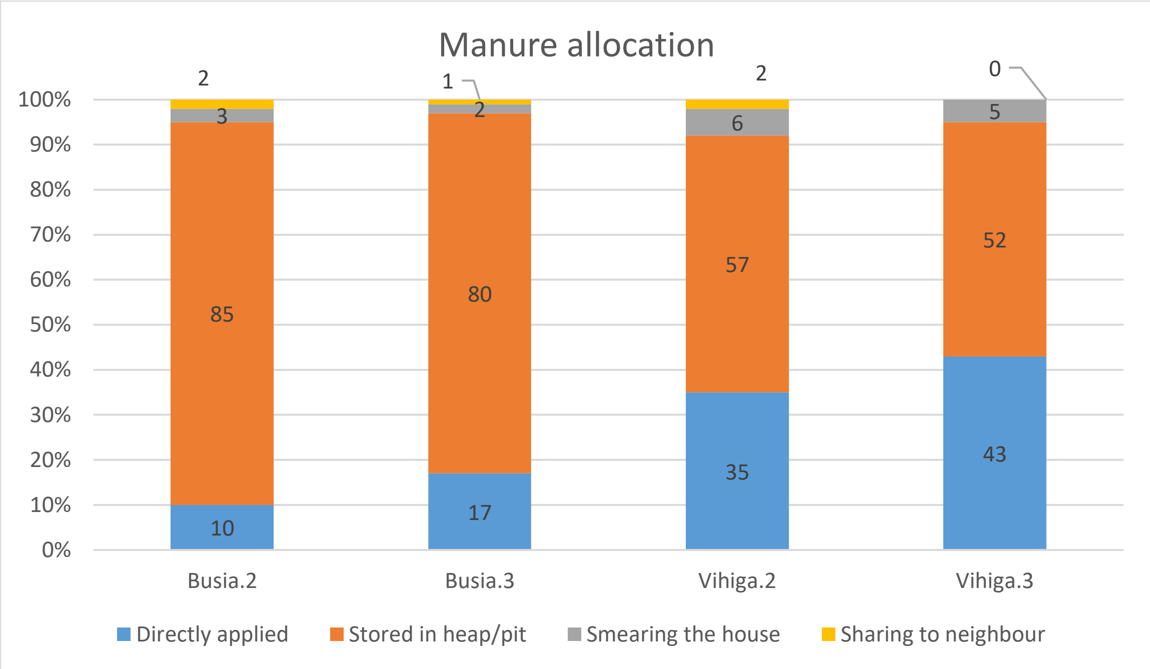


Figure 13 Manure allocation to direct application on field, storage in heap/pit and use for smearing the house and sharing to neighbours (in % and kg)

In total 26 farmers allocated some of the manure direct. The highest percentage of manure allocated directly to the farm was observed in Vihiga compare to Busia, with 35% and 43% for type 2 and 3 respectively. In terms of fresh manure, on average 3336 kg and 6625 kg was applied directly on a yearly level to the fields in type 2 and 3 in Vihiga respectively.

Reasons for direct application have often been very site specific. For rather infertile or slope fields direct application was a means to boost fertility sufficiently in shorter time compared to composted manure, which helped improve maize and napier grass growth. Varying degree of even applications over the fields were reported, with some farmers paying attention to it while others only apply on some spots within fields without paying attention to even distribution. Another form of direct application mentioned is the spot application. Farmers reported to apply fresh manure after crop harvest to balance nutrient gradients in the fields, where plants showed deficiency symptoms, before the next season. Also, on spots with striga infestation (*Striga hermonthica*) farmers applied fresh manure regularly. Disadvantages or threats of direct manure application were also mentioned. Among them a big risk is that the fresh manure can lead to crop burning, which negatively affects germination of seeds, especially if fresh manure is used in planting holes. Besides that, also leaching of the nutrients through heavy rains was another aspect mentioned by farmers repeatedly.

Many farmers mentioned to use both direct application and storage. Often direct application was used for fields closer to the homestead and stored manure for fields further away. Especially manure from the night housing or day stalls was stored in heaps/pits. The one collected in the compound was applied direct. The reason mentioned was that manure from the compound is already mixed with feed refusals or grasses and thus decomposition can be faster, which makes it suitable for direct application. Another reason was that often the manure heap/pit was located close to the night stall, so it is comfortable to store there the manure from the stall. Besides that, was the compound in many homesteads located next to one of the fields, where some farmers preferred to allocate it directly.

Comparing the data of 2016 and 2018 with each other only a few changes were observed (Table 18). In Vihiga three farmers, one from the treatment group and two from the control group, changed from storing manure to applying all manure fresh. This was the reason in some site-specific conditions, like very slope fields with low fertility. One farmer from the treatment group in Busia who practised direct application started to store manure in a pit. Farmers reported that they started to allocate also manure to napier grass with positive effects on leaf growth. A few farmers also mentioned that they adapted the application of manure and apply manure more evenly in all fields now, compare to application to fields close to the homestead which was practised earlier.

3.2.3 Manure storage

In general, three main locations were manure is stored were distinguished, the open heap, the compost pit and pits covered with polythene film. Across all type and locations more farmers used a compost pit compared to an open heap. Table 18 shows that among the type 2 farmers 72% and 69% of the manure in Vihiga and Busia respectively, was stored in a compost pit, and 58% and 50% in type 3. Farmers had the impression that "the manure volumes become more if stored in a pit". Two main reasons why farmers intended to stop or avoid the using of the heap for storing their manure were problems associated with rain runoff or erosions which reduced the manure quantity and chicken scattering the manure from the heap. An open heap was used by 25% of type 2 farmers in Busia and not used by type 2 farmers in Vihiga. Among type 3 farmers 16% and 33% of farmers used an open heap in Vihiga and Busia respectively. Contrary, some farmers mentioned that the transport of manure is much easier and related workload is reduced if stored in a heap compare to the pit, which was an important point especially for older farmers or female headed households.

Table 18 Manure storage in different storage types in Farm type 2 and 3 in Vihiga and Busia, one farmer in Busia had two manure storage places, that were counted 0,5 each.

Farm type	Storage type	Busia		Vihiga	
		%	*n=*	%	*n=*
Type 2 (Busia: *n*=8, Vihiga: *n*=7)	Open heap	25	2	0	0
	Compost pit	69	5.5	72	5
	No heap/pit	0	0	14	1
	Covered with plastic	6	0.5	0	0
	In a house/structure	0	0	14	1
Type 3 (Busia: n=12, Vihiga: n=12)	Open heap	33	4	16	2
	Compost pit	58	7	50	6
	Covered with plastic	9	1	0	
	No heap/pit	0	0	34	4

Comparing the 2016 and 2018 data, four farmers, among them three from the treatment group changed from using a heap to using a compost pit. In addition, 5 farmers without storage had a pit in 2018. Some farmers started to have the pit or felt reinforced to use the pit as a reaction to the workshops. The table 19 below shows the observed changes

Table 19 Comparison of manure storage between 2016 and 2018 by treatment and control group , 26 farmers kept the same storage (13 of them from the treatment group, 13 from control group), some farmers changed from no storage (none), 4 farmers joined the PhD project after the DFC in 2016,

2016 2018	heap pit	heap direct	Pit direct	direct pit	none heap	none pit	other pit	other none	pit other
Farmers from treatment group	3	0	1	1	1	3	0	0	1
Farmers from control group	1	1	1	0	2	2	1	1	0
Total	4	1	2	1	3	5	1	1	1

The use of polythene sheet was not yet dominant in either of the two areas, only one farmer used it on one of the two heaps in his homestead. Some others had a sheet but did not actively used it. Due to the fear of theft and high opportunity costs, the practise was not yet widespread. Yet, farmers were aware of the opportunity to cover the heap. The advantage of reducing volatilisation and leaching of nutrients was known by some farmers. Therefore, some farmers located the heap/pit purposefully under trees and in shady areas to reduce sun radiation.

Besides the storage location also the organic materials mixed into the manure heap were looked at. Two main motives were mentioned by farmers for adding other materials inside the heap/pit. Firstly, it adds additional nutrients to the heap (n=5), secondly the manure "decomposes faster with additional materials" (n=3). Table 20 shows that in Vihiga all type 2 farmers add organic materials in the heap, among the type 3 farmers it was only 66%, the lowest value among cattle owing farmers. In Busia 88% of farmers of type 2 mixed materials inside the heap/pit and all the type 3 farmers.

Table 20 Heap/pit management Fraction of farmers mixing additional materials into the heap, fraction of farmers turning the manure heap and fraction of farmers emptying the manure heap every season (all in % from total farmers) in Vihiga and Busia per farmer type and per treatment/control group

		Number of farmers mixing other materials in heap/pit		**Number of farmers turning the manure heap/pit**		**Number of farmers empty the manure storage every season**	
	Count (n)	In %	count	In %	count	In %	count
Vihiga Treatment	13	69	9	46	6	46	6
Vihiga Control	14	57	8	57	8	21	3
Busia Treatment	12	75	9	58	7	33	4
Busia Control	13	77	10	54	7	42	5
Vihiga type 2	7	100	7	86	6	43	3
Vihiga type 3	12	66	8	58	7	33	4
Busia type 2	8	88	7	63	5	38	3
Busia type 3	12	100	12	75	9	42	5

Table 20 shows also the number of farmers that turned the manure heap/pit. In Vihiga farmers turned the heap mainly to dry the manure before application to the field to avoid fertilizer burning or rotting of seeds by excess water in the manure. In Busia mixing the heap to obtain a homogenous well rotten manure mix was also mentioned.

Further in relation to the manure management the frequency of emptying the manure heap/pit was looked at. Less than half of the farmers in all locations and type store the manure for one season. In Vihiga only 43 % of the type 2 farmers and 33% of the type 3 farmers emptied the heap/pit every season, dominantly the heap was emptied at field preparation and planting time. In Busia 38% of type 2 and 42% of type 3 farmers emptied the heap/pit twice a year. If the manure amount was not much, some farmers keep it for one year and applied it in the main planting season only (n=6). Other farmers had sufficient amounts and did not need to apply all manure, so that some remained every season (n=10). Appendix 8 contains additional explanations on manure storage management.

3.3 Compost and manure management of non-cattle owners

3.3.1 Animals

Despite farmers of type 1 have no or only little livestock, some of them collected manure or other materials for composting. Table 21 shows that 60% of farmers had chicken on their homestead, on average seven chicken. Besides these tree farmers also had goats and one farmer had two pigs.

Table 21 Amount of animal (chicken, goat and pigs) owned by type 1 farmers (n=13)

	Average number	Times mentioned
Chicken	7	9
Goat	2	3
Pig	2	1

3.3.2 Manure use

Manure was often limited available for type 1 farmers. Therefore, some farmers reported to apply the manure only to the fields closer to the house because of lack of enough manure to fertilize all fields. Other farmers also mention that they applied the manure where they had striga (*Striga hermonthica*) in their fields.

Table 22 Manure used (%), manure sources used (%) and other materials used (%) by type 1 farmers (n=13)

	In %	Times mentioned
Manure/Compost used in fields		
No	31	4
Yes	69	9
Manure source		
Neighbour	38	5
Own	38	5
Materials used as manure		
Cattle	55	5
Chicken	33	3
Compost	11	1
Green materials	33	3

Table 22 shows that 69% of the farmers in type 1 use manure or compost in their fields. Farmers (38%) reported that cattle owners share the manure with them. Farm type 1 farmers pick it up some days before planting from on average two neighbours. The manure was either fresh, but mostly stored for some time with other green materials. 38% also have own sources of manure. In relation to the materials farmers reported to use, cattle manure was the biggest source with five farmers using it, besides also chicken droppings were used by three farmers, as well as three farmers that used a mix of green materials (Table 22). Farmers also reported that the number of cattle owners that share manure to others is decreasing, so that the amount of manure they can apply to their fields is decreasing. Further information on farmer's challenge of getting manure can be found in Appendix 10.

Chapter 4 Resource flow maps

Below the average resource flow map of Busia type 2/Vihiga type 2/Busia type 3/Vihiga type 3 can be seen followed by the two explorative cases. These two cases are the collection of substantial amount of urine (and manure) through housing in zero grazing unit vs. the loss of most urine due to lack of a urine collection facility (case 1) as well as the application of all manure to a heap/pit vs. the application of all manure to the fields direct (case 2).

4.1 Average resource flow maps of manure and urine N

The average resource flow maps of excreta expressed in kg N, showed some differences in the effect of different management decisions. One factor shown in all the resource flow maps is the potential of improved urine collection facilities. Between 35% (class 3) and 50% (class 2) of urine N was lost during the storage period, of averagely 4 or 7 days. The lowest collection of urinary N occurred in Vihiga type 3 (Figure 17), with 36% of collection compared to above 40% for the other groups (Figure 14,15,16). One of the explanatory factors is that in Vihiga type 3 most time was spend on communal grazing areas, where all urine was lost. If stall floors were cemented and optimised to allow higher amount of urine being collected and storage losses were reduced through improved storage facilities and shorter collection times, then urine capture efficiency could be further improved.

While in Vihiga (Figure 15, 17) the ratio of manure N applied directly to the fields compare to manure N stored in a heap was 0.7 it was only 0.16 in Busia (Figure 14,16). In relation to this, one of the interesting observations can be made in the resource flow diagram of type 3 in Vihiga (Figure 17). The fraction of collected manure N is much lower compared to the other 3 groups. However, despite of this a similar percentage of manure N compared to the other groups (only type 2 in Vihiga has a higher value) is transferred to the fields. One reason explaining this is the ratio between manure applied directly and manure stored, which is the highest in type 3 in Vihiga. Since losses through direct application are low, in Vihiga type 3 the low collection fraction is compensated with a high application of manure directly on the fields, which results in a similar fraction of total N at the end applied to the fields as compared to the other farm types.

Type 3 farmers (Figure 16,17) tend to graze their cattle more in communal grazing lands compared to type 2 farmers (Figure 14,15). An explanation for this might be that type 3 farmers kept both improved and local cattle in their farm and have more cattle in total. Often farmers tended to have less efficient management with their local breeds. They were kept partly on communal areas, so that available resources like compound grazing space and time for cutting fodder grasses were allocated to dairy cattle, which were kept in the compound and zero grazing units. Vihiga type 2 (Figure 15) had the highest fraction of N transferred to the fields and the lowest amount of N that was lost. This is related to the condition that in this group the lowest fraction of manure was excreted to the communal areas and relatively more was excreted in the stall and the compound.

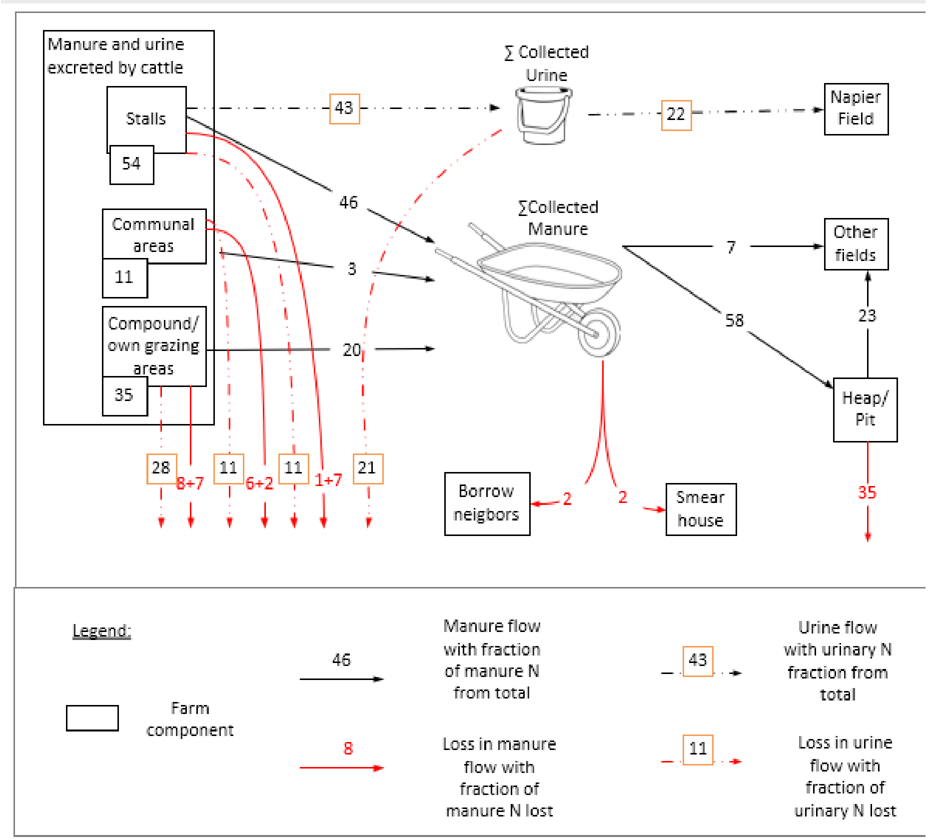


Figure 14 N-flow of manure and urine in % of loss and recovery for Busia type 2; Absolute amounts excreted: 17148 kg manure farm^{-1} year^{-1}, 104 kg N farm^{-1} year^{-1}, 4648 kg urine farm^{-1} year^{-1}, 46 kg N farm^{-1} year^{-1}. The two numbers in the manure loss describe the amount uncollected + the amount volatilised and leached before collection.

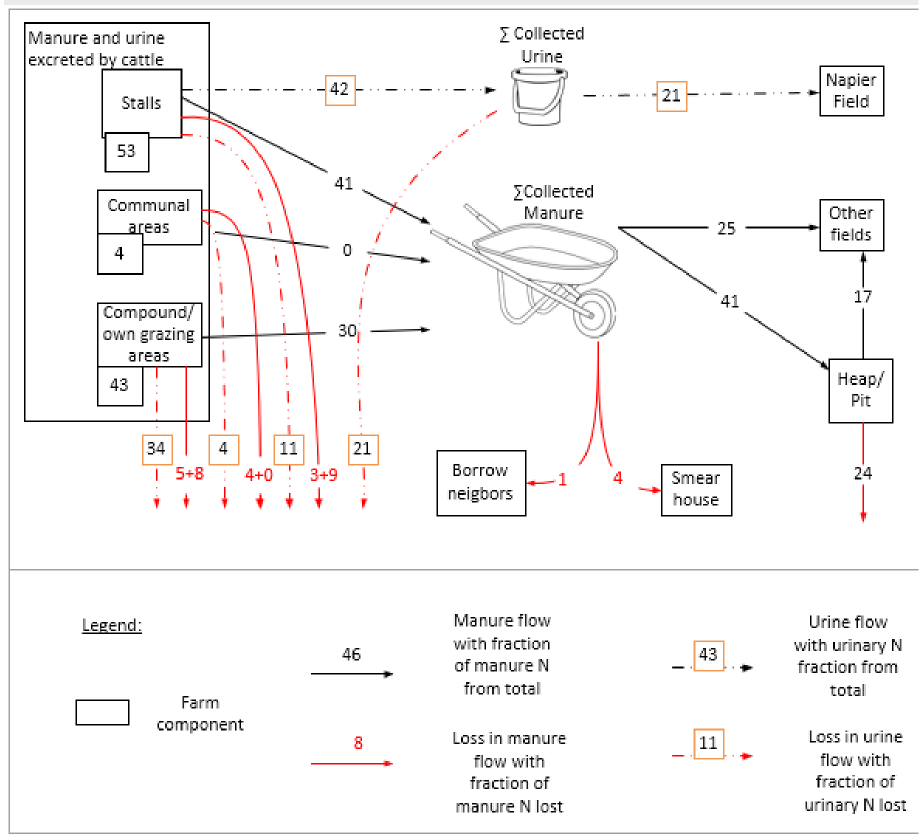


Figure 15 N-flow of manure and urine in % of loss and recovery for Vihiga type 2; Absolute amounts excreted: 10588 kg manure farm^{-1} year^{-1}, 64 kg N farm^{-1} year^{-1}, 1179 kg urine farm^{-1} year^{-1}, 12 kg N farm^{-1} year^{-1}. The two numbers in the manure loss describe the amount uncollected + the amount volatilised and leached before collection.

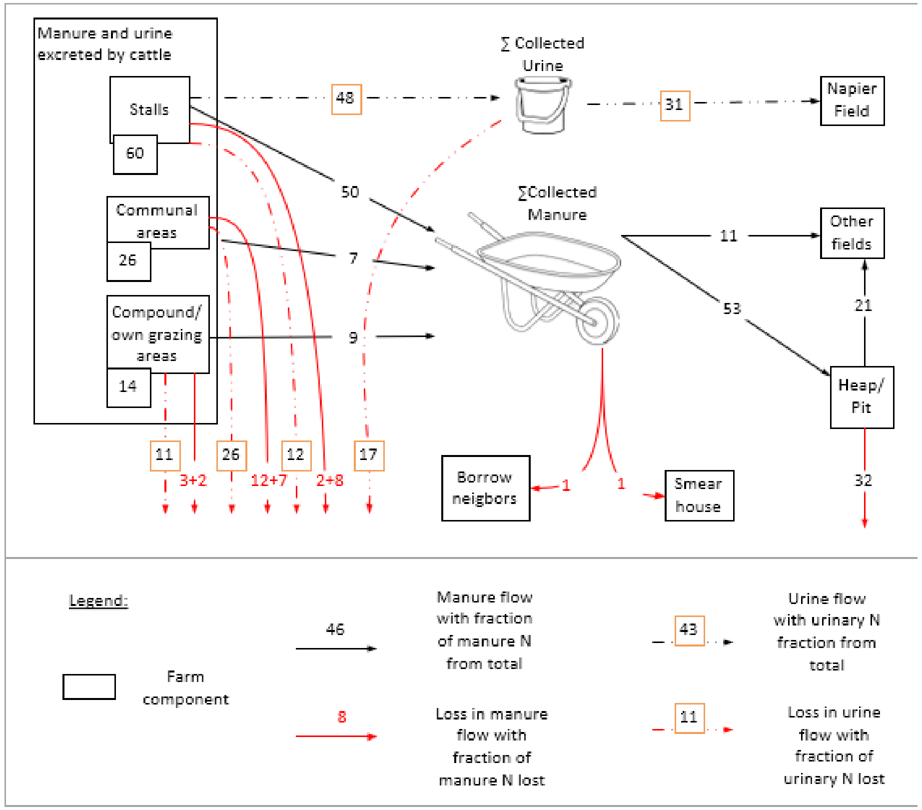


Figure 16 N-flow of manure and urine in % of loss and recovery for Busia type 3; Absolute amounts excreted: 18154 kg manure farm^{-1} year^{-1}, 110 kg N farm^{-1} year^{-1}, 12848 kg urine farm^{-1} year^{-1}, 128 kg N farm^{-1} year^{-1}. The two numbers in the manure loss describe the amount uncollected + the amount volatilised and leached before collection.

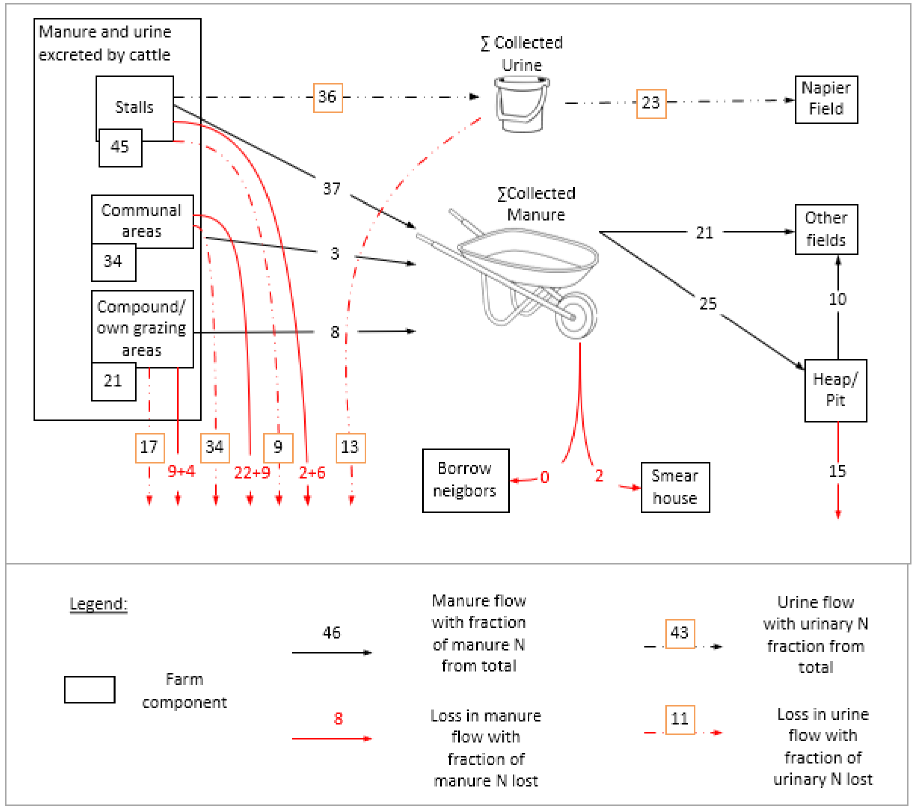


Figure 17 N-flow of manure and urine in % of loss and recovery for Vihiga type 3 ; Absolute amounts: 17121 kg manure farm^{-1} year^{-1}, 104 kg N farm^{-1} year^{-1}, 5417 kg, urine farm^{-1} year^{-1} , 54 kg N farm^{-1} year^{-1}. The two numbers in the manure loss describe the amount uncollected + the amount volatilised and leached before collection.

4.2 Explorative case 1 – Substantial collection of urine and manure

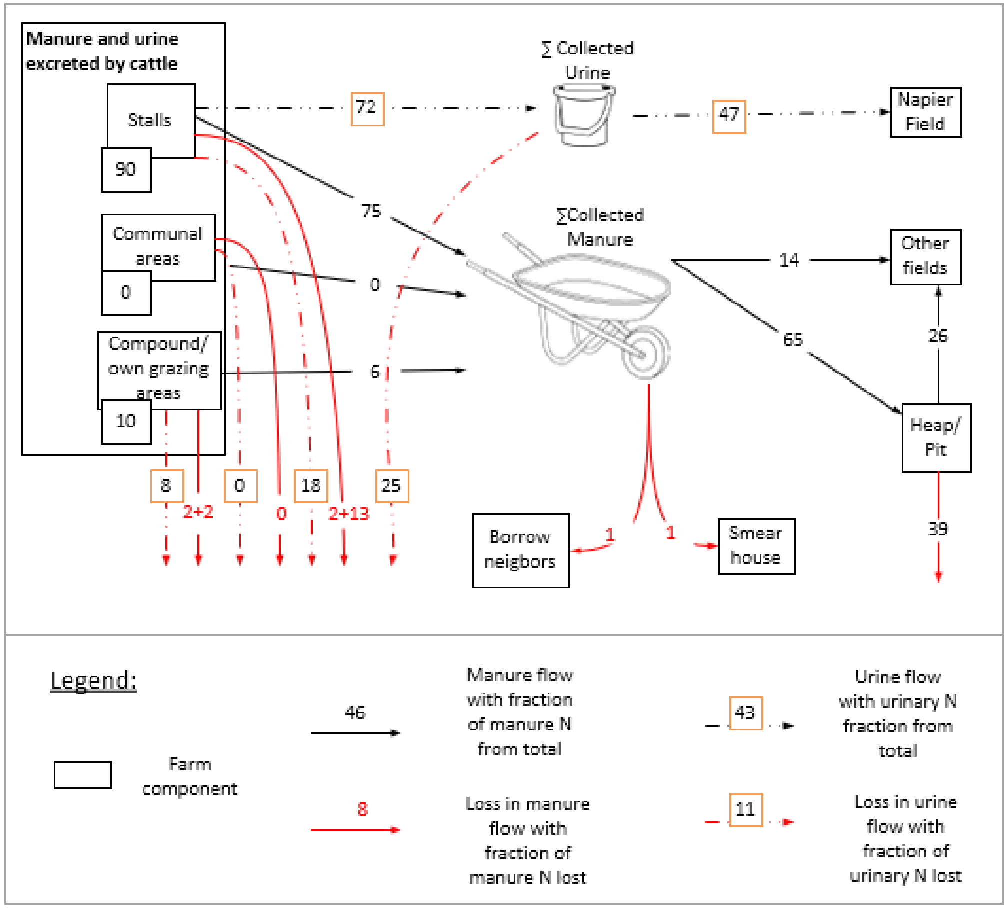


Figure 18 Case 1 Substantial collection of urine (and manure) in a zero-grazing system N-flow of manure and urine in % of loss and recovery in type 3 farm system in Busia. The two numbers in the manure loss describe the amount uncollected + the amount volatilised and leached before collection.

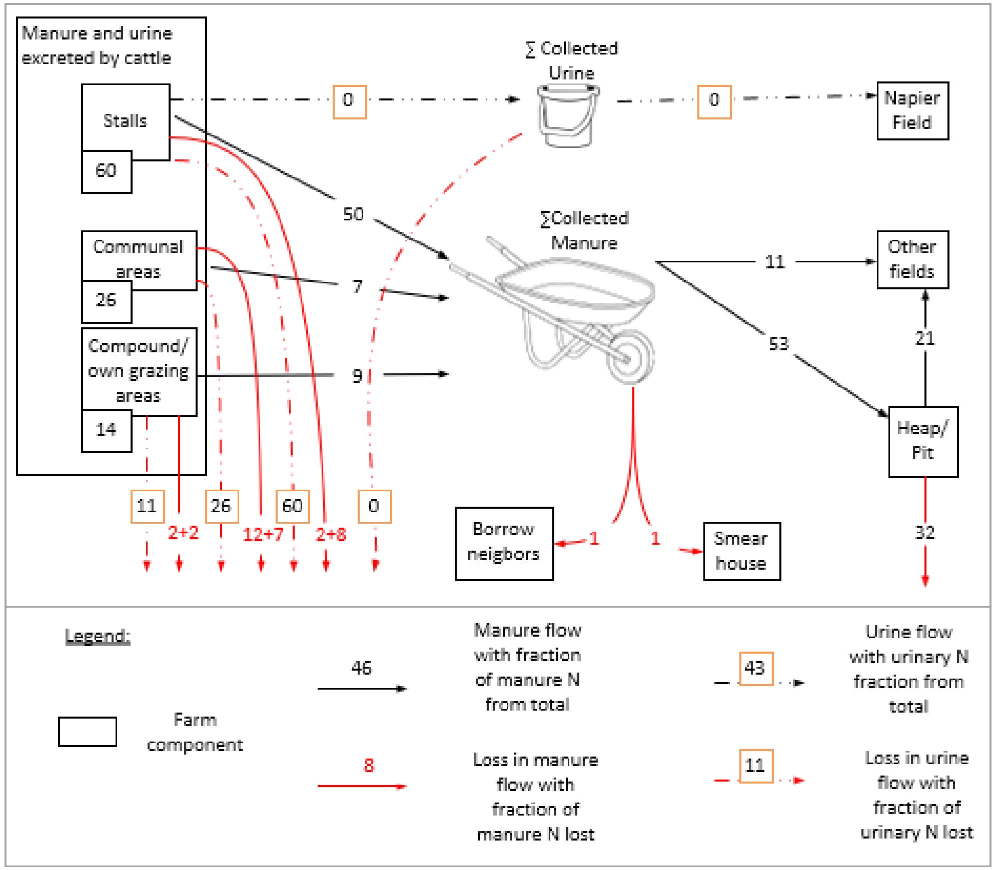


Figure 19 Case 1 No collection of urine N-flow of manure and urine in % of loss and recovery in type 3 farm system in Busia. The two numbers in the manure loss describe the amount uncollected + the amount volatilised and leached before collection.

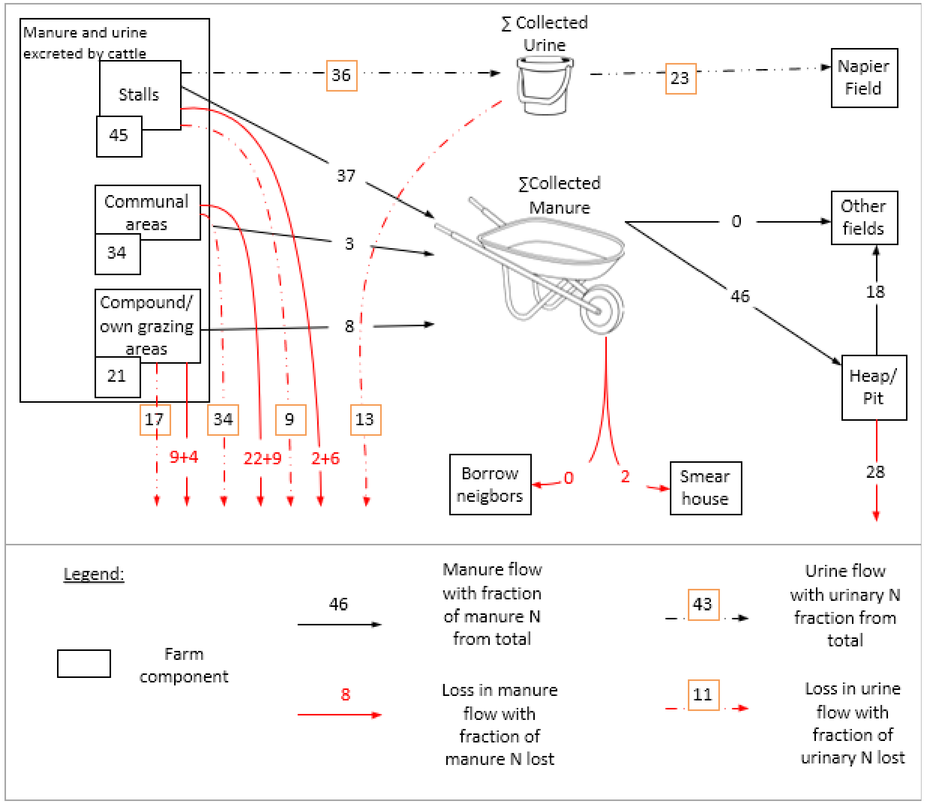
Case 1 shows the effect of capturing most urine and manure through a zero-grazing system, where cattle stay 90% of the day inside. This situation was compared with one where no collection of urine takes place. The biggest variation in the presence of a urine collection facility was observed between type 3 farmers in Busia. Therefore, the average resource flow of this group was chosen as a basis for case 1.

Comparing the two situations it showed that if the cattle were housed mainly in the stalls and urine was collected, up to 47% urinary N (60 kg N year^{-1} farm^{-1}) was captured and applied to the napier grass fields. This amount is potentially lost if urine is not collected and the animals are housed less in the stall. Comparing the situation of no collection of urine with the average resource flow map from Busia type 3 (Figure 16), where cattle stayed 60% in stall, where urine was collected and where 31% of urinary N (40 kg N year^{-1} farm^{-1}) was applied to the napier grass field, it can be seen that even if animals were not housed more in stalls (same 60%), potentially this 31% of urinary N (40 kg N year^{-1} farm^{-1}) was lost if no urine collection in stall took place.

Furthermore, the comparison with the average situation in Busia type 3 showed that housing the animals 30% more in the stalls (90% in Figure 18 compare with 60% in Figure 19) can increase the amount of manure captured and applied to the fields by 8% (32% in Figure 16, 40% in Figure 18) and the amount of urine by 16% (47% in Figure 18 and 31% in Figure 16). The effect for manure N was even larger if cattle were housed 90% of the time in the stalls and all manure was applied directly to the fields. Then a total of 79% of excreted manure N was applied to the fields and losses were reduced to 21% of the total excreted N in manure.

4.3 Explorative case 2 – Substantial direct fresh manure application

This case focuses on comparing a situation where all manure is applied directly, with one where all manure is stored in a pit. Among type 3 farmers in Vihiga the largest variation in % of manure applied directly or stored in a heap/pit was observed in the surveys. Therefore case 2 was applied on the base resource flow from Vihiga type 3 farmers. The figures 20 and 21 below show a huge effect of direct application of manure to the efficiency of N recovery. In the case where manure was stored in a heap/pit only 18% (19 kg N year^{-1} farm^{-1}) was applied to the fields and 82% of all manure N (84 kg N year^{-1} farm^{-1}) was lost. If the same amount of manure was collected and all 46% manure N (48 kg N year^{-1} farm^{-1}) was applied directly, only 54% (56 kg N year^{-1} farm^{-1}) was lost. Based on this it could be relevant to include direct application in NUANCES-FARMSIM, since here it appears more efficient than composting.



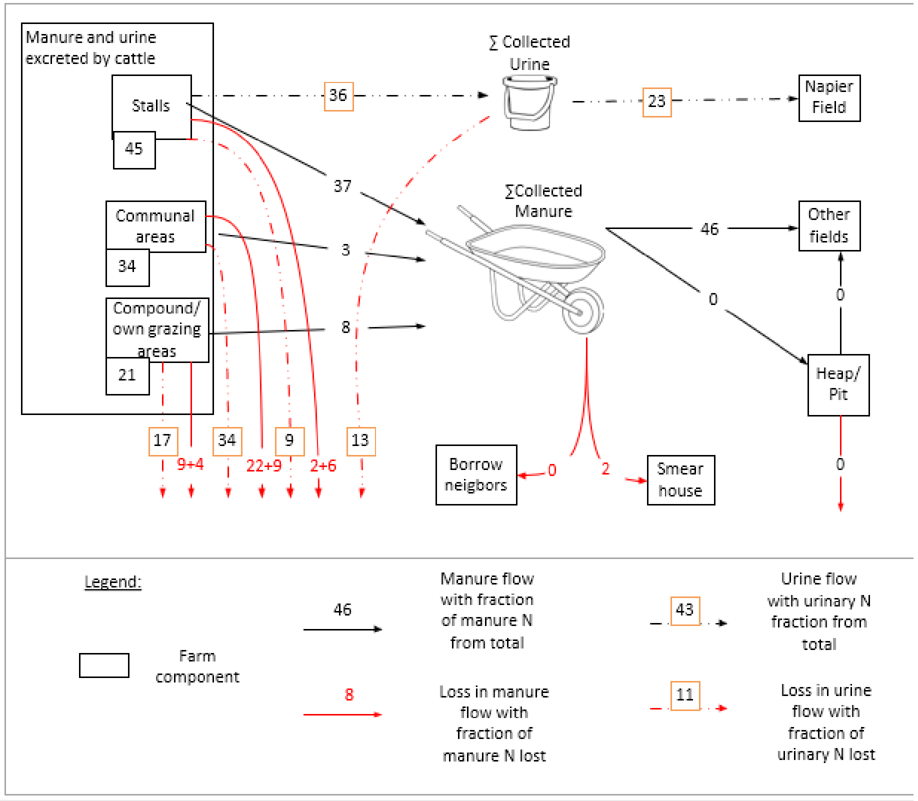


Figure 20 Case 2 Application of all manure to a heap/pit
N-flow of manure and urine in % of loss and recovery in Vihiga type 3. The two numbers in the manure loss describe the amount uncollected + the amount volatilised and leached before collection.

Figure 21 Case 2 Application of all manure to the field direct
N-flow of manure and urine in % of loss and recovery in Vihiga type 3. The two numbers in the manure loss describe the amount uncollected + the amount volatilised and leached before collection.

Chapter 5 Explorations in NUANCES-FARMSIM

Through the survey some practises were identified which have not been looked at deeply through previously research. Namely among these the two most interesting practises were the use of urine and the direct application of fresh manure to the fields. The resource flow maps have further shown that these practises could represent significant flows.

This chapter further investigates the ability of integrating these flows into NUANCES-FARMSIM and the results obtained from the integration. Due to resource constraints only the integration of urine application to the model was realised. The first chapter therefore briefly described how this was integrated and how direct fresh manure application could theoretically be integrated. Following this the first results and effects of integrating urine into the model will be shown.

5.1 Including urine recovery and direct application of manure in NUANCES-FARMSIM

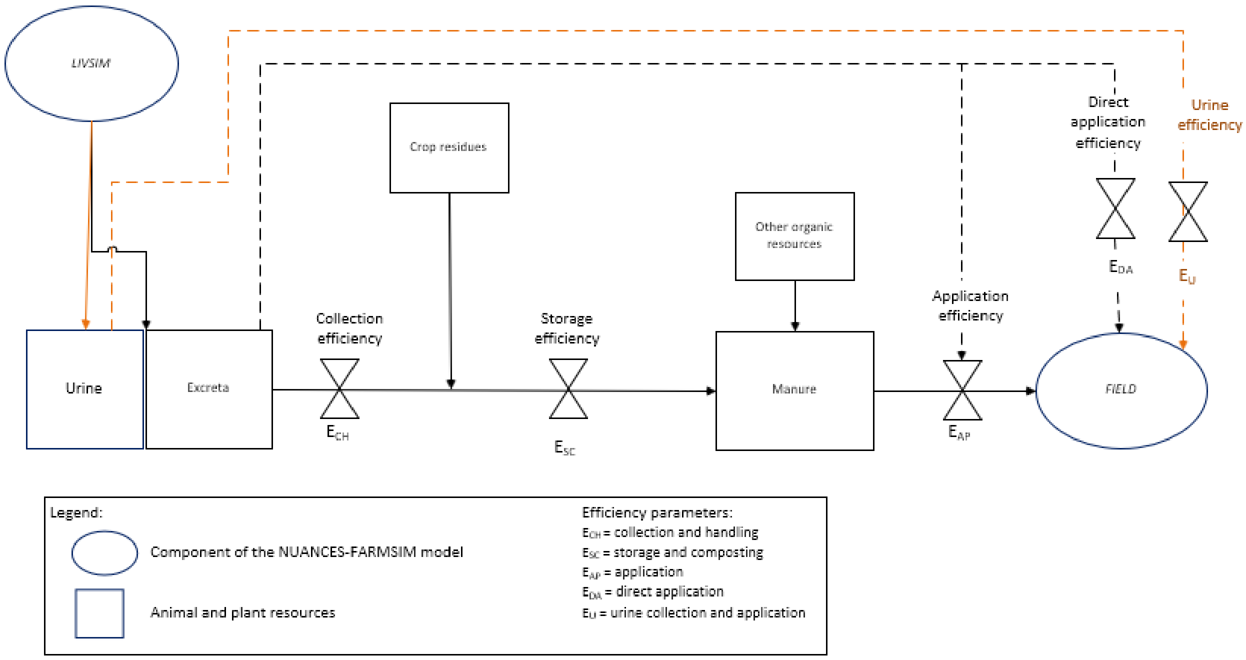


Figure 22 Integration of urine and fresh manure application to the model

Figure 22 shows the integration of urine and fresh manure application to the model. For each field the fraction from the total collected urine applied to that field can be determined by the user as an input variable. For example, for the four fields (maize, maize, maize, napier) in the example used in this research, urine was only applied to napier. In the future also application to other fields like maize and banana should be possible, as this was observed in the interviews as a practice. For the urine integration a urine collection fraction was determined as a user input variable. As output variables the 'herd Urinary N' and the 'farm urinary N available' were available information.

For the potential integration of direct fresh manure application to the model the following could be done. The excreted manure by the cattle should be used as a starting point. An input parameter could be used to determine the fraction of fresh manure applied to the fields directly and the fraction of manure stored, together they have a value of '1'. Then the fraction of the fresh manure applied to the different fields of a farm need to be determined. Currently the field parameter 'manure' is used for composted manure. A distinction in 'composted manure' and 'fresh direct manure' would be needed throughout the model.

5.2 Results of urine integration

Figure 23 shows the yield of the napier grass field (field 4) on which urine was applied for the 4 typical urine management farms. A yield difference between typical urine management farms 1 and the other three farms can be seen over the months, with increasing difference over time.

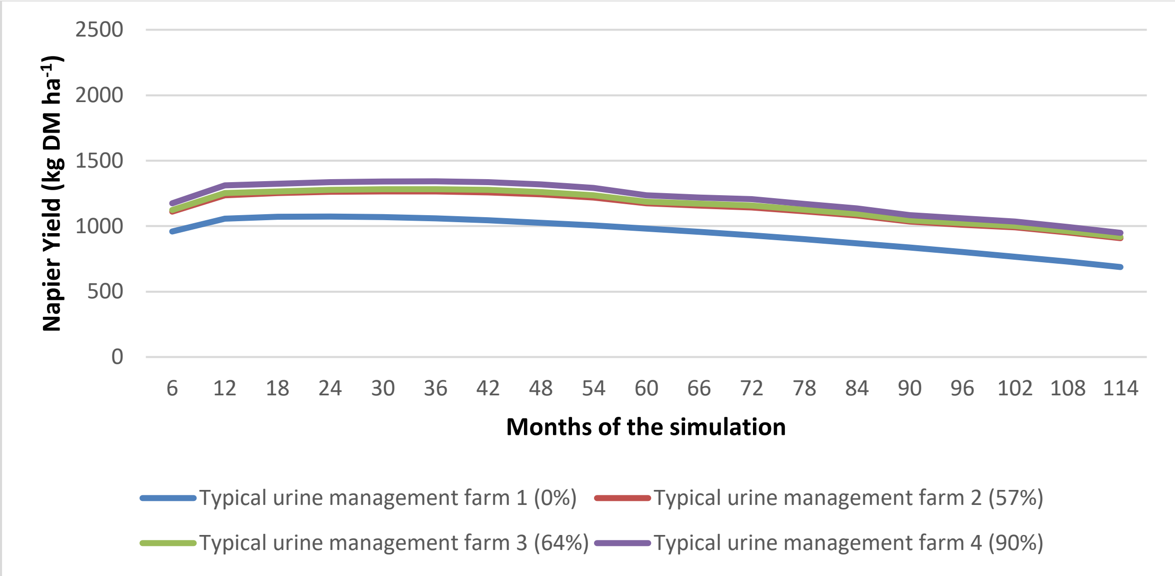


Figure 23 Yield of the napier field for the four cases over the 10 years simulation. The first yield is reported after 4 months, followed by a yield after every 6 months. The yield of three growing cycle of two months is summed by the model.

In order to understand the reason for the relatively small difference observed between the typical urine management farms and the decreasing yields, two rates of P fertilizer (10 and 100 kg ha^{-1}) were applied to the napier field in the four typical management farms. Figure 24 and 25 show the napier yield of the four typical management farms when 10 kg P ha^{-1} and 100 kg P ha^{-1} are applied. Comparing the yield with the one of Figure 23 above, a response to the P fertilizer can be observed. The yield in all cases increased when P fertilizer was applied. Further, the. yield decrease over time was reduced. Further can be seen that the relative difference between the typical management farms is increasing.

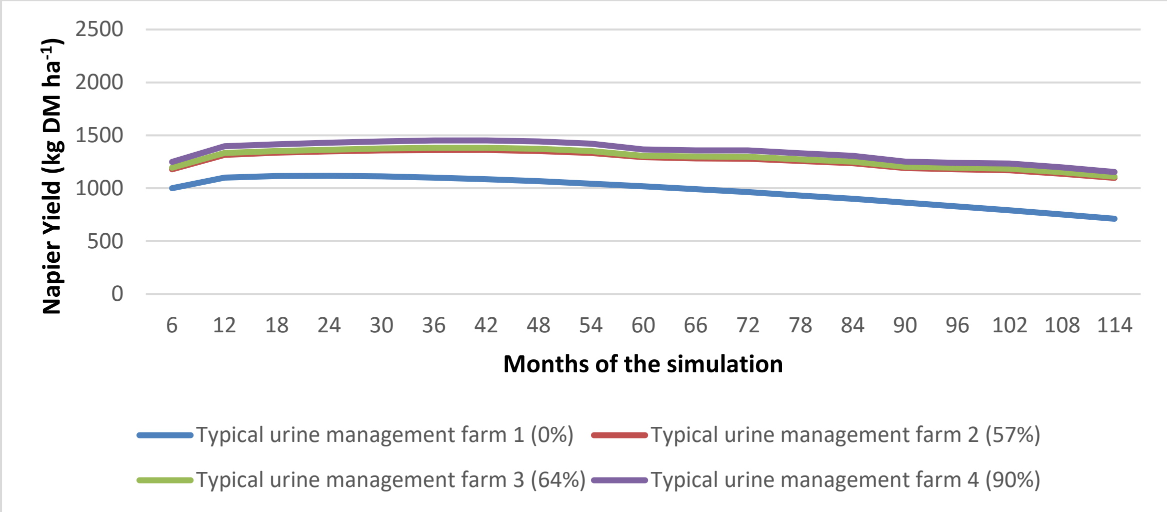


Figure 24 Napier yield of the four cases with 10 kg P ha^{-1} fertilizer applied The first yield is reported after 5 months, followed by a yield after every 6 months.

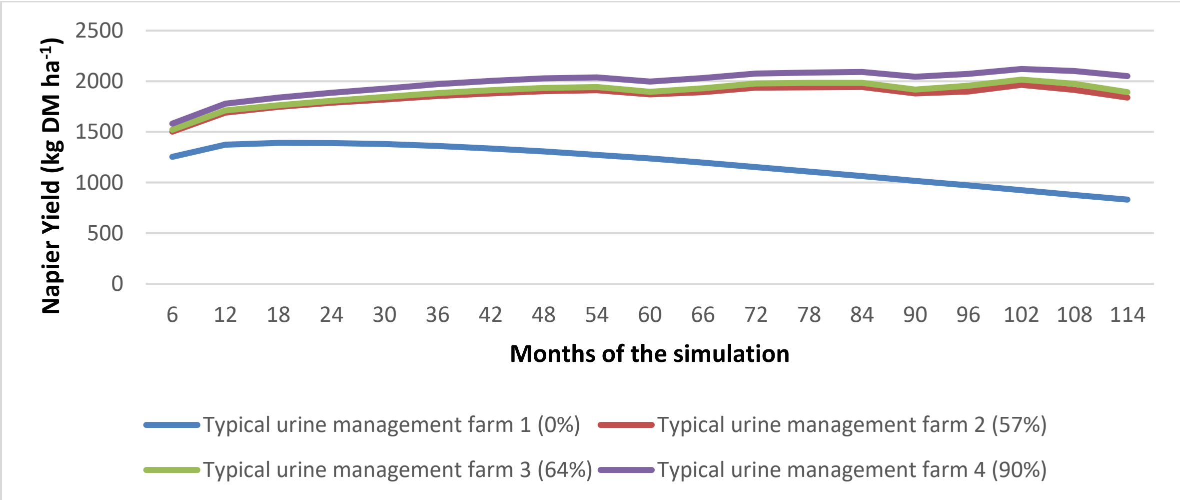


Figure 25 Napier yield of the four cases with 100 kg P ha^{-1} fertilizer applied. The first yield is reported after 5 months, followed by a yield after every 6 months.

Figure 26 shows the SOC over the 10 years period per months. Only a small difference between the typical urine management farms was observed after the 10 years simulation period. The Soil Carbon content (g C kg^{-1} soil) reduces from over 20 g C per kg soil to below 10 g C per kg soil in all cases, during the 10 years simulation.

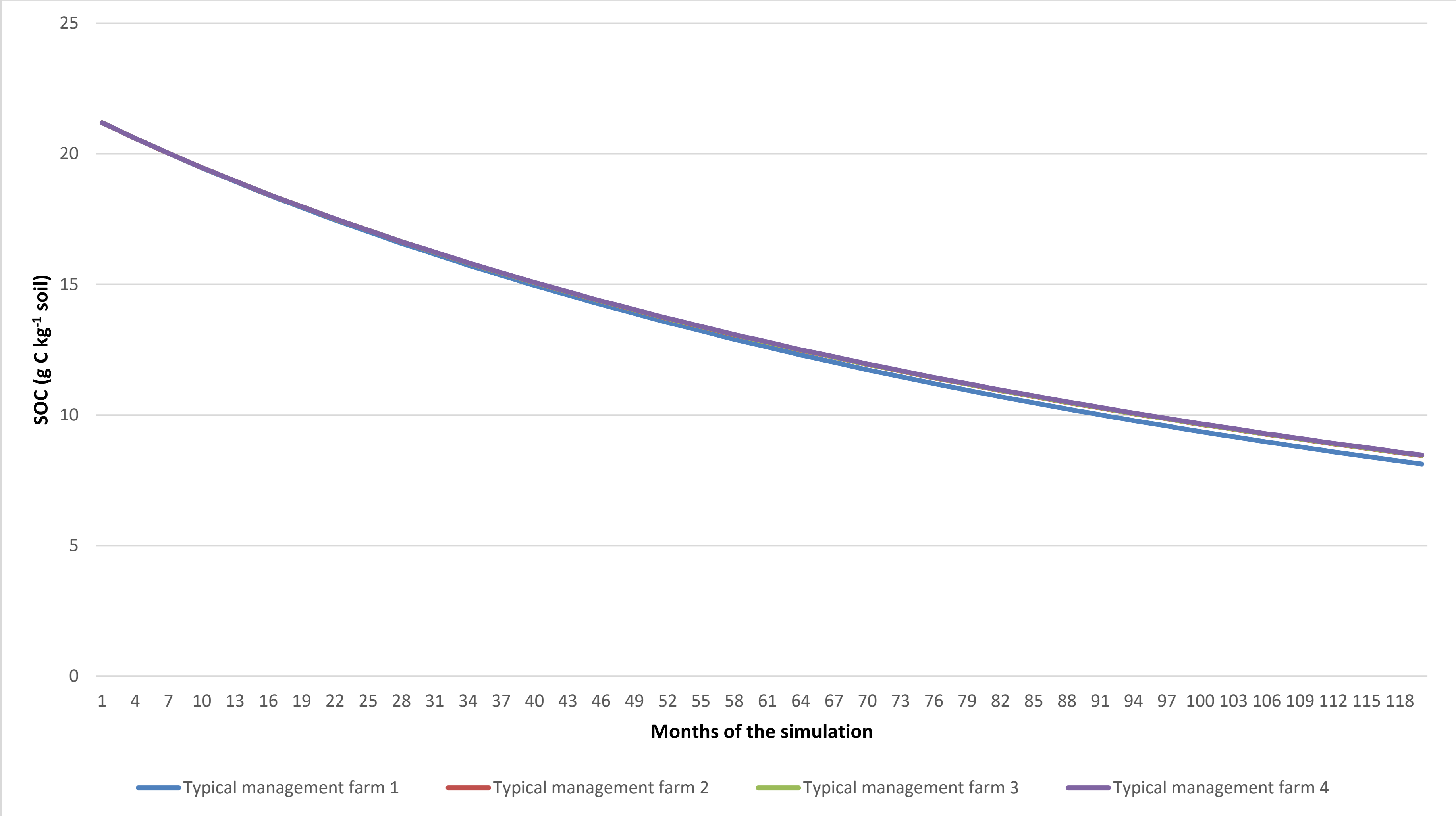


Figure 26 SOC of field 4 over the simulation period

Chapter 6 Discussion

This chapter evaluates the methodology used for this study and the main outcomes of the results. The results of the interviews revealed two practises dominating among farmers in the survey, which were previously not considered in the NUANCES-FARMSIM model. These are the use of urine and the direct application of fresh manure to the fields.

6.1 Urine collection

Contrary to what was reported previously about cattle keeping in East Africa, the findings in this study show that the habit of collecting urine is widespread. Most of the cemented and some of the mud floors destined for cattle keeping had a collection facility present. This is contrary to what Rufino et al. (2006) stated, saying that urine is mostly not recycled due to grazing of animals and physical loss in the stalls. Also, Castellanos-Navarette (2015) found that only two of ten farmers recycled urine. Further Rufino et al. (2007) indicated that despite 50% of the N excreted by the cattle is through urine, farmers do not use it. In this survey it was found that around 80% of farmers collected part of the excreted urine. The observations in this study showed that collection frequency varied between farmers, with some farmers collecting urine daily (n=7) and others collecting urine only biweekly or monthly (n=3). To ease frequent collection this survey showed that collection facilities need to be improved. This was also found by Ikpe and Powell (2002) in West-Africa. Training efforts and simple improvements in the collection facilities could yield a substantial improvement (in terms of resource recirculation and efficiency of N).

The resource flow maps further showed that on average cattle owing farmers recycled between 21% and 31% of urinary N, but in an intensive use of a zero grazing unit up to 47% of urinary N was recycled through urine collection. Based on the collected urine amounts reported in the survey (Figure 18, Case1), this is up to 60 kg N year^{-1} farm^{-1}. Taking the averagely small total cultivated crop area of 0,05 ha for napier and 0,35 ha for maize into account, this can be substantial. Due to sampling in the rainy season the collected amounts in this research may be overestimated, but the determined amounts are within the range reported by earlier research (Lekasi et al., 2001). One of the open questions that remain in this context is whether farmers in Western Kenya can manage to adopt such an intensive management of their farmers, including the high collection fractions used in case 1 (Figure 18). Answering this question goes beyond the scope of this research. Here only the promising potentials of urine collection can be demonstrated in this respect.

Practises, like urine application which increase napier yield can have an indirect positive effect on the retention of crop residues as mulch in the fields. The retention of crop residue in the fields increases when alternative feeds, like napier grass are available for cattle (Castellanos-Navarrete et al., 2015; Valbuena et al., 2015). Farmers in this study retained between 20% and 50% (class 3, class 2) of crop residues in their fields. Castellanos-Navarrete et al. (2015) found for the same area that 22% of crop residue was maintained in the field while the rest is fed to cattle. One reason for small amounts of residue retained in the fields is that farmers are facing challenges supplying sufficient fodder and meeting the fodder demand especially when cows are milked (Hall et al., 2008; Lukuyu et al., 2009; Njarui et al., 2011). Napier grass needs high levels of nitrogen for its growth (Orodho, 2006), which could be partially supplied by urine application. Enabling the analysing and quantification of crop yield changes and fodder availability on the farm with NUANCES-FARMSIM by integrating urine flows (excretion-collection-application) into the model would be highly interesting in this context.

Farmers confirmed in this survey what Rufino et al. (2006) reported earlier for the region, the use of bedding is very limited because raw materials are not available. The use of bedding material has been frequently reported as an opportunity to capture urine and faeces and reduce losses. Rufino et al. (2007) found that additions of C-rich, fibrous bedding materials to the stall floor can absorb and immobilise urinary N. However, observations in this research showed that many farmers clean the stall/housing area every 1-2 days and collect manure in this process. This practise makes the use of bedding difficult, since straws would be collected as well or the area could not be cleaned regularly, making it appear inapplicable for farmers. Yet, the observations made in this study allow the consideration of a new approach here. Farmers collected urine separately by a drainage line in the stall floor, through which urine flows into a separate bucket outside the stall. If bedding cannot be used in the stall, stover could be used in the bucket to immobilise some of the urinary N.

6.2 Direct application of fresh manure

This survey showed that the amount of manure applied directly can be substantial, although it is on average less than manure stored. In this sample direct application of fresh manure to the fields was shown to be relatively common. 66% of farmers apply at least a certain amount of manure directly. The findings indicate that direct fresh manure application has been overlooked in previous research. Rufino et al. (2006) reported that in western Kenya direct application proportions were small compared to the total manure produced, despite poorer farmers in their study, with 1-2 local cattle are reported to apply 60% directly. The resource flow maps further showed that when fresh manure is applied directly to the field instead of composted up to 28% of additional manure N can be recycled. Castellanos-Navarrete et al. (2015) found that, up to 22% of N can be provided if significant amounts of fresh manure are applied. This indicates that from an N-efficiency perspective direct fresh manure application can be a mechanism to compensate for less manure available in the farm system by increased recycling of manure N. Ammonia losses are significantly reduced if manure is incorporated in the soil (Rufino et al., 2006). It is important to take into consideration that here the analysis has only been done until the application to the field. Following these results, the effects of direct fresh manure application to the farming system would need to be evaluated. Several significant questions remain for further research to be answered, like the risk of burning the crops and management approaches to inhibit this. The results of the surveys further showed that farmers in Vihiga apply more manure directly compare to farmers in Busia for both type 2 and 3. A reason could be that fields in Vihiga are closer to the homestead, while in Busia they are more spread, which makes direct application in Busia more difficult. Also, the risk of burning of crops is one of the reasons mentioned by farmers in Busia for not applying manure directly. To sum up the findings of this research show that integration of direct application of fresh manure as observed in this survey could be considered in the NUANCES-FARMSIM model.

6.3 Manure management

In relation to manure management substantial improvements can be achieved when floors are cemented, iron roofs are used as cover and handling of manure is improved (Rufino et al., 2006). In this survey it was shown that all farmers, both local and improved cattle owner, had iron roofs and 48% of class 3 farmers had cemented floors. A compost pit was used by 60% of farmers to store manure. The comparison between 2016 and 2018 showed that especially in the treatment group farmers changed from using a compost heap to using a pit for storing manure. This shows that farmers already used facilities accordingly to this earlier advice. One of the reasons for this is that dairy farmers where encouraged in the past by NGOs to construct stalls in exchange for improved breed dairy cows (Mwamuye et al., 2013; Wambugu et al., 2011; Wanjala & Njehia, 2014). This also explains why cemented floors were not very dominant among local cattle owners.

In terms of manure collection this survey showed that significant regular manure collection rates in both the stalls and the grazing areas were reported. In this sample on average 82% of manure was collected on the compound. Contrary findings were made in earlier studies, where manure was not collected in the compound and thus less than 50% of the total N excreted was recycled in the farm (Rufino et al., 2006). In this survey only collection of manure in communal grazing areas was low (5%) and few farmers grazed local cattle for around 1 hour in communal grazing areas (n=3) or on the roadside (n=8). Due to growing population pressure, grazing in communal areas is reducing compared to the past (Rufino et al., 2006; Tittonell, 2008). Further the findings in this study indicate that practises of farmers have changed and that collection of manure on compounds might have been overlooked in previous research. In their own grazing areas half of all farmers (*n=20*) showed to collect on average 74% more manure in 2018 compared to 2016, especially farmers in the control group have increased their collection amounts. A reason for the different observation in manure collection fractions between this and other studies could be the method used in this research. The presented values are based on farmers estimates, which potentially vary a lot and tend to be overestimated. In a few situations observations on the collection techniques used by the farmers were made, but due to resource constraints cross checking of farmers estimates were not done on every farm. No specific findings were made as well that indicated that farmers estimates are overestimated, therefore no reliable factor for correcting or reducing farmers estimates was present as well.

This survey showed that farmers collected manure quite frequently, on average every 1-2 days. This was also found in the study by Castellanos-Navarrete et al. (2015). Regular, daily to weekly collection of manure is advised, however in this study it was observed that in practise farmers took manure collected in the stall from rather enclosed and protected areas to more open areas on the heap or pit where exposure to rainfall, solar radiation and volatilisation was often high (Castellanos-Navarrete et al., 2015).

6.4 Manure amounts

In order to determine the manure amounts it was a useful approach to identify and measure the local manure collection units and use these as units to calculate manure amounts on the farms. It was shown that local farmer units need to be used carefully; e.g the small bucket mentioned by farmers weighted more than the ordinary bucket. This makes weighting of local units with standardised measures very important since it enables comparing own results with reference values reported earlier.

Farms in Busia collected more manure than those in Vihiga, which is explained by larger farm sizes and thus a larger number of cattle that can be supported per farm in Busia. Comparing amounts of manure collected with values reported in the literature showed that observed amounts in both locations and all farm types fall within the higher ranges published. In this study, manure collection amounts between 4009 kg and 5468 kg year^{-1} TLU^{-1} fresh manure and 11 to 15 kg day^{-1} TLU^{-1} were found. Teenstra et al. (2015) reported values of 5000 to 8000 kg of solid manure in extensive tropical production systems on a yearly level and 15-20 kg fresh manure per day per cow (bodyweight 250-400 kg). Values between 280 kg dry matter(840 kg fresh manure) and 2800 kg dry matter (8400 kg) year^{-1} TLU^{-1} were reported by Castellanos-Navarrete et al. (2015). Otieno K et al. (1996) observed in densely populated areas of western Kenya that two cattle in an intensely managed zero grazing unit produce around 25 kg day^{-1} of manure.

In 2016 no data was collected on manure amounts. But the comparison of cattle numbers (TLU) showed that more than half of all farmers had about 1 cattle more (higher TLU by 1) in 2018, with no observed difference between treatment and control groups. This indicates that more manure was available to these farmers in 2018 compared to 2016.

6.5 Explorations in NUANCES-FARMSIM

In the modelling results, a clear yield response was seen from the additional urine application. The relative difference between the different typical urine management farms show that urine application makes a difference. A yield difference of around 18% in the first year to above 38% in the 10^{th} year of the simulation was shown. This is above experimental results recorded in earlier studies where applying urine with dung led to a 13% increase in grain yield (Ikpe and Powell, 2002). Further also a yield response to additional P fertilizer was observed. This allows the assumption that sufficient amount of N was applied to the napier field when urine was applied. It is in line with other studies done before. In many Kenyan studies the P response was pronounced than that of N and often the P&N interaction was significant (Orodho, 2006). The P response was also observed in the modelling results of this study. These results indicate that urine application might supply sufficient N for napier growth, but with time fields might become P limited and effect the yield. Thus, in order to increase napier yields further additions of P might become necessary. Encouraging farmers to collect and apply urine could be a viable option for increasing yields. Support in relation to construction of facilities is needed, also some of these facilities still need to be developed or introduced in this area, for example improved urine collection buckets. Further supporting farmers to apply even small amounts of P fertilizer could yield substantial improvements.

The work done in this study can only be a first trial of integrating urine application into the model. Therefore, some elements need to be further worked out and the different components need to be calibrated and validated. Firstly, the amount of urinary N excreted by cattle and the amounts available for application to the fields need to be adjusted. Further this need to be aligned with the collection percentage determined through the user input. Secondly, at the moment only application of urine to napier was realised, yet the surveys in this study showed that farmers also apply urine to maize and banana gardens. In a full integration of urine application in the model this should be possible for all crops that are part of the model. Thirdly, despite some papers research the effect of slurry or urine application to napier grass, more research is needed for example in relation to nitrogen response to napier grass and P limitations, but also strategies to improve urine cycling efficiencies. The other aspect identified in the interviews and the resource flow maps is the application of direct fresh manure into some fields. Looking into the potential effects on the resource flows it should be considered to integrate this into the model. This study has provided some ideas for its integration based on the observations made. The implementation of this in the model still needs to be realised. Extensive research on direct fresh manure use has been done for Europe but rather few works have dealt with fresh manure application for the East-African condition. Research in relation to mitigation methods of crop burning and the effect of integrating fresh manure to the fields is needed.

Chapter 7 Conclusions

The survey performed in this study showed that some practises that have been dominant in the target group received little attention so far in the implementation of NUANCES-FARMSIM. The surveys showed that urine collection is a major practise among farmers in both locations in the treatment and control groups. The surveys further showed that direct application of fresh manure is a widespread practise among farmers. Comparing the development of the treatment and control groups mixed results were obtained. In relation to manure storage treatment groups have increasingly started the use of a manure pit compare to the control groups. For manure collection in grazing areas control groups showed higher increases compare to the treatment groups.

Resource flow maps showed the importance of the identified practises for nitrogen utilization on the farm. In the resource flow maps the effects of direct manure application for the nutrient capture in the farming system was shown. Farms with a high amount of direct application of fresh manure had less losses due to better nutrient cycling efficiencies. The application of urine on the fields showed that significant amounts of urinary N can be recycled, especially with an intensive use of a zero-grazing unit.

The modelling trials of integrating urine collection and application in the system aimed at getting a first impression on the effects of including urine. This yielded some interesting observations. Relative yield differences were observed between the typical urine management farms. Especially in combination with small amounts of P fertilizer a promising yield response was also observed. Summarising the results, it can be concluded that integration of urine application is recommended. Yet, only a first trial of urine integration has been provided here. Several aspects still need to be overworked like the application to other crops. The integration of fresh manure application to fields is also interesting, especially its potential of reducing major losses currently observed is an interesting opportunity. Research in this aspect is needed to further analyse the impact of integrating it in NUANCES-FARMSIM and identify mechanisms to overcome the associated risks of crop burning. The ability of modelling theses flows enables the analysis of the variations in current management options and the effects they have on the efficiency of the farming system. Further it allows improvement pathways to be developed and recommended for farmers in the future. Thus, it supports greatly the aim of NUANCES-FARMSIM.

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Appendix

Appendix 1 Survey

Humidtropics-FARMSIM detailed characterisation survey

Explain to the respondent the following and at the end ask whether he or she wants to take part in the survey.

In the Humidtropics-FARMSIM project we try to understand why and how people are using inputs and how they are cultivating their farm and managing their livestock. In this survey we would like to understand more on the way people are managing their livestock, the manure collection, storage and application. If you agree on this we would like to also take some pictures.

You have been taking part in previous surveys of this project. Do you want to take part in this survey and would you allow us to start with the survey? All answers and pictures will be kept confidentially and not be shared with others than the project partners.

The respondent must be the person most capable of answering these questions. It may be the household head or the spouse, but at least a person that is involved in the farm on a daily basis.

Part A: General information

	A.1. General information
Household –ID[1]	
Date (dd/mm/yyyy)	
County	
Control / Treatment	
Village	
Name Interviewer	
Name of the respondent	
Gender	
Age	
Position in household[1]	
Mobile phone number	

[1]**Position in household:**
1= Household head
2= Joint household head
3= Spouse of head
4= Other family member

5= Other, none family member

Part B: Household Roster *Include only members who live there at least 3 months per year.*

B.1. How many people are there in your household ____________

ID		Number of male	Number of female	Highest Level of Education (code a)	How many are working on the farm? If not full time, note percentage of time.
1	Respondent				
2	Household head				
	People per age group				
3	0 – 16				
4	17 – 35				
5	36 – 60				
6	Over 60				

		a) HIGHEST LEVEL OF EDUCATION
		1= Can not read or write 2= Can read and write 3= Primary 4= Secondary 5= Post-secondary

Part C: Livestock

C.1. Number of small ruminants and other livestock species owned of by the household

Sheep (no.):_________ Goats (no.):__________

Pigs (no.):__________ Donkeys (no.):__________ Chicken (no.)_________

Other valuable livestock, type: ______________________ no: _________

type: ______________________ no: _________

C.2. Number of cattle owned ______ and herd characteristics:
(!! Ask here very carefully, especially about the local animals, sometimes they are crossbreeds)

Cattle	Sex (M/F)	**Breed** (Name breed. If exact breed is unknown,	Age group 1= <6 mo;	If male, used as oxen? (Y/N)

ID #		note; pure, cross or local breed)	2= >6mo & < 3y/ 1st calving; 3= adult	
1.				
2.				
3.				
4.				
5.				
6.				
7.				

Cattle feeding

C.3. Where do you feed your cattle on, during the wet and dry season?

Fraction: all of the feed (100%) almost all (87.5%), more than half (75%), half (50%), less than half (25%) only a little bit (12.5%) or none (0%).

Feed sources (e.g. stover, concentrates, grasses (type?), grazing on compound, free grazing/common land):	Fraction (wet season)	Fraction (dry season)
1.		
2.		
3.		
4.		
5.		
6.		

D.3.2.Which months are the dry season and which are the wet season?

Wet: ____

Dry: ____

C.4. How much of the crop residue from the field do you feed your cattle (all (100%) almost all (87.5%), more than half (75%), half (50%), less than half (25%) only a little bit (12.5%) or none (0%)?

____

Why this practise?

Has it changed? Why? When? (! Refer to earlier survey information here !!!!)

C.5. Is there a proportion of the feed that the cattle leaves/ not eats? Y/N _____________

D.34.2. If yes, how much of the feed applied is left by the animals? (all (100%) almost all (87.5%), more than half (75%), half (50%), less than half (25%) only a little bit (12.5%) or none (0%)?

____

D. 34.2 (!!!) Maybe check: Is this different if they are tethered or in the stall? [Only specify if refusals are collected and put on the heap, when tethered, otherwise neglect]

____

What is done with the refusals?____

Part D. Manure management

Part 1 CATTLE HOUSING

STALL

D.1. Where do you keep your animals overnight (e.g. stall, main house, outside tethered,..)?

____

____

D.2. Indicate, which of the following facilities is present AND whether it is activity used of as the place where the animal is kept overnight?

Facilities	Present Y/N	Experiences with use/ pros and cons/active use
Floor (c= concrete,		

s=sand, earth, o=other)		
Roof (I=iron sheet, n=natural material straw etc.)		
Urine collection facility		
Other (Feed on ground in Through		

Observation: Picture of stall,

D.3. **Where do you keep the animal during** the day (talk through the 24hrs of a day)? Is this different for the dry seasons (you are there during the **wet season**, so you can first talk about today and then ask for difference in dry season)? Is this **different for local or improved cattle?** If so, specify. Note in hours or in fractions (all (100%) almost all (87.5%), more than half (75%), half (50%), less than half (25%) only a little bit (12.5%) or none (0%).

area	Fraction (wet season)	Fraction (dry season)
Stall (night housing)		
Stall (other, during the day)		
Communal grazing land		
Grazing field (part of own land)		
Small patch tethered in own compound		
Roaming around		
Other:		
Other:		

Other:		

Why this practise?   Has it changed? Why? When?

BEDDING MATERIAL

D.4. Do you use straw/others as bedding material in the stable (apart from refusals)?

Y/N __________________ Why/why not?

____

____

D.8. If yes, what type of material do you use?

____

____

D.9. If yes, where do you get the material from?

____

____

D.5. Is there seasonal differences? Yes/No ______________

D.10.2 If yes, what are these differences?

____

____

D.6. How much ("new") material do you apply in the stable per week?

____

D.7. What happens with this material? E.g. is it removed separately from the stall or removed together with the manure?

____

If removed separately, how much material do you collect/remove from the stable in a week?

____

Why this practise?

Has it changed? Why? When?

What are the greatest constraints for using bedding material?

SLURRY COLLECTION

D.8. If a collection facility for urine/slurry is present, what is your experience with collecting slurry (urine and manure together)?

____

____

D.9. What is the advantages and challenges of slurry collection?

____

____

D.10. If no urine collection facility is present, have you heard about sumps/facilities for collecting urine/slurry ? Y/N _____________________________________

D.10.2 Have you considered to use it? Y/N

____

D.10.3 Why/why not?

____

PART 2 MANURE COLLECTION AND STORAGE

COLLECTION

D.11. What proportion of the manure do you collect when the animals are inside the stable? And how frequently? all (100%) almost all (87.5%), more than half (75%), half (50%), less than half (25%) only a little bit (12.5%) or none (0%).

___________________Frequency: ___________________________________

D.12. How do you collect the manure (WB= Wheelbarrow, B=Bucket, other= specify below)? (Weigh the unit)

____

12.2. How much of this unit (wheelbarrow, bucket, other,) do you collect (e.g. 1,2,3,...) and how frequent?

_____________________________frequency:

____

D.13. What is done with the manure that is kept in the stable?

____

Observation: (Picture of manure in stable/ amount collected) Weighing of manure collected!!!!!!

D.14. Do you collect manure when the animals are grazing?
Yes/No____

14.2. If yes, can you estimate, what proportion of the manure do you collect when the cows are grazing? all (100%) almost all (87.5%), more than half (75%), half (50%), less than half (25%) only a little bit (12.5%) or none (0%)

14.3 How frequent do you collect the manure?

Location	proportion	Frequency
Stall (night housing)		
Stall (other, during the day)		
Communal grazing land		
Grazing field (part of own land)		
Small patch tethered in own compound		
Roaming around		
Other:		

D.15. How do you collect the manure (WB= Wheelbarrow, B=Bucket, other= specify below)? (Weigh the unit)

D.15.2 How much of this unit (wheelbarrow, bucket, other,) do you collect (e.g. 1,2,3,...) and how frequent?

Location	Unit	How much? (1,2,3,)	Frequency
Stall (night housing)			
Stall (other, during the day)			
Communal grazing land			
Grazing field (part of own land)			
Small patch tethered in own compound			
Roaming around			
Other:			
Stall (night housing)			

D.16. Is there seasonal differences?

Location	Difference
Stall (night housing)	
Stall (other, during the day)	
Communal grazing land	
Grazing field (part of own land)	
Small patch tethered in own compound	
Roaming around	
Other:	

Observation: Where animals graze, distance from home field, fodder in grazing area etc.
Weighing:

MANURE APPLICATION

D.17. Do you apply some of the manure directly from the stable on the field? Y/N ________

D.18. Do you use some of the manure for other purposes (e.g. Fuel, cement) Y / N ________

D.18.2 If yes, which?____

D.19. How much of the manure do you apply in which way? (all (100%) almost all (87.5%), more than half (75%), half (50%), less than half (25%) only a little bit (12.5%) or none (0%)?

D.20. How do you transport the manure (WB= Wheelbarrow, B=Bucket, other= specify below)? (Weigh the unit)

D.20.2 How much of this unit (wheelbarrow, bucket, other,) do you apply (e.g. 1,2,3,...) and how frequent?

Applied to	%	Unit	Amount	Frequency
heap/pit				
Directly applied to field				
used differently, Namely:............				
Other:				

Why this practise?

Has it changed? Why? When?

Observation of amounts/picture/weighing

D.21. If manure is applied directly to the field, to which field do you apply the manure directly? Why that field?____

D.22. At which time of the season? How often?

____

D.23. Is there difference in the seasons? Y/N _______________________________

D.23.2.If yes, which months is different and how is it different?

____

MANURE STORAGE

D.24. How do you store the manure?

1) Open heap, 2) compost pit, 3) covered with plastic, 4) direct application to the fields,   5) other, specify____

Why this practise?

Has it changed? Why? When?

Picture of Manure heap/pit/ floor/roof if present

D.25. Do you empty the manure storage completely Every season ? Y/N ________________
If not specify how not:____

D.26. Do you mix feed refusals, crop residues, kitchen waste etc. into the manure heap? Y/N ____

D.26.2 If yes, how do you collect/transport the material (WB= Wheelbarrow, B=Bucket, other= specify below)? (Weigh the unit)

D.26.3 If yes, how much of this unit (wheelbarrow, bucket, other,) do you mix into the heap (e.g. 1,2,3,...) and how frequent?

Material	unit	How often	frequency
Crop residue			
Feed refusal			
Kitchen waste (if possible to specify)			
Other			

Why this practise?

Has it changed? Why? When?

D.28. Do you turn the heap during storage? Y/N ___________________________________

D.28.2. If yes, how often?

____

D.28.3. How?

____

Why this practise?

Has it changed? Why? When?

D.29. Indicate for each of the following steps how much time you spend on it and with how many people:

Step	Time spent	Unit & frequency	Nr. People	notes
Manure collection in stable				
Manure collection on compound				
Manure collection in communal area				
Transporting manure				
Manure pit, heap (turning, etc...)				
Application to the field (BS= before storage, AS= after storage in pit)				
Other steps:				

D.30. Is there a time in the year that manure management (steps mentioned in above table) is reduced because of labour shortage? Y/N ____

D.31. If yes, which months is restricted?

D.32. If yes, by which activity is it restricted (e.g. off farm work, harvesting, sowing)

Month	Activity

Part E: Challenges and changes of manure management

(!) For the next questions: to get the underlying reasons, ask many *why* questions (!)

E.1. What are the biggest challenges to improve manure management?

____
____
____
____

E.2. What are observed benefits/challenges of the current way you manage the manure (take into account possible changes in the past 2 years as discussed earlier in the survey)?

____

____

E.3. What have been advantages/disadvantages of the old practises? ___________________

____

Table for recording local manure units *only if applicable*

Local unit (e.g. bucket, wheel barrow)	Measured amount (in Kg or g)	Notes
1:..........................		
2:..........................		
3:..........................		
4:..........................		
Manure weight fresh manure and heap (use most common local unit)		
Manure fresh a:......................		
Manure pit b:......................		
Material mixed into heap		
Other		

Pictures to be taken:

File location:

picture	**File name**
Manure in stable,	
Stable itself	
Manure heap	
Grazing land	
Transportation unit, bucket, wheelbarrow	

Humidtropics-FARMSIM detailed caracterization survey

Part F Questions for non-cattle owner. This questionnaire forms part of a larger questionnaire on manure management and is only used in combination with the larger questionnaire.

Part F. Questions for non-cattle owner

F.1. Do you use any manure for your fields? Y/N

____

F.2. Where do you get this manure from?

Source (e.g. Neighbour, ...)	Type (cattle, specify other animal, ...)

F.3. How much manure can you get for your field in a season?

____

____

F.4. Which challenges do you face with getting manure for your fields?

____

____

____

Why this practise?

Has it changed? Why? When? (! Refer to earlier survey information here !!!!)

Appendix 2 Model parameterization

Crop data

Data from the NUANCES-FARMSIM manual have been used to parameterise the different crops.

Table 23 Crop parameter used for the parametrisation of the model

	Maize	Napier grass
crop_id	1	3
Legume	0	0
legume_type	0	0
harvest_index	0.40	0.80
shoot_root_ratio	6	6
light_determined_yield (kg DM ha^{-1}	10000	35700
water_conv_eff	36	69
par_a	0.99	0.99
par_b	-0.47	-0.47
par_r	0.90	0.90
max_grain_N	0.032	0.020
min_grain_N	0.010	0.003
max_stover_N	0.010	0.020
min_stover_N	0.004	0.003
max_grain_P	0.009	0.008
min_grain_P	0.002	0.002
max_stover_P	0.004	0.008
min_stover_P	0.001	0.002
max_grain_K	0.008	0.030
min_grain_K	0.003	0.009
max_stover_K	0.024	0.030
min_stover_K	0.010	0.009
dry_matter_content	1	1
carbon_content	0.42	0.42
root_C	0.32	0.32
root_N	0.005	0.007
root_P	0.001	0.004
fixation_rate_N2	0.0	0.0

Soil data used for the parametrisation of the model

Based on soil data collected in the NUANCES-FARMSIM project at farms in Busia and Vihiga, the following soils parameters have been used in the model parametrisation.

Table 24 Soil data of the four fields used for the parametrisation of the model

Field ID	Crop	Bulk density (kg/m3)	Top soil depth (m)	Clay (%)	Silt (%)	pH (H2O) (-)	SOC (%)	Total N (%)	Olsen P (mg/kg)	Exch. K (mmol(+)/kg)
Field 1	Maize	1510	0.2	34	34	5.5	1.45	0.125	20	18
Field 2	Maize	1510	0.2	30	30	5.5	1.1	0.09	6.35	18
Field 3	Maize	1510	0.2	28	28	5.5	0.95	0.08	3.9	18
Field 4	Napier	1510	0.2	30	30	5.5	1.15	0.09	6.35	18

Climate data

Table 25 Climate data used for the parametrisation of the model

Months	January	February	March	April	May	June	July	August	September	October	November	December
Rainfall (mm)	60	110	100	200	220	210	50	160	130	110	80	100

Appendix 3 Herd composition in 2016

Location	**Farmer Type**	**Total TLU per farm**		**TLU local cattle**		**TLU dairy cattle**		***n=***
		Mean	**St.dev**	**Mean**	**St.dev**	**Mean**	**St.dev**	
Busia	**2**	5	2	5	2	0	0	8
Busia	**3**	3	2	1	1	2	2	9
Vihiga	**2**	2	1	2	1	0	0	7
Vihiga	**3**	3	1	1	1	2	1	10

Table 26 Herd composition in 2016

Appendix 4 TLU change 2016-2018 data

Table 27 Changes in cattle numbers (TLU) between 2016 and 2018

	Control Vihiga	Treatment Vihiga	Control Busia	Treatment Busia
same	2	4	2	3
reduced	5	4	3	1
increased	5	4	7	8
total	12	12	12	12

Appendix 5 Cattle feeding

Farmers were asked to estimate the proportion of different feeds in the diets of the animals. In cases where farmers estimates summed to above or below 100%, the data was scaled to 100%. For the feed composition calculation, the average amount (%) per feed was calculated for the different farm types. Then a weighted fraction was obtained based on the amount each feed was mentioned in order to scale the data to a ratio of 100%. Only relevant feeds have been considered here; those feeds only mentioned by one farmer or used less than 5 % in total have not been considered. The % of feed sources show differences in feed volumes. Besides these feeds also some farmers fed dairy meal, salt lick regularly, which was not measured in %.

The following table shows most important feed sources during raining season by farmer type.

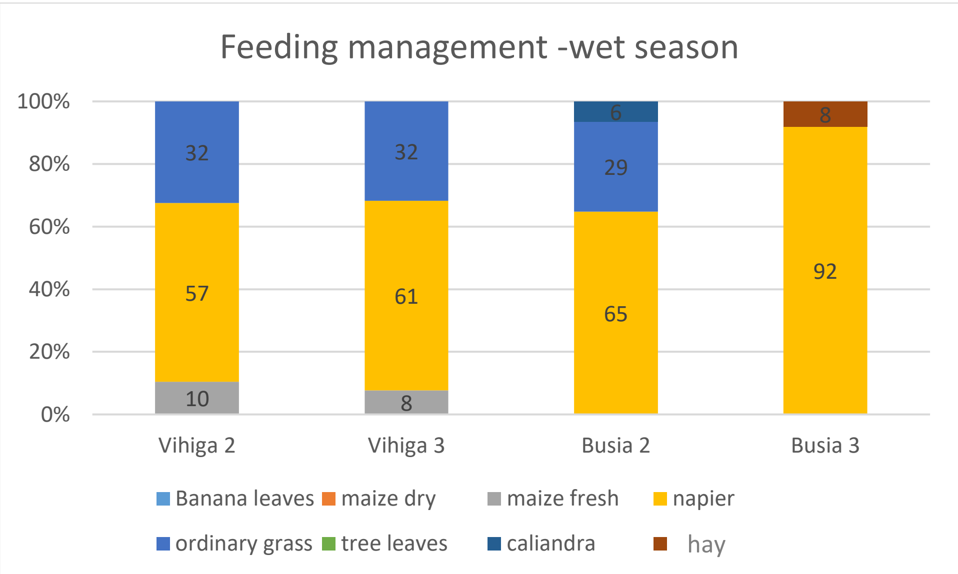

Figure 27 Feeding management in wet season

The main feed sources have been napier grass and other local grasses. In Vihiga also fresh maize stover was used by farmers. In Busia type 2 farmers also feed calliandra (*Calliandra calothyrsus*), but in small amounts.

Based on analysis of external data from the NUANCES-FARMSIM monitoring surveys, it has further been shown that farmers feed around 1kg concentrate to the cows.

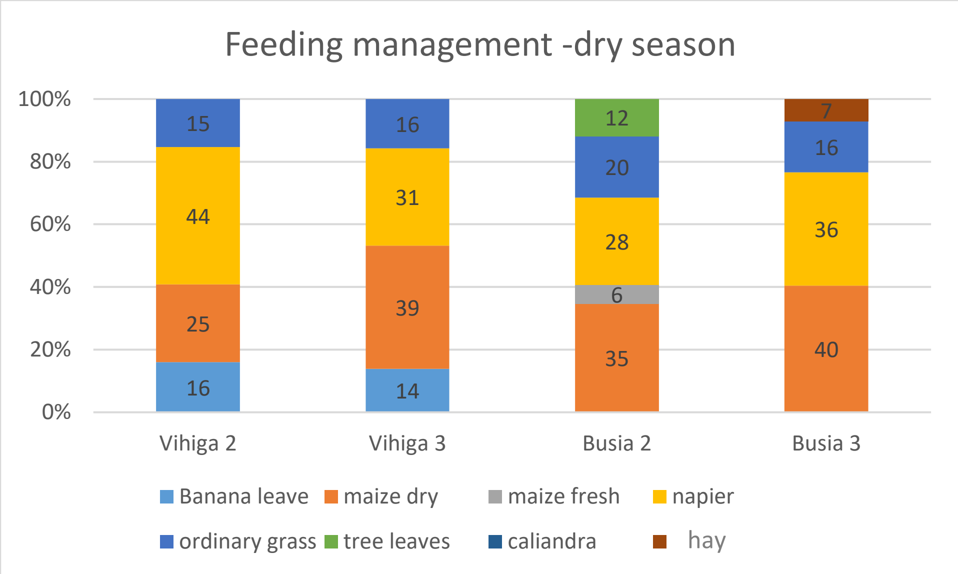

Figure 28 Feeding management in dry season

Reason for cattle feeding

In addition to the quantitative analysis of the feeding regime farmers were also asked about the underlying reasons for their management. The two main important reasons farmers indicated for their feeding management is the support of milk production and the availability of the feed. In Busia milk production was mentioned particularly often among the type 3 farmers, which are characterised by their dairy cattle also. One of the farmers (Busia control cl.3) explained it this way: If the cow gets nutritious fodder it drinks also more water and then has a better digestion, which makes it eat more and thus also it can give more milk. Another farmer (Busia control cl.3) also mentioned that dairy meal and mud lick was good, since it also facilitates the cow to drink more water and thus can give more milk. Also, the balance between carbohydrates and proteins, e.g. napier grass was mentioned to effect milk production positively. A few farmers also make the connection between investing in dairy meal and getting more milk and thus profit.

Feed availability was mentioned also much by the type 3 farmers predominantly. The availability of the feed was an aspect there, but also farmers mentioned that they aim to utilize all feed resources available, so nothing is wasted or unused. Also, seasonal differences were important, like the availability of grasses, especially napier grass in wet season. Maize as a fodder was reported to be mainly reserved for dry season feeding when grasses are relatively absent. Other valuable feeds like calliandra (*Calliandra calothyrsus*) was mentioned not to be available enough in any season.

Further also a balanced diet was important for many farmers, since the variation in feed enables the cattle to eat more and thus be strong and healthy. On the one side diversity of feed was used in order to satisfy the cattle, however on the other side it was also mentioned as a trigger to enable the cow to eat more fodder and as a result grow bigger and stronger. Some farmers also mentioned that the diversity of feeds assures that the animals get all the needed nutrients and stay healthy. Another aspect mention with respect to the dry season was that farmers reserve certain feeds like banana for that period so the animal can eat much of it in that season if it is not used as general feed in the rest of the year. In relation to the health of the cattle one farmer also mentioned further that feeding a balanced diet and dairy meal is also a good investment because the cows get more disease resistant and thus one avoids costs for more costive treatments.

In relation to the feeding of maize residues some farmers mention that they need to use part of the stalks to feed it due to the absence of alternatives in the dry season. But also, the conflict between feeding it and keeping it as green manure in the field was mentioned. (more on this topic can be found in subchapter Crop residues).

Some farmer reported that they use mainly the upper part of the maize stalk to feed the cattle, since this part is softer, and the animals eat more and leave less residue. Thus, the lower part of the stalk is kept in the fields as mulch/green manure to increase soil fertility and enable a good yield in the next seasons. But some farmers also mentioned that they need some of the maize residues as feed sources in the dry season. In the wet season maize was only fed fresh when plants not barring any cops are uprooted and then fed to cattle.

Changes in cattle feeding

Two main aspect have been changed in the past years according to the reports of farmers. One of the most significant changes not only in the past 3-4 years but already over a longer time is the changes in the feeding regime due to limited availability of communal grazing areas. Many farmers reported that also in the past years, the land that was previously available for the cattle to roam around or for the farmers to cut grasses has almost all gone now. However, some farmers also reported that one reason they stopped using communal grazing areas is that the animals get sick if grazing there or that cows got hurt by cars when grazing at the roadside.

Another big area of change for farmers was the changes reported in the general feeding management especially also the use of dairy meal. Some farmers especially from the treatment groups reported to have started the use of dairy meal and observed that it indeed increased the milk production, but also the amount of manure excreted, which has positive effect also on yields. Many farmers also use dairy meal mainly when cows are calving. Also farmers reported that they tried to feed dairy meal to their cows, but the cows refused to eat it, since they are not used to this feed A farmer described that he is now also using banana stem as a result of limited land and grass availability. Some farmers in Busia also explained that they had previously used an intercrop of desmodium (*Desmodium intortum, Desmodium uncinatum*) and maize, since its fodder qualities, but stopped this because desmodium drains the soils from energy lacking then for a sufficient maize yield and due to its labour intensive management. On the other side also one farmer mentioned to have started to plant calliandra after it was introduced in the workshops as good fodder. Also changing the housing to zero grazing units was reported to have changed the feeding management of the homesteads greatly. Some farmers also mentioned that they are worried that changing the diet from what the animals are used to will lead to decrease in the volumes cattle eat.

Feed refusal

Feed refusal described the fraction of feed given to the cows and refused by them. A reason for this can be the unpalatability of the material. 36 of 40 farmers with cattle experience feed refusal in the feeding management, this is 90% of cattle farmers. Feed refusal ranged between 12% and 17%. No patterns were observed between type or locations. In 0 a boxplot of the data can be found, showing its spread.

Table 28 Feed refusal in wet and dry season

Location	Farmer Type	Refusal dry %	Refusal wet %	n=
Busia	2	15	17	8
Busia	2	12	15	12
Vihiga	3	13	12	7
Vihiga	3	12	13	12

Appendix 6 Manure and urine local units overview

Table 29 Local manure collection units

Unit	Average weight kg	Median weight kg	Min weight kg	Max weight kg	n=
basin	23	20	8	47	12
bucket	25	22	5	53	24
Jerry can cut	30	27.5	4	47	8
Justwithjembe	21	21	21	21	1
smallbucket	35	43	9	52	3
spate	2	2	2	2	1
wheelbarrow	34	39	14	44	8

Table 30 Local urine collection units

Unit	Average weight kg	Median weight kg	Min weight kg	Max weight kg	n=
basin(urine)	46	46	46	46	1
bucket(urine)	29	30	6	49	6
Cup(urine)	3	3	3	3	1
Small jerry-can cut(urine)	26	31	6	36	4

Appendix 7 Manure allocation

Table 31 Manure allocation in % and kg

Loc_FC	allocated to farm direct		allocated to heap/pit		allocated to smearing house		allocated to share to neighbours		Amount manure collected per farm	n=
	%	kg	%	kg	%	kg	%	kg	kg	
Busia.2	10	1543	85	13118	3	463	2	308	15434	8
Busia.3	17	2778	80	13071	2	326	1	163	16339	12
Vihiga.2	35	3336	57	5432	6	572	2	190	9530	7
Vihiga.3	43	6625	52	8012	5	770	0	-	15409	12

Appendix 8 Reason for manure storage

Napier grass is not appreciated by many farmers, since it starts to germinate and grow inside the heap. Two main arguments were used by farmers for turning the manure. In the Vihiga groups the main argument mentioned is that it facilitates the drying of the manure. For that the manure is turned inside the heap/pit especially during the weeks before the planting time. Main reason stated for this is that a high water content increases the risk of either fertilizer burning or rotting of seeds. Besides also the manure gets lighter if it is dry, which reduced the workload if applied to the fields. A few other farmers remove the compost from the heap/pit. The manure is spread for several days outside on the ground, so that the water content reduces.

In the Busia groups it was more mentioned that the compost needs to get turned, so all the materials with different decomposition speeds and age in the heap/pit gets well mixed so that a homogenous compost develops and all elements get well rotten. Most farmers indicated that there is no time shortage effecting turning of the manure heap/pit. Only one farmer indicated not to have sufficient time for more frequent turning of manure and some other farmers rather mention that it is heavy work.

Four reason can be found why farmers do not empty the manure heap every season. Firstly, some farmers seem not to have sufficient amounts of manure in order to apply twice yearly, so they choose to keep all manure for the main planting season. Secondly a few farmers also have more compost as they need during planting seasons on their own farm, so they use manure twice yearly, but not all of it so that some remains for the next season or is sold also in some seldom cases. Thirdly farmers that apply fresh manure every few days, do not use all of the manure in the heap or pit, but keep those that is not well decomposed at the planting time in the composed pit/heap. Lastly for some few farmers the workload is too high or the farm is not well accessible, especially for old or single female and male farmers with less resources and access to additional labour this can be a limiting factors.

Appendix 9 Number of days manure is exposed to the open per farmer type and location

Table 32 Manure expose to open among type 2 and 3 farmers

	Farmer type 2		Farmer type 3	
Location	Days manure exposed to open	Times mentioned	Days manure exposed to open	Times mentioned
night place	1	15	1	26
compound	1.5	14	2	22
day stable	7	1	1	7
grazing field	6	4	NA	2
communal grazing land	1	2	NA	1
stall	-	-	1	1
brothers land	-	-	7	1
urine	4	6	6	7

Appendix 10 Type 1 farmers challenge of getting manure

In relation to the challenge of getting manure, farmers mainly narrated that the only opportunity to get sufficient manure is through buying the manure. Borrowing manure from neighbours is common among type 1 farmers, however many farmers also indicated that it is much more difficult now, since most people now need the manure for their own farm. Some farmers acknowledged that cattle owning farmers invest a lot of resources, like feed and time into the cattle and thus need to use the manure themselves. Borrowing manure is often only enough for smearing the house with it, but not a sufficient amount to use for the application on the fields.

The two main aspects farmers mention in this respect as a challenge with getting manure is the financial constraints of buying the manure and secondly the lack of workmanship in order to transport the manure to the homestead. A farmer indicated that 1 carload was sold for 500-750 KES

Besides some farmers also mention that the manure is not even available to buy (check location), since cattle owning farmers need all of it for their own farms. So the conclusion for many farmers was the need to get cattle for themselves.

Only one farmer indicated that there is no challenge in getting manure since it is provided for free by the neighbour.