UNIVERSITY OF NAIROBI

EVALUATION OF OPTIONS FOR MINIMISING GREENHOUSE GAS EMISSIONS THROUGH IMPROVED MANURE MANAGEMENT IN SMALLHOLDER DAIRY FARM SYSTEMS IN NANDI COUNTY, KENYA

BY

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DEDICATION

This thesis is dedicated to my late father George Rarriw Owino, my mother Dorothy Owino and siblings Denise Owino, Patricia Rarriw and Beverly Owino for the unwavering support they gave me during the entire period of this study.

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ABSTRACT

An increase in atmospheric greenhouse gas (GHG) concentrations, mainly methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) from agricultural activities, is a global concern as it leads to climate change. There is also a problem with nutrient mining, especially of nitrogen in smallholder farms. Human population growth and increased demand for livestock products, including milk, are expected to intensify the dairy sector which would lead to higher GHG emissions and low availability of nutrients in farms leading to low productivity. The main objective of this study was to develop options for minimizing nutrient losses and greenhouse gas emissions through improved manure management in smallholder dairy farm systems in Nandi County, Kenya. This study applied a transdisciplinary approach focusing on minimizing GHG emissions and nutrient losses through improved manure management of smallholder dairy farmers. Beginning with household survey followed up by Focus Group Discussions and finally validated with Key Informant Interviews. This study found that Nandi County has three livestock confinement systems of *Only Fence* (90%), *Fence and Roof* (2.5%) *and Fence*, *Roof and Floor* (7.5%). The study also observed seven manure management systems; heaping fresh manure (49%), heaping dry manure (44%), biogas (2.7%), slurry (2.7%), splitting urine (0.3%), compost (0.3%) and storing urine (0.3%). It was observed that 94% of manure was managed as uncovered heaps of either fresh or dry manure. Manure stored in such manner lost about 50% of N during a three-month storage experiment; the N lost is substantial. The study analysed and found GHG (CH_4, CO_2, and N_2O) emissions from uncovered solid storage manure heaps have the highest emissions from *Fence, Roof, and Floor* as the manure from *Only Fence* systems have already lost most of the urine N through leaching. In terms of GHG (CH_4, CO_2, and N_2O) emissions converted to Global Warming Potential for comparison, manure from FRF managed as solid storage emitted the highest contribution (37%). Solid storage of manure yielded mean methane conversion factor (0.043%) and mean emission factor for N_2O (0.003%). The key technical socio-economic and institutional constraints to improving manure management were that smallholder dairy farmers had a low opinion of using manure from their farms on high-value crops. These farmers also had a low opinion on the need to improve manure quality in terms of handling, storage, and application due to a lack of available farm labour. This study shows that dairy cattle manure is valued highly by the farmers and shows that a critical source of information for improving manure management is local radio. This study observed that majority of the farmers had received information on manure management within the last five years. The farmers in this study preferred heaping either fresh or dry manure as it was the least labour intensive way to manage manure produced from the various animal confinements. The general conclusion of this study is that smallholder farmers in Nandi County, like many other smallholder farmers, have diversified farm activities and are willing to improve manure management after being informed of the losses. This study recommends the engagement of institutions focusing on dairy agriculture, industry, traders, and farmers. This engagement is to explore ways to incentivize or lower costs for robust manure management systems such as biogas systems that would be more effective in minimizing N losses while mitigating GHG emissions.

Keywords: Manure management, Nutrient losses, Greenhouse emissions, smallholder dairy farmers, Livestock confinement systems

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LIST OF ABBREVIATIONS/ACRONYMS AND SYMBOLS

C	Carbon
CH_4	Methane
CIDP	County Integrated Development Plan
CO_2	Carbon dioxide
F system	Fence only animal confinement
FF system	Fence and Floor animal confinement
FR system	Fence and Roof animal confinement
FRF	Fence, Roof and Floor animal confinement
GHG	Greenhouse gases
HH	Household
IEBC	Independent Electoral and Boundaries Commission
LH1	lower highland 1
LH2	lower highland 2
MMS	Manure Management Systems
N	Nitrogen
N_2O	Nitrous Oxide
UM	Upper midlands
SSA	Sub-Saharan Africa

DEFINITION OF KEY TERMS

Agro-ecological Zones: "This includes identification, and categorisation of multiplicity of agronomic, economic and environmental criteria that determine the performance of an agro-ecosystem, and then determine the nature and extent of changes that need to be introduced to achieve greater productivity" (Jalloh *et al.* 2012).

Climate change: "This is large scale change in the climate system that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades and causes substantial disruptions in human and natural systems" (IPCC, 2014).

Livestock housing systems: "These are areas of confinement of livestock for feeding and sleeping and include areas that are just enclosures, or semi or fully intensive units and is described by either availability of fence, roof, floor" (Rufino *et al.* 2007).

Manure management: "This refers to the practices that are involved in handling of manure from collection, transport, storage up to before application" (IAEA, 2008).

Smallholder dairy farmers: According to Cohn *et al.* (2017), "These are farmers who keep dairy animals among other crop enterprises on acreage smaller than 2 ha. These farms vary drastically in size, function and structure".

Transdisciplinary approach: “This involves conducting research in the community outside a single scientific discipline that has arisen due to the need to study objects of increased complexity without their separation from the environment” (Brandt *et al* 2013).

CHAPTER ONE: INTRODUCTION

1.1 Background

The projected global population increase is estimated to be between 9–10 billion by the year 2050; this will lead to increased expectation for nourishment and will require that agricultural production increases significantly (FAO, 2013). Over the past decades, livestock industries have been observed to grow rapidly to satisfy the demand for meat and dairy products (Fetzel *et al.* 2017, van Wijk *et al.* 2009). Currently, it is estimated that agricultural production including land use change is contributing approximately 25% to total anthropogenic GHG emissions (Tubiello *et al.* 2015). A significant source of greenhouse gas (GHG) emissions worldwide is livestock production due to the emissions of nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) throughout the production process (Gerber *et al.* 2013a). The contribution of livestock production to total anthropogenic GHG emissions is 12% (Tubiello *et al.* 2014). Greenhouse gas emissions from livestock are either indirectly (e.g. from feed production activities and conversion of forest into pasture) or directly (e.g. from enteric fermentation and manure management) generated (FAO, 2013). With increasing human population, livestock will increase in its focus as a source of milk and meat. There is global concern to reduce anthropogenic greenhouse gas emissions to mitigate climate change, and more so from livestock related GHG emissions (Gerber *et al.* 2013b).

GHG emissions due to livestock production are mainly originating from three major sources: a) CH_4 emissions from ruminants, b) CH_4 and N_2O emissions due to manure management and application and c) faeces and urine excretion on rangelands. Another pathway leading to N_2O emissions is environmental N losses from manure and urine during storage, application, and deposition on rangelands in form of NH_3 volatilisation and NO_3 leaching. This NH_3 and NO_3 is transported downwind/downstream and during its transformation N_2O can also be produced. This pathway of nitrous oxide emissions in the process of volatilisation is mostly summarised as an indirect emission pathway.

Tropical Africa is characterised by low levels of agricultural productivity, due to farming without adequate fertiliser and manure (Sánchez, 2010). Poor available nitrogen (N) in soils characterise majority of African arable lands, and in these areas nutrient recycling is critical to maintain the productivity of the land to maximise the benefits from nutrient inputs (Rufino *et al.* 2006). The increasing need for agricultural productivity especially on poor soils due to nutrient mining practices of smallholder farmers has been observed to benefit with inclusion of livestock excreta and synthetic fertiliser as the two major N sources for agricultural land (Markewich *et al.* 2010).

There is an existing effort to dairy farming intensification through a number of means, for example, interventions that are integrated, giving farmers access to markets and giving farmers the knowledge to apply towards enhancing the milk production and sales (Chagunda *et al.* 2016, Woodfine 2009). This implies increased and improved feeding of livestock on intensive smallholder systems. The diets that livestock are exposed to may have a significant impact on manure (urine and faeces) chemistry and furthermore on GHG emissions during manure storage and following application to land surfaces (Markewich *et al.* 2010). When animals are housed indoors or on feedlots manure storage becomes necessary (FAO 2013). Data on greenhouse gas emissions per unit of production of manure are required especially for evidence-based assessment of manure management practices especially for African smallholder systems, but are currently lacking (Pelster *et al.* 2016, Rufino *et al.* 2006). If data becomes available for different manure management options (e.g., heaping manure, slurry based practices, coverage of manure with plastic, composting of manure, etc.), it will enable the enumeration through assessment of the best manure management options in terms of GHG emissions and nutrient retention as a function of Nitrogen (N) availability in manure.

Greenhouse gas emissions estimates for African regions are mainly based on the IPCC Tier 1 emission factor approaches (Kouazounde *et al.* 2014); these are often inadequate for site-level assessments and with underlying data mainly being produced for temperate regions in Organization for Economic Cooperation and Development (OECD) States. Country level emissions from African agriculture are dominated by grazing livestock (Hickman *et al.* 2011). Improving the technical understanding of the way soil organic matter is managed at farm level is considered critical as compared to modelling and projecting crop production at field level (Markewich *et al.* 2010, van Wijk *et al.* 2009). The use of animal manure and legume intercropping are well-established practices, but others such as composting are not so well established and so is the knowledge that nutrient quality varies site by site. In Kenya, Omiti *et al*. (2009) found that between 86% and 91% of farmers use of manure in semi-arid and semi-humid zones.

1.2 Problem Statement

The IPCC 2006 emission reporting guidelines provide simple approaches on how to estimate GHG emissions from different manure management systems. However, currently we do not know which of those systems are in use by smallholder dairy farmers in developing countries. There is also lack of information on how the specific nutrients nitrogen (N) and carbon (C) are lost from these identified smallholder farmers practices of managing manure. Data on greenhouse gas emissions from manure from the specific manure management systems in the employ of African smallholder dairy farmers is also lacking. In order to assess the management options from smallholder farmer practices, there is need to combine information on nutrient losses from manure from smallholder dairy farms with GHG emissions from manure from the same farms, and to analyse the practices to determine what system minimises nutrient losses as well as reduces GHG emissions. Furthermore, it is important to understand community perceptions on practices of improving the current smallholder farmer manure management. Moreover, there is a requirement in policy that farmers be targeted for training in manure management practices that are applicable and possibly already in use in some places for the different production systems. Lekasi *et al.* (2001) showed that smallholder farmers in Maragua District of Central Kenya on all the smallest farms (0.1–0.6 ha) did have ideas on how to improve manure quality such as through either composting or biogas slurry.

Given a focus on GHG emissions due to manure management, there is existing interest by farmers to improve manure quality and that this would be necessary to be carried out with smallholder dairy farmers. The first step would be running a survey on manure management systems used by smallholder dairy farmers. Linking the survey with measurements of GHG fluxes from common manure management systems needs to follow. This will allow conducting the first Kenyan regional analysis of emissions based on information in livestock management and manure characteristics and management, thereby considering climate, as outlined in the IPCC (2006b) guidelines. The study region selected and used for this study was able to show multi-criteria approach to use farm data to generate variables for GHG estimation that could be scaled to regional levels (Rosenstock *et al.* 2013, Rufino *et al.* 2014).

Smallholder dairy farmers are the main milk producing category in SSA, with Kenya leading. Nandi County in Kenya was selected due to the importance and practice of dairy farming to the County economy (EADD 2010a; Republic of Kenya 2014). It ranks fifth in national milk production . Pelster *et al.* (2017) found western Kenya to have low input intensity for their farming systems, and thus did not relate GHG fluxes management activities at the farm level.

1.3 Research Questions

1. Which type of manure management systems are currently implemented by dairy farmers? And how are those managed?
2. How much N and C are lost from the various systems during manure handling and storage?
3. What is the emission strength of the different manure management systems regarding CH_4, CO_2 and N_2O emissions from manure under the various manure management systems?
4. What are the best manure management systems feasible to smallholders?
    a) For minimising N (as well as C) losses during storage
    b) For mitigating GHG emissions?
    c) In terms of cost-benefits against chemical fertiliser?

1.4 Objectives

1.4.1 Main objective

The main objective is to develop options for minimising nutrient losses and greenhouse gas emissions through improved management of manure in smallholder dairy farm systems in Nandi County, Kenya.

1.4.2 Specific objectives

1. To characterise the manure management systems utilised by the dairy farmers in the study region.
2. To estimate N losses during storage for the different management systems.
3. To quantify CH_4, CO_2 and N_2O emissions from manure from the various manure management systems and to develop management system-specific emission factors.
4. To determine and explore with the community manure management strategies that would minimise N and C losses while mitigating GHG emissions.
5. To generate community perceptions driving choice of manure management strategies.

1.5 Justification and Significance

1.5.1 Justification of the study

It has been observed there is need to generate smallholder farmers activity data as a means to improve the understanding of the systems in place (Rufino *et al.* 2007). Therefore, characterising current manure management systems being used by smallholder dairy farmers will enable the generation of activity data. Manure has been observed to lose nutrients N in storage (Markewich *et al.* 2010). There is need to know how much loss of nutrients manure will undergo under common smallholder dairy farmer manure management practices. On a national scale, quantification of the GHG emissions associated with manure management will enable nations improve their GHG emissions reporting and there is need to improve from the current Tier 1 to Tier 2 IPCC calculations (Chadwick *et al.* 2011, Pelster *et al.* 2016). Thus, with developed smallholder dairy farmers' activity data, it would make it possible to do Tier 2 greenhouse gas emissions estimations from management of manure. The data available on ways to minimise nutrient losses from manure and also reduce GHG emissions has been done under laboratory conditions and focused on the science problem (Lekasi *et al.* 2003, Markewich *et al.* 2010).

Greenhouse gas emissions from manure and the length of storage of manure before incorporation into crop farms would be best estimated with data on farm practices as a study (Hammond *et al.* 2015). Cattle are important assets for smallholder farmer as the can easily be sold for cash when cash is required (Rufino *et al.* 2006). The existing programs on integrating farmer interventions in farm manure management, farmer market-access and application of acquired knowledge have focused on improving farmer incomes (Bebe *et al.* 2003, van der Lee *et al.* 2016). There are still reasons to assess, with smallholder dairy farmers, ways to achieve the same objectives factoring in their practices and interests. There are, lastly, reasons to assess the smallholder dairy farmer practices in terms of quantification of nutrient N cost that would be saved if farmers improve their manure management practices.

1.5.2 Significance

This study will generate information through activity data that will enable understanding of the diverse manure management practices in smallholder dairy farm systems. This information will be useful to scientists and others to be able to design experiments to quantify actual nutrient N and C losses from common manure management systems. Scientists and others will be able to know how common smallholder manure management systems emit GHGs and use this information to generate and test mechanistic models e.g. to explore feedbacks of GHG emissions from manure management due to changes in climate or manure management systems. The options developed with smallholder dairy farmers on manure management will enable ease of designing farmer training manuals and provide the evidence-base for policy makers to develop farmer-oriented policies and training programmes for extension agents and farmers.

Knowledge of the costs of implementing the best manure management system that reduces nutrient losses and minimises GHG emissions will aid in designing of cost models and also aid policy makers in the formulation of training manuals to use in providing cost-related feedback to communities on various options that the communities can engage in with regard to manure management and use. Identifying options for improvements with regard to minimising nutrient losses and testing such options with the smallholder dairy farmers will likely result in significant increases in food and feed production due to higher rates of nutrients returned to cropped fields (Diogo *et al.* 2013). This smallholder dairy farming sector is best to adapt climate smart agricultural practices about farm manure management as this sector is the major source of farmyard manure for their cropping systems. This will give various stakeholders decision making support in introducing climate-smart agricultural practices. The IPCC (2006) guidelines specify a commitment to undertake climate smart agriculture and reduce emissions from agriculture; this has led to the need to establish manure management systems that would lead to reduced emissions and higher quality manure for crop farmers' use.

1.6 Scope and limitations of the study

This study assessed options for minimising greenhouse gas emissions through improved manure management in smallholder dairy farming systems in Nandi County. This study surveyed 335 households of this population after stratification of Nandi County into 3 agro-ecological zones (AEZ) in 2015 to 2017. Ten key informants representing were interviewed, with three Focus Group Discussions (FGD) conducted and separated by gender. Nine selected farms representing the common manure management practices and all livestock confinement systems were selected as a source to collect approximately 100 kg of manure from each. The manure was sampled for nutrient N and C analysis four times, GHG emissions from manure was done daily for 91 days. In order to collect fresh manure these farms came from two major AEZs. Dairy livestock population was derived from Kenya Population Census 2009 and further appraised with the 2014 Livestock Production and Marketing data from the national ministry in charge of livestock. This study did not cover non-dairy livestock as well as large-scale farms.

1.7 Layout of the thesis

This thesis begins with chapter one the introduction of the research that starts with background information, problem statement objectives and justification for the research. The thesis continues in chapter two with a review of literature focusing on manure management systems in dairy farming, nitrogen loses from manure management, GHG emissions from manure and factors and challenges on improving manure management. Chapter three focuses on methods that were applied to achieve the objectives of the study. Chapters four to six present and discuss the results of the study, each one focussing on one study objective, as follows: Chapter four - characterisation of the manure management systems utilised by the dairy farmers in the study region; Chapter five - estimation of N losses during storage for the different management systems and quantification of greenhouse gases (CH_4, CO_2 and N_2O) emissions from manure from the various manure management systems and development of management system-specific emission factors, and; Chapter six - community manure management strategies that would minimise N and C losses while mitigating GHG emissions and community perceptions driving choice of manure management strategies. This is concluded by chapter seven that offers the key findings, conclusions and recommendations on assessment of options for minimising nutrient losses and GHG emissions from manure management.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter focuses on themes related to smallholder dairy farmers and farm manure management. It explores in a systematic manner the extent to which currently smallholder dairy farmers are using to manage manure and how this is related to greenhouse gas emissions and nutrient losses during manure storage. This includes key components of manure management, effects of manure storage from known practices on nutrient N loss and GHG emissions from manure systems. These are then related to constraints for the smallholder dairy farmers, factoring in costing of the smallholder farmer practices.

2.2 Manure management systems in the dairy industry

Livestock manure is a critical nutrient resource that is available to smallholder farmers at low cost. Additional nutrient sources are even more important since agricultural soils in Sub-Saharan Africa (SSA) are often degraded, likely due to intensive use with minimal inputs which subsequently lead to low yields (Blackie 2005, Dahlin and Rusinamhodzi 2014, Place *et al.* 2003, Smaling and Dixon 2006, Smith *et al.* 2014a, 2014b). Although mineral fertiliser consumption in SSA has increased marginally (2% over the past four decades), application rates remain very low (mean application rate is approximately 7.1kg ha^{-1}) (Druilhe and Barreiro-hurlé 2012, Motavalli and Marler 1998). It has been suggested that increased crop yields could be achieved through the application of additional nutrients (Jefwa *et al.* 2014). Manure has been listed as a source for N, and global estimates are that 128.3 Tg of N have been introduced through manures against 70.2 teragram that has been introduced through mineral fertiliser (Potter *et al.* 2010). Therefore, opportunities to improve nutrient retention through appropriate manure management should be considered within the wider context of having the potential to improve livelihoods of rural families and consistent with the drive towards climate smart agriculture (CSA) (Kirigia *et al.* 2013, Lekasi *et al.* 2001, Rufino *et al.* 2007). Besides being beneficial for plant growth, manure is also recognised by farmers for its monetary value, particularly with the rising costs for inorganic fertilisers (Kirigia *et al.* 2013, Lekasi *et al.* 2001, Tittonell *et al.* 2010a).

However, not all livestock manure has the same quality. Different types of livestock and different duration of storage of manure changes the physical and chemical properties of the manure. This subsequently leads to variance on nutrient retention and availability to crops when manure is added to the soil (Lekasi *et al.* 2001, Markewich *et al.* 2010, Meisinger and Jokela 2000). Improved management of livestock production with better integration of animal manure into crop production can effectively increase nutrient use efficiency (NUE) (Moe *et al.* 2017, Zhu *et al.* 2013). Studies on cattle manure have shown that average nutrient losses from solid cattle manure are estimated at 40%. However, variation in manure storage conditions (storage period, temperature and aeration) and manure characteristics (moisture content and degradability) strongly affect organic matter degradation and nutrient loss, causing manure nutrient values to vary (Oenema and Berentsen 2005; Smith 2013; Won *et al.* 2017).

Manure contains microbially available C, inorganic N, and water, which are involved in microbial production of CH_4 and N_2O (Chadwick *et al.* 2011). During anaerobic decomposition of organic matter in manure faecal matter methane is generated (Møller *et al.* 2004, Owen and Silver 2015). Nitrous oxide is generated by nitrification and denitrification of the majority manure' inorganic N (Chadwick *et al.* 2011). The composition of solid manure piles are heterogeneous with anaerobic and aerobic zones within the manure heaps depending on manure management practices and moisture content in the manure (Owen and Silver 2015). This shows the gaps that exist in terms of GHG emissions from manure during storage as different parts of the manure will decompose differently thereby emitting GHGs in a manner that needs quantification for reliable estimated to be used.

Some or all of the following components are included in a typical manure management system: location or manure production area (i.e. feedlot, free stall barn or confinement building); area where manure is treated (solids separator, digester, aerator, or open area where it's left to weather elements); facility where manure is stored (holding pond, manure tank, stackhouse or open area (either closed or open) where manure is heaped), and; manure utilisation area (crop or pasture fields, collection tanks). The reason adduced for manure collection and handling systems is to gather efficiently and transport manure along these components of a manure management system (IPCC 2006a, Teenstra *et al.* 2014). Li *et al*. (2015) states that the two main sources of slurries and dairy farm manures are separated solids from dairy farm effluent (DFE) and manure that's gathered from feed pads, feedlots and barns/animal shelters.

The European standard classification states that farm yard manure includes excreta from cattle and material used for cattle bedding collected from cattle housing, while slurry includes excreta from cattle scarped from the floor with urine and some wash down water collected from dairy animal housing facilities, and all types have varying nutrient concentrations (Houlbrooke *et al.* 2011). There are significant amounts of the primary nutrients (N, K, and P) and other essential nutrients that are contained in dairy cattle manure, making it an excellent nutrient source for crop growth

(Chadwick *et al.* 2015). Currently and in the future what will be considered a primary issue with dairy cattle, is reducing adverse environmental impacts in dairy farming systems (Hubbard and Lowrance 1998, VanderZaag *et al.* 2014).

2.3 Nitrogen losses under different management systems

Currently there is rapid transformation in tropical smallholder agriculture, especially in nutrient cycling. This is happening as globally the development efforts escalate the focus to increased utilisation of mineral fertilisers to enhance crop production across Sub-Saharan Africa (Herrero *et al.* 2010, Shepherd and Newell-Price 2013). The key element for improving crop yields in smallholder farms is nitrogen (N) which loses up to 50% from initial amount during manure storage (Rufino *et al.* 2006, Shah *et al.* 2012). Thus, minimising N losses would also improve the sustainability of smallholder farming practices. There is a large variability in manure nutrient contents as well as variability of N loss (10-40% in a month) within East Africa (Markewich *et al.* 2010, Muhereza *et al.* 2014, Rufino *et al.* 2014). This variability in N loss is due to different manure management practices, including manure handling either as solid or slurry, thus impacting manure N capture and recycling through crops (Alvarez *et al.* 2014, Powell and Russelle 2009). The variability of manure nutrient content and of N loss have largely been informed by how manure is studied, based on farmers' collection from the various types of farms and the duration of storage of manure (Castellanos-Navarrete *et al.* 2015). There is need to acquire accurate information on nutrient N losses from manure when stored through smallholder dairy farmer practices.

Studies conducted on manure management in East Africa (Castellanos-Navarrete *et al.* 2015; Rufino *et al.* 2007; Rufino *et al.* 2006; Snijders *et al.* 2009; Zake *et al.* 2010) have all documented various manure management practices. The key manure management practices in East Africa range from heaping to composting and which could be either covered or uncovered. The Intergovernmental Panel on Climate Change (IPCC 2006b) uses the assumption that most manure in SSA is left on pasture land while studies on smallholder dairy farmers found that storing manure in uncovered heaps was the most common manure practice noted and this was attributed to the type of animal housing and availability of labour on the farm (Lekasi *et al.* 2001, Rufino *et al.* 2006, 2007). The manure collection in East Africa highlands ranges from daily to weekly when animals are confined in roofed and floored housing and this varies if animals are corralled which is the majority practice for mixed systems (Castellanos-Navarrete *et al.* 2015).

Manure handling can affect particularly its nitrogen (N) losses. Between 13% and 40% of nitrogen in manure can be lost before it is applied and incorporated into the soil (Lekasi *et al.* 2003, Tittonell *et al.* 2010a, Won *et al.* 2017, Wortmann and Shapiro 2006). Previous studies have also shown that combining shortened manure collection intervals and low-cost covering of the manure heap allows for substantial amounts of nutrients to be deposited on cropland (Bouwman *et al.* 2013, Chadwick *et al.* 2015, EcoChem 2017, Kalu 2015, Snijders *et al.* 2009, De Vries *et al.* 2015). Before suggesting ways of improving manure management and using these improvements to increase productivity and climate change mitigation, it is critical to first understand the current state of the existing manure management systems.

The studies on nutrient content have not effectively discussed the fate of nutrients (C and N) from African smallholder livestock manure due to little being known about the management of manure being practiced by smallholders in Sub-Saharan Africa (Oenema *et al.* 2007). There also exists large variability in manure nutrient content as well as variability in manure loss of N within SSA smallholder farms (Hartz *et al.* 2000, Muhereza *et al.* 2014, Nyaata *et al.* 2000). This variability is further demonstrated by Powell and Russelle (2009) that dairy cattle management, either through manure collection or corralling on cropland, impacts manure N capture and recycling through crops. Markewich *et al.* (2010) quantified N losses especially from manure for periods less than 30 days and suggested that periods longer than 30 days be studied to know the temporal N losses from manure. Thus, there is a gap on the variability range of nutrient N and the losses of nutrient N from manure stored for longer than 30 days.

Smallholder dairy farms studied observed increasing intensification which other studies observed would lead to improvement in manure management. Increasing dairy farming production through intensification makes manure collection easier as observed by Nyaata *et al.* (2000). This will lead to larger quantity of manure being stored for longer in smallholder dairy farms and provides for opportunity to improve on nutrient quality through handling to reduce nutrient (N) losses and the gap on quantity of nutrient (N) losses that can be realised from manure stored for periods longer than 30 days.

2.4 Quantification of GHG emissions from livestock manure

Anthropogenic greenhouse gases (GHGs) such as nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) are strongly linked to the increase in mean global temperatures over the last century (Papakostas *et al.* 2010). Globally, agriculture contributes approximately 11% to the total anthropogenic emissions, although inclusion of other land uses (Agriculture, Forestry and Other Land Use [AFOLU]) brings the total up to about 21% of total anthropogenic GHG emissions (Tubiello *et al.* 2015).

African agriculture produces 15% of the global agricultural emissions, with manure management from African agriculture accounting for approximately 5% of global livestock manure emissions (Tubiello *et al.* 2014). The largest proportion of these agricultural GHG emissions are a result of enteric fermentation in ruminants, which accounts for 40% of GHG emissions (FAO 2011, Tubiello *et al.* 2014, Valentini *et al.* 2014), although livestock manure still accounts for 25% of total agricultural GHG emissions (Tubiello *et al.* 2014). Methane emissions from African livestock is estimated at 44% and N_2O emissions estimated at 29% of livestock emissions globally (FAO 2011, Hickman *et al.* 2011).

The number of empirical studies measuring GHG emissions from African agricultural systems are limited; therefore, there is high uncertainty in the existing GHG inventories. This includes studies that used GHG calculators to estimate emissions and compared the derived estimates with actual GHG emission measurements (Pelster *et al.* 2017, Richards *et al.* 2016, Valentini *et al.* 2014). This uncertainty casts doubt on the ability of countries to deliver on the targets aimed at the Nationally

Determined Contributions (NDCs) because the current status and the effects of interventions are highly uncertain (Richards *et al.* 2016). One way to improve the accuracy of the current emissions inventories from livestock is to move from Tier 1 (using IPCC derived estimates) to Tier 2 (using actual farm activity data) methodology, which is strongly promoted by the IPCC (2006b) guidelines for countries where a significant share of a country's emissions are represented by livestock (IPCC 2006). In order to move from Tier 1 to Tier 2 there is need to include livestock activity data, which will also enable countries to develop interventions to achieve climate change mitigation (COP 2015, IPCC 2016).

The Tier 2 methodology to calculate national GHG inventories for livestock manure management systems contains several components: animal demographics, manure management systems (i.e. farm practices data), Emission Factors (EF) and Methane Conversion Factors (MCF) for the different animal categories, and annual nitrogen excretion rates. This data, unfortunately, is missing for most of SSA, resulting in not only high uncertainty for national inventories but also makes it difficult to identify and target mitigation options (IPCC 2006b, Kouazounde *et al.* 2014, Lesschen *et al.* 2011, Rosenstock *et al.* 2013, Rufino *et al.* 2014, Smith *et al.* 2014, Waithaka *et al.* 2007). Deriving baseline data in SSA is particularly challenging because livestock systems are diverse, and production is often spread out over many small farms. Understanding and quantifying this diversity is critical to moving from Tier 1 to Tier 2 methodology.

In order to promote wide use of manure by smallholder farmers, better information is needed from scientific research on animal confinement systems, manure management systems, duration of manure storage, manure application rates, quantify nutrient N losses and estimating GHG emissions. Cattle producers need to be assisted through extension information services (FAO 2013, Hubbard and Lowrance 1998).

2.5 Improving manure management

The definition of smallholder farmers has previously been majorly tied to land size and its utilisation for either crop, livestock or mixed farming (Bebe *et al.* 2003; Elias *et al.* 2018). There also exists information on smallholder dairy farmers having interests on manure management (Bebe *et al.* 2003, Lekasi *et al.* 2003). These interests on such farmers calls for the need to look at the components of smallholder dairy farmers and characteristics beyond acreage to include: acreage for grazing, number and type of dairy livestock, manure collection, transportation, and storage practices that enable full scale farmer analysis (Rufino *et al.* 2013). These characteristics are needed to define smallholder farmer manure practices, which have previously been focused on the manure handling and have had nothing to do with livestock housing influence on manure management as well as knowledge source on information on manure management. Smallholder dairy farmers have diverse manure management opportunities due to various characteristics like controlling for weather and varying social and economic demographics (Lory *et al.* 2008).

Smallholder dairy farmers' demographic and farm characteristics data are required to identify drivers of confinement systems, manure management and their effects on GHG (CH_4 and N_2O) emissions as well as nutrient losses. These when acquired are useful to provide suggestions on management interventions to reduce GHG emissions and nutrient losses from livestock manure. Adaptation of smallholder dairy farming communities to improved manure handling, storage and use requires manure collection systems' integration to provide a consistent, reliable product

(Kasulo *et al.* 2012, Lekasi *et al.* 2003). Different end products find their way to a manure treatment system because scrape, flush and cross-gutter systems do collect and transfer manure (Lenkaitis 2012). Each manure collection and transfer system has its own advantages and challenges and costs from an initial construction, operation, maintenance and labour expenses standpoint (Castellanos-Navarrete *et al.* 2015). There is thus need to quantify these costs in relation to the quality of the final manure product (Rufino *et al.* 2007).

Smallholder farmers residing in high potential areas often mine their soil nutrients through extraction of harvested crops, weeds removal, livestock grazing, cutting forage for livestock feed, or fodder selling (Kirigia *et al.* 2013, Lekasi *et al.* 2003). The dairy farmer community is continuously being encouraged to get more production from their farms in terms of milk yield and also to use organic methods of farming (Bebe *et al.* 2003, Delve 2001). Smallholder farmer projects are set to transform the lives of people by increasing household dairy income through integrated farmer interventions in the dairy value chain (EADD 2010). Such programs are in existence to improve production but have no specific focus on the environment neither a specific focus on costing improvement of manure management practices.

The ease of conversion of dairy cattle into cash when required makes them important to smallholders (Bebe *et al.* 2002, Rufino *et al.* 2006). The huge farming population being targeted by stakeholders makes the sector as best to adapt climate smart agricultural practices about manure management. Developing the cost of implementation for each manure management system will aid the communities by providing cost related feedback on the various options that the communities can engage in regarding manure storage and use. Manure collection systems applied in livestock operations are influenced by many factors, including; farm topography, dairy cattle management style, bedding type in use, and manure application methods; these dictate the design of the manure collection system and determine the ultimate success of a manure collection system (Karmakar *et al.* 2010, Paul *et al.* 2013). Traditional manure collection systems have evolved based primarily on the degree of animal comfort that the farmer can afford and increased farm labour efficiency, with longer term manure storage and application of manure on land being the major ultimate use of collected manure (Lenkaitis 2014). Sectors now recognise the externalised impacts on manure management systems and are also aware of the relatively concentrated set of actors involved in the production of impacts such as nutrient saturation, and climate impacts through emissions of GHGs (Fiedler *et al.* 2018). This emphasises the need for reduction of impacts of manure management on the environment and to target the actors responsible for its management and use.

2.6 Summary

A major issue in farm manure management for smallholder dairy farmers is the lack of information on manure degradation as well as management practices suitable to their environment. There is also lack of smallholder dairy farmer characterisation to know the distribution of manure management practices in relation to labour, awareness, number of livestock, livestock confinement and agro-ecological zones. There is also a lacuna in knowledge on how manure stored under these smallholder dairy farmers practices lose nutrients N and emit GHGs. This would be necessary in generating appropriate costing of nutrient N losses as well as highlighting areas of improvement that would be key in developing options for minimising GHG emissions through improved manure management for smallholder dairy farmers.

CHAPTER THREE: STUDY AREA AND METHODS

3.1 Introduction

This chapter describes the study area, the methods used in addressing the research objectives and the data. It begins by describing the contextual setting of the study area, Nandi County, focusing on its biophysical and socio-economic setting. This chapter also describes the conceptual framework and the mixed methods approach used in the study beginning from desktop studies, through field work, laboratory experimentation, to data analysis for each objective. It then describes the data synthesis approaches to address the broad objective of the study.

3.2 Study area location and description

This study was conducted in Nandi County, Kenya (it covers the area 34°.5 E and 35°.5 E, -0.15° N and 0.50°N) (Fig 1). Mean annual temperatures in Nandi County range from 18°C-22°C, although temperatures in the lower elevation areas can be as high as 26°C (Mutoko *et al.* 2015, Nandi County Government 2018). The height above sea level (altitude) ranges from over 2200 m asl in the north east of the county to approximately 600 m asl in the south. This area has a high potential for agriculture (GOK 2015, Mudavadi *et al.* 2001). Subsistence farming is dominant, with average total land sizes being approximately 4.5 ha per household. Throughout the county, dairy production is common, with maize as the primary staple crop and tea as a major cash crop (Nandi County Government 2015) (Fig 3.2).

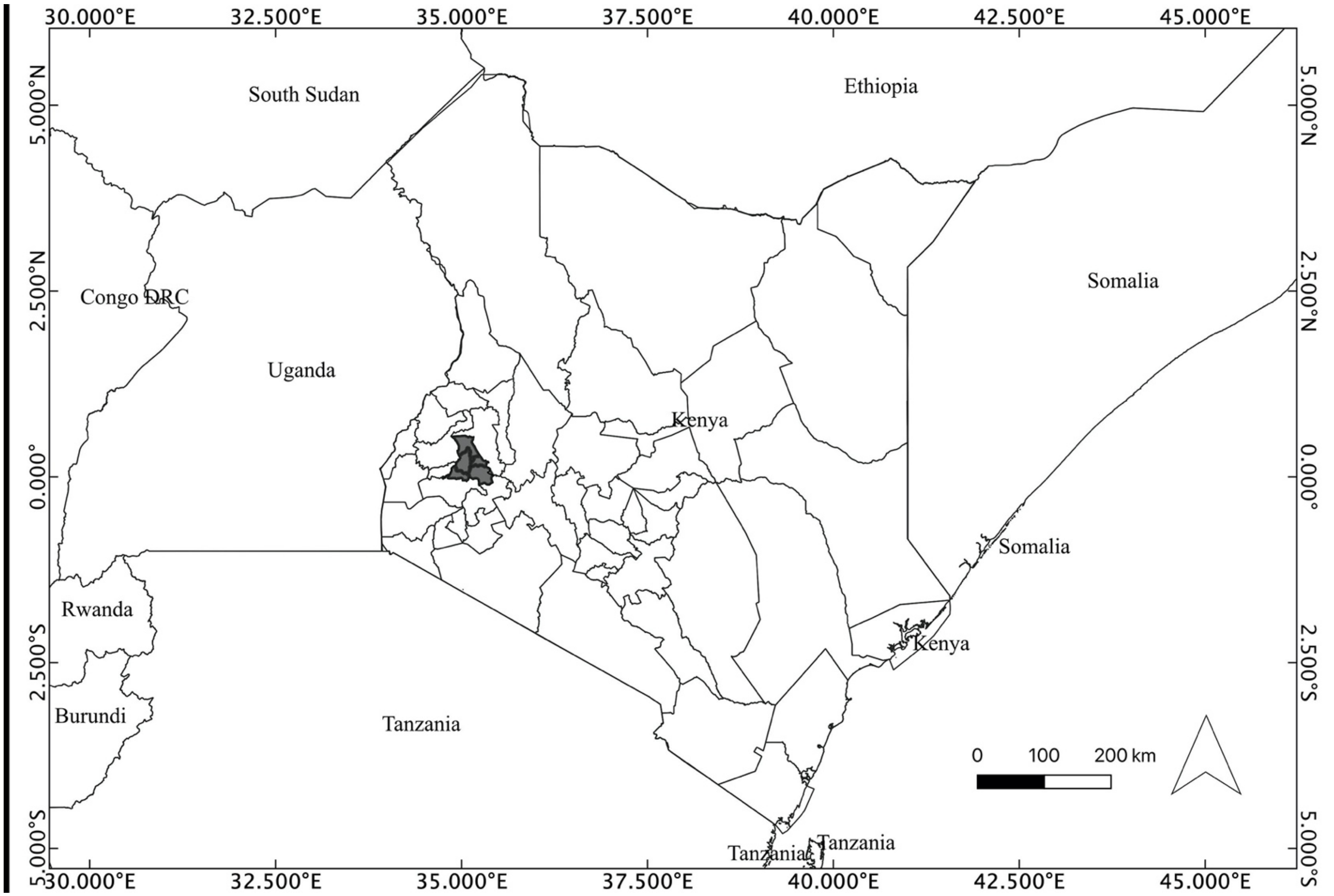


Figure 3:1:Map of Kenya showing the location of Nandi County

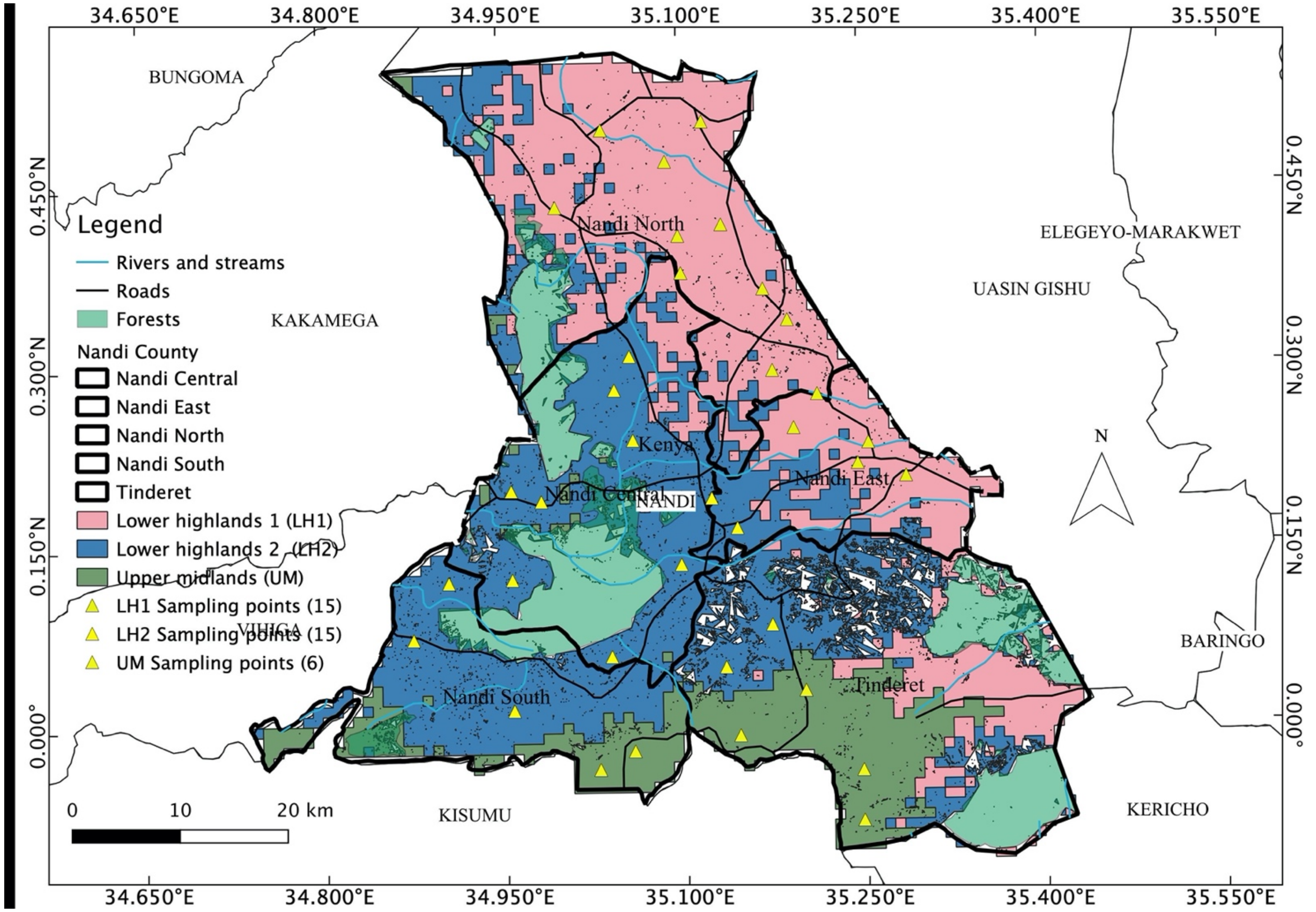


Figure 3:2: Nandi County showing roads, streams and rivers, gazetted forests (green) and sub-counties

3.3 Biophysical setting

3.3.1 Climate

Nandi County generally receives a mean range of rainfall of 1,200 mm to 2,000 mm per annum (Nandi County Government 2018). The short rains start in mid-September and end in November, while the long rains start in early March until end of June (Yego *et al.* 2018). The county usually experiences a dry spell from end of December to mid-March (see Figure 3.3). The lowest rainfall is experienced in the north-eastern and eastern parts of the county (Nandi County Government 2018). The rainfall intensity and distribution has a direct relationship to economic activities in the county with dairy farming being carried out throughout the entire county (GOK 2015). Nandi County experiences mean temperatures ranging between 18°C-22°C during the rainy season and during the dry season the temperatures are as high as 23°C, with mean annual temperatures reaching as high as 26°C (GOK 2015). Between the period 1980 and 2005, the temperatures during the short rainy season remained relatively constant while the mean long rainy season temperatures showed an increasing trend (Kirui *et al*. 2015; Nandi County Government, 2018). Between the period 1980 and 2015, rainfall in Nandi County showed an increasing trend by almost 50 mm especially during the long rainy season (Kirui 2014; Nandi County Government 2018). Climate projections based on two IPCC (2014) Representative Concentration Pathways (RCP 10 and RCP 8.5) indicate that there is the likelihood of further decreases in rainfall and a possibility of a significant rise in drought stress. In both scenarios, the trends point to increasing climate risks for livelihoods in the county (Githui *et al.* 2009; Kirui 2014; Kirui *et al.* 2015; Nandi County Government 2018).

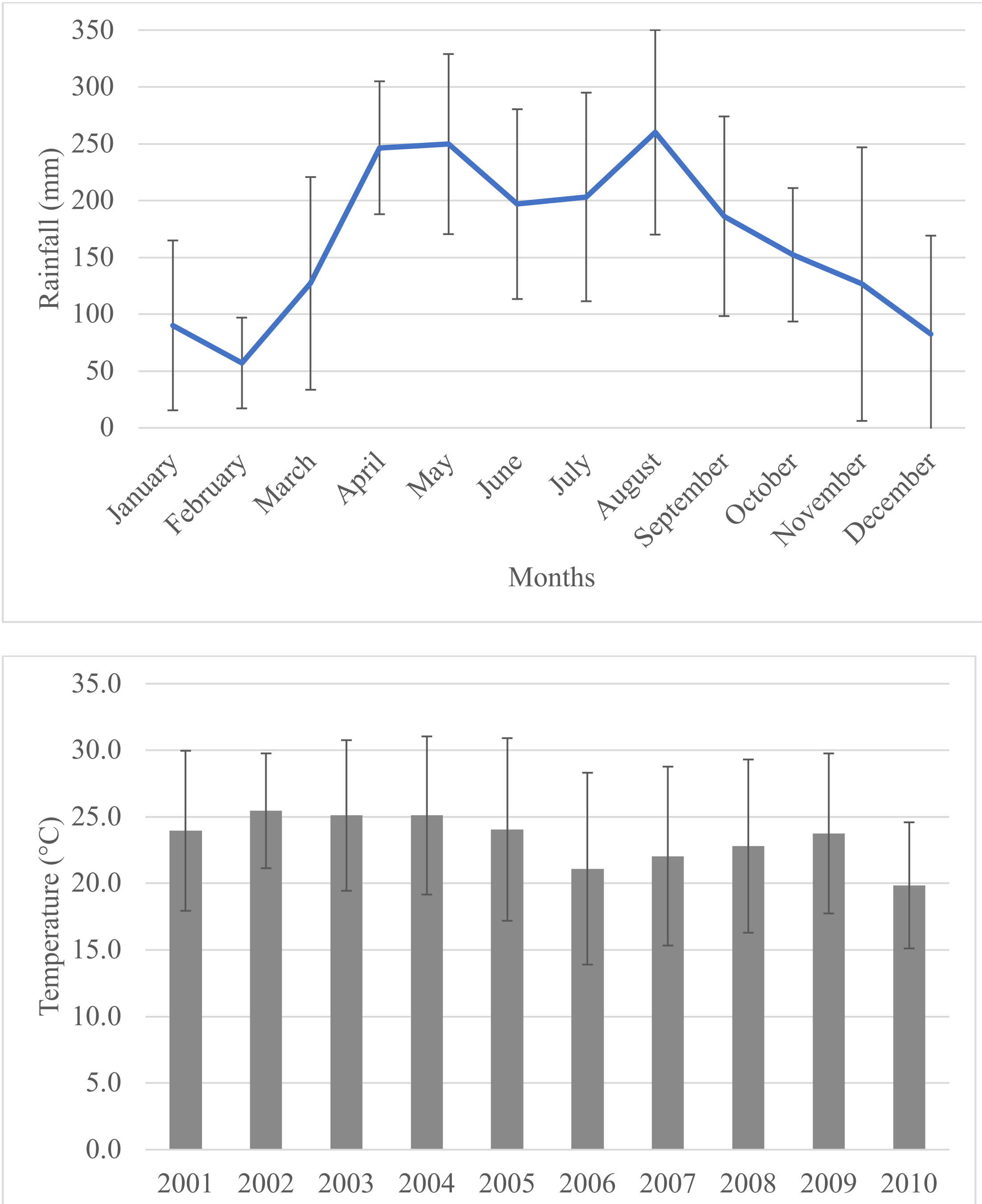


Figure 3:3: Mean Monthly Rainfall (in mm) and Mean Annual Temperature (°C) for the period 2001 to 2010 in Nandi County (GOK 2015). The thin bars show maximum and minimum for each measure.

3.3.2 Vegetation

Forests comprise 12% of the total land area of Nandi County. The forests are Tinderet, Kimondi, Nandi South, Serengonik and Nandi North (Nandi County Government 2018) (Figure 3.2). The forests are characterised by a diverse species of trees. The Kimondi and Serengonik forests are composed of exotic plantations and mixed indigenous hardwoods measuring 2,635.8 Ha (Maua *et al.* 2018). The eastern plateau parts and the portions lying below the escarpment on the Nyando plains are medium potential areas covered mainly by bushes and shrubs (Jeruto *et al.* 2015, Nandi County Government 2018). Gradual reduction of forest area has been observed from 2009 (16%) to 2019 (12%). The South and North Nandi Forest Reserves are at an altitude below 1,900 meters above sea level, contrasting with North Tinderet Forest Reserve which lies between 2,300 meters to 2,500 meters above sea level (Figure 2) (Yego *et al.* 2018).

Nandi County has seven different Agro-Ecological Zones, namely: lower humid highland (LH1), lower sub-humid highland (LH2), lower semi-humid highland (LH3), upper highland (UH), upper humid highland (UM1), upper sub-humid midland (UM2), and upper midland (UM3) (Kassam *et al* 1993; Kirui 2014; Songok *et al* 2011).

3.3.3 Land uses and resources

In Kenya’s factors of production, land is the most important besides labour and capital (Beru *et al* 2018; Ongeri 2014). It is not only a critical resource, but also the foundation of economic development for the country. Land use refers to the activities to which land is subjected to and is often determined by; economic returns, socio-cultural practices, ecological zones and public policies (Briassoulis 2019; Deng *et al.* 2016). The major land types in Nandi are the Nandi escarpment, woodlots, wetlands, rivers, forests, open grasslands with vegetation, valleys and hills, tea plantations and the Kapsabet plateau. These are used for infrastructure, agriculture, nature reserves, water catchments, urban and rural settlements, industry, tourism, recreation and mining, (GOK 2015; Maua *et al.* 2018; Nassiuma and Nyoike 2014). Other uses include fishing, cultural sites, energy and forestry. A larger population in the county derives their livelihoods from land based activities (GOK 2015; Maua *et al.* 2018; Mutoko *et al*. 2015). Nandi County's rainfall and altitude are the main determinants of the agriculture activity in any given agro-ecological zone of the county (GOK 2015; Sahoo *et al.* 2018). The other determinants include the topography and soils. The county experiences strong winds usually observed at the onset of the long rains and have been mentioned to cause damage to other economic activities or crop. The effect of evapo-transpiration is strongest in the dry months of December and January (GOK 2015; Marete *et al.* 2019).

The cattle production systems can be classified broadly as (1) large-scale dairy production system ; (2) small-scale dairy/meat/traction production system; (3) small-scale dairy production system, and; (4) small-scale dairy/meat production system. There are three different breeds of cattle within these production systems, namely; pure breeds (graded cattle; Fresian, Jersey and Ayshire), cross breeds, and local zebu cattle. The cattled are reared under different systems, including semi-zero grazing, free grazing/tethering, or zero grazing systems and depend on fodder crops, natural forage and agricultural by-products as their main feed source (Nandi County Government 2018). The production systems mentioned previously are distributed across the different AEZs (Kassam *et al.* 1993; Kirui *et al.* 2015; Ndung'u *et al.* 2019). Small-scale dairy production is confined to agro-ecological zones UM1-4 and LH2-3. Large- scale dairy production is practiced in agro-ecological zone LH1-3 (Table 3.1). Small scale or large scale dairy farmers are not found in agro-ecological zone LM1-4 (Table 3.1) which covers 61% of the total study area, whereas large scale dairy/meat and small scale dairy/meat production systems are found across all the AEZs (Mudavadi *et al.* 2001).

Table 3:1: Description of Agro-ecological zones of Nandi County by type of crop, temperature and rainfall (GOK 2015)

Agro-ecological Zone	Altitude (m)	Annual Mean Temperature in °C	Annual Average Rainfall (mm)	Long rains (mm)	Short rains (mm)
UH1	Forest	Reserve			
LH1 Dairy/Tea zone	1900-2400	18.0-15.0	1300-2100	630-850	550-800
LH2 Maize/Wheat/pyrethrum zone	1900-1400	18.0-15.0	1300-1800	600-750	500-700
LH3 Wheat/Maize/Barley zone	1900-2300	20.5-15.5	1280-1650	500-680	500-600
UM1Coffee zone		-	-	-	-
UM4	1600-2000	1200-1600	400-600	400-600	500-600

3.3.4 Physiography and drainage

Nandi County has hillytopography. Its physiography can be divided into five units, namely; the Kapsabet plateau (part of Uasin Gishu plateau), the wooded highlands, the rolling hills to the west of the County, and foothills of Tinderet volcanic mass in the southeast, the dissected Nyando Escarpment at the southern border (Nandi South Sub-County) and the Kingwal swamp in the centre (Baraton-Chepterit) (Githui *et al.* 2009; Nandi County Government 2018; Owuor *et al.* 2018).

The Mokong and Kimondi Rivers flow westwards through the Nandi County eventually joining the Yala River. The course of some rivers such as River Kipkaren is slightly northwest (Nandi County Government 2018). The Kapsabet plateau is characterised by an undulating land surface traversed by rivers that form a sub-parallel consequent drainage system incised on the lava surface (Nandi County Government 2018). Geologists indicatethat volcanic lava flowed along the gently sloping plateau northward, having been diverted by a hill at Kabiyet to flow southward across the Kingwal swamp and west towards Sarora Hills. There is a highly rugged landscape fifteen kilometres to the east of the road from Nandi Hills towards Kisumu and Songhor over which volcanic lava flowed (GOK 2015). Rivers in Tinderet form a northwest quadrant of radial drainage pattern (GOK 2015). The Kibos, Kundos, Ainabngetuny and Kipkurere Rivers have deeply incised valleys, flowing southwest. The Kipterges and Kingwal Rivers and their tributaries drain the north western flank of Tinderet highlands. In the centre of the Nandi County, the rivers mentioned produce substantial waterfalls, dropping from the top of harder bands in volcanic rocks to the level of a swamp which foots the scarp (GOK 2015). The Kingwal swamp is a site of a hollow in the original landmass and lies at a height of over 1,960 metres. The nearest basement system rock outcrop is at the swamp near Chepterit. The rivers flow to the west of Nandi County over a series of rapids composed of hard bends in the basement system gneisses. Drainage is prevented to the north and east of the county by volcanic rock and to the south by agglomerates of Tinderet (Nandi County Government 2018). The Equator runs alongside the escarpment line in the area (GOK 2015).

3.3.5 Water resources

Nandi County is endowed with permanent springs numerously scattered across all the sub-counties. Shallow wells have also been dug in homesteads especially in Nandi hills, Emgwen, Chesumei and Mosop sub-counties. Dams constructed before 1963 are also found in parts of Mosop and capture water from major catchments in the area (Nandi County Government 2018).

3.3.6 Biophysical vulnerabilities

Nandi County has been facing deforestation as the major environmental threat, with adverse effects on ecosystems (KNBS 2013; Maua *et al.* 2018). This is caused both by illegal and commercial logging compounded by forest encroachment by communities. The degradation of natural vegetation and enhanced soil erosion, particularly during the rainy season, have been caused mainly by overgrazing. Landslides are experienced along the escarpment during the rainy season, causing property damage and loss of life, and the most affected areas include Uson and Cherondo in Tinderet sub-county (Kirui 2014; Nandi County Government 2018). Land is a prime resource in high potential areas such as Nandi County due to its settlement, agricultural potential and industrial development. Increased population growth has resulted to ever increasing pressure on the limited land leading to degradation through pollution of rivers and streams from excessive use of agrochemicals and erosion. Therefore, population pressure and poverty have contributed significantly to land and soil degradation (Maua *et al.* 2018; Mutoko *et al.* 2015; Nandi County Government 2018).

3.4 Socio-economic setting

3.4.1 Demography

The 2019 Kenya Population and Housing Census (KPHC) documents the total human population of Nandi County as 885,711, with 199,426 households. The population is projected to increase to 1,153,844 people by 2030 and to 1,492,522 people by the year 2050 (KNBS 2019a; NCPD 2017).

3.4.2 Political and administrative context

The county has five administrative Sub-Counties and 11 Divisions. There is a total of 99 locations and 299 sub locations. The county has six constituencies, namely; Chesumei, Mosop, Emgwen Aldai, Tinderet and Nandi Hills (GOK 2015, Nandi County Government 2018). The constituencies are each represented by a Member of Parliament and their respective wards each have an elected Member of County Assembly. The county is represented by an Elected Governor, Senator and Women Representative.

Nandi County was established by the IEBC which is mandated by the Constitution of Kenya through Article 89 of the 2010 Kenyan Constitution (GoK 2015). Within Nandi County county, the Assembly has oversight role for the devolved functions which are executed by an elected governor who forms the executive. It is in this executive that agriculture and livestock is domiciled and the Nandi County Livestock Production Directorate is in charge of offering extension and monitoring the dairy in the county (Nandi County Government 2018). The directorate also oversees the farming of other livestock types; goats, sheep, pigs bees and poultry. The county livestock population and production projections are done by the national Government State Department of Agriculture and reported in the Livestock Survey and the Kenya Population and Housing Census Reports is (Republic of Kenya 2014).

3.4.3 Social and economic aspects

The primary school net enrolment rate is 96% compared to the secondary school net enrolment rate of 51%: the difference in the rate indicates a large number of school dropouts in the county (NCPD 2017). Education challenges are also infrastructural with observations showing schools in the county lacking adequate number of classrooms, libraries, ICT centres and equipped laboratories (GOK 2015, Nandi County Government 2018). Additionally, especially at higher levels of learning the cost of education is high for many. The rate of school dropouts (4.1% in primary and 1.4% in secondary schools) is also a concern. The county has been observed to have low transition rate (44.6%) from secondary to higher institutions of learning hampers educational development.

Economic activities majorly range from farming tea, maize and sugar cane with dairy animals in almost every homestead. According to the 2019 Kenya Population and Housing Census report, 66% of the national population was engaged in wage employment (KNBS, 2019a). Approximately 2% of Nandi county residents are in formal employment while the other residents engage in the informal sector, modern self-employment, small-scale agriculture and agro-pastoralism(Nandi County Government 2018). 44% of the Nandi County population is outside the labour force and 7% is classified as seeking work with none available.

The main economic activity in the county. Declines in agricultural production has been seen to elicit adverse effects on livelihoods in terms of food insecurity and reduced incomes (Beru *et al.* 2018; Marete *et al.* 2019). Most of the food crops popular with farmers are grown on small-scale farms once per year with majority of Nandi County farmers growing tea as the main cash crop. Approximately 10% of the maize crop is harvested while still green for domestic consumption thereby reducing the final tonnage of harvested maize and this practice exposes many households to early incidences of hunger (Nandi County Government 2018).

The county is along the highway to Kisumu from Eldoret town and thus well connected to major roads connecting it to the Eldoret and Kisumu International Airports. Commerce in the county revolves around the hospitality and service industry, general merchandise and agricultural products (Mutoko *et al.* 2015; Nandi County Government 2018; Songok *et al.* 2011). Research and innovation as well as Information, communication and technology uptake in the county is low. Tourism is not well marketed in the county. Extensive marketing is required in order to tap the tourism potential due to there being different species of wildlife in the county. These realisations put Nandi County at an advantageous position in terms of development of trade (KNBS 2010a).

3.4.4 Health setting

The most common diseases in Nandi County are diarrhoea, upper respiratory tract infections, skin diseases, malaria and urinary tract infections (Maiyo and Obey 2016; Ngule *et al.* 2016). Malnutrition is also a major challenge across Nandi County (Gitau 2015; Gitau *et al.* 2019; Nandi County Government 2018). The most affected groups are the elderly, mothers, adults, young children and infants (under 1 year). All forms of malnutrition (severe, chronic and moderate) exist. Stunting stands at 29.9% in the proportion of children under 5 years as compared to 26% at the national level. 11% of the children are underweight, and the wasting rate is at 4%. The obesity rate currently stands at 3.7% and is rising and among the population. Exclusive breastfeeding is at 54% for the infants. These poor indicators are caused by among others: inadequate and inconsistent information, hard to reach areas, low staffing levels, inadequate nutrition commodities, and faulty assessment tools (Jepkemei *et al.* 2019; Gitau 2015).

3.4.5 Socio-economic vulnerabilities

Generally, many of the houses in Nandi County are low cost. It has been observed that unplanned settlements, built using temporary materials such as iron sheets and timber, are sprawling in most of the major towns and centres such as Kabiyet, Mosoriot, Kapsabet and Nandi Hills (GOK 2015; Kirui *et al.* 2015; Maua *et al.* 2018; Nandi County Government 2018). Decent housing remains a big challenge in Nandi County. Three and a half percent of the population in the county lived in urban areas in 2012. The entire rural population uses firewood and kerosene for heating and lighting and only 0.2% of the county population is connected to electricity while the county can serve up to 6.4% of the current population (GOK 2015, Nandi County Government 2018). The cooking fuel sources are kerosene, LPG gas, wood fuel and charcoal and though LPG gas is used in very few households (GOK 2015; Kalenda *et al.* 2015; Subedi *et al.* 2014). The infrastructural facilities in Nandi County are in poor state and inadequate e.g. water, energy supply and road network.

Rainfall pattern has been adversely affected by climate change and the normal planting seasons have been affected due to unpredictable weather (GOK 2015; Hoffmann *et al.* 2001; Nandi County Government 2018; VanLeeuwen *et al.* 2012). The rainfall intensity and distribution have a direct relationship with human economic activities in Nandi County. The areas with above 1500 mm rainfall annually form the extended Agro-Ecological Zones for the current and potential tea cultivation (UM1 and LH1) (GOK 2015). The east and northeast which are relatively drier receive an average rainfall of 1200mm annually and are suitable for sugarcane, coffee and maize growing. Throughout the entire county, dairy farming is carried out (Nandi County Government 2018, Nassiuma and Nyoike 2014). Nandi County has a high potential to produce various agricultural crops ranging from fruit trees, tree crops, cereals, pyrethrum and horticultural crops, due to the reliability of the rainfall in some of the key AEZ in the county (GOK 2015).

Ogola *et al.* (2015) did a study that indicates that smallholder farmers with exotic animals for production were 2.78 times more likely to take up higher decent work practices than farmers with cross breeds or indigenous animals. Studies have shown a strong correlation between decent work index and level of education. This was true especially for farmers who had not proceeded beyond secondary level of education or were illiterate (Ogola *et al.* 2015). This issue on literacy and type of animal are key on how they affect the various practices of smallholder dairy farmers. Dairy farming is susceptible to climate change through changes in rainfall patterns and increased temperatures. These factors affect water availability and feed, breeds and animal health, and in turn milk production (Kasulo *et al.* 2012). Rainfall pattern changes affect pasture growth patterns thereby impacting the quantity and quality of both fodder and feed grains produced outside dairy farming areas. The reason why some farmers do not know about the rainfall pattern changes may be that between 2008 and 2012 period there was no clear defined trend in the amount of rainfall that Nandi County had received (Kasulo *et al.* 2012). Kasulo *et al.* (2012) study implied that smallholder communities may not see climate change and its impacts as an immediate problem.

3.5 Conceptual framework and research design

This Conceptual Framework (CF) shows that the manure management system employed causes loss on nutrients N and GHG emission from manure management (Figure 3.4). This suggests there is a strong relationship between factors affecting the manure management system and information of the impacts of those factors on smallholder dairy farmers practices. It also suggests there is a strong relationship among the mentioned variables; livestock housing, nutrient losses, GHG emissions, manure management and information drivers of practice. The CF hypothesises that there would be different activity data when characterisation of manure management systems is observed for smallholder dairy farmers. It suggests that the manure from different housing would have different nutrient loss rates as well as different GHG emissions and that knowledge of challenges impacting practice can improve manure management, which can further be supported through training on nutrient N loss management based on the smallholder dairy farmer characterisation. The independent variables in this study were temperature and precipitation, while the dependent variables were smallholder dairy farmers manure practices, information awareness on manure management, nutrients leaching and GHG emissions.

The research design employed in this study was stratified random sampling for the household survey conducted through structured questionnaire, Purposive sampling for the Focus Group Discussions (FGD) and Key Informant (KI) interviews separated by gender was done. A further random sampling was done for the few farms where manure was to be sourced for experimentation.

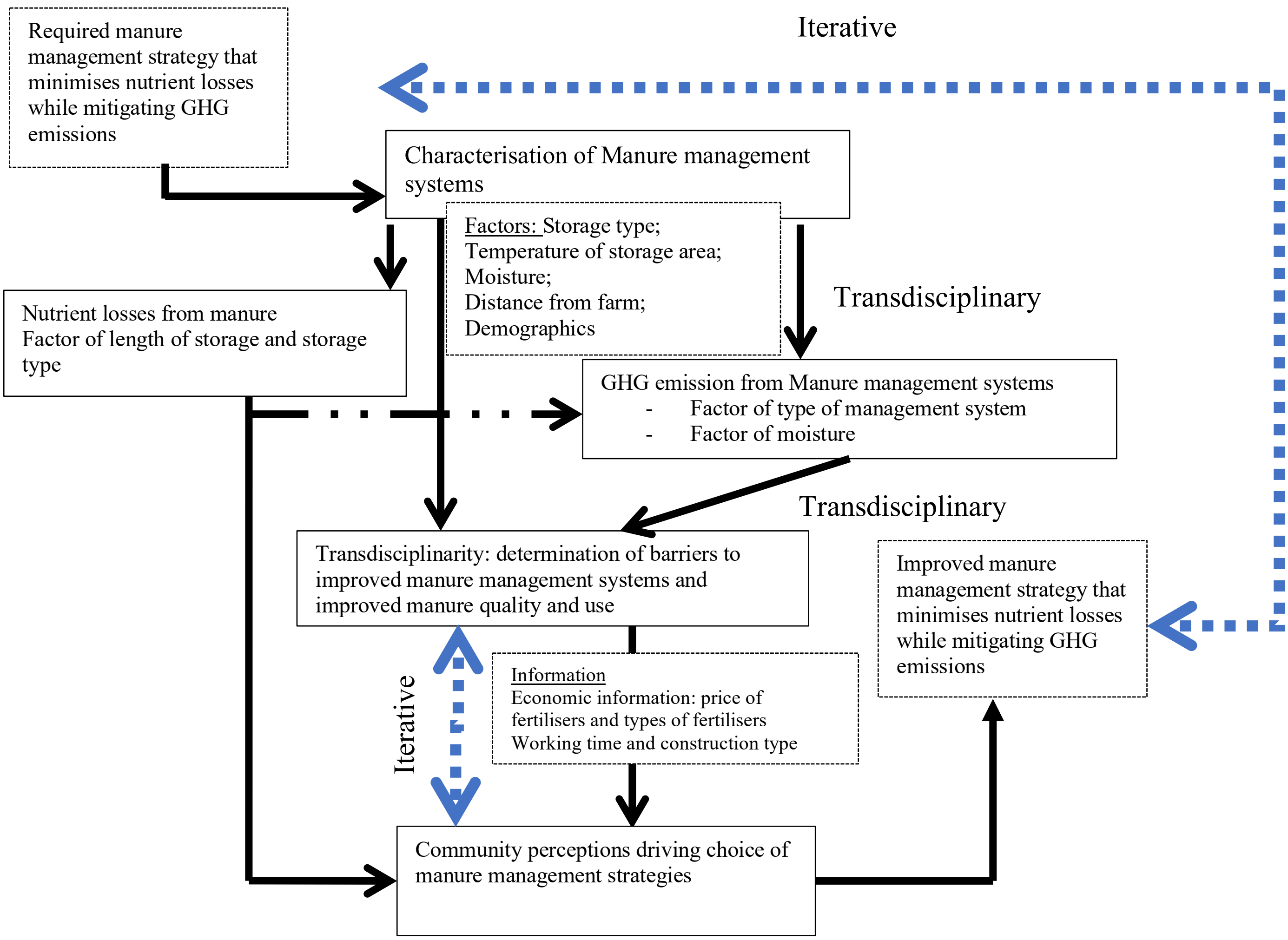


Figure 3:4: Conceptual framework

3.6 METHODS

3.6.1 Objective 1: To characterise the manure management systems utilised by the dairy farmers in the study region

3.6.1.1 Desktop studies

Literature related to smallholder dairy farmers and manure management systems was reviewed. This included livestock housing systems, manure collection and storage practices, and drivers of biogas systems. Other information collated from literature was on how climate affects the type of livestock keeping and how climate also affects manure from different manure handling practices.

3.6.1.2 Stratification of Nandi County

Nandi County was stratified into three biophysical clusters by joining climate variables and classifying spatially explicit biophysical characteristics of precipitation, temperature and elevation. The clusters were combined using a grid square clipped to the Nandi county shape file and classified into three classes (see Figure 3.5). The developed clusters formed the area by proportion in size where random sample points were generated using a geographical information system (KNBS 2016; QGIS 2017; Wilkes *et al.* 2020; World Resource Institute 2015).

3.6.1.3 Participatory mapping

Nandi County has been recognised for its high agricultural potential (Mudavadi *et al.* 2001, Republic of Kenya 2014). A participatory engagement for map validation was conducted, including expert knowledge from agricultural and livestock stakeholders, to delineate production groups based on sub-location. Our approach resulted in three independent clusters of agro-ecological zones in the county (see Figure 3.5). The first cluster (LH1 cluster) comprised an area of approximately 934.3 km^2, with elevations above 1900 m asl, and high level of seasonal variation in precipitation thus having distinct short rains and long rains. The second cluster (LH2) comprised an area 1100.7 km^2 with an elevation ranging from1400-1900 m asl and low level of seasonal variation in precipitation characterised by unimodal rainfall in the months of March to October. The last cluster (UM) comprised an area of 364.7 km^2 with elevations below 1400 m asl and high seasonal variation in rainfall. Forested areas (> 80% tree cover) were masked out as not relevant for the sampling in this case (see Figure 3.6).

A road network was applied to restrict the sampling space across the three strata using a buffer size of 2 km for accessibility reasons, including replacement points (one reserve per sampled village) with a minimum distance among points of 3 km (see Figure 3.6). Sampling points (36 points) were generated with QGIS factoring nearness to roads and masking away forested areas with assumption that there were no people living in the forest as well as none on the road. The 36 sampling points were hence located away from forests because these forests in Nandi County are predominantly gazetted as national forests, which, grazing is prohibited in Forest Conservation and Management Act number 34 of 2016's section 64 (1) (Republic of Kenya 2016). Area of the clusters was used in the weighting to realise the number of sampling points to be assigned to each of the three clusters, resulting in six sites located in the UM cluster and 15 sites each being in the LH2 and LH1 clusters and (see Figure 3.6).

3.6.1.4 Household survey process

The study population as a sampling frame was the farming community in Nandi County while the study's target population was the dairy cattle farmers' households. This study used for acquisition of activity data a survey of households which was done using a questionnaire tool to be delivered as interview that was customized from the Integrated Modelling Platform for mixed Animal Crop systems (see Appendix 1). This tool was modified from IMPACT to collect detailed household-level data to capture the within-household variability on livelihood and key performance indicators. This tool was developed initially to encourage data sharing through standard protocols, and allowing linking of tools to facilitate evaluations of various smallholder farming practices (CCAFS 2016; Diogo *et al.* 2013; Herrero *et al.* 2010; ILRI, 2016; Lekasi *et al.* 2003; Rufino *et al.* 2013; Wilkes *et al.* 2020). The smallholder farmer household was the unit of analysis. The procedure and formula below was employed in order to get a good representative of the targeted population.

Sample size was computed using Fischer's formula as described by Mugenda and Mugenda (2003) and shown in Equation 1:

$$n = \frac{N}{1+Ne^2} \qquad \text{Equation 1}$$

Where the sample size is n, the targeted population N (N= 413117- adult population of Nandi County removing youth below 15 years which comprised 45% of the total human population (KNBS 2010b, NCPD 2017). The desired confidence level is **e** (e=5%) of the sample population. The population of Nandi County which is 751129 (KNBS 2010b) removing 45% who are youth below the age of 15 (NCPD 2017) gives 413117 which was considered the study population in the computation of the sample size. The confidence level was taken to be 5% level if significance with the calculation shown in Equation 2 below:

$$n = \frac{413117}{1+413117(0.05)^2} = 399.61 \approx 400 \qquad \text{Equation 2}$$

At each of the 36 random points (see Figure 3.6) approximately 12 smallholder farmers were targeted for interviewing. Cumulatively, this generated a total sample size of close to 400 smallholder farmer households of which 336 consented to being interviewed. The study response rate was actualised at 84.8%. This data was above the response rate of 70% which is considered good (e.g. Babbie, 2013).

The household questionnaire was administered from October 2015 to March 2016, targeting the person responsible for caring (feeding and milking) for the cattle, and using a digital platform called Open Data Kit (ODK) (ODK 2017). In case of absence of the household head during the interview dates, the senior-most member available was interviewed. In the execution of the actual household survey, the enumerator after interviewing the first household bypassed the second and third and interviewed the fourth household. This was continued until the computed estimated sample size was attained.

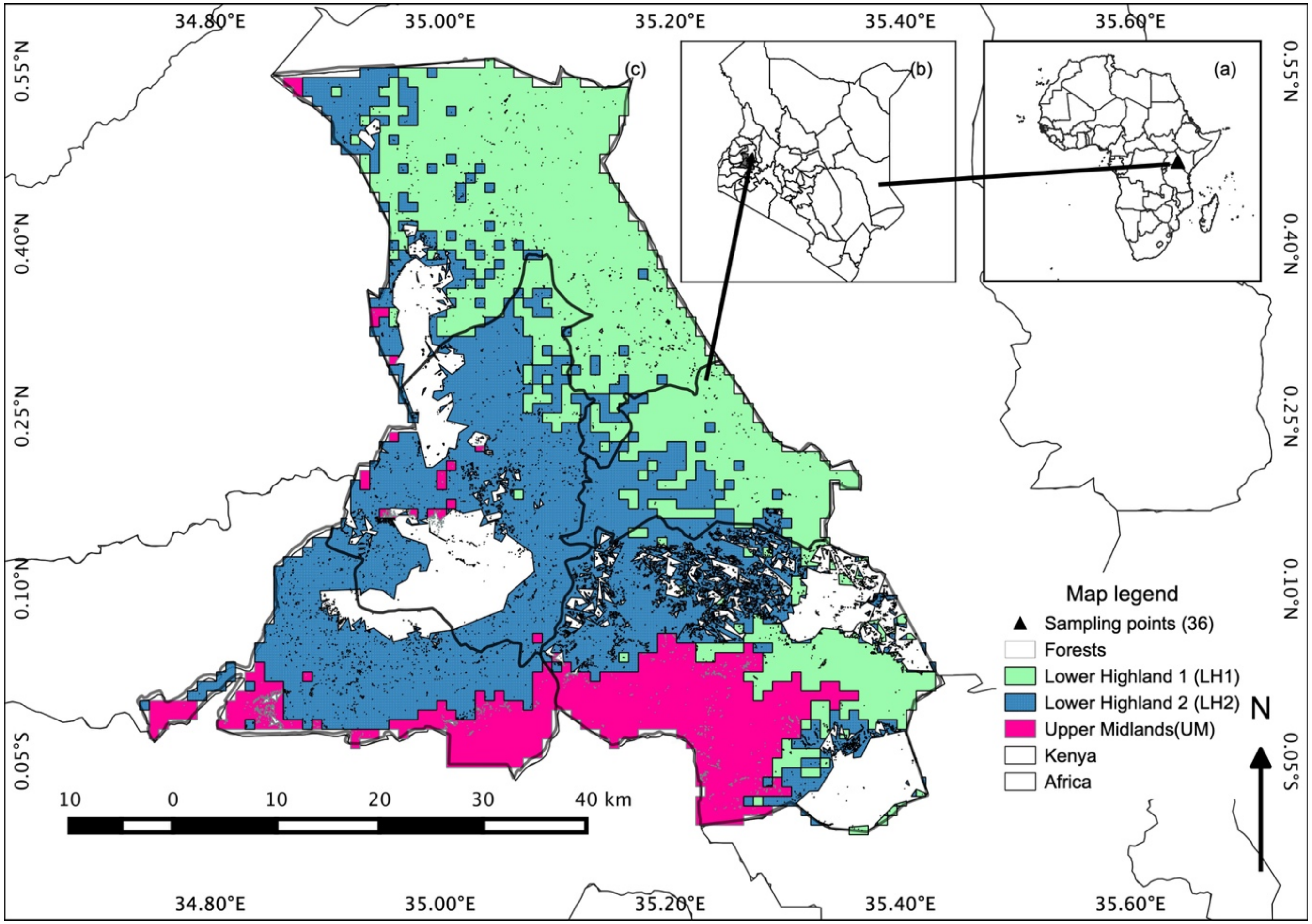


Figure 3:5: Map of Africa, Kenya and nandi county as main, showing the derived biophysical zones.

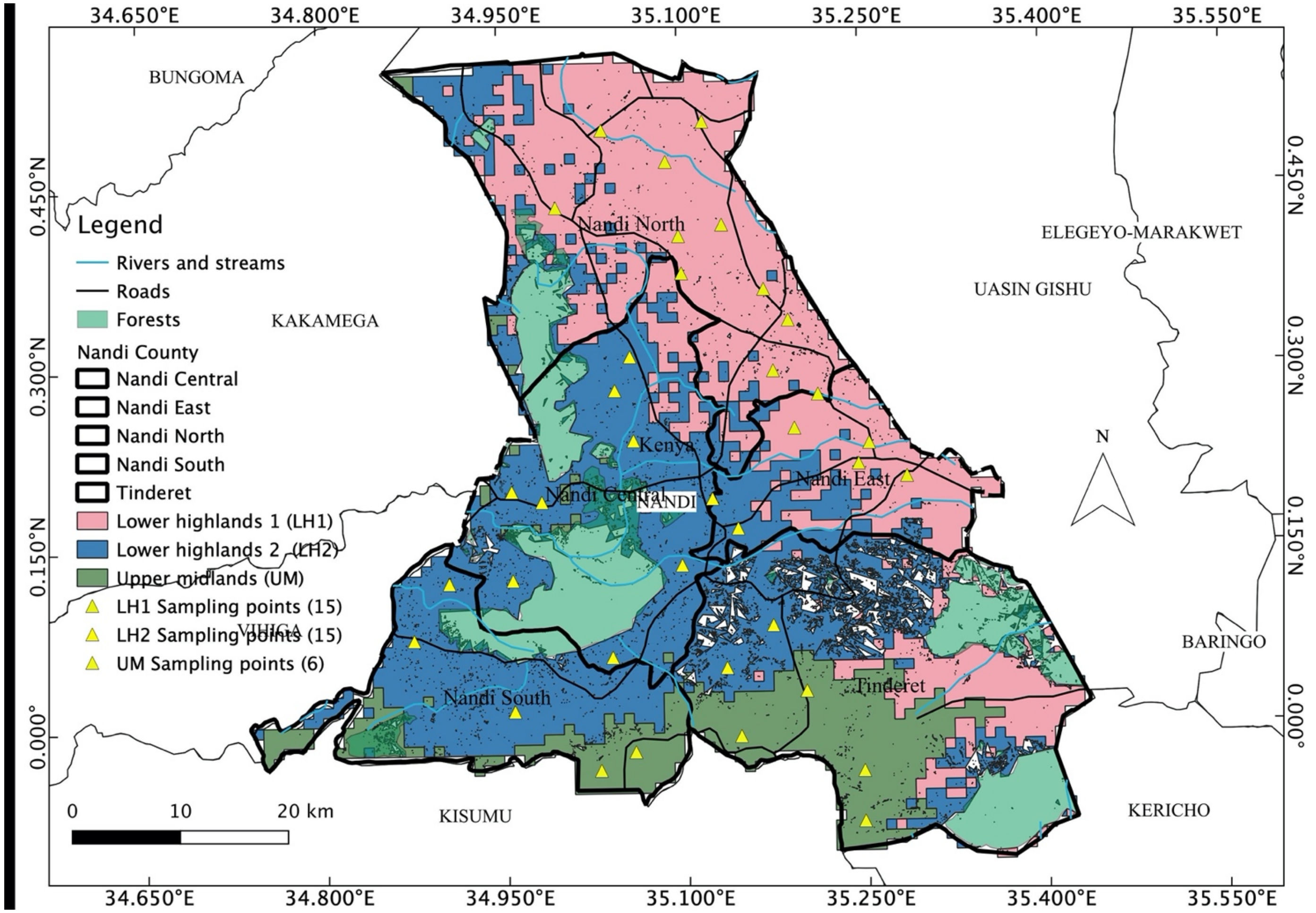


Figure 3:6: Detailed map of Nandi County showing the sampling points in each of the derived biophysical zones.

3.6.1.5 Data analysis

A determination though frequency and factor comparison of the primary income categories (poultry, others, crop and dairy,) as well as farm utilisation and acreage and other farmer demographic data on literacy, age and gender was made. Dairy cattle confinement systems generally fall into four categories; ‘Fence, Roof and Floor (FRF)’, ‘Fence and Floor (FF)’, ‘Fence and Roof (FR)’ and ‘Fence Only (F)’. “Fence” refers to boundary confining movement, “Roof” is a structure providing shade and protection from insolation and precipitation, and ”Floor” refers to an impermeable surface constructed to prevent leaching so that “FR”, for example, means that there is no constructed floor, rather, it is the natural earth surface that comprises its floor

Animal confinement systems were used to define manure management systems. Smallholder dairy farmers systems of manure management thus derived were characterised based on the location of manure deposition, state of manure being deposited and storage type of the collected manure. The state was either dry (period more than 24 hours from excretion) or fresh (period less than 24 hours from excretion) or slurry (liquid manure). Deposition location was the location from where the collected manure was sourced from on the farm; as either on F or FR or FRF, since FF, which was included in the survey design, was not observed in the field. Storage of the collected manure was characterised as: a silo for composting; a pit for fresh, dry or slurry; or a lagoon for slurry especially from FRF, and; pile/heap of either fresh or dry manure.

The slurry was characterised according to source of manure, whether from anaerobic digesters or from FRF systems. Liquid manure management (slurry) comprised of (1) stored urine (2) solid and liquid manure in lagoon/pits/silos (3) split slurry, where farmers drained the liquid through allowing leaching and sun drying by spreading the solid remains and (4) composting manure. The manure from these practices were categorized into Slurry, Fresh Heap or Dry Heap. The manure management systems derived were mapped to reflect distribution of practices on the ground.

The length of storage of manure before utilisation on crop/pasture farms, an indicator of manure quality, was classified into three periods; ‘less than 30 days’, ‘3-4 months’ and ‘greater than 4 months’. This was from the literature where storage length was related to the resulting quality of manure (Markewich *et al.* 2010). The time of manure incorporation into crop farms was compared to the planting season of the crops on which manure was used.

Each surveyed household and farm where manure was deposited on farm were geo-referenced. The number of the different cattle confinement systems and manure management systems as well as the mean farm size and land area available for grazing within each biophysical cluster were calculated using both descriptive and inferential statistics on R-Studio Version 1.0.136 (Rstudio Team 2016) using a one way ANOVA with block effect (cluster) and treatment effects (confinement systems) which allowed the use of contrasts for the clusters and confinement systems which was done using TukeyHSD range test using $p<0.05$. A T-Test was used for any pairwise comparison of measurements that were just compared by gender but still with a 95% confidence level.

3.6.2 Objective 2: To estimate N losses during storage for the different management systems

3.6.2.1 Desktop Studies

Different information on how manure loses nutrients during storage, and the relationship of manure nutrient losses and livestock housing as well as manure storage practices were assessed. Further information was studied on how the manure storage periods impact nutrient losses. This information on nutrient losses was sourced from online sources and university libraries of peer reviewed literature with a special focus on manure nutrient losses due to manure storage practices that are similar to the smallholder dairy practices in Nandi County. Further information studied included; what manure storage systems lose most nutrients, how different manure from different livestock confinement systems lose nutrients, how weather affects nutrient losses from manure, and what amendments can be done to minimise nutrient losses from manure.

3.6.2.2 Collection of manure samples for analysis (field work)

Fresh manure was collected from Nandi County, Kenya. Three smallholder dairy farmers per confinement system were selected to represent these confinement systems across the agro-ecological zones in Nandi County, Kenya (see Table 3.2), and therefore were representative of the animal confinement systems existing in Nandi County. This group also represented the smallholder dairy farmers that use 'solid storage' as a manure management system. From each of the nine smallholder dairy farmers, the fresh manure collected was approximately 100 kg, totalling 941.62 kg cattle manure (deposited in the night and during the morning of collection) between 27^{th} and

28th January 2017 (see Plates 3.1 and 3.2).The manure after collection was placed into polythene bags and packed into three covered 30 litre buckets and transferred to the laboratories at Mazingira Centre of the International Livestock Research Institute (ILRI) in Nairobi, Kenya.

Table 3:2: Summary of the farms where manure for the experiment were sourced

Confinement system	Main income category	Number of dairy animals	Longitude (WGS 84 EPSG 4326)	Latitude (WGS 84 EPSG 4326)
F	Crops	6	35.03058168	0.069974315
F	Dairy	12	35.07595832	0.396123333
F	Crops	5	35.28798001	0.197049520
FR	Dairy	2	35.14228130	0.166212006
FR	Dairy	2	35.16811733	0.085272902
FR	Crops	4	35.16260178	0.089217694
FRF	Other-Salary	4	35.10651666	0.129926667
FRF	Dairy	3	35.23589550	0.215495427
FRF	Crops	4	35.06003239	0.226800228

The manure from each farm was mixed to form a composite sample for representing the confinement system found in the study area and split into three heaps per confinement system totalling to nine heaps (Table 3.1, Plate 3.3). This was done as a data quality measure to minimise variations among farms with similar livestock confinement so as to be representative of the most common manure management system of 'solid storage' of fresh heaps (Peters *et al.* 2003).

Photo taken 26/01/2017 Source: Author

Plate 3:1: Researcher collecting fresh manure from smallholder dairy farmer enclosure.

Photo taken 26/01/2017 Source: Author

Plate 3:2: Researcher putting collected fresh manure in a bucket lined with black polythene bag.

Photo taken 26/01/2017 Source: Author

Plate 3:3: Uncovered manure heaps in concrete chambers showing containers (green) to collect leachate

3.6.2.3 Manure quality measurement (laboratory measurements)

The manure quality measurements were undertaken at ILRI (located at 1.2921° S, 36.8219° E, 1874 m asl.) in Nairobi, Kenya, and samples were analysed in replicates for each of the confinement systems found in the smallholder dairy farms - Fence Only (F), Fence and Roof (FR), Fence, and Roof and Floor (FRF). Fence and Floor (FF) systems was not observed hence there was no manure from this system. The mean annual rainfall at the laboratory site is approximately 900 mm, ranging from 500 mm to 1500 mm in any one year, with over 70% of this precipitation occurring during the long rains between March and May (Ombuna *et al.* 2017). The remaining 30% of rainfall occurs predominantly between October and December. The mean daily maximum temperature ranges from 25.5°C in January (warmest month) to 22.0°C in July (coldest month) for most parts of Nairobi (WMO 2017)

.

Manure sub-samples (125 g) were removed from each heap on four dates (day 0, 28, 57 and 91) defining three experimental periods (Period 1, days 0-27; Period 2, days 28-56; and Period 3, days 57-91) for total C and N concentration and dry matter (DM%) content determination. Samples were collected from the manure heaps by inserting a plastic pipe (diameter 5.08 cm) and pushing through to the middle of the heap (see Table 3.3). Manure water content was calculated by weighing 100 g of fresh manure and then weighing it again after drying at 35°C in a ventilated oven until a constant weight was achieved. Total Carbon and Nitrogen concentrations were determined using a three 10-mg sub-sample of dried, acidified (4:1 ratio of 0.5M HCl: sampled manure from the study heap) and ground (Retsch MM 400 mixer mill, Retsch GmbH, Haan, Germany) manure. The manure was analysed on an automated elemental combustion analyser (ECS 4010 CHNSO Analyzer, Costech International S.o.A., Milan, Italy). Carbon and Nitrogen elemental analysis was used to derive the C and N ratios in the manure. At the beginning of the analytical cycle, the helium carrier gas is passed flushed through with quantity that is selected by the user depending on the composition and size of the sample. The samples are inserted sequentially into the combustion reactor prior to the arrival of oxygen. The material sample and tin capsule react with oxygen and combust at temperatures of 1700-1800 °C and the sample is broken down into its base elemental components represented by the compounds N_2, CO_2, H_2O and SO_2. High capacity copper wires absorb the extra oxygen not used for sample combustion. The gases flow through the gas chromatographic (GC) separation column which is maintained at a constant temperature (± 0.1 °C). As they pass through the GC column, the gases are separated and are detected sequentially by the Thermal Conductivity Detector (TCD). The TCD releases a signal, which is proportional to the amount of measured element in the sample. The machine software compares the elemental peak to a known reference standard material (after calibration) and generates a report for each element on a weight basis. For Continuous Flow Isotope Ratio Mass Spectroscopy, the separated gases are carried to the mass spectrometer interface and into the Mass Spectroscopy source (COSTECH 2005).

Leachate was checked daily from sealed collection containers (20 litre capacity) that collected all the liquid that drained from the manure heaps in the concrete chambers. Any available leachate from the containers was measured for total daily quantity using a measuring jar calibrated to the nearest ml. A 14 ml sub-sample was sourced from the measured daily quantity and frozen in plastic falcon tubes for Total N (Kjeldahl N) analysis using the Kjeldahl method (Baur and Ensminger 1977).

3.6.2.4 Data analysis

The C-N Analyser was used to establish the quantity of C and N in the prepared dry matter of manure piles and the quantity of C and N was used in the calculation of nutrient losses for each confinement system and period. The C and N concentration results from the analysis was multiplied by the amount of dry matter after which total direct N lost from the manure was determined by subtracting the final N concentration from initial N concentration in the manure. Differences in the Total N of the leachate from the observed three different confinement systems (F, FR, FRF) together with the dry matter for each of the four sampling period were compared to account for loss of N for each of the four periods (Table 3.3). The C and N data of the manure from the four different confinement systems (F, FF, FR, FRF) were analysed for difference using ANOVA with fixed factors "period of sampling" and "confinement system" and tabulated.

Table 3:3: Measurements carried out on manure

Date (Four sampling dates)	Period	Confinement	Moisture content (%)	Manure Dry Weight (kg)	C (%)	N (%)	C: N ratio	Kjeldahl N (g)
29th Jan 2017	Period 1							
Feb 26th 2017	Period 2	From the characterised confinement systems	Established for the period 1	Established for the period 1	Established for all periods	Established for all periods	Established for all periods	Established for all periods
Mar 28th 2019	Period 3							
May 1st 2019	Period 3							

3.6.3 Objective 3: Quantification of CH_4, CO_2 and N_2O emissions from manure from the various manure management systems and to develop management system specific emission factors

3.6.3.1 Desktop studies

Information was collected on manure GHG emissions during storage and this specifically focused on manure emissions from dairy farm systems. Different information on how manure emits GHGs during storage and the relationship of manure GHG emissions and livestock housing as well as manure storage practices were assessed. Further information was studied on how the manure storage periods impact GHG emissions. This information on GHG emissions was sourced from peer reviewed literature through online sources and university libraries, with a special focus on how manure emits GHGs in manure storage practices that are similar to the smallholder dairy practices in Nandi County. Further information studied included; what manure storage systems emits most GHG and at what specific rates the specific GHGs emitted, how different manure from different livestock confinement systems emit GHGs, how weather affects GHG emissions from manure, and what amendments can be done to minimise GHG emissions from manure.

3.6.3.2 Manure GHG measurement (laboratory work)

The manure was placed in a concrete heap chamber that would allow for measurements of GHG emissions (see Plate 3.4). This was also left uncovered to mimic farm conditions of uncovered heaps of fresh manure. Each of the manure heaps was weighed and placed into separate $1m^2$

concrete chambers (Plate 3.4) for 92 days (from 31 January until 1 May 2017), which corresponds to the end of the dry season and the transition into the long rains. This length of study was selected for two reasons (1) existing literature shows only measurements for up to 30 days and (2) the period correlates with field observations on smallholder dairy farmers major manure storage practices.

Photo taken 26/04/2017 Source: Author

Plate 3:4: All the nine chambers with manure heaps for GHG emissions as well as leachate collection

The concrete chambers were constructed with 30 cm high walls, with a plastic trough (collar) set into the top of each wall and an outlet tube (diameter 5.08 cm) in the centre that was sealed with a densely meshed fabric to allow for leachate to flow out without losing the solid parts of the manure. A container 20 litre was placed at the end of each drainpipe to collect all the leachate from the individual chambers (Plate 3.4). The covering chamber was $1m^3$ and had both a septum for sampling of the GHG and a ventilator on the other side to avoid pressure build up (see Plate 3.5). Greenhouse gas emissions (CH_4, CO_2 and N_2O) were quantified on a daily basis for the duration of the study using non-steady state, non-flow through chambers (Butterbach-Bahl *et al.* 2011, Pelster *et al.* 2017) (see Plate 3.5). A concrete moat was installed around the manure, filled with water and then a large (approximately 1 m^3), ventilated and vented, air-tight chamber was placed over the top of the manure. The chamber was left in place for 24 minutes and during this period, 60 ml air samples were removed via a gas-tight syringe injected through a septum at the following time intervals: 0, 4, 8, 12 and 24 minutes (see Plate 3.5). Each of the gas samples was then put in pre-evacuated (using a vacuum pump) 10 ml glass serum vials capped with grey septum. The samples were immediately analysed for CO_2, CH_4 and N_2O concentrations in an SRI 8610C (2.74 m Hayesep-D column) gas chromatograph fitted with a ^{63}Ni-electron capture detection for N_2O detection, and a flame ionisation detector for CH_4 and CO_2 (with CO_2 passing through a methaniser). The flow rate of the carrier gas (N_2) was 25 mL min^{-1}. The gas sampling was done once per day at 9.00am, although on days with significant precipitation, it was sampled twice (before – if possible, and after the rains) to determine if there was any difference due to incoming water to the manure. This sampling programme run 30th January 2017 through to 30 April 2017, a period of 90 days.

Photo taken 17/03/2017 Source: Author

Plate 3:5: Researcher collecting daily gas samples for GHG measurement of flux

Weather data (air temperature and precipitation) was collected at the measurement site (1.2921° S, 36.8219° E, 1874 m asl) from a weather station that was installed <100m from the experiment location. Outdoor air temperature was measured using a thermometer from Decagon ECT (Decagon Devices, Pullman, Washington, USA) air temperature sensor that records automatically every 5 minutes, while precipitation was measured using a double-spoon tipping bucket rain gauge (Decagon ECRN-100). The data were logged digitally on a Decagon Em50 data collection system and downloaded weekly.

Greenhouse gas emissions concentrations were derived using gas chromatographs (GC) (Butterbach-Bahl *et al.* 2011). The GC was equipped with a Flame Ionization Detector (FID) and Thermal Conductivity Detector (TCD) to detect CO_2, CH_4 and N_2O. This TCD configuration on the SRI 8610 GC system is used for the analysis of gases. Water, oxygen, other non-hydrocarbons and nitrogen respond well with detection limits in the 100ppm range (GMI 2015). The SRI 8610 GC eliminates TCD burn out with its filament protection. The SRI 8160 GC for FID allows for hydrocarbon detection down to 1 nanogram and responds linearly over a majority of its range. Hydrocarbons ionize in the hydrogen gas flame and are attracted to the metal collector electrode. A ceramic ignitor glows permanently to prevent flameouts and re-ignites when the flame is flooded with water (GMI 2015). If the TCD and FID are connected in series on the SRI 8610 GC one may perform two analyses of the same sample at once (SRI 2017).

Manure greenhouse gas emission fluxes were calculated by the rate of change in concentration over a given time in the chamber headspace. This was calibrated for average air pressure and daily temperature as shown in equation 3:

$$F_{GHG} = \left(\frac{dc}{dt}\right) * \left(\frac{M}{V_m}\right) * \frac{V}{M_m} \qquad \text{Equation 3}$$

Where the $\mathbf{F_{GHG}}$ is flux of the GHG being calculated, **dc/dt** is the change in concentration over time, which was transformed from minutes to hours, $\mathbf{V_m}$ is the molar volume of gas corrected with average daily temperature and atmospheric pressure (Butterbach-Bahl *et al.* 2011, Pelster *et al.* 2017), **M** is the molar mass of the element C for CO_2 and CH_4 and N for N_2O, $\mathbf{M_m}$ is the mass of Carbon or Nitrogen from dry matter of manure **,** **V** is the volume of the chamber headspace. The units for $\mathbf{F_{GHG}}$ are CH_4 and CO_2 in mg C $kg^{-1}hr^{-1}$ and for N_2O in µg N $kg^{-1}hr^{-1}$.

All the 5 single day measurements per chamber were used to determine the slope for the CO_2, CH_4 and N_2O emission rates. Quality control of the fluxes were done to ensure only true fluxes for GHG were used in the analysis. This entailed checking if the fluxes had correlation values CH_4 R^2 >0.80, CO_2 R^2>0.99 and N_2O R^2>0.70 in order to be used for further analysis. The hourly fluxes were then transposed to daily fluxes by multiplying daily F_{GHG} with 24 hours and from these, cumulative fluxes for each GHG were determined.

3.6.3.3 Data analysis

A two-way ANOVA was used to test for differences in cumulative GHG emissions using confinement type and period as the two factors (Rstudio Team 2016). Calculation of the global warming potential (GWP) was done for CH_4, CO_2 and N_2O using Myhre *et al.* (2013) guidelines so as to be able to compare the GHGs emitted from manure from each of the four livestock confinement systems. In these guidelines, CH_4 has 34 and N_2O has 298 times greater GWP than CO_2 on a per mass basis over a time horizon of 100 years (Myhre *et al.* 2013).

3.6.4 Objective 4: To determine and explore with the community manure management strategies that would minimize N and C losses while mitigating GHG emissions

3.6.4.1 Desktop studies

Information was collected on community perceptions and practices to manure management and this focused specifically on barriers to manure handling, manure removal from livestock housing systems and source of awareness of farm practices. Different information on barriers to improvement of manure management and livestock housing as well as manure storage practices were assessed. Further studies were done on community barriers and drivers of practice change and how climate information affects smallholder farmers' use of manure.

3.6.4.2 Focus group discussions

Focus Group Discussions (FGDs) were used to evaluate the barriers to manure management and assess options for improved manure management. A questionnaire was administered through the FGD groups to determine the practices in regard to manure collection, storage and manure management systems (see Appendix 2). This survey was delivered to three groups each located in cluster LH1, LH2 and UM then each split into two groups based on gender (see Table 3.4). The FGDs were used to rank and evaluate the households' feedback on household and institutional constraints to improve manure management. The FGDs evaluated and ranked intervention options and highlighted the manure management system that they would find easiest to implement with reasons. The FGDs then were used to appraise the manure management practices found in Nandi County using a community perception analysis (Aueatchasai and Fongsuwan 2015; Marin *et al* 2009; Ngugi 2003).

Table 3:4: Focus Group Discussion dates and locations

Biophysical Cluster	FGD Location and composition	Dates
LH1	Kilibwoni (Male 12 vs Female 13)	26th July, 2016
LH2	Chepkumia Church (Male 7 vs Female 17)	27th July, 2016
UM	Chemase Church (Male 11 vs Female 18)	28th July, 2016

3.6.4.3 Data analysis

The same procedure was followed as in Objective one. The dataset comprised household survey results and the FGDs. Content analysis was used to analyse the part of household surveys that corresponded with FGDs and this was then tabulated. Focus Group Discussion themes were developed, narratives compiled and cluster analysis was used to determine the natural groupings in the survey. The other variables on source of information on manure management, awareness, type of constraints were analysed using frequency tables.

3.6.5 Objective 5: To generate community perceptions driving choice of manure management strategies

3.6.5.1 Desktop studies

Information was collected on costs of various inputs and practices to supplement cropping, input sources and incentives available to farmers. Different information on how various practices lead to cumulative losses in terms of costs for farmers and how improved manure management practices can save farmers costs were assessed. Further studies were done on costs and subsidies available to smallholder farmers from policy standpoints.

3.6.5.2 Key informant interviews (field work)

Key informant interview questionnaires were used in collecting information as an administered questionnaire or interview from 11 KI (see Appendix 3). They were purposely sampled from Nandi County. These included interviews from milk collection actors (KCC and Brookside), Chebut Tea Factory, large scale dairy farmers, Ministry of Agriculture and Livestock and university lecturers.

3.6.5.3 Market survey (field work)

A market survey was carried in six key markets out to determine the costs of inputs, compost and N fertilizers, labour for various dairy farm jobs, and construction materials for making biogas. The survey also looked for key output prices like price of compost manure, non-compost manure, buying frequency, and buyer. Issues on manure production were captured through questions on age of manure preferred, where manure was used, and farmer perception of using manure.

3.6.5.4 Data analysis

In order to generate perceptions of the common manure management practices, cluster analysis was applied to variables representing the following constructs: gender, age, education level, total available household labour, grazing acreage, total acreage, total number of dairy livestock available in the household, main income category of the household, and quantity of manure management systems in the farmer household. These variables were factors (gender, income category and education level), integer (age, household labour, dairy cattle population and quantity of manure management systems per household) and numeric with decimals (grazing acreage and total acreage). These key variables would be used to cluster 'natural groupings' of these nine variables to derive the optimum number and type of clusters. This was attained by minimising the squared Euclidean distance within a decreasing number of identified clusters containing an increasing number of positively correlated variables and using Base R Package (RStudio V 1.1.442) within which plotted dendrogram and derived plot showing optimal number of clusters using k means was generated (Chibanda *et al.* 2009). Each of the variables used in clustering was described as percentages (income category, gender, education level) and means (total acreage, household labour numbers, age, acreage under grazing, number of manure management systems in use per household and household dairy numbers). The resultant clusters were then described according to technical, socio-economic and institutional constraints prohibiting optimal manure management.

CHAPTER FOUR: CHARACTERISING MANURE MANAGEMENT SYSTEMS

4.1 Introduction

This chapter addresses objective one of this study. It describes the characterisation of the manure management systems utilised by the Nandi County's smallholder dairy farmers. The focus on this characterisation begins with demographic description of the smallholder dairy farmers in terms of age, gender, gendered education levels, area inhabited in terms of the agro-ecological zone (AEZ), and the main income category. Farm use and acreage are presented by the AEZ and income categories. The livestock numbers and housing systems are presented by AEZ and income categories. The manure management systems being used by the smallholder dairy farmers are presented by AEZ and income categories.

4.2 Results

4.2.1 Smallholder dairy farmers demographics

At each of the 36 random points (see Figure 4.1) about 12 farmers were targeted for interviewing of which 336 out of total target of 400 consented to be interviewed for this study. The study's actual response rate was 84.8%. The study did not acquire 100% of the targeted households due to some smallholder households refusing the interview, or sharing the same compound, farm and dairy livestock, thus creating a larger amalgamated household, or due to the pre-selection of GPS locations, the physical location of some households would have moved the interviewer out of the range of the specific GPS point into another and would skew the locations.

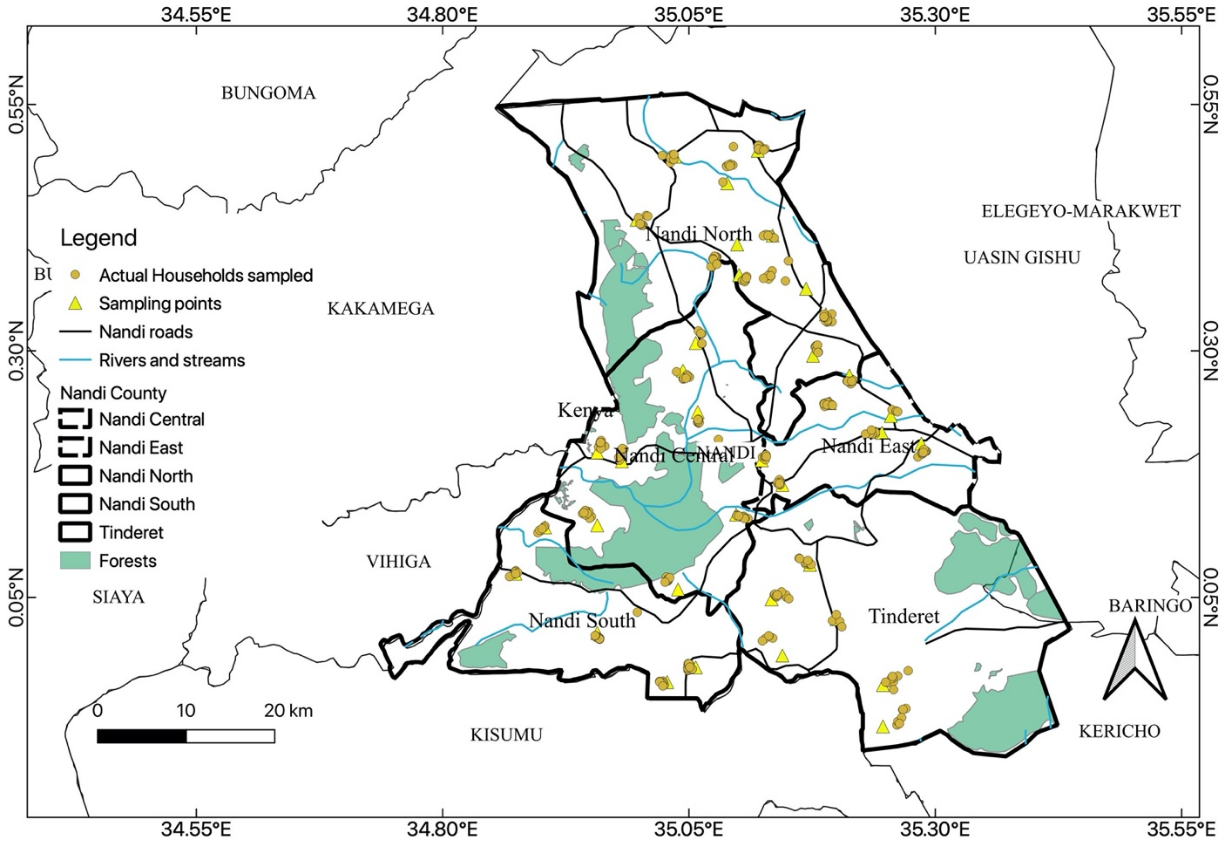


Figure 4:1: Map of Nandi county showing the clustering of the interviewed 336 households and 36 sampling points

4.2.1.1 Number and gender of farmers

The majority of respondents (63%) were male with a mean age of 44 ± 1.0 years old, while females (37%) had a mean age of 42±1.1 years old. The study findings in Table 4.1 show the percent frequency of the gender in each agro-ecological zone (AEZ) and mean age of each gender in each AEZ.

Table 4:1: Mean age by gender of the households (n=336) of smallholder dairy farmers for all the Agro-ecological zones (LH1, LH2 and UM)

AEZ	Percent	Male	Percent	Female
LH2	28%	45±1.5	16%	43±1.5
UM	12%	42±2.3	4%	41±3.6
LH1	22%	46±1.7	17%	42±1.6
Total	63%	44±1.0	37%	42±1.1

4.2.1.2 Distribution of household by the caretaker of dairy livestock

The majority class of persons who actively care (feeding and milking) for the dairy livestock in the household were the household heads (52%). The AEZ cluster LH2 had the male gender as the the greatest number of household livestock caretakers (28%) that were actively caring for dairy livestock (Table 4.2). The majority gender that takes care of livestock in the study area is male (62%).

Table 4:2: Percent of the households (n=336) class that actually take care of the dairy livestock in Agro-ecological zones (LH1, LH2 and UM) and the category for "Others" is labourers and relatives (non-immediate family)

AEZ	Gender	Head	Spouse	Child	Others	Total
LH2	Male	22%	0%	4%	2%	28%
	Female	2%	14%	1%	0%	16%
UM	Male	8%	0%	1%	2%	12%
	Female	0.3%	3%	0.3%	0%	4%
LH1	Male	19%	0%	2%	1%	22%
	Female	1%	14%	2%	0.3%	17%
Total		52.3%	31%	10.3%	6.3%	

4.2.1.3 Education level of farmers

The study findings show that majority of households in Nandi County had reached only primary school and below (48%) (Table 4.3). the LH 1 and 2 had 8% and 9% of the population that had tertiary education, which translates to 85% of the population of smallholder dairy farmers who had tertiary education. The total population of farmers who had tertiary level of education was 20%. The results further show that males from AEZ cluster LH2 were the majority (28%).

Table 4:3: Education level of households (n=336) of smallholder dairy farmers for all the Agro-ecological zones (LH1, LH2 and UM) by gender.

AEZ	Gender	Non formal and Illiterate	Non formal but literate	Primary School	High School	College	University	Total
LH1	Male	0%	1%	10%	7%	3%	1%	22%
	Female	1%	2%	5%	5%	4%	0%	17%
LH2	Male	1%	0%	9%	12%	4%	2%	28%
	Female	1%	1%	7%	4%	2%	1%	16%
UM	Male	1%	0%	7%	2%	1%	1%	12%
	Female	0%	0%	2%	1%	1%	0%	4%
Total		3%	4%	41%	32%	14%	6%	

4.2.1.4 **Major income categories of farmers**

The study findings show major income categories of the households of smallholder dairy farmers in Nandi County. Most of the farmers main livelihood activity (providing more than 50% of their monthly household income) was dairy (49%) (Table 4.4). LH1 had most farmers making their livelihood from dairy at 29%. Poultry farming was observed to be insignificant at 1% of the total.

LH2 smallholder farmers making their main livelihood from crop farming was majority at 23%. The study observed that the main livelihood for the surveyed farmers in Nandi County was agriculture (91%) against farmers who had non-agricultural income as their main livelihood category (9%) (Table 4.4). The smallholder farmers in AEZ clusters LH2 and UM had cash crops, and tea and sugar cane, respectively, as their major income activity.

Table 4:4: Major income categories for households (n=336) in the Agro-ecological zones (LH1, LH2 and UM) by gender. The category "Other" included persons with income from employment or business that is non-agricultural.

AEZ	Gender	Crops	Poultry	Dairy	Other	Total
LH1	Male	4%	0%	17%	2%	22%
	Female	4%	0%	12%	1%	17%
LH2	Male	16%	0%	10%	2%	28%
	Female	7%	0%	6%	3%	16%
UM	Male	7%	1%	3%	0%	12%
	Female	3%	0%	1%	0%	4%
Total		41%	1%	49%	9%	

4.2.1.5 Relationship between education and income categories

This study showed that the largest number of farmers whose major income was from crops were in AEZ LH2 (18%); they were mostly male with high school level education. The highest percentage of farmers for whom poultry was their major income livelihood activity were in AEZ UM (1%); this group was also dominantly male with only primary school level education (67%). Farmers with dairy as the major income livelihood category majority were male with only primary school level education (18%). Farmers who had employment or non-agricultural business as a major income livelihood category majority were female in LH2 with only primary school level education (24%) (Table 4.5).

Table 4:5: Distribution of education levels for the major income categories for the households (n=336) in the Agro-ecological zones (LH1, LH2 and UM) by gender (Each income category totals 100% of its value in Table 8).

Income category	AEZ	Gender	No formal and Illiterate	No formal but literate	Primary School	High School	College	University
Crop	LH1	Male			2%	4%	3%	
	LH1	Female			4%	3%	1%	1%
	LH2	Male	3%		9%	18%	4%	4%
	LH2	Female	1%	1%	7%	7%	1%	1%
	UM	Male	1%		10%	4%	1%	1%
	UM	Female	1%		4%	1%	1%	
Poultry	LH1	Male						
	LH1	Female						
	LH2	Male						
	LH2	Female				33%		
	UM	Male			67%			
	UM	Female						
Dairy	LH1	Male		1%	18%	10%	4%	2%
	LH1	Female	1%	5%	6%	8%	5%	
	LH2	Male			10%	7%	4%	1%
	LH2	Female	1%	1%	5%	2%	2%	
	UM	Male			4%	1%	1%	1%
	UM	Female			1%	1%		
Other	LH1	Male			7%	7%		7%
	LH1	Female	3%		3%		7%	
	LH2	Male			3%	14%	3%	7%
	LH2	Female		3%	24%	3%		3%
	UM	Male			3%			
	UM	Female						

4.2.1.6 Relationship between education and livestock confinement systems

The most popular diary livestock confinement system was the *Only Fence* type (Figure 4.2). The majority (47.3%) of smallholder dairy farmers with an education level of "no formal/primary level" were using *Only Fence* confinement system (Figure 4.2). Many farmers who used the *Fence and Roof* confinement system had high school level education (1.2%), while the majority of farmers who used the *Fence, Roof and Floor* confinement system had tertiary level education (4.2%) (Figure 4.2). The study observed that no farmer had installed the *Fence and Floor* confinement system and from validation the farmers through FGD stated that that was an impractical way to construct as roof is more important if any construction should be done.

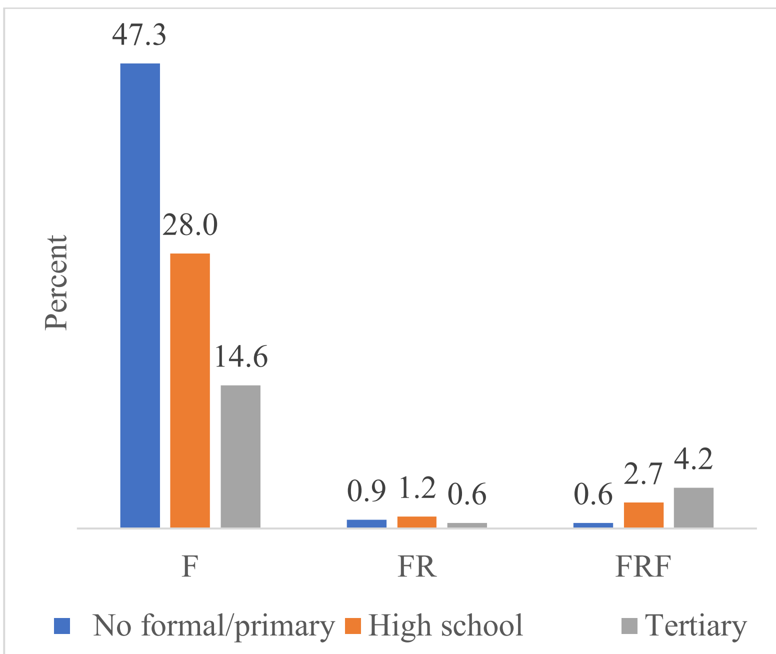


Figure 4:2: Percent of smallholder dairy farmers (n=336) livestock confinement systems (F= Only Fence, FR= Fence and Roof, FRF= Fence, Roof and Floor) by level of education reached (No formal literate, no formal illiterate and primary level as No formal/primary; high school and tertiary for college and University) (Total 100% for all education levels). There was no FF – Fence and Floor – confinement system in the study area.

Livestock confinement of smallholder dairy farmers

Most farmers in the study area had animal confinement as *Only Fence* and this held for all the agro-ecological zones LH1, LH2 and UM (Table 4.9 a,b,c). *FRF* was the second most common confinement system, then FR; no farm had a *Fence and Floor* system (Table 4.10). The animal confinement system *Only Fence* had males as the majority practitioners in all the AEZ. In AEZ LH1 and UM the male farmers education level for the *Only Fence* confinement was majority primary school and below (30% and 53%, respectively). Though for AEZ LH2 38% of the males were majority practicing *Only Fence* confinement system (Table 4.9 a,b,c). The males were majority for the confinement system *Fence and Roof,* the male farmers were the majority for all the AEZs. The education levels for these male farmers practicing FR was observed to be majorly above high school level of education. Within the *Fence, Roof and Floor* confinement systems, the female farmers in AEZ LH1 were majority at 60% and also had majority (50%) with high school and tertiary level of education. In LH2 female farmers with primary school level education had majority *Fence and Roof* confinement systems (22%). The confinement *Fence, Roof and Floor* confinement systems were owned majorly by male crop farmers in AEZ LH2 and with high school level education (12%).

Table 4:6: Frequency of the livestock confinement systems in the households (n=336) by Agro-ecological zone (LH1= a), LH2=b) and UM=c)), Gender, Main Income categories and Education level (Each confinement system percent totals to 100%). There was no FF system in the study area.

a)

AEZ	Gender	Education Level	Income	Only Fence	Fence and Roof	Fence, Floor and Roof
LH1	Male	No formal but literate	Dairy	1.7%		
LH1	Male	Primary School	Crops	2.5%		
LH1	Male	Primary School	Dairy	23.5%	33.3%	
LH1	Male	Primary School	other	1.7%		
LH1	Male	High School	Crops	5.0%		
LH1	Male	High School	Dairy	11.8%	33.3%	10.0%
LH1	Male	High School	other	0.8%		10.0%
LH1	Male	College	Crops	2.5%		10.0%
LH1	Male	College	Dairy	4.2%		10.0%
LH1	Male	University	Dairy	2.5%		
LH1	Male	University	other	1.7%		
Sub total				58.0%	67.0%	40.0%
LH1	Female	No formal and Illiterate	Dairy	0.8%		
LH1	Female	No formal and Illiterate	other	0.8%		
LH1	Female	No formal but literate	Dairy	6.7%		
LH1	Female	Primary School	Crops	5.0%		
LH1	Female	Primary School	Dairy	7.6%		10.0%
LH1	Female	Primary School	other	0.8%		
LH1	Female	High School	Crops	3.4%		
LH1	Female	High School	Dairy	9.2%		20.0%
LH1	Female	College	Crops	0.8%	33.3%	
LH1	Female	College	Dairy	5.9%		10.0%
LH1	Female	College	other	0.8%		10.0%
LH1	Female	University	Crops			10.0%
Sub total				42.0%	33.0%	60.0%
Total				100%	100%	100%

b)

AEZ	Gender	Education Level	Income	Only Fence	Fence and Roof	Fence, Roof and Floor
LH2	Male	No formal and Illiterate	Crops	3.0%		
LH2	Male	Primary School	Crops	9.8%		
LH2	Male	Primary School	Dairy	11.4%		7.7%
LH2	Male	Primary School	other	0.8%		
LH2	Male	High School	Crops	15.9%	20.0%	23.1%
LH2	Male	High School	Dairy	9.1%		
LH2	Male	High School	other	1.5%	20.0%	7.7%
LH2	Male	College	Crops	2.3%	20.0%	7.7%
LH2	Male	College	Dairy	3.8%		7.7%
LH2	Male	College	other	0.8%		
LH2	Male	University	Crops	2.3%		15.4%
LH2	Male	University	Dairy	0.8%		
LH2	Male	University	other	1.5%		
Sub total				62.9%	60.0%	69.2%
LH2	Female	No formal and Illiterate	Crops	0.8%		
LH2	Female	No formal and Illiterate	Dairy	0.8%		
LH2	Female	No formal but literate	Crops	0.8%		
LH2	Female	No formal but literate	Dairy	1.5%		
LH2	Female	No formal but literate	other	0.8%		
LH2	Female	Primary School	Crops	6.8%		
LH2	Female	Primary School	Dairy	5.3%	40.0%	
LH2	Female	Primary School	other	5.3%		
LH2	Female	High School	Crops	6.1%		7.7%
LH2	Female	High School	Poultry	0.8%		
LH2	Female	High School	Dairy	3.0%		
LH2	Female	High School	other	0.8%		
LH2	Female	College	Crops	0.8%		7.7%
LH2	Female	College	Dairy	3.0%		
LH2	Female	University	Crops	0.8%		7.7%
LH2	Female	University	other			7.7%
Sub total				37.1%	40.0%	30.8%
Total				100%	100%	100%

c)

AEZ	Gender	Education Level	Income	Only Fence	Fence and Roof	Fence, Floor and Roof
UM	Male	No formal and Illiterate	Crops	4.1%		
UM	Male	Primary School	Crops	28.6%		
UM	Male	Primary School	Poultry	4.1%		
UM	Male	Primary School	Dairy	14.3%		
UM	Male	Primary School	other	2.0%		
UM	Male	High School	Crops	10.2%	100.0%	
UM	Male	High School	Dairy	2.0%		
UM	Male	College	Crops	4.1%		
UM	Male	College	Dairy	4.1%		
UM	Male	University	Crops	2.0%		
UM	Male	University	Dairy			50.0%
Sub total				76.0%	100%	50.0%
UM	Female	No formal and Illiterate	Crops	2.0%		
UM	Female	Primary School	Crops	10.2%		
UM	Female	Primary School	Dairy	4.1%		
UM	Female	High School	Crops	4.1%		
UM	Female	High School	Dairy	2.0%		
UM	Female	College	Crops	2.0%		50.0%
Sub total				24.0%		50.0%
Total				100%	100%	100%

The study in Table 4.7 shows the acreage for various land uses in the smallholder farms and that the household's area in acres that were large were in LH1 for male and female. The large cash crop acreage was in UM for both male and female. In terms of horticulture, the largest acreage was in UM for both female and male. Acreage available for grazing realised in LH, both male and female had the largest areas. Acreage available for trees realised for UM males and LH1 females as having the largest acreage with trees on farm. In terms of total acreage, the UM AEZ had the largest acreage for both male and female. Appendix 6 further shows the farmland uses and acreage further characterised by AEZ, gender, income category then by education level of the household caretaker of dairy.

Table 4:7: Frequency of the livestock confinement systems in the households (n=336) by Agro-ecological zone (LH1, LH2 and UM) (percent totals to 100%). There was no Fence and Floor confinement system in the study area.

Confinement systems	LH1	LH2	UM	Total
Only fence	35.8%	39.4%	14.6%	89.8%
Fence and Roof	0.9%	1.5%	0.3%	2.7%
Fence and Floor	-	-	-	-
Fence, Floor and Roof	3.0%	3.9%	0.6%	7.5%

Smallholder dairy farmer households with the *Fence, Roof and Floor* confinement system in LH1 had the largest household mean acreage (2.1±1.45 acres) in the study area. Households with the largest acreage for cash crops (5.9±2.04 acres) were in UM and practised *Only Fence* confinement system (Table 4.11). The households with *Fence Floor and Roof* animal confinement systems in UM had the largest acreage (0.8±0.25 acres) under horticulture which included kitchen gardens. Households with *Only Fence* confinement systems in LH1 AEZ had the largest acreage under grazing (4.3±0.68 acres). Households with *Only Fence* confinement systems in UM AEZ were observed to have the largest acreage (3.9±3.67 acres) under trees. The households with *Only Fence* confinement systems, especially in LH1, had the largest total acreage (8.9±1.14 acres).

Table 4:8: Mean acreage of each farm use (n=336) by Agro-ecological zone (LH1, LH2 and UM) and confinement systems, mean acreage of confinement systems and mean acreage AEZs.

AEZ	Confinement Systems	Household area (Acres)	Cash crop (Acres)	Horticulture area (Acres)	Grazing area (Acres)	Trees area (Acres)	Total Acreage (Acres)
LH1	Only fence	0.7±0.08	3.0±0.43	0.3±0.05	4.3±0.68	0.6±0.22	8.9±1.14
LH2	Only fence	0.3±0.03	2.5±0.27	0.3±0.07	1.7±0.22	0.3±0.05	5.2±0.48
UM	Only fence	0.5±0.07	5.9±2.04	0.4±0.11	2.4±0.64	3.9±3.67	13.1±4.71
LH1	Fence and Roof	0.2±0.13	0.5±0.29	0.2±0.15	1.7±0.85	1.1±0.94	3.8±1.74
LH2	Fence and Roof	0.4±0.15	1.5±0.65	0.2±0.09	0.6±0.16	0.1±0.06	2.9±0.77
UM	Fence and Roof	0.5	2.5	0.2	0.2	0.1	3.5
LH1	Fence, Floor and Roof	2.1±1.45	2.2±0.78	0.2±0.05	1.6±0.46	0.7±0.18	6.6±1.52
LH2	Fence, Floor and Roof	0.4±0.06	5.4±1.46	0.2±0.04	1.8±0.72	0.6±0.23	8.4±2.01
UM	Fence, Floor and Roof	1.0	1.1±0.88	0.8±0.25	0.8±0.70	0.4±0.13	4.1±1.95
	Only fence	0.5±0.04	3.2±0.40	0.4±0.04	2.9±0.31	1.0±0.61	7.9±0.92
	Fence and Roof	0.4±0.10	1.3±0.42	0.2±0.06	0.9±0.33	0.4±0.32	3.3±0.67
	Fence, Floor and Roof	1.1±0.59	3.8±0.88	0.2±0.05	1.6±0.42	0.6±0.14	7.3±1.22
LH1		0.8±0.13	2.9±0.29	0.3±0.05	4.0±0.62	0.6±0.20	8.6±1.03
LH2		0.3±0.03	2.7±0.28	0.3±0.06	1.7±0.21	0.3±0.05	5.4±0.46
UM		0.5±0.07	5.7±1.93	0.4±0.10	2.3±0.60	3.7±3.46	12.6±4.45

4.2.2 Smallholder dairy farmers acreage and land uses

4.2.2.1 Acreage of various farm uses

The study showed crop farmers who were males in LH1 had large ‘household area’ (1.3±0.41 acres) and the largest acreage for cash crop (5.9±1.49 acres) (Table 4.6). In terms of acreage available for grazing LH1 males with income from ‘Other’ sources had largest acreage (5.6±4.88 acres). Upper Midlands males with dairy income had the largest (16.6±16.34 acres) acreage for trees as well as the largest total farm acreage (26.1±18.53 acres) (Table 4.6). Male farmers in LH1 and LH2 had more acreage available for agricultural use while female crop farmers in UM had more acreage available for agricultural use (Figure 4.3).

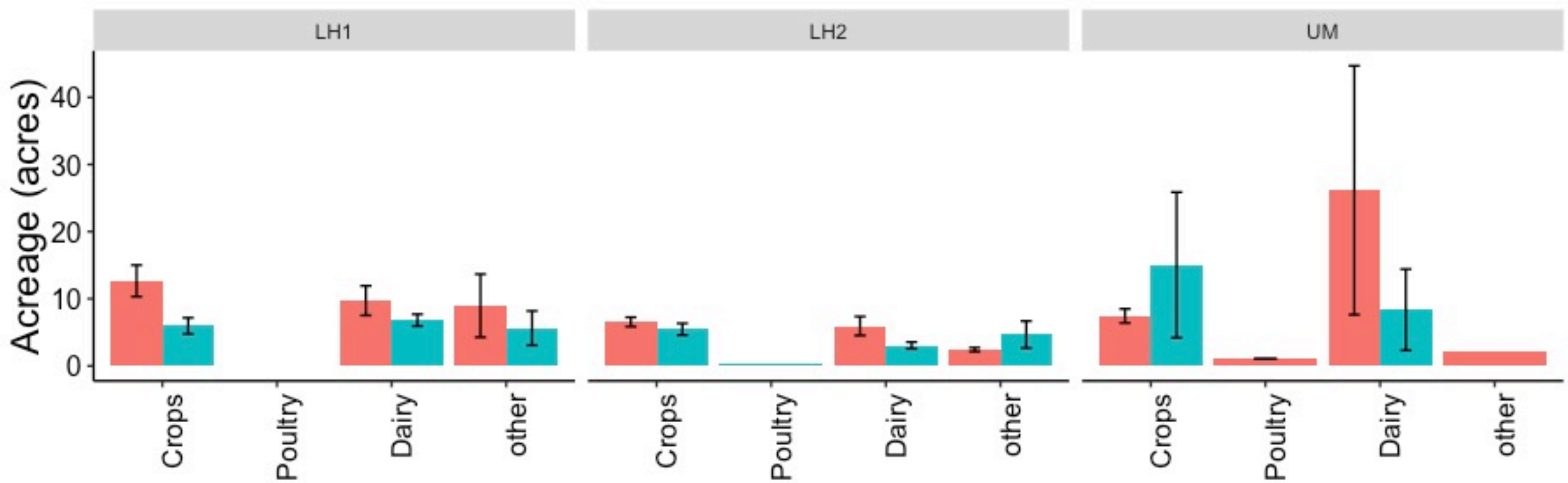


Figure 4:3: Proportions of mean total acreage (acres) of each livelihood income category in each agro-ecological zone (LH1, LH2 and UM) for different household income categories and by gender. Mean total acreage (acres) for different household income categories in each Agro-ecological zone (LH1, LH2 and UM) - (Red is Male, Blue is Female)

Table 4:9: Mean acreage (acres) for households (n=336) and land uses in the Agro-ecological zones (LH1, LH2 and UM), by Gender and Main income categories (± Standard error of the mean).

AEZ	Gender	Income category	Household area (Acres)	Cash crop (Acres)	Horticulture area (Acres)	Grazing area (Acres)	Trees area (Acres)	Total Acreage (Acres)
LH1	Male	Crops	1.3±0.41	5.9±1.49	0.3±0.07	4.7±1.42	0.6±0.16	12.7±2.34
LH1	Female	Crops	0.4±0.10	2.4±047	0.4±0.15	2.3±0.54	0.4±0.16	6.0±1.20
LH2	Male	Crops	0.3±0.03	3.9±0.55	0.4±0.15	1.5±0.17	0.4±0.09	6.5±0.70
LH2	Female	Crops	0.3±0.05	2.7±0.64	0.5±0.15	1.8±0.43	0.2±0.05	5.5±0.87
UM	Male	Crops	0.5±0.08	4.9±0.92	0.3±0.06	1.5±0.45	0.2±0.08	7.4±1.05
UM	Female	Crops	0.6±0.13	12.0±9.78	0.3±0.11	2.0±0.98	0.1±0.044	15.0±10.84
UM	Male	Poultry	0.2	0.3	0.1	0.2	0.3	1.1
LH2	Female	Poultry	0.2	0.0	0.0	0.1	0.0	0.3
LH1	Male	Dairy	0.6±0.10	3.0±0.75	0.3±0.06	5.0±5.29	0.8±0.44	9.7±2.20
LH1	Female	Dairy	1.0±0.38	2.0±0.41	0.4±0.13	3.0±0.39	0.5±0.16	6.8±0.88
LH2	Male	Dairy	0.3±0.06	2.4±0.62	0.3±0.05	2.6±0.72	0.4±0.14	5.9±1.41
LH2	Female	Dairy	0.2±0.05	1.0±0.16	0.2±0.05	1.5±0.29	0.2±0.03	3.1±0.49
UM	Male	Dairy	0.7±0.25	3.1±0.77	0.7±0.39	5.0±2.40	16.6±16.34	26.1±18.53
UM	Female	Dairy	0.3±0.12	4.7±3.64	1.0±0.98	2.2±1.42	0.2±0.08	8.4±6.05
LH1	Male	Other	0.6±0.29	2.2±1.22	0.2±0.12	5.6±4.88	0.3±0.09	9.0±4.70
LH1	Female	Other	0.4±0.06	4.1±2.09	0.3±0.09	0.7±0.28	0.2±0.09	5.6±2.56
LH2	Male	Other	0.4±0.16	1.1±0.17	0.3±0.11	0.4±0.06	0.2±0.04	2.4±0.29
LH2	Female	Other	0.6±0.27	2.2±0.92	0.2±0.05	1.5±0.95	0.3±0.12	4.7±2.01
UM	Male	Other	0.4	1.2	0.1	0.3	0.3	2.3

NB: Cash crop for LH1- Tea, LH2- Maize and UM- Sugarcane

Table 4:10: Mean acreage for various farmland uses by smallholder dairy farmers (n=336) by Agro-ecological zones (LH1, LH2 and UM) and gender (± Standard error of the mean).

AEZ	Gender	Household area (Acres)	Cash crop (Acres)	Horticulture area (Acres)	Grazing area (Acres)	Trees area (Acres)	Household area (Acres)
LH1	Male	0.7±0.11	3.4±0.64	0.3±0.05	5.0±1.05	0.8±0.33	10.1±1.73
LH1	Female	0.8±0.27	2.2±0.33	0.4±0.09	2.6±0.30	0.5±0.12	6.5±0.68
LH2	Male	0.4±0.03	3.1±0.38	0.3±0.09	1.8±0.29	0.4±0.07	6.0±0.65
LH2	Female	0.3±0.06	1.9±0.34	0.3±0.07	1.6±0.27	0.2±0.03	4.3±0.57
UM	Male	0.5±0.09	4.1±0.66	0.4±0.12	2.4±0.77	4.8±4.61	12.3±5.29
UM	Female	0.5±0.11	10.3±7.52	0.5±0.23	2.0±0.79	0.1±0.03	13.5±8.36

NB: Cash crop for LH1- Tea, LH2- Maize and UM- Sugarcane

4.2.3 Smallholder dairy households' dairy livestock demographics

Livestock numbers

This study shows LH1 had more adult dairy cows than the other AEZs, UM had the most adult dairy oxen, youngest dairy cows (heifers) were in LH2 and same to youngest dairy bulls (steers) (Table 4.8).

Table 4:11: Mean dairy livestock numbers per household (n=336) in each Agro-ecological zone (LH1, LH2 and UM), by gender and main income categories. Mean acreage per AEZ and mean acreage per main income categories is shown on the lower rows (± Standard error of the mean)

AEZ	Gender	Income categories	Adult dairy cow	Adult dairy oxen	Young dairy cow	Young dairy bull
LH1	Male	Crops	3.2±0.52		2.7±0.54	0.3±0.13
LH2	Male	Crops	2.5±0.20		7.7±4.22	0.1±0.04
UM	Male	Crops	2.6±0.58	9.3±8.78	2.1±0.45	
LH1	Female	Crops	2.1±0.26	0.2±0.23	1.9±0.33	
LH2	Female	Crops	2.8±0.38		2.3±0.37	4.3±4.16
UM	Female	Crops	2.3±0.37	0.1±0.10	2.3±0.40	
UM	Male	Poultry	2.0			
LH2	Female	Poultry	1.0		1.0	
LH1	Male	Dairy	3.8±0.55	0.1±0.04	3.1±0.46	0.5±0.36
LH2	Male	Dairy	2.7±0.37	0.5±0.49	6.9±5.10	0.1±0.06
UM	Male	Dairy	2.5±0.67	0.6±0.39	2.9±0.55	
LH1	Female	Dairy	3.5±0.59		2.3±0.28	0.1±0.06
LH2	Female	Dairy	1.9±0.20		2.1±0.29	0.1±0.07
UM	Female	Dairy	2.7±1.67	2±1.53	2±1.00	
LH1	Male	Other	4.7±2.14		1.2±0.48	0.8±0.83
LH2	Male	Other	1.9±0.35	0.1±0.13	1.3±0.31	
UM	Male	Other	2.0		1.0	
LH1	Female	Other	5±1.41		3.8±0.95	0.3±0.25
LH2	Female	Other	3.3±0.99		2.3±0.87	0.1±0.10
LH1			3.5±0.32	0.1±0.03	2.6±0.23	0.3±0.16
LH2			2.5±0.15	0.1±0.11	5.1±1.88	0.8±0.67
UM			2.5±0.32	4.7±4.22	2.2±0.27	0.02±0.02
		Crops	2.6±0.16	1.7±161	4.3±1.61	0.8±0.73
		Poultry	1.7±0.33		0.3±0.33	
		Dairy	3.2±0.26	0.2±0.11	3.6±1.09	0.2±012
		Other	3.4±0.60	0.03±0.03	1.9±0.37	0.2±0.18

4.2.4 Manure management in smallholder households

Manure management practices in Nandi County

The study observed seven manure management practices (Biogas use, storing urine separately, split slurry into solid and liquid, solid manure storage, heaping fresh manure and storing, heap dry manure, composting) in the three different AEZs in Nandi County (Table 4.12). The study showed that majority of smallholder dairy farmers managing manure were in AEZ LH2 (47%). The study also shows that heaping manure either fresh or dry accounted for 93% of the manure management practices in Nandi County (Table 4.13). The photographs in plates 4.1 and 4.2 show examples of how the farmers were handling manure from their farms.

Table 4:12: Manure management systems in households (n=336) in Nandi County showing frequency by Agro-Ecological Zone and totals for all is 100%.

AEZ	Biogas	Store urine	Slurry	Split solid manure	Heap fresh manure	Heap dry manure	Compost	Total
LH1	1.2%		0.6%	0.3%	20.8%	18.4%		41.3%
LH2	1.5%	0.3%	1.5%		22.3%	20.8%	0.3%	46.7%
UM			0.6%		6.3%	5.1%		12.0%
Total	2.7%	0.3%	2.7%	0.3%	49.4%	44.3%	0.3%	

Photo taken 15/12/2016 Source: Author

Plate 4:1: Manure heaped as solid storage in a *fence and roof* livestock confinement in Nandi County

Photo taken 15/12/2016 Source: Author

Plate 4:2: Only Fence (F) livestock confinement where manure is just deposited on the ground

Table 4:13: Percentage of manure management systems against the livestock confinement in households (n=336) in each of the Agro-Ecological Zones of Nandi County (Percentage for all totals to 100%)

	AEZ	Gender	Biogas	Store urine	Slurry	Split solid manure	Heap fresh manure	Heap dry manure	Compost
Only fence	LH1	Male	0.9%				10.7%	8.9%	
Only fence	LH1	Female	0.3%				8.0%	7.1%	
Fence and Roof	LH1	Male					0.6%	0.3%	
Fence and Roof	LH1	Female					0.3%	0.3%	
Fence, Floor and Roof	LH1	Male			0.3%		0.6%	0.6%	
Fence, Floor and Roof	LH1	Female			0.3%	0.3%	1.8%	1.2%	
Fence and Floor	LH1	Male							
Fence and Floor	LH1	Female							
Only fence	LH2	Male	0.6%				10.4%	10.1%	
Only fence	LH2	Female					7.1%	6.5%	
Fence and Roof	LH2	Male	0.3%				0.6%	0.6%	
Fence and Roof	LH2	Female					0.6%	0.6%	
Fence, Floor and Roof	LH2	Male	0.6%		1.2%		2.1%	1.8%	0.3%
Fence, Floor and Roof	LH2	Female		0.3%	0.3%		1.2%	0.6%	
Fence and Floor	LH2	Male							
Fence and Floor	LH2	Female							
Only fence	UM	Male					4.7%	3.9%	
Only fence	UM	Female					0.9%	0.6%	
Fence and Roof	UM	Male					0.3%	0.3%	
Fence and Roof	UM	Female							
Fence, Floor and Roof	UM	Male			0.3%				
Fence, Floor and Roof	UM	Female			0.3%		0.3%	0.3%	
Fence and Floor	UM	Male							
Fence and Floor	UM	Female							

Cleaning of livestock confinements

Manure is removed from livestock confinement areas during cleaning with varying frequency of cleaning. Most of the smallholder dairy farmers (92.8%) cleaned their livestock confinements daily with no water and no beddings added to their confinements. Household heads were observed to be the majority of persons who daily clean the livestock confinement systems with no use of water and no addition of livestock bedding (53%) (Table 4.13). The study further shows that in LH1 AEZ, males with primary school education whose main income is from dairy were the majority who cleaned their livestock confinement systems daily (9.4%) (Table 4.14, 4.15, 4.16) (see Appendix 7).

Table 4:14: Percentage of smallholder dairy farmers (n=336) on cleaning frequency of their livestock confinement in each Agro-ecological zone (LH1, LH2 and UM) whether water is used during cleaning and also whether livestock bedding is added to the manure after cleaning).

AEZ	No-water use, no-bedding use				No water use, yes bedding use	Yes-water use, no-bedding use			Yes-water use, yes bedding use
	daily	<1month	1-3 months	>1 year	<1month	<1month	1-3 months	3-12 months	<1month
Total	92.8%	1.2%	0.3%	0.3%	0.3%	3.3%	0.6%	0.3%	0.9%

Table 4:15: Percentage of smallholder dairy farmers (n=336) on cleaning frequency of their livestock confinement in each Agro-Ecological Zone by gender, confinement systems and also whether water is used during cleaning and also whether livestock bedding is added to the manure after cleaning. (each frequency of cleaning totals to 100% as well as the total below for the frequencies total to 100%).

AEZ	Gender	Confinement systems	No water use, no bedding use				Yes, water use, no bedding use			No water use, Yes bedding use	Yes, water use, Yes bedding use
			daily	<1month	1-3 months	>1 year	<1month	1-3 months	3-12 months	<1month	<1month
LH1	Male	Only fence	22%								
LH1	Male	Fence and Roof	1%								
LH1	Male	Fence, Roof and Floor					9%	50%		100%	33%
LH1	Female	Only fence	16%								
LH1	Female	Fence and Roof									
LH1	Female	Fence, Roof and Floor		25%	100%	100%		50%	100%		
LH2	Male	Only fence	27%								
LH2	Male	Fence and Roof	1%								
LH2	Male	Fence, Roof and Floor		25%			55%				67%
LH2	Female	Only fence	16%								
LH2	Female	Fence and Roof	1%								
LH2	Female	Fence, Roof and Floor		50%			18%				
UM	Male	Only fence	12%								
UM	Male	Fence and Roof									
UM	Male	Fence, Roof and Floor					9%				
UM	Female	Only fence	4%								
UM	Female	Fence, Roof and Floor					9%				
Total			92.8%	1.2%	0.3%	0.3%	3.3%	0.6%	0.3%	0.3%	0.9%

Table 4:16: Relationship between person cleaning the confinement in the households (n=336) by AEZ and frequency of cleaning the confinement (Totals for the frequencies is 100%)

		No water use, no bedding use				Yes, water use, no bedding use	No water use, Yes bedding use			Yes, water use, Yes bedding use
AEZ	Person	daily	<1month	1-3 months	>1 year	<1month	<1month	1-3 months	3-12 months	<1month
LH1	Head	20%				9%	100%	50%		33%
LH1	Spouse	14%	25%	100%	100%			50%	100%	
LH1	Child	5%								
LH1	Other	2%								
LH2	Head	24%	25%			45%				67%
LH2	Spouse	14%	50%			18%				
LH2	Child	5%								
LH2	Other	2%				9%				
UM	Head	9%				9%				
UM	Spouse	3%				9%				
UM	Child	2%								
UM	Other	2%								
Total		92.8%	1.2%	0.3%	0.3%	3.3%	0.3%	0.6%	0.3%	0.9%

Length of manure storage before use

The study observed three storage lengths for manure in Nandi County were less than 30 days, 30-120 days and greater than 120 days (Table 21). Majority of the farmers stored manure for less than 30 days in all AEZ. The use of the stored manure was on their own farms as a farm input to crops and pasture.

Table 4:17: Length of storage of manure in the farms (n=336) before use by Agro-Ecological Zones (AEZ totals 100%).

AEZ	Length of Storage	F	FR	FRF	Totals
LH1	Monthly (<30 days)	48.4%			48.4%
	Seasonally (30-120 days)	44.4%	2.4%	0.8%	47.6%
	Yearly (>120 days)	3.2%		0.8	4.0%
LH2	Monthly (<30 days)	48.7%	0.7%	1.3%	50.7%
	Seasonally (30-120 days)	36.0%	2.0%	6.0%	44.0%
	Yearly (>120 days)	3.3%	0.7%	1.3%	5.0%
UM	Monthly (<30 days)	56.6%		1.9%	57.5%
	Seasonally (30-120 days)	28.3%		3.8%	31.6%
	Yearly (>120 days)	7.6%	1.9%		9.5%

4.3 Discussion

This study found that the majority (>98%) of the farmers interviewed kept dairy cattle within the AEZs suiting the economic activity (Nandi County Government 2018, Staal *et al.* 2002). To characterize the manure management systems that the smallholder dairy farmers utilize, the study looked at the demographics, acreage, animal numbers, animal confinement systems, and management practices of cleaning the confinements. These characteristics led to key observations that smallholder dairy farmers in Nandi County were majorly male, showing the size and type of labour force at the farms (Nandi County Government 2018). The study disagrees with observations from Marete *et al.* (2019) whose study in Nandi County found that majority of the smallholder crop farmers were women. The insistence in this current study is that male farmers look at dairy cows as a major investment thus males are more concerned on direct engagement in dairy farming activities (Bebe *et al.* 2002, Rufino *et al.* 2006). There were no significant differences in mean ages between male and female smallholder dairy farmers. This finding is in agreement with other studies on smallholder farmers in Kenya (Nandi County Government 2018; Ndambi *et al.* 2019; Vanlauwe and Giller 2006). The study findings show that there is more to smallholder dairy farmers characterisation than just using acreage and dairy numbers. This study shows that more variables: labour availability, education level, acreage available for grazing, total farm acreage, dairy numbers, gender and main income of the farmers, do make a better case for characterisation of smallholder dairy farmers. This study observed that manure management practices vary from farmer to farmer even with similar livestock confinement systems. This observation majorly could be a subject of awareness levels of farmers on manure management practices and varying importance of manure to the farmers. Smallholder dairy farmers' acreage and land uses in this study were in agreement with Marete *et al.* (2019) observations. Their study found that smallholder farmers have been diversifying their main income sources and still keeping dairy livestock. Staal *et al.* (2002) observed that in AEZs where dairy farming was an activity, it was a major source of income for most smallholder households. This study observed that most farmers engaged in dairy keeping across the AEZs, regardless of their main source of income. Smallholder dairy farmers who had high-value crops (tea, maize, and sugarcane) were observed to have larger land sizes than those farmers for whom dairy was their main income. Diversification with cash crops was found in previous studies to be a key intensification strategy by smallholder farmers as farm size decreases and labour costs increase over time (Herrero *et al.* 2014, Mudavadi *et al.* 2001, Snijders *et al.* 2009). This is the main reason why farmers prefer less extensive confinement systems, such as FR and FRF systems, which are less space-intensive than *Only Fence* systems when land sizes reduce. This study clearly defines a suite of farm practices data such as acreage for various uses, livestock numbers, confinement systems and manure management that can be used in baseline inventories; in previous studies, especially for smallholder farmers, these have been highlighted as being critical for characterisation, but lacking (Carletto *et al.* 2015; Rufino *et al.* 2007; van Wijk *et al.* 2009). The study now proposes the assessment of smallholder farmers with more than just total acreage data and also the integration of these variables to show patterns that are occurring within the smallholder dairy farmers households.

To assess the options to minimise nutrient losses and GHG emissions, these farm data need to be looked at the beginning with livestock confinement. The three major livestock confinement types in Nandi County appear to be related to the education level of the farm owner. Farmers with higher education generally have more varied income sources and also had a higher tendency to enhance manure use and generally engaged in improved farming practices (Ayuya *et al.* 2015).

Furthermore, Rufino *et al.* (2006) noted that use of the 'fence, floor and roof' confinement system would increase with increasing population density. Less extensive animal confinement systems such as FR and FRF confinement systems ensure that manure management becomes relevant due to the increase in centralised manure deposition, which was consistent with our findings. It showed a higher proportion of farmers using the FR and FRF systems managing more of their manure than farmers who use the F only confinement system. Smallholder farmers with high-value crops (e.g. tea and sugarcane) had a larger total acreage than farmers who had dairy as their main source of income. Diversification with cash crops was found to be a key intensification strategy as farm size decreases, and labour costs increase (Msangi *et al.* 2014). Consequently, diversification forces farmers to use improved farm management practices such as the FR and FRF confinement systems.

There was an agreement between this study with other studies showing that housing of dairy cattle constitutes an essential aspect of manure management (Snijders *et al.* 2009; Wilkes *et al.* 2020). This study's dominant confinement system (Only Fence, F) resulted in the production of mainly solid manure as this specific confinement system allows for the loss of the liquid part of the excreta through leaching and GHG emissions (Markewich *et al.* 2010). Our results further strengthen the case that other manure management methods are common in the highlands of East Africa other than pasture deposition that's expected (IPCC 2006b). Ensuring that stored manure contains the liquid part of manure has been known to improve the quality of manure (Rufino *et al*. 2006), and this is easily achieved with the FRF system than with the F system. The liquid part contains labile nutrients that are important in crop production (Odedina *et al.* 2011; Tittonell *et al.* 2005).

The systems employed by farmers for manure management may be related to the availability of adequate labour. Over 50% of farmers said that the cost or availability of labour was a major constraint for improved manure management, which has also been suggested by Rufino *et al.* (2006) and Waithaka *et al.* (2007). However, investments in capital and greater labour availability would be necessary to make such changes in confinement systems. Similarly, about 85% of the farmers surveyed mentioned that reduced access to information was a very important or essential constraint in improving manure management, so improvements in education using manuals such as Goopy and Gakige (2016) could also result in better manure management systems (Teenstra *et al.* 2014; Wilkes *et al.* 2020). This observation on value of education is also consistent with the education level of farmers where farmers with FR and FRF systems tended to have higher education levels than those using the F system. Similar findings were shown by Teenstra *et al*. (2014). The latter mentioned that a key barrier to improved manure management is poor access to information on the value of manure.

The driving factor for the type of confinement systems is shown for the current study to be the education level of the farm owner. With higher education, there was tendency to have varied income from various other sources which was not limited to land size. It has also shown farmers with advanced education have higher propensity to enhance manure use adoption and generally engage in improved farming practices (Akpan *et al.* 2013, Ayuya *et al.* 2015, Jolliffe 2004). Small holder farmers with high value crops (tea, maize and sugarcane) had larger land sizes than farmers who dairy was their main income, diversification with cash crops is found in previous studies to be a key intensification strategy as farm size decreases and labour costs increase (Herrero *et al.* 2014, Mudavadi *et al.* 2001, Snijders *et al.* 2009). This causes the farmers to prefer different confinement systems when land sizes reduced FR and FRF systems increased. That farm practices data is needed for baseline inventories have been highlighted in previous studies (Carletto *et al.* 2015).

Analysing the interviewed farmers (89.8%) using the F system, almost half (48.7%) have access to dry manure. It was often left on the pasture or in the paddock despite having crops that could be fertilised with this manure. Chadwick *et al*. (2011) reported on the potential use of manure in crop farming if better managed. Duration of manure storage was related to the crop type farmers were growing. Most frequent manure application rates were observed in small gardens (horticultural crops and fodder plots), while the most prolonged manure storage was found for farmers planting sugarcane. The latter being most likely driven by the long growth period of sugarcane (Lindell and Kroon 2010). A study by Markewich *et al.* (2010) stated that large amounts of nitrogen (N) are lost when manure is stored for periods > 30 days. Systems of manure handling and storage also has significant effects on measures of nutrients losses. Logically, substantial gains in crop growth can be achieved through improved manure handling and storage (Petersen *et al.* 2013).

This characterisation raises the variables that are useful in showing how the components of transdisciplinarity can be realised. Further, to assess GHG emissions and nutrient N losses, this study N characterisation allows for a base of comparisons and is useful to determine the groupings of farmers to understand the drivers of practice.

4.4 Conclusion

Based on this study findings, smallholder dairy farmers of Nandi County, when characterised through AEZ, gender, education level, income category and data on dairy livestock and acreage of farm uses, type of livestock confinement, confinement cleaning frequency, manure management and length of manure storage, do provide a basis to analyse for practices of manure management and establish relationships between farmer practice and resultant manure management systems. The characterisation of manure management practices found in Nandi County is majorly related to the type of livestock housing. This was observed in all AEZs across gender, education level, and income categories. Solid storage of manure through heaping fresh collected or dry manure from livestock confinement systems was observed to be the major manure management practice. This activity data provides a smallholder dairy farmer baseline, which reliably generates the manure management practices linked to animal housing and then the manure handling across AEZs. This is useful as blocks that offer a base to measure further GHG emissions and nutrient losses from solid storage, which was the significant manure management practice.

CHAPTER FIVE: GREENHOUSE GAS EMISSIONS AND NUTRIENT LOSSES FROM SMALLHOLDER DAIRY FARMERS MANURE MANAGEMENT PRACTICES

5.1 Introduction

This chapter describes the daily GHG emissions and nutrient losses from manure management systems utilised by the smallholder dairy farmers in Nandi County. It addresses objective two and three of the study. The focus is on GHG emissions and nutrient losses from uncovered manure heaps which began with selection from common manure management practices for each livestock confinement system that was prevalent in the first objective. The manure was stored as uncovered solid storage heaps and GHGs and nutrient losses measured daily as described in the methods. The GHGs and nutrient losses are presented in comparison with each livestock confinement system.

5.2 Results

5.2.1 Weather measurements affecting manure

The weather elements measured on site for the manure GHG emissions and nutrient losses experiment was daily mean temperature and precipitation. This is shown in Figure 9 and 10 below. The study recorded cumulative precipitation for the three months to be 188 mm and the daily mean temperature during the same period as 19.7±1.28 °C.

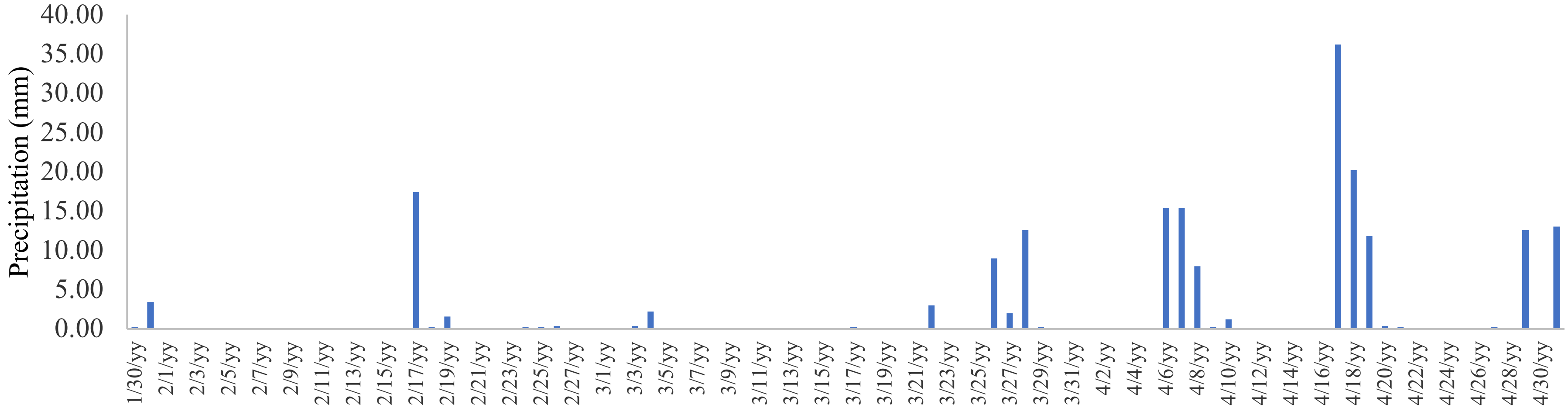


Figure 5:1: The 91-day mean daily precipitation during the manure GHG emissions and nutrient losses experiment

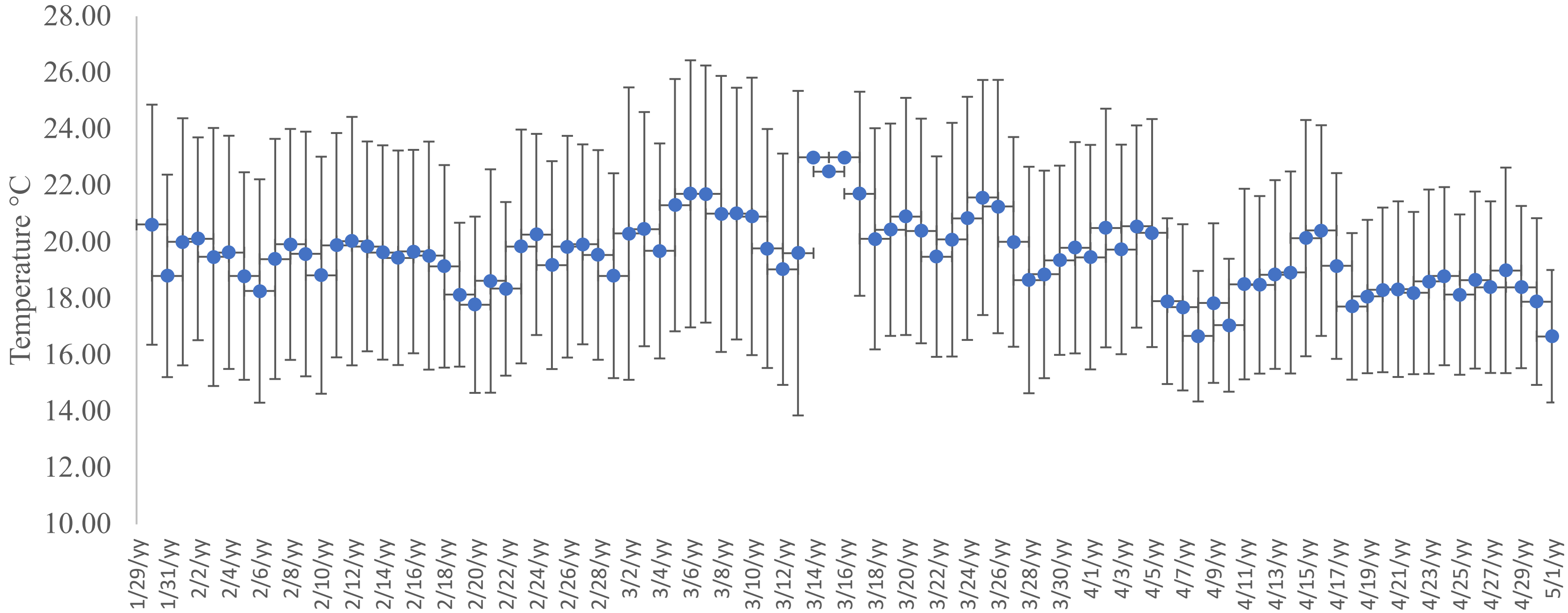


Figure 5:2: 91-day and mean daily temperature during the manure GHG emissions and nutrient losses experiment (bars show full daily range)

5.2.2 Manure moisture content

The study findings showed that the manure with least moisture was from the *Only Fence* livestock confinement system and the manure with the most moisture from *Fence, Roof and Floor* in Period 1 when samples were collected (Table 5.1). At the end of the study in Period 4, the manure statistically had no significant difference in moisture content after being exposed to rainfall and sunlight without being covered for the entire duration.

Table 5:1: Mean manure moisture and dry weight changes during storage (period 1-fresh samples, period 2-after 28 days, period 3-after 56 days, period 4-after 91 days) for each livestock confinement system (F-Only Fence, FR- Fence and Roof and FRF-Fence, Roof and Floor)

Period	Confinement	Manure Moisture Content (%)	Manure Dry Weight (kg)
1	F	72.1 ± 0.18	28.3±0.45
1	FR	73.5±0.17	25.3±0.17
1	FRF	79.3±0.06	24.2±0.20
2	F	87.3±0.11	
2	FR	87.8±0.04	
2	FRF	88.3±0.15	
3	F	87.9±0.08	
3	FR	85.0±0.03	
3	FRF	87.9±0.10	
4	F	86.0±0.89	
4	FR	85.5±1.23	
4	FRF	85.8±2.16	

5.2.3 Manure nutrient changes

Solid manure C/N analysis

The study recorded percent concentration for C:N ratio which was derived from the manure during the experiment. Initial quantity of C was estimated to enable calculation of methane conversion factor. To calculate the nitrous oxide emission factors, the quantity of nitrogen was also estimated before experimentation. It showed that in the initial Period 1 manure from *Fence, Roof and Floor* had the highest amount of C and N with the C:N ratio being highest and manure from *Fence and Roof* confinement with the least C:N ratio being from manure from *Only Fence.* These were done for each treatment for each period showing the number of days in storage). The data is shown according to the animal confinement systems (Fence Only- F, Fence and Roof- FR and Fence, Roof and Floor-FRF) (Table 5.2).

Table 5:2: Changes in the carbon to nitrogen percentage, quantity of C and N in initial manure and mean C:N ratio of manure according to the period of observation (period 1-fresh samples, period 2-after 28 days, period 3-after 56 days, period 4-after 91 days) and for each livestock confinement system (F-Only Fence, FR- Fence and Roof and FRF-Fence, Roof and Floor)

Period	Confinement	C kg	N kg	C g kg^{-1}	N g kg^{-1}	C (%)	N (%)	C:N ratio
1	F	11.1	0.52	392.8	18.3	39.3	1.8	21.6±0.81
1	FR	9.8	0.42	389.5	16.8	39.0	1.7	23.2±0.34
1	FRF	10.3	0.47	423.5	19.2	42.4	1.9	22.2±0.76
2	F					35.9	1.8	20.8±1.22
2	FR					38.1	1.8	21.3±0.30
2	FRF					40.6	1.9	21.5±0.14
3	F					34.8	1.8	19.1±0.53
3	FR					43.8	2.1	21.6±1.39
3	FRF					37.2	1.9	19.5±0.87
4	F					31.2	1.9	16.0±0.34
4	FR					32.6	1.6	20.5±0.91
4	FRF					35.5	1.6	23.3±2.80

Nutrient C:N ratios from heaped solid storage as manure management

The periodic C:N ratio was recorded for each livestock confinement with F and FR showing decreasing ratio between Period 1 and 4 (Figure 5.3). Manure from FRF showed stability of C:N ratio between Period 1 and Period 4. Manure from FRF was significantly different from both F and FR manure ($p<0.05$) and this difference was in Period 4.

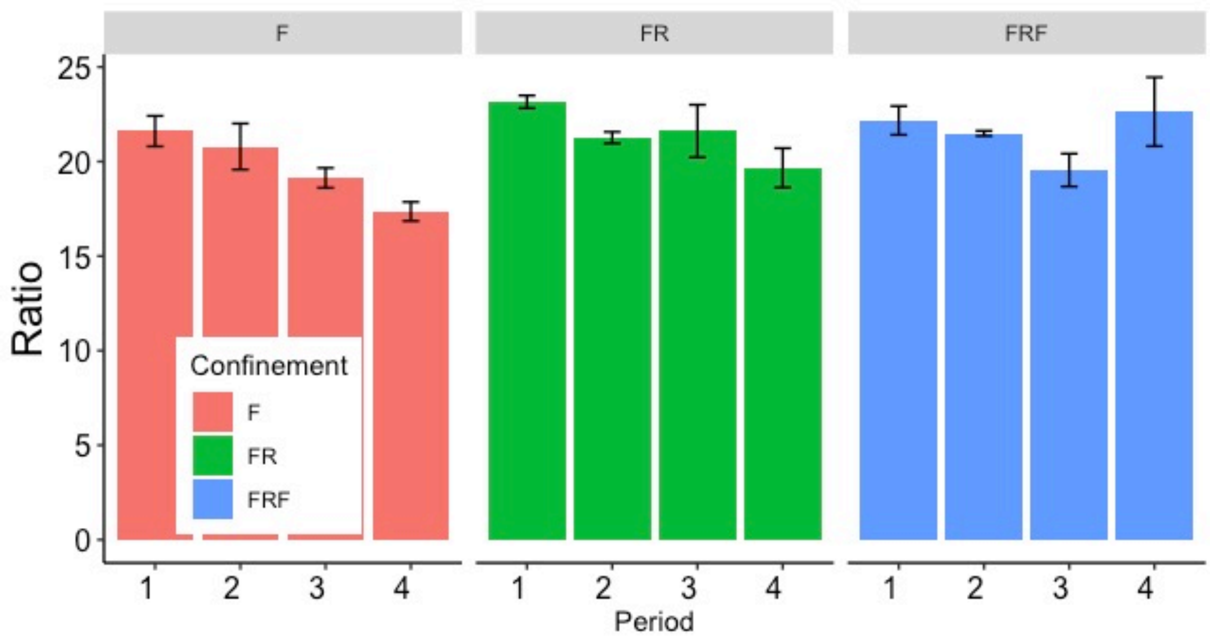


Figure 5:3: C:N ratio from manure for each of the measured period by livestock confinement systems (Only Fence-F, Fence and Roof-FR, Fence, Roof and Floor-FRF)

Leachate produced

The cumulated daily leachate produced for the livestock confinement systems was derived from each chamber containing manure from each livestock confinement. The resultant means taken showed that manure from *Only Fence* produced the most leachate when compared to manure from FR and FRF (Figure 5.4 and Table 5.3).

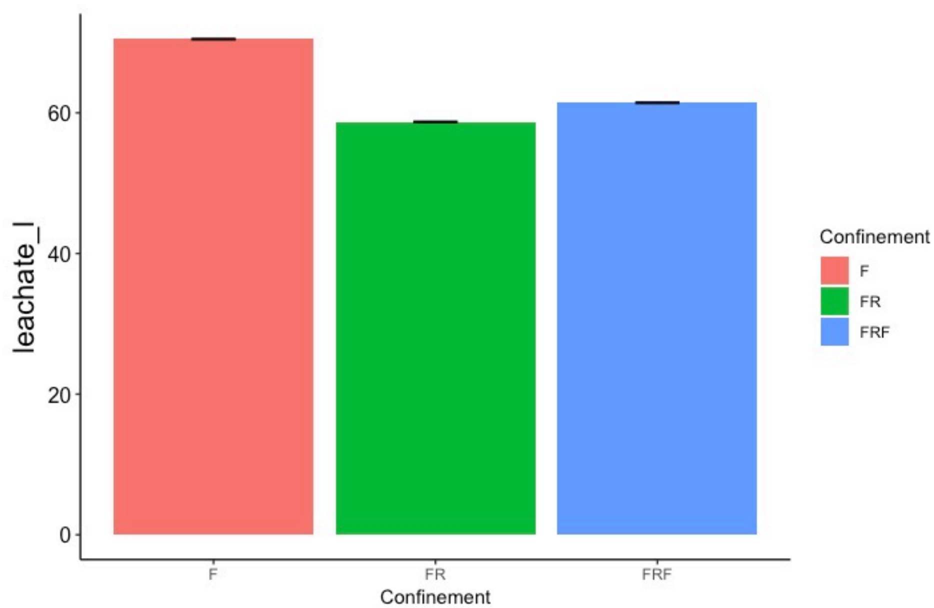


Figure 5:4: Mean total (91-day) leachate in litres produced from the manure experiment for each livestock confinement system

Table 5:3: Mean total leachate for each of the study period (P1-Day 0- Day 28, P2-day28-Day 56, P3 Day57-Day91, P4-at Day 92 after end of experiment) for each of the confinement system

Confinement	Period	Sample days no	Leachate (litres)
F	1	28	5.7±0.047
F	2	28	0.04±0.001
F	3	35	63.4±0.200
F	4	1	1.4±0.262
FR	1	28	3.9±0.035
FR	2	28	0.02*
FR	3	35	53.0±0.193
FR	4	1	1.8±0.122
FRF	1	28	4.2±0.030
FRF	2	28	0.65±0.007
FRF	3	35	56.1±0.198
FRF	4	1	0.5±0.233
F		92	70.5±0.08
FR		92	58.7±0.08
FRF		92	61.4±0.08

* means samples were too few for Standard Error to be realised

Total organic nitrogen in leachate

This study observed that the mean total organic nitrogen in the leachate for the manure from each confinement system and the most leached was from FR (Figure 5.5 and Table 5.4). The lowest N recorded was the manure from *Fence, Roof and Floor* confinement system.

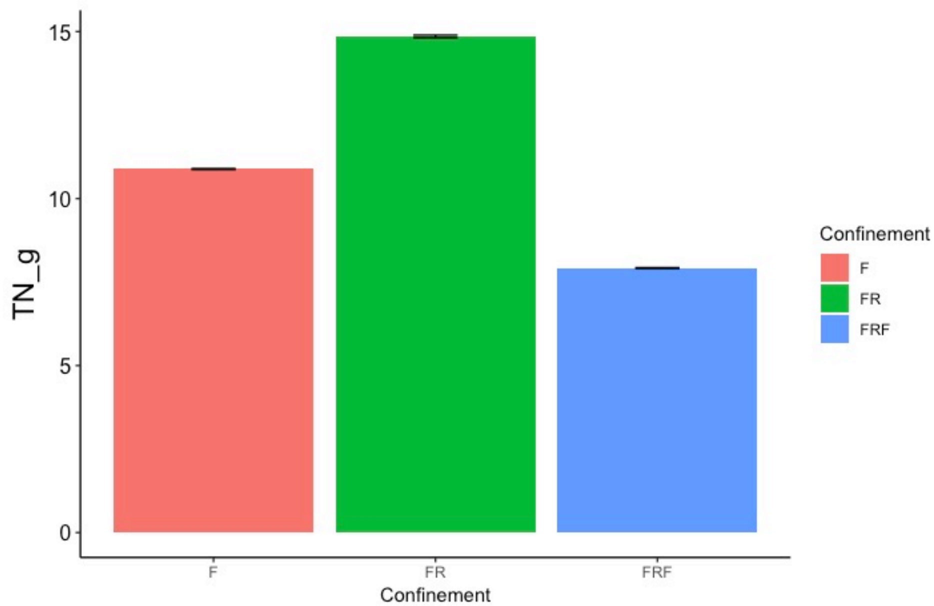


Figure 5:5: Total (91-day) organic nitrogen (in grams of N) measured in leachate from the manure experiment from each livestock confinement system

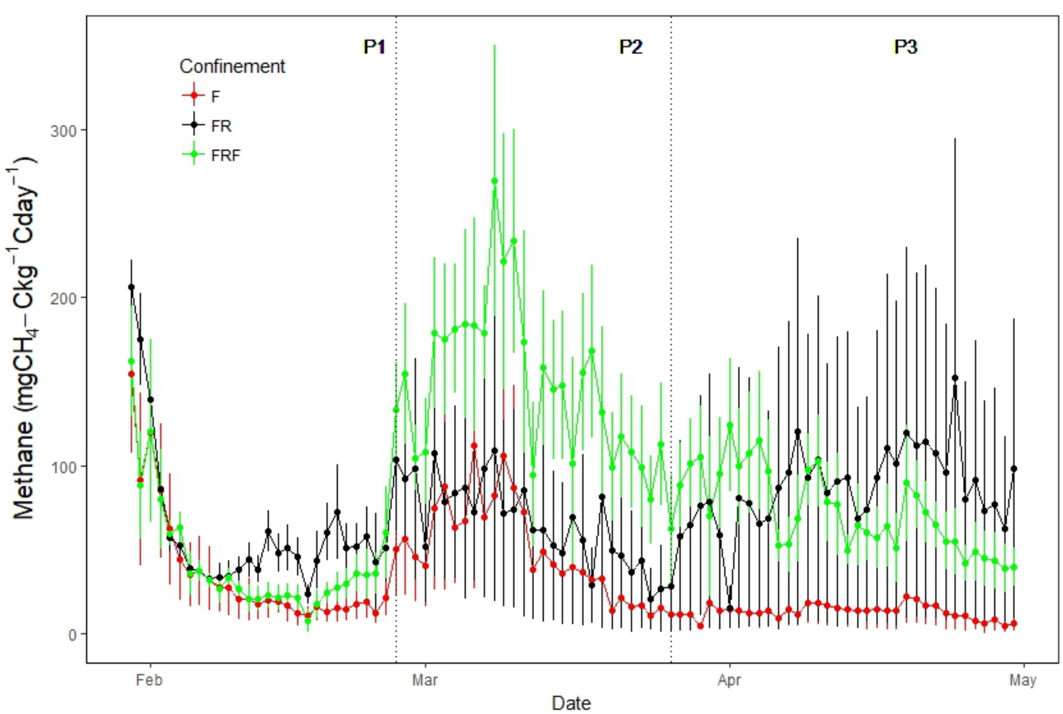
Table 5:4: Mean total organic nitrogen (TNg) from leachate for each of the study period (P1-Day 0- Day 28, P2-day28-Day 56, P3 Day57-Day91, P4 Day92) for each of the confinement system

Confinement	Period	Sample no	TN(g)
F	1	28	0.85±0.007
F	2	28	0.004
F	3	35	9.92±0.036
F	4	1	0.12±0.016
FR	1	28	0.57±0.005
FR	2	28	0.001
FR	3	35	14.06±0.103
FR	4	1	0.22±0.028
FRF	1	28	0.68±0.004
FRF	2	28	0.13±0.001
FRF	3	35	7.06±0.026
FRF	4	1	0.06±0.029
F		92	10.88±0.015
FR		92	14.85±0.039
FRF		92	7.92±0.011

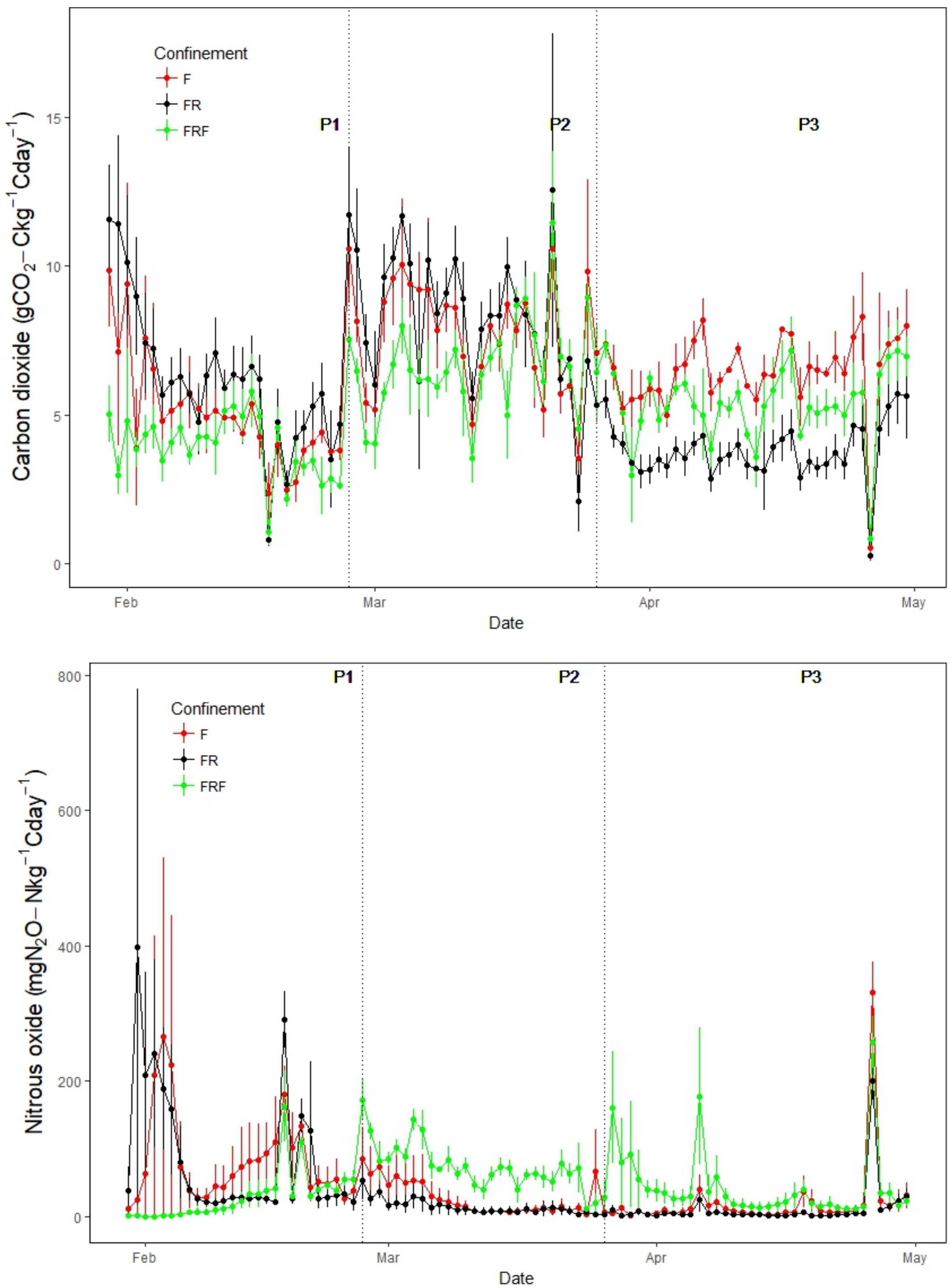
5.2.4 Manure GHG emissions

Manure daily GHG emissions

The findings as shown in Figure 5.6 show the daily calculated flux for each GHG emission (CH_4-C, CO_2-C, N_2O-N) from the manure experiment for each the three livestock confinement systems. The study realised that CH_4-C started high and dropped during P1 then peaked in P2 and remained high for P3 for the manure from *Fence and Roof* and *Fence, Roof and Floor* (Figure 5.6a). The study observed that CO_2-C was similar for all the manure from the three confinement systems (Figure 5.6b). The findings for N_2O-N shows that the *Only Fence* and *Fence and Roof* peaked in P1 with *Fence, Roof and Floor* remaining high in P2 and P3 (Figure 5.6c).



a



b

c

Figure 5:6: Daily GHG emissions for the 91-day observation was done for each of the 3 GHGs a) CH_4 - C, b) CO_2 - C c) N_2O – N (P1- Day 0-2 Day 28, P2 - Day 29-Day 56 and P3-Day 57-Day 91) (Standard error bars are shown for each day for each GHG emission)

Global warming potential

The study compared the cumulative GHG emissions for each confinement system through conversion into Global warming potential (GWP). Manure from FRF managed as solid storage emitted the highest contribution (37%) (Table 5.5). Manure from F and FR livestock confinement had statistically no significant difference with 32% and 31% contribution respectively (Table 5.5).

Table 5:5: Cumulative GHG emissions from manure in solid storage for 91 days, Global warming potential (GWP), Methane Conversion Factors (MCF) and Emission Factors for Nitrous oxide (efN)

Confinement	CH_4-C	CO_2-C	N_2O-N	CH_4	CO_2	N_2O	Percent total	MCF	efN
	(g C kg-1)	(g C kg-1)	(g N kg-1)	g CO2-eq.%	g CO2-eq. %	g CO2-eq.%			
F	2.8	477	3.6	6%	29%	65%	32%	0.022%	0.0022%
FR	6.6	457	3.1	14%	28%	58%	31%	0.051%	0.0023%
FRF	7.7	406	4.3	13%	21%	66%	37%	0.057%	0.0029%
Mean total				11%	26%	63%		0.043%	0.0025%

Emission factors

Emission factors (EF) for methane were calculated for each of the dairy livestock categories for Nandi County using the dairy animals' data from smallholder households. The data showed that 40% of the animals surveyed during the study period were pregnant adult female cattle were and had EF 9.72 kg CH_4 $head^{-1}$ yr^{-1}, while the lowest EF was for male calves at 1.92 kg CH_4 $head^{-1}$ yr^{-1} .The methane conversion factors from manure emissions are shown in Table 5.5. The solid storage for manure which was derived from heaping fresh and dry manure resulted in a nitrous oxide emission factor of 0.003% kg N_2O-N/kg N (Table 5.5).

5.3 Discussion

This chapter shows the resulting N losses as well as GHG emissions from manure management. The focus of these losses is also the environment with which the manure loses N as well as emits GHG. The weather, in terms of precipitation and temperature, showed a distinct dry period at the start of the experiment with no rains and then a wet season at the tail end of the experiment. This allowed the study to proceed in a manner comparable to when smallholder dairy farmers would heap their manure and leave it out in the open until when ready to use on their farms. The manure, when left in the open, is subject to weather elements of sun and precipitation.

Initial manure moisture content leads to comparisons with other studies, and this study found that smallholder dairy farmers have manure that has high dry matter content than many studies (Lenkaitis 2012, Markewich et al. 2010). Statistically, the manure was not significantly different initially in terms of C and N between FRF and FR livestock confinement systems. Both FRF and FR were found to be significantly different from F at the initial period. This confirms that manure deposited in the field loses much of the initial moisture which has nutrients N through leaching and evaporation (Markewich *et al*. 2010, Weiske and Petersen 2006). The initial total C in this study for all manure was also higher than manure used by (Hao et al. 2001, Lenkaitis 2012). Total N manure used in this study was higher than that used by (Chadwick *et al*. 2011, Hao *et al*. 2001) for only two confinement systems - F and FRF, and manure from FR systems had lower initial total N than that calculated by (Hao *et al*. 2001, Tittonell *et al*. 2010b).

Initial C: N ratio in this study was higher than the one calculated by Hao *et al*. (2001) and similar to a study in Kenya by Tittonell *et al*. (2010) for manure from all the confinement systems. These differences are explained by this study which shows that manure from smallholder dairy farmers in Nandi County had higher quantities of labile nutrients C and N. Measurements of total organic nitrogen losses from leachate revealed that manure from the *Only Fence* had already lost much of N through leaching prior to collection and *Fence, Roof and Floor* did not lose much through leaching.

This study observed that most C was lost through CO_2 emissions. These results were similar to the emission values observed by the Hao *et al*. (2001) study in Canada on emissions from manure composting. Thus, this confirms both manure decomposition processes were similar in this study as well as in Hao's (2001) study. GHG emissions from manure management systems and the length of storage of manure before incorporation into crop farms has been previously suggested to best be estimated with data on the farm practices. A study by Hammond *et al*. (2015) realised that GHG emissions in agricultural spaces from manure rises in tandem with improvements to farmers' income and food security. The results of this study support the Hammond et al. (2015) finding since the highest GHG emissions from manure are from the FRF livestock confinement system which is the main type of confinement system practised by smallholder farmers with the highest income and best management practices amongst the survey population in Nandi County.

The observation that manure from FRF confinement is the highest contributor to the GHG emission is attributed to the large losses of C and N leaching from the manure in the solid storage heaps during the study period. The initial moisture content of manure from this study (Table 5.1) were all higher than the manure used by (Hao *et al*. 2001). This finding showed that diets for livestock in Nandi county is rich and also that the manure in Nandi. County has high nutrient N content. This study quantified emissions from manure stored as solid storage, thereby providing actual quantities for CO_2, as had been observed by Gerber *et al.* (2013b). Gerber *et al.* (2013b) had stated that GHG emissions during manure storage could be significant, and there is a need for actual measurements to aid in improving the accuracy of estimation. Various studies have proposed a reduction of storage time of manure to about 30 days to achieve reduced emissions (Gerber *et al*. 2013b, Petersen *et al*. 2013). This study (Figure 5.6) realized that the first 28 days characterised as the first period was not relevant for CO_2. The difference shows that emissions vary according to the source of manure, implying different manure management practices have different implications on GHG emissions. This study observed that most C lost from emissions was lost through CO_2 (26%). This was similar in trend to (Arias-Navarro *et al*. 2017, Castaldi *et al*. 2010) whose studies also had similar observations on emissions from manure composting. The similarity of observation on CO_2 emissions confirms both manure decomposition processes were similar. All GHGs (CH_4, CO_2, and N_2O) emissions were low in this study of GHG emissions from manure from different Nandi County smallholder dairy farmers. This is attributed to the large losses of C and N through leaching from the manure in solid storage heaps for the study period (Markewich *et al*. 2010, Pelster *et al*. 2016).

From the initial manure weight and the population of dairy cattle that were in the targeted farms, the GHG emissions can be predicted if all the dairy cattle manure was to be managed as solid storage. Various studies have proposed reduction of storage time of manure to about 30 days as recommended to achieve reduced emissions (Gerber *et al*. 2013b, Petersen *et al*. 2013). This study found that emissions did continue beyond 30 days and thus agreed that if manure storage is to be longer than 30 days then amendments such as covering the manure need to be done to the manure

(Markewich *et al*. 2010). In terms of the carbon dioxide equivalent (CO_2eq), CH_4 contributed 11% and N_2O representing 63% of the emissions.

This study estimated emissions from manure sourced from field conditions, which realised that for the solid storage of manure heaps, the N_2 being emitted is substantial. There are studies such as Luo *et al*. (2015) that also advise caution regarding Emission Factors (EFs) that are obtained during a three month measurement period suggesting that longer-term experiments should be done to refine the EF further. This current study, when compared with Amon *et al*. (2001) EFs disagrees with Luo *et al*. (2015) on the accuracy of three-month sampling as the EF for N_2O had the same range for all the confinement systems for the same manure management practice. Furthermore, it has been observed by GHG emission studies (Amon *et al*. 2001, Owen and Silver 2017, Zhu *et al*. 2018) that the greatest N_2O fluxes were generally associated with rainfall events, which agreed with this study. The key finding from this study was that the manure GHG emissions estimation was based on farmers' practice in Nandi County, where the majority (94%) stored manure for less than 3 months as uncovered heaps. This, therefore, offers an accurate base to launch climate change adaptation initiatives.

In order to develop options for minimising nutrient losses and greenhouse gas emissions, this study shows how poor management of manure causes these losses. Combined with farmer characterisation that leads to knowledge of the animal housing that sources the manure, the study has shown how FRF as a housing practice offers initial high-quality manure that has high nutrients and also emits most GHG due to the initial high quality thus if storage is effected through covering and preventing leaching from the manure, the FRF provides for good manure management in terms of minimising nutrient N losses and GHG emissions in smallholder dairy farm systems.

5.4 Conclusion

This data provides a GHG emission baseline, which reliably measures the effects of management interventions on farm level up to the regional level. However, additional studies covering more counties as well as studies that focus on determining the MCFs and N_2O EF from liquid/slurry are desperately needed to improve the accuracy of these emission estimates. Furthermore, there exists a lacuna in animal diets analysis especially variability and on availability to smallholder dairy farmers' animals for its effects on manure management methane emissions. The MCF values from IPCC guidelines could be improved with actual methane emissions measurements from a wide range of common manure management systems in-situ. Characterization of the smallholder dairy farms provided the manure management practices, which together with the GHG emission estimation from manure in solid storage provide data for CH_4, CO_2, and N_2O GHGs, and this is useful for regional scaling to compare Tier 1 currently in use for major GHG estimations and, Tier 2 IPCC 2006 guidelines which requires data on emissions from manure management, livestock numbers for a particular region and feed estimations for the regions. The estimated emissions if Tier 1 or Tier 2 can be differentiated for each livestock category and thus highlighting the livestock category that should be targeted in mitigation actions. That manure from different housing systems was compared to provide opportunities in training farmers based on their current practices that combine animal housing and manure management on how this affects the loss of nutrients as well as emits GHGs.

CHAPTER SIX: COMMUNITY PERCEPTIONS OF DRIVERS FOR MANURE MANAGEMENT STRATEGIES

6.1 Introduction

This chapter describes community perceptions on constraints limiting improved manure management, analysis of varied farmer information sources that farmers access on the relevance to improved manure management and derives the cost benefit perception analysis of the manure management systems utilised by the Nandi County smallholder dairy farmers. It addresses objective four and five of the study. The chapter focuses on manure management practices for each livestock confinement system that was observed and derived in the first objective. This chapter then looks through various smallholder dairy farmers community perceptions to these constraints and synthesises it into factors that would be relevant to smallholder farmers in order to improve manure management and then suggests the manure management system that farmers mostly prefer for improved practice.

6.2 Results

6.2.1 Cluster analysis of Nandi County Smallholder dairy farmers

The results of cluster analysis which is done to show natural groupings formed using the household data variables in Table 6.1a, b below. The variables selected and used for each cluster are; gender percentage, income percentage, education level percentage, mean age, mean available farm labour, mean dairy cattle numbers available in the farm, mean acreage available for grazing, mean total farm acreage and mean number of manure management systems per farm. The study derived four clusters (Male crop farmers - MC, Female crop farmers - FC, Male dairy farmers - MD, Female dairy farmers - FD) that contain the smallholder dairy farmers in Nandi County. Male crop cluster has majority male household heads (92%), with crop farming as major income category (78%) and majority of the farmers in this cluster have high school level of education (65%) (Table 6.1a). This cluster further shows that these smallholder dairy farms have a mean of three labourers available in the farm, for a mean of six dairy cattle, 2.9 acres of grazing land, 8.2 acres of total land and at least two manure management practices (Table 6.1). The results show FC to have majority female household heads (80%), with crop farming as the major income category (74%) and majority having attained primary school level of education (71%) (Table 6.1). These FC farms have mean number of three labourers available in the farm, mean of five dairy cattle, available grazing acreage 1.6 acres and mean total acreage 6.8 acres with one manure management system used in the farm (Table 6.1). Male dairy (MC) cluster has majority male household heads (95%), dairy farming as the major income category (85%) with these farmers having attained primary school level of education (69 %) (Table 6.1). This MC farms also have three labourers, mean of 7 dairy cattle, and mean available grazing acreage 3.2 acres out of a total 7.2 acres of the farm with one manure management system used in the farm (Table 6.1). Male dairy (MC) cluster has majority male household heads (95%), dairy farming as the major income category (85%) with these farmers having attained primary school level of education (69 %) (Table 6.1). This MC farms also have three labourers, mean of 7 dairy cattle, and mean available grazing acreage 12949.9 m^2 out of a total 29137.4 m^2 of the farm and one practice for manure management. The female dairy (FD) cluster is majority female household heads (88%), dairy farming as the major income category (90%) with majority having attained college of level education (38%) (Table 6.1). This FD cluster has a mean of two labourers available on farm, six dairy animals, using 10926.5 m^2 for grazing out of total 35207.7 m^2 available with one MMS.

Table 6:1a,b: Cluster analysis results showing the four clusters and their mean values (a) of farmers, and distribution of main income and education level (b) (n=336) in Nandi County. (MMS -Manure Management System)

a)

MC	n=102	FC	n= 65	MD	n=99	FD	n=69
Gender No	Male: 92%	Gender No	Female: 80%	Gender No	Male: 95%	Gender No	Female: 88%
Income No	Crops: 78%	Income No	Crops: 74%	Income No	Dairy: 85%	Income No	Dairy: 90%
Education level No	High School: 65%	Education level No	Primary School: 71%	Education level No	Primary School: 69%	Education level No	College: 38%
Age No	Mean: 42.7	Age No	Mean: 42.5	Age No	Mean: 45.4	Age No	Mean: 43.8
Labour No	Mean: 3.0	Labour No	Mean: 3.4	Labour No	Mean: 2.8	Labour No	Mean: 2.2
Dairy No	Mean: 5.5	Dairy No	Mean: 5.3	Dairy No	Mean: 6.6	Dairy No	Mean: 5.5
Grazing No	Mean: 2.9	Grazing No	Mean: 1.6	Grazing No	Mean: 3.2	Grazing No	Mean: 2.7
Acreage No	Mean: 8.3	Acreage No	Mean: 6.8	Acreage No	Mean: 7.2	Acreage No	Mean: 8.7
MMS No	Mean: 1	MMS No	Mean: 1	MMS No	Mean: 1	MMS No	Mean: 1

MC- Male crop farmers, FC- Female crop farmers, MD- Male dairy farmers, FD- Female dairy farmers b)

MC	Income	Crops:	Poultry:	Dairy:	Other:		
	No	78%	0%	15%	7%		
	Education level	No formal and Illiterate:	No formal but literate:	Primary School:	High School:	College:	University:
	No	6%	0%	12%	65%	11%	7%
FC	Income	Crops:	Poultry:	Dairy:	Other:		
	No	74%	2%	8%	17%		
	Education level	No formal and Illiterate:	No formal but literate:	Primary School:	High School:	College:	University:
	No	5%	2%	71%	14%	3%	6%
MD	Income	Crops:	Poultry:	Dairy:	Other:		
	No	5%	2%	85%	8%		
	Education level	No formal and Illiterate:	No formal but literate:	Primary School:	High School:	College:	University:
	No	0%	2%	69%	14%	7%	8%
FD	Income	Crops:	Poultry:	Dairy:	Other:		
	No	6%	0%	90%	4%		
	Education level	No formal and Illiterate:	No formal but literate:	Primary School:	High School:	College:	University:
	No	3%	16%	17%	26%	38%	0%

MC- Male crop farmers, FC- Female crop farmers, MD- Male dairy farmers, FD- Female dairy farmers

6.2.2 Technical and socio-economic constraints

Based on the biophysical clusters and farmer variables cluster analysis the community of smallholder dairy farmers were grouped based on agro ecological zone and gender (Table 6.2). Using these grouping, the community perceptions of technical and socio-economic constraints of farmers that hinder improvement to manure management were analysed. It revealed that the smallholder dairy farmers had a low opinion of use of manure from their farms on high value crops and also had a low opinion on the need to improve manure quality in terms of handling, storage and application (Table 6.2). The smallholder dairy farmers in total majorly cited the reason 'lack of farm labour' as very important factor limiting improved manure management (23%), this was followed by 18.5% stating that the lack of manure collection capacity was very important as a reason not to improve manure (Table 6.2). The farmers (24.2%) opined that lack of manure storage capacity was important to very important as a constraint, with 13.7% citing lack of manure treatment capacity as important to very important constraint.

The farmers (20.4%) opined that lack of manure transport capacity ege wheelbarrow was important to very important as a constraint to improving manure management. This was followed by 12.5% of the farmers saying that lack of suitable equipment to apply manure was important to very important as a constraint. The percentage was low for farmers who opined that lack of land was important to very important either due to unavailability of land (3.7%) or high cost of land (2.9%) as a constraint. 18.5% of the farmers opined that they do not have enough collateral to get credit to make investments in manure management such as installation of biogas plants (Table 6.2).

The smallholder farmers when asked to compare transport costs of manure with mineral fertilisers majority 94% thought that is not important as they could reach the shops easily as well as also acquire manure from their farms easily. These smallholder farmers (28.1%) thought that manure had too high labour costs compared to mineral fertilisers in terms of application. The constraint with the least importance was that ‘manure had too low benefits when used as fertiliser’, compared to the benefits when used as a fuel (dung cakes), with 98.5% thinking improving manure to use on crop farm was not so important (Table 6.2).

Table 6:2: Frequency technical and socio-economic constraints to smallholder dairy farmers (n=336) to improve manure management in Nandi County (Percent per issue is 100%)

Issue and importance	LH1_Male	LH1_Female	LH2_Male	LH2_Female	UM_Male	UM_Female	Totals
Lack of farm labour							
Very important	3.9%	3.3%	7.5%	4.5%	3.0%	0.9%	23.0%
important	9.0%	6.0%	7.5%	3.6%	2.4%	0.9%	29.3%
Not so important	9.6%	8.1%	13.4%	8.4%	6.3%	2.1%	47.8%
Lack of manure collection capacity							
Very important	6.9%	2.4%	5.1%	2.4%	1.2%	0.6%	18.5%
important	6.0%	8.1%	7.5%	6.3%	2.1%	0.9%	30.7%
Not so important	9.6%	6.9%	15.8%	7.8%	8.4%	2.4%	50.7%
Lack of manure storage capacity							
Very important	1.5%	1.5%	3.0%	1.8%	1.5%	0.3%	9.6%
important	4.5%	2.4%	3.0%	3.0%	1.5%	0.3%	14.6%
Not so important	16.4%	13.4%	22.4%	11.6%	8.7%	3.3%	75.8%
Lack of manure treatment capacity							
Very important	0.6%	0.3%	1.5%	0.6%	0.3%		3.3%
important	2.1%	0.9%	3.3%	2.4%	0.9%	0.9%	10.4%
Not so important	19.7%	16.1%	23.6%	13.4%	10.4%	3.0%	86.3%
Lack of manure transport capacity							
Very important	0.6%	0.3%	2.7%	1.2%	0.9%		5.7%
important	3.0%	1.8%	4.5%	2.7%	2.1%	0.6%	14.6%
Not so important	18.8%	15.2%	21.2%	12.5%	8.7%	3.3%	79.7%

Lack of suitable equipment to apply manure							
Very important		0.6%	0.3%		0.3%		1.2%
important	3.3%	2.1%	3.0%	1.8%	1.2%		11.3%
Not so important	19.1%	14.6%	25.1%	14.6%	10.1%	3.9%	87.5%
Lack of land to apply manure, because there is none available							
Very important	0.9%	0.9%	0.3%	0.3%			2.4%
important	0.3%	0.3%			0.9%		1.5%
Not so important	21.2%	16.1%	28.1%	16.1%	10.7%	3.9%	96.1%
Lack of land to apply manure, because the prices of land are too high							
Very important	0.6%	0.6%	0.3%				1.5%
important	0.6%	0.3%			0.3%		1.2%
Not so important	21.2%	16.4%	28.1%	16.4%	11.3%	3.9%	97.3%
Not enough collateral to get credit for investments?							
Very important	0.9%	1.5%	3.0%	0.6%	0.6%		6.6%
important	3.0%	1.5%	3.9%	3.6%			11.9%
Not so important	18.5%	14.3%	21.5%	12.2%	11.0%	3.9%	81.5%
Too high transport costs, compared to the use of mineral fertilisers							
Very important	0.6%	0.3%	0.6%				1.5%
important	0.9%	0.9%	2.1%	0.6%			4.5%
Not so important	20.9%	16.1%	25.7%	15.8%	11.6%	3.9%	94.0%

Too high labour costs, compared to the use of mineral fertilisers							
Very important	0.9%	0.9%	0.9%	0.9%		0.6%	4.2%
important	5.7%	4.5%	7.8%	3.3%	2.1%	0.6%	23.9%
Not so important	15.8%	11.9%	19.7%	12.2%	9.6%	2.7%	71.9%
Too low benefits when used as fertiliser, compared to the benefits when used as a fuel (dung cakes)							
Very important	0.3%		0.3%				0.6%
important	0.6%	0.3%					0.9%
Not so important	21.5%	17.0%	28.1%	16.4%	11.6%	3.9%	98.5%

The groupings were done by Agro ecological zone (Lower highland 1-LH1, Lower highland 2-LH2 and Upper midlands -UM) and gender (male-M and female-F).

6.2.3 Institutional constraints prohibiting optimal manure management in general

An assessment was made of smallholder dairy farmers grouped by agro ecological zones and gender on their perception of institutional constraints from sectors that the farmers find relevant to them as source of suitable information on issues of manure. The majority of smallholder dairy farmers viewed lack of information to improve manure from institutions that serve farmers as the biggest constraint (45.1%) to these institutions (Table 6.3). This was closely followed by the perception of 86.3% farmers that these institutions lack access to the available information for which they find as important to very important. Majority 62.2% of the smallholder dairy farmers find that these institutions lack access to loans for investments into manure management is important to very important. These farmers (52.8%) also opined that these institutions lack access to required equipment and machines is important to very important (Table 6.3).. These institutions lack trading infrastructure and also lack regulations, leading to possible privileging of groups was viewed by majority (52.8% and 71.3% respectively) as not so important. The majority of the farmers view spatial separation of livestock farms and arable farms due to specialisation as 'not so important' as an institutional constraint (90.4%) (Table 6.3)..

Table 6:3: Frequency institutional constraints to smallholder dairy farmers (n=336) to improve manure management in Nandi County (Percent per issue is 100%).

Issue and importance	LH1_Male	LH1_Female	LH2_Male	LH2_Female	UM_Male	UM_Female	Total
Lack of information to improve the manure management							
Very important	10.1%	5.7%	11.3%	8.4%	6.9%	2.7%	45.1%
important	7.5%	7.5%	11.9%	7.2%	4.5%	1.2%	39.7%
Not so important	4.8%	4.2%	5.1%	0.9%	0.3%		15.2%
Lack of access to available information							
Very important	10.1%	5.7%	11.0%	7.5%	6.0%	2.4%	42.7%
important	7.8%	8.1%	12.5%	8.4%	5.4%	1.5%	43.6%
Not so important	4.5%	3.6%	4.8%	0.6%	0.3%		13.7%
Lack of access to loans for the required investments							
Very important	4.8%	2.7%	9.3%	5.1%	3.9%	0.3%	26.0%
important	9.3%	6.6%	8.4%	8.1%	3.6%	0.9%	36.7%
Not so important	8.4%	8.1%	10.7%	3.3%	4.2%	2.7%	37.3%
Lack of access to required equipment and machines							
Very important	2.1%	2.1%	5.1%	3.6%	1.5%		14.3%
important	8.7%	5.1%	12.5%	6.9%	4.5%	0.9%	38.5%
Not so important	11.6%	10.1%	10.7%	6.0%	5.7%	3.0%	47.2%
Lack of trading infrastructure							
Very important	0.9%	0.9%	1.5%	2.7%			6.0%
important	7.8%	6.0%	14.6%	8.4%	3.6%	0.9%	41.2%
Not so important	13.7%	10.4%	12.2%	5.4%	8.1%	3.0%	52.8%
Lack of regulations, leading to possible privileging of groups							
Very important	1.2%	0.6%	3.3%	2.1%	1.2%	0.6%	9.0%
important	3.0%	2.1%	6.6%	3.9%	3.0%	1.2%	19.7%
Not so important	18.2%	14.6%	18.5%	10.4%	7.5%	2.1%	71.3%
Spatial separation of livestock farms and arable farms due to specialisation							
Very important	2.1%	0.6%	1.2%	1.2%	0.3%		5.4%
important	0.9%	1.5%	1.2%	0.3%	0.3%		4.2%
Not so important	19.4%	15.2%	26.0%	14.9%	11.0%	3.9%	90.4%

The groupings were done by Agro ecological zone (Lower highland 1-LH1, Lower highland 2-LH2 and Upper midlands -UM) and gender (male-M and female-F).

6.2.4 Value of the type of manure as a fertiliser on own farm

Smallholder dairy farmers were assessed for their perceptions on the value of slurry from dairy cattle and from other animals. The study showed that the farmers who perceived dairy cattle slurry as important to very important; majority (10.2%) were farmers with *Only Fence* confinement systems; 0.9% were farmers with *Fence and Roof* and 5.1% as farmers with *Fence, Roof and Floor* animal confinement systems. Majority of the smallholder dairy farmers did not perceive dairy cattle slurry as very important or just important (83.9%) and similarly majority (94.4%) of smallholder dairy farmers did not perceive slurry from other types of livestock as very important or just important (Table 6.4).

Comparison was made of farmers perception of importance of solid manure from dairy livestock as compared to solid manure from other livestock. Majority of the farmers in the study thought solid manure from dairy cattle was important to being very important (93.5%) as compared to farmers (77%) who perceived solid storage as important to very important if sourced from non-dairy cattle (Table 6.5). This study further observed that none of the farmers with FRF animal confinement thought that manure from dairy cattle was not so important (Table 6.5).

Table 6:4: Frequency of the value of slurry to smallholder dairy farmers (n=336) in Nandi County by gender, Agro-ecological zone and by Livestock confinement (Percent per issue is 100%)

Issue and Importance	Confinement	LH1_Male	LH1_Female	LH2_Male	LH2_Female	UM_Male	UM_Female	Total
Slurry from dairy cattle								
Very important	Only fence	2.1%	0.9%	3.3%	1.2%	1.8%		9.3%
Very important	Fence and Roof			0.6%				0.6%
Very important	Fence, Floor and Roof	0.3%	0.3%	1.2%	0.6%			2.4%
important	Only fence	0.6%		0.3%				0.9%
important	Fence and Roof			0.3%				0.3%
important	Fence, Floor and Roof	0.3%	0.6%	0.9%	0.3%	0.3%	0.3%	2.7%
Not so important	Only fence	17.9%	14.3%	21.2%	13.4%	9.3%	3.6%	79.7%
Not so important	Fence and Roof	0.6%	0.3%		0.6%	0.3%		1.8%
Not so important	Fence, Floor and Roof	0.6%	0.9%	0.6%	0.3%			2.4%
Slurry from Other livestock								
Very important	Only fence		0.3%	0.3%	0.3%			0.9%
Very important	Fence and Roof			0.3%				0.3%
Very important	Fence, Floor and Roof	0.3%	0.3%	0.9%	0.3%			1.8%
important	Only fence	0.9%		0.3%				1.2%
important	Fence and Roof			0.3%				0.3%
important	Fence, Floor and Roof		0.3%	0.3%	0.3%	0.3%		1.2%
Not so important	Only fence	19.7%	14.9%	24.2%	14.3%	11.0%	3.6%	87.8%
Not so important	Fence and Roof	0.6%	0.3%	0.3%	0.6%	0.3%		2.1%
Not so important	Fence, Floor and Roof	0.9%	1.2%	1.5%	0.6%		0.3%	4.5%

The groupings were done by Agro ecological zone (Lower highland 1-LH1, Lower highland 2-LH2 and Upper midlands -UM) and gender (male-M and female-F).

Table 6:5: Frequency of the value of solid manure to smallholder dairy farmers in Nandi County by gender, Agro-ecological zone and by Livestock confinement (Percent per issue is 100%)

Issue and Importance	Confinement	LH1_Male	LH1_Female	LH2_Male	LH2_Female	UM_Male	UM_Female	Total
Solid manure from dairy cattle								
Very important	Only fence	15.5%	10.7%	16.7%	11.6%	9.6%	3.0%	67.2%
Very important	Fence and Roof	0.3%	0.3%	0.6%	0.6%	0.3%		2.1%
Very important	Fence, Floor and Roof	1.2%	1.5%	1.8%	1.2%		0.3%	6.0%
important	Only fence	3.9%	4.2%	4.2%	2.7%	0.9%	0.6%	16.4%
important	Fence and Roof	0.3%						0.3%
important	Fence, Floor and Roof		0.3%	0.9%		0.3%		1.5%
Not so important	Only fence	1.2%	0.3%	3.9%	0.3%	0.6%		6.3%
Not so important	Fence and Roof			0.3%				0.3%
Not so important	Fence, Floor and Roof							
Solid manure from Other cattle								
Very important	Only fence	11.3%	9.3%	12.2%	9.6%	7.2%	1.8%	51.3%
Very important	Fence and Roof	0.3%	0.3%	0.6%	0.6%	0.3%		2.1%
Very important	Fence, Floor and Roof	0.6%	0.9%	1.5%	1.2%			4.2%
important	Only fence	4.5%	4.2%	4.5%	2.7%	1.2%	0.6%	17.6%
important	Fence and Roof	0.3%						0.3%
important	Fence, Floor and Roof		0.6%	0.6%		0.3%		1.5%
Not so important	Only fence	4.8%	1.8%	8.1%	2.4%	2.7%	1.2%	20.9%
Not so important	Fence and Roof			0.3%				0.3%
Not so important	Fence, Floor and Roof	0.6%	0.3%	0.6%			0.3%	1.8%

The groupings were done by Agro ecological zone (Lower highland 1-LH1, Lower highland 2-LH2 and Upper midlands -UM) and gender (male-M and female-F).

6.2.5 Investments (time/money) to improve manure management

The smallholder farmers were queried if they had spent any money or time in the last five years to improve manure management within their households. These results were tabulated as shown in Table 6.6 below showing majority of the smallholder dairy farmers did spend time or money in improving their on farm manure management, and these majorly (57.3%) were the farmers with *Only Fence* livestock confinements. Majority of these farmers who had spent time or money to improve manure were male smallholder farmers in LH2 with *Only Fence* confinement systems (13.7%) (Table 6.6).

Table 6:6: Frequency of smallholder dairy farmers (n=336) in Nandi County investment of either Time or Money to improve manure management within the last 5 years. This is aggregated by Agro-ecological zones, gender and confinement systems (Total for all is 100%). NB: M – Male, F – Female.

Invested	Livestock confinements	LH1_M	LH1_F	LH2_M	LH2_F	UM_M	UM_F	Total
Yes	Only fence	14.9%	10.4%	13.7%	8.7%	6.6%	3.0%	57.3%
Yes	Fence and Roof	0.6%	0.3%	0.3%				1.2%
Yes	Fence, Floor and Roof		0.9%	0.6%			0.3%	1.8%
No	Only fence	5.7%	4.8%	11.0%	6.0%	4.5%	0.6%	32.5%
No	Fence and Roof			0.6%	0.6%	0.3%		1.5%
No	Fence, Floor and Roof	1.2%	0.9%	2.1%	1.2%	0.3%		5.7%

The groupings were done by Agro ecological zone (Lower highland 1-LH1, Lower highland 2-LH2 and Upper midlands -UM) and gender (male-M and female-F).

6.2.6 Area of improvement in terms of manure management

Analysis of farmer manure management aspects in terms of manure collection, storage, treatment, transport and application was done and tabulated in Table 6.7 below. This table showed that for manure collection the most (57.6%) was done in *Only Fence* livestock confinement. Majority of smallholder dairy farmers did improvement in terms of manure storage (71.6%) with the same farmers majorly having *Only Fence* as the livestock confinement system. The study observed that these farmers majorly also cited that they have put in effort in areas such as improving manure treatment (87.2%), manure transportation (71.9%) and manure application (68.4%) (Table 6.7).

Table 6:7: Frequency of smallholder dairy farmers (n=336) in Nandi County aspects of improvement of manure management within the last 5 years. This is aggregated by Agro-ecological zones, gender and confinement systems (Total for each aspect is 100%).

Issue	Livestock Confinement	LH1_Male	LH1_Female	LH2_Male	LH2_Female	UM_Male	UM_Female	Total
Manure Collection								
Yes	Only fence	14.9%	10.7%	13.7%	8.7%	6.6%	3.0%	57.6%
Yes	Fence and Roof	0.6%	0.3%	0.3%				1.2%
Yes	Fence, Floor and Roof		0.9%	0.6%			0.3%	1.8%
No	Only fence	5.7%	4.5%	11.0%	6.0%	4.5%	0.6%	32.2%
No	Fence and Roof			0.6%	0.6%	0.3%		1.5%
No	Fence, Floor and Roof	1.2%	0.9%	2.1%	1.2%	0.3%		5.7%
Manure Storage								
Yes	Only fence	17.0%	12.8%	18.2%	11.6%	9.0%	3.0%	71.6%
Yes	Fence and Roof	0.6%	0.3%	0.3%		0.3%		1.5%
Yes	Fence, Floor and Roof	0.3%	1.5%	0.6%	0.3%		0.3%	3.0%
No	Only fence	3.6%	2.4%	6.6%	3.0%	2.1%	0.6%	18.2%
No	Fence and Roof			0.6%	0.6%			1.2%
No	Fence, Floor and Roof	0.9%	0.3%	2.1%	0.9%	0.3%		4.5%
Manure Treatment								

Yes	Only fence	19.7%	14.9%	23.6%	14.3%	11.0%	3.6%	87.2%
Yes	Fence and Roof	0.6%	0.3%	0.6%	0.6%	0.3%		2.4%
Yes	Fence, Floor and Roof	0.9%	1.8%	1.8%	1.2%	0.3%	0.3%	6.3%
No	Only fence	0.9%	0.3%	1.2%	0.3%			2.7%
No	Fence and Roof			0.3%				0.3%
No	Fence, Floor and Roof	0.3%		0.9%				1.2%
Manure transport								
Yes	Only fence	18.2%	13.1%	18.5%	11.9%	6.9%	3.3%	71.9%
Yes	Fence and Roof	0.6%	0.3%	0.3%				1.2%
Yes	Fence, Floor and Roof	0.3%	1.2%	1.2%	0.3%		0.3%	3.3%
No	Only fence	2.4%	2.1%	6.3%	2.7%	4.2%	0.3%	17.9%
No	Fence and Roof			0.6%	0.6%	0.3%		1.5%
No	Fence, Floor and Roof	0.9%	0.6%	1.5%	0.9%	0.3%		4.2%
Manure application								
Yes	Only fence	17.6%	13.1%	16.7%	10.7%	6.9%	3.3%	68.4%
Yes	Fence and Roof	0.6%	0.3%	0.3%				1.2%
Yes	Fence, Floor and Roof	0.3%	0.9%	0.6%		0.3%	0.3%	2.4%
No	Only fence	3.0%	2.1%	8.1%	3.9%	4.2%	0.3%	21.5%
No	Fence and Roof			0.6%	0.6%	0.3%		1.5%
No	Fence, Floor and Roof	0.9%	0.9%	2.1%	1.2%			5.1%

The groupings were done by Agro ecological zone (Lower highland 1-LH1, Lower highland 2-LH2 and Upper midlands -UM) and gender (male-M and female-F).

6.2.7 Considerations to improve manure management

When smallholder dairy farmers were asked for their reasons for having interest to improve manure management, the results showed that these farmers perceived that manure has effect on farm hygiene, water quality, odour, nutrient improvement for crops, selling value of manure, incentivisation and restrictions from government to manage manure (Table 6.8). The majority (18.8%). of smallholder farmers stated that their need to improve manure management was very importantly motivated by the need to improve human health. The issue most smallholder dairy farmers (19.1%) found important was abatement of odour problems from manure for themselves as well as their neighbours as reason to improve manure management. Restrictions and incentives from government to improve manure was cited as irrelevant as reason to manage manure by smallholder dairy farmers (74% and 72% respectively) and these came majorly (72.8% and 74.3%) from farmers with *Only Fence* livestock confinement (Table 6.8).

Table 6:8: Frequency of smallholder dairy farmers (n=336) in Nandi County consideration to improve manure management within the last 5 years. This is aggregated by Agro-ecological zones and gender (Total for each issue is 100).

Issue and importance	LH1_Male	LH1_Female	LH2_Male	LH2_Female	UM_Male	UM_Female	Total
Improve on farm hygiene, considering human health							
Important to. Very important	6.30%	4.80%	13.80%	7.80%	4.50%	0.60%	38%
Not important	16.10%	12.50%	14.60%	8.70%	7.20%	3.30%	62%
Improve on farm hygiene, considering animal health							
Important to. Very important	5.70%	5.10%	13.50%	7.80%	5.10%	0.60%	38%
Not important	16.70%	12.20%	14.90%	8.70%	6.60%	3.30%	62%
Improving on water quality, from the point of view of human health							
Important to. Very important	6.30%	4.80%	12.60%	7.80%	4.50%	0.60%	37%
Not important	16.10%	12.50%	15.80%	8.70%	7.20%	3.30%	64%
Improving on water quality, from the point of view of animal health							
Important to. Very important	6.30%	5.10%	11.70%	7.80%	4.50%	0.30%	36%
Not important	16.10%	12.20%	16.70%	8.70%	7.20%	3.60%	65%
Abatement of odour problems, also for neighbours							
Important to. Very important	4.50%	4.50%	10.50%	6.00%	4.20%	0.60%	30%
Not important	17.90%	12.80%	17.90%	10.50%	7.50%	3.30%	70%
Improving fertiliser value (nutrients) for the own cash crops							
Important to. Very important	3.90%	4.20%	9.90%	4.80%	3.90%	0.60%	27%
Not important	18.50%	13.10%	18.50%	11.70%	7.80%	3.30%	73%
Improving fertiliser selling value (income) when sold to Other farms							
Important to. Very important	0.006	0.009	0.021	0.009	0	0	5%
Not important	21.80%	16.40%	26.30%	15.60%	11.70%	3.90%	96%
Incentive measures by the government and/or Other institutions							
Important to. Very important	0.30%	0.00%	0.30%	0.00%	0.00%	0.00%	1%
Not important	22.10%	17.30%	28.10%	16.40%	11.70%	3.90%	99%
Restrictive measures by the government and/or Other institutions							
Important to. Very important	0.30%	0.00%	1.20%	0.00%	1.20%	0.00%	3%
Not important	22.10%	17.30%	27.20%	16.40%	10.50%	3.90%	97%

The groupings were done by Agro ecological zone (Lower highland 1-LH1, Lower highland 2-LH2 and Upper midlands -UM)

6.2.8 Information to improve manure management

The number of smallholder dairy farmers who received information within the last 5 years on improving manure management were analysed and tabulated in Table 6.9 below. The observations showed that majority (73.4%) of the smallholder dairy farmers who received information to improve manure management were in *Only Fence* livestock management system.

Table 6:9: Frequency of smallholder dairy farmers (n=336) who have received information on manure management in the last 5 years aggregated by Agro-Ecological zone, gender and confinement system (Total is 100% for all)

	Livestock Confinement	LH1_Male	LH1_Female	LH2_Male	LH2_Female	UM_Male	UM_Female	Total
Yes	Only fence	18.2%	11.9%	19.1%	12.2%	9.0%	3.0%	73.4%
Yes	Fence and Roof	0.6%	0.3%	0.6%	0.6%	0.3%		2.4%
Yes	Fence, Floor and Roof	0.6%	0.9%	1.2%	0.6%	0.3%	0.3%	3.9%
No	Only fence	2.4%	3.3%	5.7%	2.4%	2.1%	0.6%	16.4%
No	Fence and Roof			0.3%				0.3%
No	Fence, Floor and Roof	0.6%	0.9%	1.5%	0.6%			3.6%

The groupings were done by Agro ecological zone (Lower highland 1-LH1, Lower highland 2-LH2 and Upper midlands -UM) and gender (male-M and female-F).

The study also looked at the perception in value of the information source on improving manure management. The study showed the most crucial value for farmers in terms of source of information to improve manure management was from other farmers for *Only Fence* (2.4%). The smallholder dairy farmers had perception of other farmers information as important (7.8%). Majority of these smallholder dairy fathers found non-commercial advisors as the most irrelevant (83.5%) (see Table 6.10).

Table 6:10: Frequency of smallholder dairy farmers (n=336) in Nandi County value of information sources on manure improvement aggregated by Agro-Ecological Zone and gender.

Issue and importance	LH1_Male	LH1_Female	LH2_Male	LH2_Female	UM_Male	UM_Female	Total
Value of another farmers information							
Very/ Important	2.7%	2.4%	3.9%	2.4%	0.5%	0.3%	12.2%
Not important/irrelevant	19.7%	14.9%	24.6%	14.0%	11.0%	3.6%	87.8%
Value of government extension workers							
Very/ Important	0.9%	1.2%	3.0%	1.5%	0.3%	0.0%	6.9%
Not important/irrelevant	21.5%	16.1%	25.4%	14.9%	11.3%	3.9%	93.10%
Value of non-commercial advisors							
Very/ Important	0.3%	0.9%	0.6%	0.0%	0.0%	0.0%	1.80%
Not important/irrelevant	22.1%	16.4%	27.8%	16.4%	11.6%	3.9%	98.20%
Value of commercial/private advisors							
Very/ Important	1.8%	1.2%	3.0%	1.5%	0.3%	0.3%	8.10%
Not important/irrelevant	20.6%	16.1%	25.4%	14.9%	11.3%	3.6%	91.90%
Value of local teachers and trainers							
Very/ Important	2.1%	1.2%	3.6%	1.5%	0.9%	0.0%	9.30%
Not important/irrelevant	20.3%	16.1%	24.8%	14.9%	10.7%	3.9%	90.70%
Value of any other actor							
Very/ Important	2.7%	2.1%	3.6%	0.6%	0.3%	0.3%	9.60%
Not important/irrelevant	19.7%	15.2%	24.8%	15.8%	11.3%	3.6%	90.40%

The groupings were done by Agro ecological zone (Lower highland 1-LH1, Lower highland 2-LH2 and Upper midlands -UM) and gender (male-M and female-F).

The study observed and analysed the various media that influences farmers behaviours in term of manure management. These media were then tabulated by gender, the AEZ and the type of confinement system (Table 6.11). Local radio was the most crucial and important source for manure management information for smallholder dairy farmers in Nandi County (24.2%). Local newspapers and farmer magazines were found to be most irrelevant as a source of information on manure management. Social media, internet and brochures were looked upon majorly as irrelevant by the farmers as information sources for improving manure management (Table 6.11).

Table 6:11: Frequency of smallholder dairy farmers (n=336) sources of information about manure management aggregated by Agro-ecological zones and gender

Issue and importance	LH1_Male	LH1_Female	LH2_Male	LH2_Female	UM_Male	UM_Female	Total
National television							
Very/ Important	5%	4%	11%	5%	4%	1%	30%
Not important/irrelevant	17%	14%	17%	12%	8%	3%	71%
Local television							
Very/ Important	8%	5%	10%	4%	3%	1%	31%
Not important/irrelevant	15%	13%	19%	13%	8%	3%	70%
National radio							
Very/ Important	6%	4%	13%	7%	6%	2%	38%
Not important/irrelevant	16%	14%	15%	10%	6%	2%	62%
Local radio							
Very/ Important	17%	13%	21%	11%	9%	4%	75%
Not important/irrelevant	6%	4%	7%	6%	3%	0%	26%
National newspaper							
Very/ Important	5%	2%	8%	2%	1%	1%	19%
Not important/irrelevant	17%	15%	21%	14%	11%	3%	82%
Local newspaper							
Very/ Important	3%	1%	4%	1%	1%	0%	10%
Not important/irrelevant	19%	16%	25%	15%	11%	4%	90%
Farmers' magazines							
Very/ Important	2%	2%	4%	2%	1%	0%	11%
Not important/irrelevant	20%	16%	25%	15%	11%	4%	89%
Farmers' group meetings							
Very/ Important	11%	7%	8%	3%	2%	1%	33%
Not important/irrelevant	12%	10%	20%	13%	9%	3%	68%
Field excursions/farm visits/open days							
Very/ Important	8%	6%	11%	5%	3%	1%	34%
Not important/irrelevant	15%	11%	18%	11%	8%	3%	67%
Individual meetings							
Very/ Important	8%	6%	13%	5%	5%	1%	37%
Not important/irrelevant	14%	12%	15%	11%	7%	3%	63%
Billboards/posters							
Very/ Important	0%	0%	0%	0%	0%	0%	1%
Not important/irrelevant	22%	17%	28%	16%	11%	4%	99%
Pamphlets/leaflets/brochures							
Very/ Important	2%	1%	4%	0%	0%	0%	7%
Not important/irrelevant	21%	17%	25%	16%	11%	4%	93%
Videos							
Very/ Important	1%	0%	0%	0%	1%	0%	2%
Not important/irrelevant	22%	17%	28%	16%	11%	4%	98%
Internet							
Very/ Important	2%	0%	3%	1%	1%	0%	8%
Not important/irrelevant	21%	17%	25%	15%	11%	4%	92%
Social media							
Very/ Important	1%	0%	2%	0%	1%	0%	4%
Not important/irrelevant	22%	17%	26%	16%	11%	4%	96%

6.2.9 Cost benefits of the various manure management practices in Nandi County

From the Focus Groups Discussions and the Key Informant interviews the appraisal of the responses of the smallholder dairy farmers in terms of perceptions on costs and benefits for various manure management practices basing on constraints faced and information access for the farmers to improve were tabulated as shown in Table 6.12 below. The farmers preferred heaping either fresh or dry manure as it was the least labour intensive way to manage manure produced from the various animal confinements. These farmers also found that heaped manure was easy to improve as it was just an aspect of turning by changing location of the heap on the farm and this could be done with manure from all types of animal. The preference by majority of the farmers for *Only Fence* animal confinement was because the leaching after deposition of dung on pasture was observed by most farmers to allow for pasture growth in the paddocks and removes the need to manage manure.

Table 6:12: Perception cost benefit of manure management practices from FGDs

Factor	Input	Labour	Finance Capital	Confinement	Requirement	Benefit	Perception preference
Biogas	Contractor Installation Capital FRF confinement	High	High	FRF/FF	Dung and urine Anaerobic digester labour	Light and energy for cooking	Most ideal but expensive
Store urine	Animal urine FRF confinement	High	High	FRF/FF	Collecting containers Information on use Animal urine labour	Horticulture manure	Not ideal due to practicality
Slurry	Dung and urine FRF confinement	low	High	FRF/FF	Impermeable floor Pit with impermeable layer Dung and urine labour	Uses on horticulture farm	Ideal but needs biogas
Compost	Airtight materials Dung and urine Bedding and feed refuse	High	Low	FRF/FF	Long curing period Know how on management	Useful for horticulture	Ideal with labour available
Split solid manure	Animal urine FRF confinement	High	High	FRF/FF	Urine collector labour	Horticulture manure	Not practical
Heap fresh manure	Dung and urine All confinement	Low	Low	FRF/FF/FR/F	Dung and urine Spade, wheelbarrow labour	Useful for pasture lands as well as farms	Most preferred for the households
Heap dry manure	Dung and urine All confinement	Low	Low	FRF/FF/FR/F	Dung and urine Spade, wheelbarrow labour	Useful for pasture lands as well as farms	Most preferred for the households

6.3 Discussion

The results of the farmers' perceptions being related to the gender of the farmers, livestock confinement, and subsequent manure management enable the design of feedback and understanding of the drivers for various levels of livestock confinement use and manure management systems employed in the farms by these smallholder farmers. The objective of this chapter was to find the various perceptions in regard to manure management and sources of information would thus need to establish what groupings of farmers exist. The independent cluster analysis enabled natural groupings to be identified from a dataset (Chibanda *et al*. 2009). This cluster analysis shows that the four groupings (male-crop, female-crop, male-dairy, and female-dairy) of smallholders having both crops as well as dairy cattle agrees with other studies (van Averbeke and Mohamed 2006, Bebe *et al*. 2002, Lekasi *et al*. 2001). Nandi County is known in other studies for having cash crops as major livelihood income for farmers (Mutoko *et al.* 2015; Nandi County Government 2018; Yego *et al.* 2018). This was confirmed by two out of the four clusters being majorly cash crop farmers and the other two being majorly dairy farmers.

Subjective assessments of the clusters are key in seeing potential areas to target farmer training, such as analysis of labour. The clusters from this study showed that these farmers have to get extra help to care for their dairy livestock (Carter 1997, Waithaka *et al*. 2007). Manure management does require labour to carry and spread on the field (Waithaka *et al*. 2007). The low labour numbers were observed in the smallholder dairy farms in Nandi County with farmers (52%) citing lack of farm labour as a major constraint, which was closely followed by 49.2% citing lack of manure collection capacity, which is also tied to labour. Farmers showed that they lack capital investments, which they perceive as key to improving dairy cattle confinement systems. These smallholder dairy farmers would prefer means of improving manure management that is low on costs since the majority of the farmers from previous studies have commented that there are benefits from managing manure (Lekasi *et al*. 2001, Waithaka *et al*. 2007).

Development of mitigation and adaptation strategies would be realised in modifying the farm-scale variables that are related to the variability in manure management, where a standardised baseline provides multiple benefits in farm analysis (Hammond *et al*. 2015). This study found that issues with manure treatment, transport, and application to farms did not matter much to them. This is due to the type of livestock confinement being majorly *Only Fence*. This finding agreed with studies suggesting that improved housing confinement to *Fence, Roof and Floor* would lead to more intensified manure management (Rufino *et al*. 2007, De Vries *et al*. 2015). *Fence, Roof and Floor* confinement creates the need to clean daily and thus puts focus on where manure is deposited and most farmers prefer slurry pits which is easier in terms of labour than heaping. This study has shown that the use of the cluster analysis with many variables shows that the broad distribution of smallholder dairy farmers, especially for Nandi County is defined majorly by gender and major income category. Further analysis on smallholder dairy farmers and the issues that affect their manure quality through improved manure management have been shown in other studies (Dahlin and Rusinamhodzi 2014, Delve *et al*. 2001). These studies observed that manure could be important when the farming system is characterised by integration between livestock and crop production. This also holds true for the observations for Nandi County smallholder dairy farmers.

Farmers go through many challenges, and in these smallholder dairy farmers go through more and synthesis of technical, socio-economic, and institutional challenges assists in knowledge gaps for which practice is affected (Zake *et al*. 2010). The linking of technical, socio-economic and institutional constraints affecting manure management in Nandi County agreed with studies by Chibanda *et al*. (2009) and van Averbeke and Mohamed (2006). In analysing the institutional constraints, smallholder dairy farmers expressed that this was a major challenge. In order to improve manure management, 84.8% thought that a lack of information coming from institutions on improving manure management is important. Thus, the myriad of institutional information fails the farmers as many had not seen an extension worker in their farms in the last five years. Thus studies have highlighted how institutional constraints can assist farmers to improve practices (Chagunda *et al*. 2016, Chibanda *et al*. 2009, Snapp *et al*. 2003). When these farmers were asked what manure type they value most for use on farm, solid manure from dairy and other livestock was higher than slurry. It confirms the availability of solid manure, as suggested in studies on dairy cattle manure (Lekasi *et al*. 2003, Rufino *et al*. 2014, Waithaka *et al*. 2007).

The groupings of the smallholder dairy farmers after analysis of the constraints to improve manure management, the value of dairy cattle manure and sources of manure improvement and management information was established, and this is useful in the assessment and valuation of options that are used by these farmers in managing manure. They would first prefer manure heaps with cover and impermeable floor as it does not require much labour (Amon *et al*. 2001, Christiaensen 2017, Markewich *et al*. 2010). The ideal for the farmers was the installation of biogas systems for energy and slurry, and the FGDs noted this is ideal with financial capital (Møller *et al*. 2014).

6.4 Conclusion

This study evaluates the various community perception on constraints to the management of manure, the value of manure, and critical sources of information that farmers value as a means to access information for manure management. The study shows the natural groupings of smallholder dairy farmers in Nandi County, shows the key technical socio-economic and institutional constraints to improving manure management, shows the dairy cattle manure value and shows the critical sources of information for improving manure management. These findings allow for feedback of farmer practices in a transdisciplinary manner to the science of minimising nutrient losses and GHG emissions that provide for effective ways to adapt to climate changes through the improvement of manure management. This allows policymakers to know where the challenges in farmer practices occur and the medium most effective to the farmers for information on manure management to be passed to farmers.

CHAPTER SEVEN: GENERAL CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary of key findings

This chapter describes key findings for the objectives of the thesis. Further, in the description and presentation, the chapter focuses on the broad objective and the elements of the conceptual framework. It addresses them in the following aspects; characterisation of smallholder dairy farmers, nutrient N losses from manure in storage, GHG emissions from manure management systems, determination and exploration with the community manure management strategies that would minimise N and C losses while mitigating GHG emissions and generation of community perceptions driving choice of manure management strategies and transdisciplinary approach in assessing options for minimising GHG emissions through improved manure management in Nandi County by the smallholder dairy farmers.

7.1.1 Characterisation of the manure management systems utilised by the dairy farmers in the study region.

The study characterised the smallholder dairy farmers in three Agro-Ecological Zones (Lower Highland 1-LH1, Lower Highland 2- LH2 and Upper Midlands- UM) and found that majority kept dairy cattle and also had varied sources of income such as cash crop farming, business (non-agricultural) and employment as major income sources. Further characterisation leads to activity data on acreage, education level and relation of gender to education level on type of livestock confinement installed, manure management systems used and the attendant practices and duration of storage of manure before application into farms. The results here show that smallholder dairy farmers in Nandi County have three livestock confinement types; *Only Fence (89.8%), Fence and Roof (2.8%)*, *Fence Roof and Floor* (7.5%) and from these have seven manure management practices; biogas, slurry, splitting urine, storing urine, heaping fresh manure, heaping dry manure and compost.

7.1.2 Estimation of nutrient N losses during storage for the different manure management systems

From the livestock confinement data and manure management systems data derived in the characterisation, this study found that 94% of manure was managed as uncovered heaps of either fresh or dry manure. The study then found that this manure lost about 50% of N in 3 months of storage. This study realised that nutrient N lost from the smallholder manure from all the livestock confinement system through the solid storage manure management for three months is substantial and there is need to change practice to minimise nutrient losses. When compared initial manure from the *Fence Roof and Floor* was better that manure from the majority *Only Fence.*

7.1.3 Quantification of CH_4, CO_2 and N_2O emissions from manure from the various manure management systems and development management system specific emission factors

The study analysed and found emissions from uncovered solid storage manure heaps have highest emissions from *Fence, Roof and Floor* as the manure from *Only Fence* systems have already lost most of the urine N through leaching. The study developed CH_4 and N_2O emission factors for GHG emissions through solid storage of manure.

7.1.4 To determine and explore with the community manure management strategies that would minimise N and C losses while mitigating GHG emissions and generate community perceptions driving choice of manure management strategies.

The study found through cluster analysis that there are four natural grouping of smallholder dairy farmers split by gender and major income categories. These clusters had low total acreage, as well as low acreage available for grazing, and the farmers had less labour available and high dairy livestock numbers. This study revealed that access to information on manure management was a major constraint to improving manure management. The farmers valued solid manure from dairy cattle more than from other livestock and also more than slurry. This study found that majority of farmers who did manage manure did it because of considerations of hygiene and water quality for human and animal health in the farms. The study found that intensification which for them was installing *Fence, Roof and Floor* animal confinement systems would make manure management key.

The study found that majority of the farmers (79.7%) had received information on manure management within the last five years and found majority (>70%) preferred local radio for information on manure management. This study after evaluating the manure management practices found in Nandi County farmers preferred heaping fresh manure and dry as their best options as these required least labour, least capital, smallest area and could be done on any livestock housing system.

This study applied the transdisciplinary approach since it was paramount to the objective of the study in creating a holistic understanding of the subject of inquiry. The study encompassed engagement of stakeholders in both academic and non-academic environment: knowledge on livestock housing systems and manure management practices were sourced from smallholder dairy farmers, the nutrient loss and GHG emissions were sourced from laboratory experimentation, appropriate selection of viable options for manure management to minimise GHG and nutrient losses came from the smallholder dairy farmers after seeing the impacts of unmanaged and poorly managed manure. These farmers came up with appropriate recommendations to improve two of their major manure management systems as they work towards further improvement using biogas systems. Integrated manure management combined with understanding of nutrient losses and GHG emissions has been suggested by various literature and this study did so with the factor of using the smallholder dairy farmers to give feedback on th e various processes (Lal *et al*. 2012, Kang'ethe *et al*. 2012, Ortiz-Gonzalo *et al*. 2017).

7.2 Conclusions

The general conclusion from this study is that smallholder farmers in Nandi County like many other smallholder farmers have diversified farm activities. They have more literate farmers and employ three main livestock confinement systems of *Only Fence*, *Fence and Roof and Fence*, *Roof and Floor;* majority (89.8%) of the smallholder dairy farmers had *Only Fence* systems. These livestock confinement systems had seven manure management practices with majority (93%) heaping manure either fresh or dry in their farms in uncovered locations. This study found an indirect relationship between smallholder livestock confinement systems and manure management practices employed for FRF and FR but observed a direct relationship in F systems. The F systems manure was dry and subject to leaching thus farmers did manage manure majorly as solid storage, but in FR and FRF farmers subjected the manure to many other manure management systems. It also revealed that nutrient N is lost in similar pattern from manure from different livestock confinement systems stored in the same manner; uncovered heaped manure management practice.

On GHG emissions from uncovered heaped manure management manure system, methane was found to be emitted differently from manure from different livestock confinement systems. Carbon dioxide is emitted in similar patterns for manure from different livestock confinement systems, which was also true for nitrous oxide from the manure from the various livestock confinement systems, the trend was the same only quantities varied.

Engagement with stakeholders realised that after cluster analysis main income category, labour, dairy livestock and grazing area acreage were driving forces for the smallholder farmers leading to four clusters based on gender with mirror differences being gender and main income category of cash crop farmers or dairy farmers. The stakeholders explained that key constraints were access to information on manure management and manure collection capacity which was subject to labour and capital. The institutional constraint that matters was access to information, capital and equipment and services for manure management. The study found that the farmers valued solid manure and thus proposed their interest to manage solid manure more as liquid manure (slurry) required more capital for change of livestock housing, technology (biogas) and labour. The study found that solid manure management of heaps was the most recommended and has ease of acceptance with farmers. It also minimises GHG emissions and nutrient N losses.

7.3 Recommendations

The study has shown the best farmers practices, nutrient loss experimentation, GHG emissions experimentation and farmer evaluation of the manure management practices related to the livestock confinement systems. The management of solid storage of manure desired and can be effective in minimising GHG emissions as well as nutrient N losses. Based on the results from this study, the following recommendations were suggested:

1. There is need to Intensify smallholder dairy agriculture through improving livestock housing to *Fence, Roof and Floor* from the majorly *Only Fence.*
2. The study notes that increased intensification would lead to larger quantity of manure and better manure (higher nutrient N retention) being available. The study further recommends that focused farmer trainings made through local radio could ensure that intensification interventions do not result in additional GHG emissions, but rather increased nutrient used efficiency and tighter on farm nutrient cycling.
3. The study recommends increased capacity building for smallholder farmers with messages targeting both manure management and its impact on GHG emissions and minimisation of nutrient losses.
4. An analysis of the various manure management methods with the community resulted in preferring methods that would be less labour and cost intensive and still fit within their seasonal use of manure. Thus, the study recommends engagement of institutions focusing on dairy agriculture, industry, traders and farmers to explore ways to incentivise or lower costs for robust manure management strategies such as biogas systems that would be more effective in minimizing nutrient losses and GHG emissions.
5. In terms of farmer oriented policy, this study has various results from smallholder dairy farmers that should be used in making farmer training manuals and also provides the evidence-base for policy makers to develop training programmes for extension agents and farmers.

6. It is important that in order to further and comprehensively understand the smallholder dairy farmers in terms of assessing options for minimising GHG emissions and nutrient losses in Nandi County that further research be conducted. This study recommends the following areas for future research:

a) The impact of slurry/liquid manure from dairy livestock on GHG emissions from manure in Nandi County

b) The impact of slurry from dairy livestock on nutrient contribution to the smallholder farms in Nandi County

c) The impact of finance and governance institutions targeting smallholder dairy farmers with manure management information on intensification and manure management in Nandi County.

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APPENDICES

1. **Household Questionnaire code in Excel- Code Usage in ODK**

type	name	label	hint	default	appearance	constraint	constraint_message	Relevant
start	Starttime	Start Time						
end	Endtime	End Time						
deviceid	Deviceid	Device ID						
subscriberid	subscriberid	Subscriber ID						
simserial	simid	Sim ID						

phonenumber	Device phonenum	Device Phone Number						
begin group	grp_sec_gen	Block A: General Information						
today	q1seca_intdate	1. Interview date			no-calendar			
select_one enumerator	q2seca_enumn	2. Enumerator Name:	(select one)		quick			
select_one county	q3seca_county	3. County Name:	Nandi		quick			

select_one constituency	q4seca_const	4. Constituency Name	(select one)		quick			
select_one ward	q5seca_ward	5. Ward Name	(select one)		quick			
text	q6seca_hhid	6. Household Code			numbers	**.>=1 and .<=300**	Use assigned values	
text	q7seca_hhname	7. Household Head Name	(firstname surname)					
text	q8seca_mob	8. Mobile Number			numbers			

select_one yes_no	q9seca_consent	9. Did the household consent to the interview	(select one)		quick			
select_one noconsent	q10seca_noco n	10. If No, Why?	(select one)		quick			${q9seca_consent}=0
text	q11seca_noco n	11. If No, Why? Specify	Explain					${q10seca_nocon}=4
note	secainfo_ifno	If no, request the supervisor to give anOther household and (start a new Questionnaire)						${q9seca_consent}=0

end group								
begin group	grpsecab_Intxtics	Household Characteristics			field-list			${q9seca_consent}=1
text	q1secab_name	12. Name of household member	(Member being interviewed)					${q9seca_consent}=1
select_one relationship	q2secab_rship	13. Relationship to HH head	(Pick only one)					${q9seca_consent}=1
select_one gender	q3secab_gender	14. Gender	(Pick only one)					${q9seca_consent}=1

integer	q4seca b_age	15. Age	years			.>=18 and .<=120	No interest in child headed households or where respondent is too old!	${q9seca_consent}=1
select_one leveledu c	q5seca b_educ lvl	16. Highest level of Education	(COMPLETED)		quick			${q9seca_consent}=1

end group								
begin group	grp_secaa_xtics	Section A: Questions						${q9seca_consent}=1
note	seca1_infor	(To be filled for each individual farm) In addition to this questionnaire its strongly recommended that the interviewer takes geopoints and photographs on completion						${q9seca_consent}=1

		(after asking permission of course) of the relevant aspects(housing, effluents, means of transport and application, etc)						
integer	q17seca1_labnoyn	17. Available farm labour (no. persons <18years of age)	Persons		quick	**.>=1**	It's individuals!	${q9seca_consent}=1
integer	q17seca1_labytm	17a. Available farm labour (average hours per day)	Hours per day		quick	**.>=1 and .<=24**	It's Time in a day!	${q9seca_consent}=1

integer	q18seca1_labnoyo	18. Available farm labour (no. persons 18-60 years of age)	Persons		quick	.>=1	It's individuals!	${q9seca_consent}=1
integer	q18seca1_labnoyotm	18a. Available farm labour (average hours per day)	Hours per day		quick	.>=1 and .<=24	It's Time in a day!	${q9seca_consent}=1
integer	q19secaa_labnoo	19. Available farm labour (no. persons >60 years of age)	Persons		quick	.>=1	It's individuals!	${q9seca_consent}=1
integer	q19secaa_labnootm	19a. Available farm labour (average hours per day)	Hours per day		quick	.>=1 and .<=24	It's Time in a day!	${q9seca_consent}=1

text	q20secaa_town	20. In this county what is your nearest town?	In Nandi County					${q9seca_consent}=1
decimal	q21secaa_hhcarea	21. Household area?	acre		quick	.>=0.0		${q9seca_consent}=1
decimal	q22secaa_cer	22. Of which arable land (cereals,Tea,Tuber crops etc)?	acre		quick	.>=0.0		${q9seca_consent}=1
decimal	q23secaa_hort	23. Of which horticulture (vegetable, fruits)?	acre		quick	.>=0.0		${q9seca_consent}=1
decimal	q24secaa_grs	24. Of which grassland for cutting and/or	acre		quick	.>=0.0		${q9seca_consent}=1

		grazing(excl. communal grazing grounds)?						
decimal	q25secaa_trees	25. Of which Other crops (i.e. Trees)?	acre		quick	.>=0.0		${q9seca_consent}=1
calculate	acreage							
note	q26secaa_tota	26. The farm is ${acreage} acres						${q9seca_consent}=1
select_one income	q27secaa_incom	27. Main Income generating activity from agriculture	(Pick only one)		quick			${q9seca_consent}=1
end group								

begin group	grpsecb_lvstcomp	Block B: Livestock Composition						${q9seca_consent}=1
note	secb_infor	(numbers present on an average day, so not the numbers produced per year as a whole, that is in consecutive rounds):	(check definition in manual)					${q9seca_consent}=1
select_one yes_no	qsecb_qual	Do you have any livestock?	(Qualifier)		quick			${q9seca_consent}=1
begin group	grp_lxtics	Livestock Characteristics			field-list			

integer	q1secb_adult	B1. Adult (dairy) cattle (milk producing and reproductive cows & bulls)	Numbers					${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q1secb_adwgt	B1a. Average weight	kg					${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q2secb_adox	B2. Adult (dairy) oxen for traction	numbers					${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q2secb_adoxwgt	B2a. Average weight	kg					${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q3secb_yd	B3. Young (dairy) stock for	numbers					${q9seca_consent}=1 and ${qsecb_qual}=1

		replacement (calves, heifers)						
integer	q3secb_ydw	B3a. Average weight	kg					${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q4secb_ydm	B4. Young (dairy) stock for meat production	numbers					${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q4secb_ydmw	B4a. Average weight	kg					${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q5secb_bc	B5. Beef Cattle	numbers					${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q5secb_bcw	B5a. Average weight	kg					${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q6secb_gs	B6. Goats/Sheep	numbers					${q9seca_consent}=1 and ${qsecb_qual}=1

integer	q6secb_gsw	B6a. Average weight	kg					${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q7secb_p	B7. Poultry	numbers					${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q7secb_pw	B7a. Average weight	kg					${q9seca_consent}=1 and ${qsecb_qual}=1
text	q8secb_ol	B8. Other livestock (please specify)	numbers					${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q8secb_olw	B8a. Average weight	kg		quick			${q9seca_consent}=1 and ${qsecb_qual}=1
end group								
end group								

begin group	grpsecc_lpd	Block C: Livestock productivity and Destination in 2015						${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q1secc_avgmcy	C1. Average litres of milk produced per cow per month	(ask for daily production) kg		quick			${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q2secc_avgmt	C2. Average number of months cow produces milk	Numbers		quick	**.>=1 and .<=12**		${q9seca_consent}=1 and ${qsecb_qual}=1
select_one destination	q4secab_dest	C3. What is the destination (use) of the produced livestock products	(Pick only one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1

end group								
begin group	grpsecd_hsy	Block D: Housing system						${q9seca_consent}=1 and ${qsecb_qual}=1
integer	q1secd_hr	D1. How many hours in a day does the animals stay in confinement? (i.e. grazing, ranging, scavenging around farm and yard)	hrs		quick	**.>=1 and .<=24**		
integer	q1secd_day	D1a. How many hours in a day are animals (cattle) out of confinement? (i.e. grazing,	hrs		quick	**.>=1 and .<=24**		${q9seca_consent}=1 and ${qsecb_qual}=1

		ranging, scavenging around farm and yard)						
select_one confinement	q2secd_conf	D2. what is the confinement system?	(Pick only one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1
select_one confinement1	q3secd_clean	D3. How often do you clean the confinement?	(Pick only one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=2 or ${q2secd_conf}=4
select_multiple relationship	q4secd_labo	D4. Who in your household cleans the confinement?						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3secd_clean}=1 or ${q3secd_clean}=2 or ${q3secd_clean}=3 or ${q3secd_clean}=4

end group								
begin group	grpsece_fdu	Block E: Fate of cattle Dung and Urine						${q9seca_consent}=1 and ${qsecb_qual}=1
select_one yes_no	q1sece_watuse	E1. Do you use water for flushing barns and waterproof floors which is removed while mixed with animal excretions?	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=2 or ${q2secd_conf}=4
select_one yes_no	q2sece_beddn	E2. Do you use bedding material which is removed	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=2 or ${q2secd_conf}=4

		while mixed with animal excretions?						
select_one yes_no	q3sece_andg	E3. Do you have anaerobic digester? (Biogas System)	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1
note	seceinfo_ifno	E3a. If no,go to E9.						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=0
decimal	q4sece_cap	E4. What is the total holding capacity in m3?	(ask for digester information)		quick	.>0.0		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1
select_multiple products	q5sece_prod	E5. which products go into the digesters?			quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1
text	q5sece_Other	E5a. if Other specify						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q5sece_prod}=9

integer	q6sece_ofmf	E6. Immediately after leaving the digester, which fraction (%) of the digestate is used for on-farm fertilization?			quick	**.>=1 and .<=100**		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1
integer	q7sece_lqsg	E7. Immediately after leaving the digester, which fraction (%) of the digestate is used for liquid storage?	(E19. is Yes)		quick	**.>=1 and .<=100**		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1
integer	q8sece_nofmu	E8. Immediately after leaving the digester, which			quick	**.>=1 and**		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1

		fraction (%) of the digestate is discharged (for non on-farm use)?				.<=100		
calculate	biogas				quick	.=100		
note	biogas1	The percentage used is ${biogas}						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1
select_one yes_no	q9sece_ursg	E9 Do you store urine separately (without mixing with dung)?	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=2 or ${q2secd_conf}=4
select_one storage	q10sece_stg	E10. What Main type of storage do you use?			quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q9sece_ursg}=1

select_multiple storage1a	q10sece_otstgr	E10a. What of floor and roof?			quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q9sece_ursg}=1 and ${q10sece_stg}=1 and ${q10sece_stg}=3
select_one yes_no	q11sece_capov	E11. Is the storage capacity enough to prevent overflow?	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q9sece_ursg}=1 and ${q10sece_stg}=1 and ${q10sece_stg}=3
select_one yes_no	q12sece_rnwt	E12. Is an overflow caused by incoming rain water?	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q11sece_capov}=0
integer	q13sece_dyov	E13. How many days per average year is it overflowing?			quick	**.<=365**		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q11sece_capov}=0

decimal	q14sece_stgc	E14. what is the storage capacity in m3?			quick	.>=1.0		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q11sece_capov}=0 or ${q11sece_capov}=1
integer	q15sece_stemp	E15. How many times per year is the storage emptied?			quick	.<=365		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q11sece_capov}=0
integer	q16sece_stdurn	E16. Which fraction of the stored urine is used as on-farm fertiliser? (rest is discharged)			quick	.<=100		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q9sece_ursg}=1
select_one yes_no	q17sece_slm	E17. Do you store liquid manure	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1 and ${q2secd_conf}=2 or ${q2secd_conf}=4

		(slurry, mixture of urine and dung)						
select_one storage	q18sece_lmstg	E18. What Main type of storage do you use?			quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q17sece_slm}=1
select_multiple storage1a	q18sece_otcstr	E18a. What of floor and roof?			quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q17sece_slm}=1
select_one yes_no	q19sece_capov	E19. Is the storage capacity enough to prevent overflow?	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q17sece_slm}=1
select_one yes_no	q20sece_rnwt	E20. Is an overflow caused by incoming rain water?	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q19sece_capov}=0

integer	q21sece_dyov	E21. How many days per average year is it overflowing?				quick	**.<=365**		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q19sece_capov}=0
decimal	q22sece_stgc	E22. what is the storage capacity in m3?				quick	**.>=1.0**		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q19sece_capov}=0 or ${q19sece_capov}=1
select_one yes_no	q23sece_ss	E23. Do you dry liquid manure to be solid and stackable?	(select one)			quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=1 or ${q2secd_conf}=3
integer	q24sece_flmd	E24. What fraction (%) of the yearly liquid manure production is dried?				quick	**.>=1 and .<=100**		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q23sece_ss}=1

note	q24sece_flmda	E24a. If 100% , go to E30						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24sece_flmd}=100
select_one yes_no	q25sece_sls	E25. Do you separate liquid manure into a liquid and solid fraction?	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q23sece_ss}=0 and ${q2secd_conf}=2 or ${q2secd_conf}=4 and ${q24sece_flmd}<100
select_one confinement1	q26sece_lfe	E26. How many times per year is the storage with liquid fraction emptied?			quick	**.<=365**		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q25sece_sls}=1 and ${q24sece_flmd}<100
integer	q27sece_rlf	E27. Which fraction (%) of the removed liquid			quick	**.>=1 and**		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q25sece_sls}=1 and ${q24sece_flmd}<100

		fraction is used as in-farm fertilizer? (rest is discharged)				.<=100		
integer	q28sece_lmp	E28. Which fraction (%) of the yearly liquid manure production is separated?			quick	.>=1 and .<=100		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q25sece_sls}=1 and ${q24sece_flmd}<100
note	q28sece_lmpa	E28a. If <=10% , go to E30						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q28sece_lmp}<=10
integer	q29sece_ylmp	E29. Which fraction (%) of the removed liquid manure is used as on-fam fertiliser?			quick	.>=1 and .<=100		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q25sece_sls}=1 and ${q28sece_lmp}>=11

select_one yes_no	q30sece_smsp	E30. Do you store solid manure (stackable products)?	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1
note	q30sece_smspn	E30a. If No go to E35						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q30sece_smsp}=0
select_multiple solids	q31sece_slds	E31. What do the solids consist of?			quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q30sece_smsp}=1
text	q32sece_otslds	E32. If Other specify						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q31sece_slds}=9
select_one storage1	q33sece_db	E33. What MAIN type of storage do you use?			quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q30sece_smsp}=1

select_multiple		E33a. What of floor and roof?						
storage1a	q33sece_stgp				quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q30sece_smsp}=1
select_one storage2	q34sece_sms	E34. How long is solid manure stored before application?			quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q30sece_smsp}=1
text	q34sece_Other	E34a. If Other specify	Answer in length					${q34sece_sms}=3
select_one yes_no	q35sece_csm	E35. Do you actively compost solid manure?	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=2 or ${q2secd_conf}=4

note	q35sece_csmn	E35a. If No go to E37							${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=0
integer	q36sece_cof	E36. Which fraction (%) of the compost is used as on-farm fertiliser?			quick	**.>=1 and .<=100**			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1
select_one yes_no	q37sece_ynm	E37. Do you use manure from your cattle confinement on your own farm?	(select one)		quick				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=2 or ${q2secd_conf}=4
select_one confinement1	q38sece_ynmh	E38. How many times do you incorporate manure to the farm?			quick	**.>=1 and .<=365**			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q37sece_ynm}=1

text	q39sece_floc	E39. How far is your farm from the cattle confinement?	Estimate		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q37sece_ynm}=1
integer	q40sece_scagr	E40. Which fraction (%) of the compost is sold or given away for off-farm agricultural use?			quick	**.>=1 and .<=100**		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1
integer	q41sece_fsmc	E41. Which fraction (%) of the yearly solid manure production is composted?			quick	**.>=1 and .<=100**		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1

note	q41sece_fsmcn	E41a. if =0% , go to E56						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q41sece_fsmc}=0
integer	q42sece_lcmw	E42a. How long in weeks is manure composted before use?			quick	.<=52		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1 and ${q41sece_fsmc}>1
integer	q42sece_lcmm	E42b. How long in months is manure composted before use?			quick	.<=12		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1 and ${q41sece_fsmc}>1
integer	q42sece_lcmy	E42c. How long in years is manure composted before use?			quick	.>=1		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1 and ${q41sece_fsmc}>1

select_one yes_no	q43sece_dsm	E43. Do you actively dry solid manure?	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q30sece_smsp}=1
note	q43sece_dsmn	E43a. if No, go to E52						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=0
integer	q44sece_dsm	E44. Which fraction(%) of the dried solid manure is used as on-farm fertiliser?			quick	**.>=1 and .<=100**		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1
integer	q46sece_oagru	E46. Which fraction (%) of the dried solid manure is sold or given			quick	**.>=1 and .<=100**		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1

		away for off-farm agricultural use?						
integer	q47sece_dsmf	E47. Which fraction (%) of the dried solid manure is used, sold or given away for fuel?			quick	.>=1 and .<=100		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1
integer	q48sece_ysmp	E48. Which fraction (%) of the yearly solid manure production is dried?			quick	.>=1 and .<=100		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1
note	q48sece_ysmpnote	E48a. if 100% , go to E51						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q48sece_ysmp}=100

integer	q49sece_smdw	E49. How long in weeks is the manure dried before use?			quick	.<=52		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1 and ${q48sece_ysmp}<100 and ${q48sece_ysmp}>1
integer	q50sece_smdm	E50. How long in months is the manure dried before use?			quick	.<=12		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1 and ${q48sece_ysmp}<100 and ${q48sece_ysmp}>1
integer	q51sece_smdy	E51. How long in years is the manure dried before use?			quick	.>=1		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1 and ${q48sece_ysmp}<100 and ${q48sece_ysmp}>1
text	q52sece_mqt	E52. What quantities of manure do you	(describe)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q37sece_ynm}=1

		apply to your farm?						
select_one confinement1	q53sece_mis	E53. How soon is manure incorporated to the soil after application?			quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q37sece_ynm}=1
select_one yes_no	q54sece_fwm	E54. Can you quantify the differences between fields having manure and those without?	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1
select_one yes_no	q55sece_acon	E55. Do you feed concentrate to your animals	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1

		(manufactured feeds)?						
note	q56sece_nacon	E56. If No, go to Block F: Opinions						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q55sece_acon}=0
text	q57sece_conq	E57. What quantity of concentrate do you feed your animals?						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q55sece_acon}=1
text	q58sece_conty	E58. What type of concentrate do you feed your animals?						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q55sece_acon}=1
end group								
begin group	grpsecf_opn	Block F: Opinions						${q9seca_consent}=1 and ${qsecb_qual}=1

note	secf_info	Manure management encompasses all steps between excretion and the eventual use as a source of plant nutrients. So the collection, the storage, possible treatments of manures, transporting and application.						${q9seca_consent}=1 and ${qsecb_qual}=1

begin group	grp_op 1	Opinion 1			fiel d- list			
note	opinio n1	1. How important do you consider some technical and socio-economic constraints prohibiting optimal manure management on your farm to be?						
select_on e ranking	q1secf _fl	F1. Lack of farm labour to handle manure	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1

select_one ranking	q2secf_mc	F2. Lack of manure collection capacity	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q3secf_msc	F3. Lack of manure storage capacity	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q4secf_mtc	F4. Lack of manure treatment capacity	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q5secf_mtrc	F5. Lack of manure transport capacity	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q6secf_seam	F6. Lack of suitable equipment to apply manure	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1

select_one ranking	q7secf_lamz	F7. Lack of land to apply manure, because there is none available	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q8ecf_lamp	F8. Lack of land to apply manure, because the prices of land are too high	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q9secf_colt	F9. Not enough collateral to get credit for investments?	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q10secf_thtc	F10. Too high transport costs, compared to the	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1

		use of mineral fertilisers						
select_one ranking	q11secf_lc	F11. Too high labour costs, compared to the use of mineral fertilisers	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q12secf_tlbf	F12. Too low benefits when used as fertiliser, compared to the benefits when used as a fuel (dung cakes)	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1
end group								

begin group	grp_op 2	Opinion 2			field-list			
note	opinion2	2. How important do you consider the institutional constraints prohibiting optimal manure management in general?						
select_one ranking	q13secf_limm	F13. Lack of information to improve the manure management	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1

select_one ranking	q14secf_laai	F14. Lack of access to available information	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q15secf_lal	F15. Lack of access to loans for the required investments	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q16secf_lare	F16. Lack of access to required equipment and machines	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q17secf_lti	F17. Lack of trading infrastructure	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q18ecf_lr	F18. Lack of regulations,	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1

select_one ranking	q19secf_ssl	leading to possible privileging of groups F19. Spatial separation of livestock farms and arable farms due to specialization	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1
end group								
begin group	grp_op3	Opinion 3 Liquid manure			field-list			
note	opinion3	3. How valuable is the use of urine						

		and liquid manure as a fertiliser on your farm to you?						
select_one ranking	q20secf_ulmc	F20. From cattle	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q21secf_ulmoa	F21. From all Other animals	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1
end group								
begin group	grp_op4	Opinion 4 solid manure			field-list			
note	opinion4	4. How valuable is the use of solid manure as a						

		fertiliser on your farm to you?						
select_one ranking	q22secf_smc	F22. From cattle	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q23secf_smoa	F23. From all Other animals	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one yes_no	q24secf_imm	F24. Have you invested (time/money) to improve your manure management in the last five years?	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1

note	q24sef_immn	if No, got to Block G: Information sources						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=0
end group								
begin group	grp_op5	Opinion 5 manure processes			field-list			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
note	opinion5	5. Did your management processes improve in regards to the following?						
select_one yes_no	q25secf_fac	F25a. Manure collection	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1

select_one yes_no	q25secf_fas	F25b. Manure storage	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one yes_no	q25secf_fat	F25c. Manure Treatment	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one yes_no	q25secf_fats	F25d. Manure transport	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one yes_no	q25secf_faa	F25e. Manure Application	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
end group								
begin group	grp_op6	Opinion 6			field-list			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
note	opinion6	6. How important was the considerations to						

		improve your manure management based on the following?						
select_one ranking1	q26secf_consd	F26. Improving on farm hygiene, considering human health?	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one ranking1	q27secf_consd	F27. Improve on farm hygiene, considering animal health	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one ranking1	q28secf_consd	F28. Improving on water quality, from the point of view of human health	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1

select_one ranking1	q29secf_consd	F29. Improving on water quality, from the point of view of animal health	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one ranking1	q30secf_consd	F30. Abatement of odour problems, also for neighbours	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one ranking1	q31secf_consd	F31. Improving fertiliser value (nutrients) for the own crops	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one ranking1	q32secf_consd	F32. Improving fertiliser selling value (income) when sold to Other farms	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1

select_one ranking1	q33secf_consd	F33. Incentive measures by the government and/or Other institutions	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one ranking1	q34secf_consd	F34. Restrictive measures by the government and/or Other institutions	(select one)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
end group								
end group								
begin group	grpsecg_infs	Block G: Information sources			field-list			${q9seca_consent}=1 and ${qsecb_qual}=1

select_one yes_no	q1secg_inf5	G1. In the last five years, did you receive any information on how to improve your manure management?	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
note	q1secg_inf5n	If No, go to G8.						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=0
select_one ranking2	q2secg_infv	G2. If Other farmers gave you the information, how valuable was it to you?	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=1

select_one ranking2	q3secg_infv	G3. If government extension workers gave you the information, how valuable was it to you?	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=1
select_one ranking2	q4secg_infv	G4. If non-commercial advisors gave you the information, how valuable was it to you?	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=1
select_one ranking2	q5secg_infv	G5. If Commercial/Private advisors gave you the	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=1

		information, how valuable was it to you?						
select_one ranking2	q6secg_infv	G6. If local teachers/trainers gave you the information, how valuable was it to you?	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=1
select_one ranking2	q7secg_infv	G7. If Other gave you the information, how valuable was it to you?	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=1

text	q7secg_infvo	G7a. Other Specify						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q7secg_infv}=1 or ${q7secg_infv}=2 or ${q7secg_infv}=3 or ${q7secg_infv}=4
note	infsource	What is the importance of the below sources in giving you information (on agricultural subjects)?						
select_one ranking2	q8secg_inag	G8. National television	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q9secg_inag	G9. Local television	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1

select_one ranking2	q10secg_inag	G10. National radio	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q11secg_inag	G11. Local radio	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q12secg_inag	G12. National newspaper	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q13secg_inag	G13. Local newspaper	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q14secg_inag	G14. Farmers' magazines	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1

select_one ranking2	q15secg_inag	G15. Farmers' group meetings	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q16secg_inag	G16. Field excursions/farm visits/open days	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q17secg_inag	G17. Individual meetings	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q18secg_inag	G18. Billboards/posters	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q19secg_inag	G19. Pamphlets/leaflets/brochures	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1

select_one ranking2	q20secg_inag	G20. Videos	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q21secg_inag	G21. Internet	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q22secg_inag	G22. Social media	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one yes_no	q23secg_yn	G23. Is there any Other source?	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q23secg_inag	G23a. Rank Other source	(select one)					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q23secg_yn}=1

text	q23secg_inago	G23b. Other specify						${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q23secg_inag}=1 or ${q23secg_inag}=2 or ${q23secg_inag}=3 or ${q23secg_inag}=4
end group								
begin group	grpsech_conl	Block H: Concluding questions						${q9seca_consent}=1 and ${qsecb_qual}=1
select_one yes_no	q1sech_fut	H1. Would you be interested to become involved in future projects directed at improvement of your manure?	(Such as nutrient analysis of manure)		quick			${q9seca_consent}=1 and ${qsecb_qual}=1

text	q2sech_aob	H2. Is there any Other information you would like to share with us? (i.e. perception on the manure policy, its implementation; or on service providers i.e. extension services; or what is bothering you etc.)						${q9seca_consent}=1 and ${qsecb_qual}=1
end group								
begin group	grpi	Geopoints and photos						${q9seca_consent}=1 and ${qsecb_qual}=1

note	q1seci _note	This should be done once interview is completed						${q9seca_consent}=1 and ${qsecb_qual}=1
geopoint	hhgps	Household GPS coordinates	get in open area for GPS reading		qui ck			${q9seca_consent}=1 and ${qsecb_qual}=1
geopoint	fmgps	Farm GPS coordinates	get in open area for GPS reading		qui ck			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q37sece_ynm}=1
image	boma	photo of the animal enclosure (boma) if any			qui ck			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=1 or ${q2secd_conf}=2 or ${q2secd_conf}=3 or ${q2secd_conf}=4

image	biogas 3	Photo of the anaerobic digester (biogas system) if any			qui ck			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1
image	liqurin e	Photo of the liquid urine storage if any			qui ck			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q17sece_slm}=1
image	compo st	Photo of the compost manure pile if any			qui ck			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1
image	soldma nr	Photo of the solid manure pile if any			qui ck			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1
image	concet rate	Photo of the concentrate	(ask for sample to photo)		qui ck			${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q55sece_acon}=1
end group								

note	Thank sno	Give thanks to the respondent						${q9seca_consent}=0
note	Thank sno2	Give thanks to the respondent						${q9seca_consent}=1 and ${qsecb_qual}=0
note	Thank syes	Give thanks to the respondent						${q9seca_consent}=1 and ${qsecb_qual}=1

2. Choice guide for ODK code

list_name	**name**	**Label**	**image**	**Filter**
enumerator	1	Jesse		
county	1	Nandi		
constituency	10	Tinderet		1

constituency	11	Aldai	1
constituency	12	Nandi Hills	1
constituency	13	Chesumei	1
constituency	14	Emgwen	1
constituency	15	Mosop	1
ward	100	Songhor/Soba	10
ward	101	Tinderet	10
ward	102	Chemelil/ Chemase	10
ward	103	Kapsimotwo	10
ward	110	Kabwareng	11
ward	111	Terik	11
ward	112	Kemeloi-Maraba	11
ward	113	Kobujoi	11
ward	114	Kaptumo-Kaboi	11
ward	115	Koyo-Ndurio	11
ward	120	Nandi Hills	12

ward	121	Chepkunyuk	12
ward	122	Ol'lessos	12
ward	123	Kapchorua	12
ward	130	Chemundu/Kapng'etuny	13
ward	131	Kosira	13
ward	132	Lelmokwo/ Ngechek	13
ward	133	Kaptel/ Kamoiywo	13
ward	134	Kiptuya	13
ward	140	Chepkumia	14
ward	141	Kapkangani	14
ward	142	Katito	14
ward	143	Kapsabet	14
ward	144	Kilibwoni	14
ward	150	Chepterwai	15
ward	151	Kipkaren	15
ward	152	Kurgung/ Surungai	15

ward	153	Kabiyet	15
ward	154	Ndalat	15
ward	155	Kabisaga	15
ward	156	Sangalo/ Kebulonik	15
yes_no	1	yes	
yes_no	0	no	
noconsent	1	respondent refuses to participate	
noconsent	2	respondent does not have the time	
noconsent	3	household head(or Other knowledgeable member) is not present at the house	
noconsent	4	Other: (specify)	
income	1	Crops	
income	2	Pigs	
income	3	Poultry	
income	4	Beef	

income	5	Dairy
income	6	Other
relationship	1	Head
relationship	2	Spouse
relationship	3	child
relationship	4	Sibling
relationship	5	Parent
relationship	6	Grandchild
relationship	7	Other relative
relationship	8	Non relative (Labourer)
relationship	9	Other relative
gender	1	Male
gender	2	Female
leveleduc	1	No formal and illiterate
leveleduc	2	No formal but literate

leveleduc	3	Primary school
leveleduc	4	High/ secondary school
leveleduc	5	College
leveleduc	6	University
leveleduc	7	Other (specify)
destination	1	100% Home consumption (HC)
destination	2	HC with <25% sold
destination	3	HC with 25-75% sold
destination	4	HC with >75% sold
confinement	1	only fence
confinement	2	Fence + Floor (man-made waterproof to prevent leaching)
confinement	3	Fence + Roof (roof to prevent rainwater to enter)
confinement	4	Fence + Floor (man-made waterproof to prevent leaching) + Roof (roof to prevent rainwater to enter)
confinement1	0	Never

confinement1	1	Daily
confinement1	2	Weekly
confinement1	3	Monthly
confinement1	4	Seasonally
products	1	Urine
products	2	Dung
products	3	bedding Material
products	4	Flush water
products	5	Crop residue
products	6	By-products from agro processing
products	7	Household garbage
products	8	Organic garden trash
products	9	Other
storage	1	Cellar/Silo/Tank
storage	2	Lagoon/Furrow

storage	3	Pit
solids	1	Urine
solids	2	Dung
solids	3	Bedding material
solids	4	Flush water
solids	5	Crop residues
solids	6	Solid fraction after separation and/or dried liquid manure
solids	7	Household garbage
solids	8	organic garden trash
solids	9	Other
storage1	1	Deep bedding
storage1	2	Pile/Heap
storage1	3	Dry lot/Kraal
storage1	4	Pit
storage1a	1	With floor

storage1a	2	With cover/roof
ranking	1	Very important
ranking	2	Important
ranking	3	Not so important
ranking1	1	Very important
ranking1	2	Important
ranking1	3	Not so important
ranking1	4	irrelevant
ranking2	1	Crucial
ranking2	2	Important
ranking2	3	Not so important
ranking2	4	Irrelevant
storage2	1	Seasonally (3-4)months
storage2	2	Yearly

storage2	3	Other

3. Questionnaire- Focus Group Discussions Guide

Data Collection from Focus Groups Discussions on constraints farmers face, information sources for improved manure management practices, benefits of using manure and strategies for improving manure that are most easily utilised that would have the least GHG emissions and nutrient loss impacts.

Background information

1. Location name________________________________
2. Date of interview______________________________
3. Name of focus group ____
4. Number of members M=________ /F= ___________
5. Type of group________________________________

A: Include list of participants and gender. The below checklist is a guide.

A1. What are the socio-economic characteristics of the households?

a) What are the major income categories for farmers?
b) Do all farmers keep dairy livestock?
c) How many people look after dairy cattle?

A2. What are the effects of manure management on

a) Energy at households;
b) Health at households;
c) Environment (Climate Change);
d) Coverage of manure management?

A3. What are the social and economic benefits of manure?

a) Social benefits of manure

b) economic benefits of manure

A5. What are the effects on animal husbandry practices/dung management and slurry use?

A6. What Manure Management costs and financing modality affects manure management?

A7. State preferences of users of the perceived advantages

A8. What are your views towards manure management?

A9. What are the obstacles around manure management?

4. Focus group discussion manure practices questionnaire

begin group	grpsece_fdu	Block E: Fate of cattle Dung and Urine					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one yes_no	q1sece_watuse	E1. Do you use water for flushing barns and waterproof floors which is removed while mixed with animal excretions?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=2 or ${q2secd_conf}=4
select_one yes_no	q2sece_beddn	E2. Do you use bedding material which is removed while mixed with animal excretions?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=2 or ${q2secd_conf}=4

select_one yes_no	q3sece_andg	E3. Do you have anaerobic digester? (Biogas System)	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1
note	seceinfo_ifno	E3a. If no,go to E9.					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=0
decimal	q4sece_cap	E4. What is the total holding capacity in m3?	(ask for digester information)		quick	.>0.0	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1
select_multiple products	q5sece_prod	E5. which products go into the digesters?			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1
text	q5sece_Other	E5a. if Other specify					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q5sece_prod}=9
integer	q6sece_ofmf	E6. Immediately after leaving the digester, which			quick	.>=1 and	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1

		fraction (%) of the digestate is used for on-farm fertilization?				**.<=100**	
integer	q7sece_lqsg	E7. Immediately after leaving the digester, which fraction (%) of the digestate is used for liquid storage?	(E19. is Yes)		quick	**.>=1 and .<=100**	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1
integer	q8sece_nofmu	E8. Immediately after leaving the digester, which fraction (%) of the digestate is			quick	**.>=1 and .<=100**	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1

		discharged (for non on-farm use)?					
calculate	biogas				quick	.=100	
note	biogas1	The percentage used is ${biogas}					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1
select_one yes_no	q9sece_ursg	E9 Do you store urine separately (without mixing with dung)?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=2 or ${q2secd_conf}=4
select_one storage	q10sece_stg	E10. What Main type of storage do you use?			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q9sece_ursg}=1
select_multiple storage1a	q10sece_otstgr	E10a. What of floor and roof?			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q9sece_ursg}=1 and ${q10sece_stg}=1 and ${q10sece_stg}=3

select_one yes_no	q11sece_capov	E11. Is the storage capacity enough to prevent overflow?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q9sece_ursg}=1 and ${q10sece_stg}=1 and ${q10sece_stg}=3
select_one yes_no	q12sece_rnwt	E12. Is an overflow caused by incoming rain water?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q11sece_capov}=0
integer	q13sece_dyov	E13. How many days per average year is it overflowing?			quick	.<=365	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q11sece_capov}=0
decimal	q14sece_stgc	E14. what is the storage capacity in m3?			quick	.>=1.0	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q11sece_capov}=0 or ${q11sece_capov}=1

integer	q15sece_stemp	E15. How many times per year is the storage emptied?			quick	.<=365	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q11sece_capov}=0
integer	q16sece_stdurn	E16. Which fraction of the stored urine is used as on-farm fertiliser? (rest is discharged)			quick	.<=100	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q9sece_ursg}=1
select_one yes_no	q17sece_slm	E17. Do you store liquid manure (slurry, mixture of urine and dung)	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1 and ${q2secd_conf}=2 or ${q2secd_conf}=4

select_one storage	q18sece_lmstg	E18. What Main type of storage do you use?			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q17sece_slm}=1
select_multiple storage1a	q18sece_otcstr	E18a. What of floor and roof?			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q17sece_slm}=1
select_one yes_no	q19sece_capov	E19. Is the storage capacity enough to prevent overflow?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q17sece_slm}=1
select_one yes_no	q20sece_rnwt	E20. Is an overflow caused by incoming rain water?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q19sece_capov}=0
integer	q21sece_dyov	E21. How many days per average			quick	**.<=365**	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q19sece_capov}=0

		year is it overflowing?					
decimal	q22sece_stgc	E22. what is the storage capacity in m3?			quick	.>=1.0	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q19sece_capov}=0 or ${q19sece_capov}=1
select_one yes_no	q23sece_ss	E23. Do you dry liquid manure to be solid and stackable?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=1 or ${q2secd_conf}=3
integer	q24sece_flmd	E24. What fraction (%) of the yearly liquid manure production is dried?			quick	.>=1 and .<=100	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q23sece_ss}=1

note	q24sece_flmda	E24a. If 100% , go to E30					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24sece_flmd}=100
select_one yes_no	q25sece_sls	E25. Do you separate liquid manure into a liquid and solid fraction?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q23sece_ss}=0 and ${q2secd_conf}=2 or ${q2secd_conf}=4 and ${q24sece_flmd}<100
select_one confinement1	q26sece_lfe	E26. How many times per year is the storage with liquid fraction emptied?			quick	**.<=365**	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q25sece_sls}=1 and ${q24sece_flmd}<100
integer	q27sece_rlf	E27. Which fraction (%) of the removed liquid			quick	**.>=1 and**	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q25sece_sls}=1 and ${q24sece_flmd}<100

		fraction is used as in-farm fertilizer? (rest is discharged)				**.<=100**	
integer	q28sece_lmp	E28. Which fraction (%) of the yearly liquid manure production is separated?			quick	**.>=1 and .<=100**	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q25sece_sls}=1 and ${q24sece_flmd}<100
note	q28sece_lmpa	E28a. If <=10% , go to E30					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q28sece_lmp}<=10
integer	q29sece_ylmp	E29. Which fraction (%) of the removed liquid manure is used as on-fam fertiliser?			quick	**.>=1 and .<=100**	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q25sece_sls}=1 and ${q28sece_lmp}>=11

select_one yes_no	q30sece_smsp	E30. Do you store solid manure (stackable products)?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1
note	q30sece_smspn	E30a. If No go to E35					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q30sece_smsp}=0
select_multiple solids	q31sece_slds	E31. What do the solids consist of?			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q30sece_smsp}=1
text	q32sece_otslds	E32. If Other specify					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q31sece_slds}=9
select_one storage1	q33sece_db	E33. What MAIN type of storage do you use?			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q30sece_smsp}=1

select_multiple storage1a	q33sece_stgp	E33a. What of floor and roof?			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q30sece_smsp}=1
select_one storage2	q34sece_sms	E34. How long is solid manure stored before application?			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q30sece_smsp}=1
text	q34sece_Other	E34a. If Other specify	Answer in length				${q34sece_sms}=3
select_one yes_no	q35sece_csm	E35. Do you actively compost solid manure?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=2 or ${q2secd_conf}=4
note	q35sece_csmn	E35a. If No go to E37					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=0

integer	q36sece_cof	E36. Which fraction (%) of the compost is used as on-farm fertiliser?			quick	**.>=1 and .<=100**	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1
select_one yes_no	q37sece_ynm	E37. Do you use manure from your cattle confinement on your own farm?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=2 or ${q2secd_conf}=4
select_one confinement1	q38sece_ynmh	E38. How many times do you incorporate manure to the farm?			quick	**.>=1 and .<=365**	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q37sece_ynm}=1
text	q39sece_floc	E39. How far is your farm from the	Estimate		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q37sece_ynm}=1

		cattle confinement?					
integer	q40sece_scagr	E40. Which fraction (%) of the compost is sold or given away for off-farm agricultural use?			quick	.>=1 and .<=100	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1
integer	q41sece_fsmc	E41. Which fraction (%) of the yearly solid manure production is composted?			quick	.>=1 and .<=100	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1
note	q41sece_fsmcn	E41a. if =0% , go to E56					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q41sece_fsmc}=0

integer	q42sece_lcmw	E42a. How long in weeks is manure composted before use?			quick	.<=52	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1 and ${q41sece_fsmc}>1
integer	q42sece_lcmm	E42b. How long in months is manure composted before use?			quick	.<=12	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1 and ${q41sece_fsmc}>1
integer	q42sece_lcmy	E42c. How long in years is manure composted before use?			quick	.>=1	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1 and ${q41sece_fsmc}>1
select_one yes_no	q43sece_dsm	E43. Do you actively dry solid manure?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q30sece_smsp}=1

note	q43sece_dsmn	E43a. if No, go to E52					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=0
integer	q44sece_dsm	E44. Which fraction(%) of the dried solid manure is used as on-farm fertiliser?			quick	**.>=1 and .<=100**	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1
integer	q46sece_oagru	E46. Which fraction (%) of the dried solid manure is sold or given away for off-farm agricultural use?			quick	**.>=1 and .<=100**	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1
integer	q47sece_dsmf	E47. Which fraction (%) of the			quick	**.>=1 and**	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1

		dried solid manure is used, sold or given away for fuel?				.<=100	
integer	q48sece_ysmp	E48. Which fraction (%) of the yearly solid manure production is dried?			quick	.>=1 and .<=100	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1
note	q48sece_ysmpnote	E48a. if 100% , go to E51					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q48sece_ysmp}=100
integer	q49sece_smdw	E49. How long in weeks is the manure dried before use?			quick	.<=52	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1 and ${q48sece_ysmp}<100 and ${q48sece_ysmp}>1

integer	q50sece_smdm	E50. How long in months is the manure dried before use?			quick	.<=12	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1 and ${q48sece_ysmp}<100 and ${q48sece_ysmp}>1
integer	q51sece_smdy	E51. How long in years is the manure dried before use?			quick	.>=1	${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1 and ${q48sece_ysmp}<100 and ${q48sece_ysmp}>1
text	q52sece_mqt	E52. What quantities of manure do you apply to your farm?	(describe)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q37sece_ynm}=1
select_one	q53sece_mis	E53. How soon is manure incorporated to the			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q37sece_ynm}=1

confinement1		soil after application?					
select_one yes_no	q54sece_fwm	E54. Can you quantify the differences between fields having manure and those without?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1
select_one yes_no	q55sece_acon	E55. Do you feed concentrate to your animals (manufactured feeds)?	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1
note	q56sece_nacon	E56. If No, go to Block F: Opinions					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q55sece_acon}=0

text	q57sece_conq	E57. What quantity of concentrate do you feed your animals?					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q55sece_acon}=1
text	q58sece_conty	E58. What type of concentrate do you feed your animals?					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q55sece_acon}=1
end group							
begin group	grpsecf_opn	Block F: Opinions					${q9seca_consent}=1 and ${qsecb_qual}=1
note	secf_infor	Manure management encompasses all steps between excretion and the eventual use as a					${q9seca_consent}=1 and ${qsecb_qual}=1

		source of plant nutrients. So the collection, the storage, possible treatments of manures, transporting and application.					
begin group	grp_op 1	Opinion 1			field-list		
note	opinion1	1. How important do you consider some technical and socio-economic constraints					

		prohibiting optimal manure management on your farm to be?					
select_one ranking	q1secf_fl	F1. Lack of farm labour to handle manure	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q2secf_mc	F2. Lack of manure collection capacity	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q3secf_msc	F3. Lack of manure storage capacity	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q4secf_mtc	F4. Lack of manure treatment capacity	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1

select_one ranking	q5secf_mtrc	F5. Lack of manure transport capacity	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q6secf_seam	F6. Lack of suitable equipment to apply manure	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q7secf_lamz	F7. Lack of land to apply manure, because there is none available	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q8ecf_lamp	F8. Lack of land to apply manure, because the prices of land are too high	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1

select_one ranking	q9secf_colt	F9. Not enough collateral to get credit for investments?	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q10secf_thtc	F10. Too high transport costs, compared to the use of mineral fertilisers	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q11secf_lc	F11. Too high labour costs, compared to the use of mineral fertilisers	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q12secf_tlbf	F12. Too low benefits when used	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1

		as fertiliser, compared to the benefits when used as a fuel (dung cakes)					
end group							
begin group	grp_op 2	Opinion 2			field-list		
note	opinion2	2. How important do you consider the institutional constraints prohibiting optimal manure					

		management in general?					
select_one ranking	q13secf_limm	F13. Lack of information to improve the manure management	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q14secf_laai	F14. Lack of access to available information	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q15secf_lal	F15. Lack of access to loans for the required investments	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q16secf_lare	F16. Lack of access to required	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1

		equipment and machines					
select_one ranking	q17secf_lti	F17. Lack of trading infrastructure	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q18ecf_lr	F18. Lack of regulations, leading to possible privileging of groups	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q19secf_ssl	F19. Spatial separation of livestock farms and arable farms due to specialization	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1

end group							
begin group	grp_op 3	Opinion 3 Liquid manure			field-list		
note	opinion3	3. How valuable is the use of urine and liquid manure as a fertiliser on your farm to you?					
select_one ranking	q20secf_ulmc	F20. From cattle	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q21secf_ulmoa	F21. From all Other animals	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1
end group							

begin group	grp_op 4	Opinion 4 solid manure			field-list		
note	opinion4	4. How valuable is the use of solid manure as a fertiliser on your farm to you?					
select_one ranking	q22secf_smc	F22. From cattle	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking	q23secf_smoa	F23. From all Other animals	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one yes_no	q24secf_imm	F24. Have you invested (time/money) to improve your	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1

		manure management in the last five years?					
note	q24sef_immn	if No, got to Block G: Information sources					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=0
end group							
begin group	grp_op5	Opinion 5 manure processes			field-list		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
note	opinion5	5. Did your management processes improve in regards to the following?					

select_one yes_no	q25secf_fac	F25a. Manure collection	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one yes_no	q25secf_fas	F25b. Manure storage	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one yes_no	q25secf_fat	F25c. Manure Treatment	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one yes_no	q25secf_fats	F25d. Manure transport	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one yes_no	q25secf_faa	F25e. Manure Application	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
end group							
begin group	grp_op6	Opinion 6			field-list		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
note	opinion6	6. How important was the					

		considerations to improve your manure management based on the following?					
select_one ranking1	q26secf_consd	F26. Improving on farm hygiene, considering human health?	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one ranking1	q27secf_consd	F27. Improve on farm hygiene, considering animal health	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one ranking1	q28secf_consd	F28. Improving on water quality, from	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1

		the point of view of human health					
select_one ranking1	q29secf_consd	F29. Improving on water quality, from the point of view of animal health	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one ranking1	q30secf_consd	F30. Abatement of odour problems, also for neighbours	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one ranking1	q31secf_consd	F31. Improving fertiliser value (nutrients) for the own crops	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one ranking1	q32secf_consd	F32. Improving fertiliser selling value (income)	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1

		when sold to Other farms					
select_one ranking1	q33secf_consd	F33. Incentive measures by the government and/or Other institutions	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
select_one ranking1	q34secf_consd	F34. Restrictive measures by the government and/or Other institutions	(select one)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q24secf_imm}=1
end group							
end group							
begin group	grpsecg_infs	Block G: Information sources			field-list		${q9seca_consent}=1 and ${qsecb_qual}=1

select_one yes_no	q1secg_inf5	G1. In the last five years, did you receive any information on how to improve your manure management?	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
note	q1secg_inf5n	If No, go to G8.					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=0
select_one ranking2	q2secg_infv	G2. If Other farmers gave you the information, how valuable was it to you?	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=1

select_one ranking2	q3secg_infv	G3. If government extension workers gave you the information, how valuable was it to you?	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=1
select_one ranking2	q4secg_infv	G4. If non-commercial advisors gave you the information, how valuable was it to you?	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=1
select_one ranking2	q5secg_infv	G5. If Commercial/Private advisors gave you the	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=1

		information, how valuable was it to you?					
select_one ranking2	q6secg_infv	G6. If local teachers/trainers gave you the information, how valuable was it to you?	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=1
select_one ranking2	q7secg_infv	G7. If Other gave you the information, how valuable was it to you?	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q1secg_inf5}=1

text	q7secg_infvo	G7a. Other Specify					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q7secg_infv}=1 or ${q7secg_infv}=2 or ${q7secg_infv}=3 or ${q7secg_infv}=4
note	infsource	What is the importance of the below sources in giving you information (on agricultural subjects)?					
select_one ranking2	q8secg_inag	G8. National television	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q9secg_inag	G9. Local television	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1

select_one ranking2	q10secg_inag	G10. National radio	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q11secg_inag	G11. Local radio	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q12secg_inag	G12. National newspaper	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q13secg_inag	G13. Local newspaper	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q14secg_inag	G14. Farmers' magazines	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1

select_one ranking2	q15secg_inag	G15. Farmers' group meetings	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q16secg_inag	G16. Field excursions/farm visits/open days	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q17secg_inag	G17. Individual meetings	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q18secg_inag	G18. Billboards/posters	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q19secg_inag	G19. Pamphlets/leaflets/brochures	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1

select_one ranking2	q20secg_inag	G20. Videos	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q21secg_inag	G21. Internet	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q22secg_inag	G22. Social media	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one yes_no	q23secg_yn	G23. Is there any Other source?	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1
select_one ranking2	q23secg_inag	G23a. Rank Other source	(select one)				${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q23secg_yn}=1

text	q23secg_inago	G23b. Other specify					${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q23secg_inag}=1 or ${q23secg_inag}=2 or ${q23secg_inag}=3 or ${q23secg_inag}=4
end group							
begin group	grpsech_conl	Block H: Concluding questions					${q9seca_consent}=1 and ${qsecb_qual}=1
select_one yes_no	q1sech_fut	H1. Would you be interested to become involved in future projects directed at improvement of your manure?	(Such as nutrient analysis of manure)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1
text	q2sech_aob	H2. Is there any Other information					${q9seca_consent}=1 and ${qsecb_qual}=1

		you would like to share with us? (i.e. perception on the manure policy, its implementation; or on service providers i.e. extension services; or what is bothering you etc.)					
end group							
begin group	grpi	Geopoints and photos					${q9seca_consent}=1 and ${qsecb_qual}=1
note	q1seci _note	This should be done once					${q9seca_consent}=1 and ${qsecb_qual}=1

		interview is completed					
geopoint	hhgps	Household GPS coordinates	get in open area for GPS reading		quick		${q9seca_consent}=1 and ${qsecb_qual}=1
geopoint	fmgps	Farm GPS coordinates	get in open area for GPS reading		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q37sece_ynm}=1
image	boma	photo of the animal enclosure (boma) if any			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q2secd_conf}=1 or ${q2secd_conf}=2 or ${q2secd_conf}=3 or ${q2secd_conf}=4
image	biogas3	Photo of the anaerobic digester			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q3sece_andg}=1

		(biogas system) if any					
image	liqurine	Photo of the liquid urine storage if any			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q17sece_slm}=1
image	compost	Photo of the compost manure pile if any			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q35sece_csm}=1
image	soldmanr	Photo of the solid manure pile if any			quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q43sece_dsm}=1
image	concetrate	Photo of the concentrate	(ask for sample to photo)		quick		${q9seca_consent}=1 and ${qsecb_qual}=1 and ${q55sece_acon}=1
end group							
note	Thanksyes	Give thanks to the respondent					${q9seca_consent}=1 and ${qsecb_qual}=1

5. Questionnaire - Key informant

Key informant Interview guide

Soliciting views of Key informants on the constraints faced by farmers on improving and using manure as well as costs of various farm inputs

A: Background information

1. Date of interview
2. Name if respondent-----------------------------
3. Position of respondent--------------------------
4. Respondent's institution------------------------

Free prior and informed consent:

I have requested an interview with you because of the unique position you occupy where you are a main stakeholder in the agriculture and livestock especially dairy industry. You are in a position to provide context to the constraints affecting farmers practice to improve manure management including costs and benefits to the farmers from improved manure management. I have some guiding questions and I will be taking notes so as not to miss anything. Is this consented by you?

Yes_________________ NO ____________________

Discuss the below issues as exhaustively and not all issues need to be discussed with the respondent

B: Guide questions

B1. Briefly tell us about your organization in relation to improving farmers manure management

B2. In your opinion, what is the overall level of satisfaction of men and women users with manure?

B3. What are the challenges you would opine affect farmers' capacity to improve manure management?

B4. What are the major challenges you feel dairy farmers manure has in order to be used as farm input?

B5. What in your opinion affects biogas pre-construction information and decision making process?

B6. What challenges are faced by farmers during biogas construction process?

B7. What challenges are faced by farmers' Training/Instructions institutions affecting improved manure management practices?

B8. What challenges are faced by farmers in term of acquiring information on improving manure management?

B9. What are the various sources of information that farmers get to use that affect various practices such as improved manure management?

B10. What are the costs of various materials you think is useful to improve manure management?

B11. Is the availability of after-sales service for some inputs a major factor of farmer practice change?

B12. What do you opine affects farmers use of Bio-slurry application and manure use on cash crops?

B13. Is there anything else you would like to add as far as improved manure management practices and biogas operational issues?

6. GPS points for households interviewed in Nandi County in each Agro-Ecological Zone (UM-Upper Midlands, LH2- Lower highland 2, LH1- Lower highland 1)

Hhno	Longitude	Latitude	AEZ
1	35.25722	-0.03318	UM
2	35.25136	-0.03629	UM
3	35.26122	-0.07945	UM
4	35.27033	-0.06275	UM
5	35.25269	-0.03656	UM
6	35.26206	-0.0759	UM
7	35.26696	-0.06401	UM
8	35.26738	-0.06366	UM
9	35.26607	-0.07194	UM
10	35.25638	-0.032	UM
11	35.25722	-0.03203	UM
12	35.26374	-0.07795	UM
13	35.26374	-0.07795	UM
14	35.26206	-0.0298	UM
15	35.25749	-0.03561	UM
16	35.2572	-0.03196	UM
17	35.27264	-0.02443	UM
18	35.2554	-0.03246	UM
19	35.24975	-0.036	UM
20	35.25779	-0.04359	UM
21	35.25663	-0.03018	UM
22	35.02535	-0.03864	UM
23	35.02379	-0.03578	UM
24	35.02032	-0.03521	UM
25	35.02085	-0.03604	UM
26	35.02378	-0.03497	UM
27	35.02383	-0.03635	UM
28	35.05093	-0.01785	UM
29	35.04911	-0.02416	UM
30	35.04978	-0.02366	UM
31	35.02347	-0.03912	UM
32	35.05005	-0.0214	UM
33	35.02189	-0.03642	UM
34	35.02044	-0.03574	UM
35	35.02359	-0.03992	UM
36	35.0488	-0.02177	UM
37	35.04923	-0.01904	UM

38	35.04937	-0.01715	UM	61	35.00294	0.42767	LH1
39	35.13514	0.00869	UM	62	35.00355	0.42759	LH1
40	35.1312	0.0109	UM	63	35.00664	0.43736	LH1
41	35.05206	-0.02271	UM	64	35.0031	0.42801	LH1
42	35.04998	-0.01728	UM	65	35.00212	0.42736	LH1
43	35.05347	-0.02276	UM	66	35.00077	0.42852	LH1
44	35.05347	-0.02276	UM	67	34.99883	0.43513	LH1
45	35.12729	0.00801	UM	68	35.00046	0.42901	LH1
46	35.05103	-0.02084	UM	69	35.07328	0.38536	LH1
47	35.13105	0.01092	UM	70	35.07338	0.38506	LH1
48	35.12461	0.00583	UM	71	35.07243	0.38547	LH1
49	35.19573	0.02635	UM	72	35.00829	0.43667	LH1
50	35.20322	0.0256	UM	73	35.03496	0.49927	LH1
51	35.19966	0.03257	UM	74	35.12677	0.50465	LH1
52	35.20531	0.02018	UM	75	35.0784	0.3952	LH1
53	35.03469	0.49658	LH1	76	35.12081	0.50389	LH1
54	35.02295	0.49822	LH1	77	35.12581	0.5048	LH1
55	35.03256	0.49876	LH1	78	35.07764	0.3956	LH1
56	35.0312	0.4909	LH1	79	35.12152	0.50851	LH1
57	35.03318	0.49437	LH1	80	35.07715	0.3952	LH1
58	35.03353	0.49783	LH1	81	35.121	0.50879	LH1
59	35.03126	0.49594	LH1	82	35.1217	0.50529	LH1
60	35.03475	0.49416	LH1	83	35.08837	0.48768	LH1

84	35.07596	0.39612	LH1
85	35.12031	0.50574	LH1
86	35.12738	0.5049	LH1
87	35.09526	0.50724	LH1
88	35.12017	0.50785	LH1
89	35.09469	0.48856	LH1
90	35.12071	0.50493	LH1
91	35.19137	0.24459	LH1
92	35.17848	0.30462	LH1
93	35.17914	0.3053	LH1
94	35.17932	0.30509	LH1
95	35.18144	0.2988	LH1
96	35.17812	0.30403	LH1
97	35.13207	0.37598	LH1
98	35.17908	0.30484	LH1
99	35.14803	0.37095	LH1
100	35.17959	0.30028	LH1
101	35.1806	0.30588	LH1
102	35.13334	0.37594	LH1
103	35.13108	0.37406	LH1
104	35.13204	0.37759	LH1
105	35.18113	0.29851	LH1
106	35.131	0.37285	LH1
107	35.15118	0.39127	LH1
108	35.19521	0.32967	LH1
109	35.13452	0.38127	LH1
110	35.18705	0.24664	LH1
111	35.19012	0.24494	LH1
112	35.18784	0.24372	LH1
113	35.19506	0.33748	LH1
114	35.19061	0.32921	LH1
115	35.18997	0.3297	LH1
116	35.19031	0.33451	LH1
117	35.1887	0.33039	LH1
118	35.19072	0.33142	LH1
119	35.18841	0.33368	LH1
120	35.18709	0.33426	LH1
121	35.18877	0.24709	LH1
122	35.18712	0.33711	LH1
123	35.19183	0.24818	LH1
124	35.21697	0.2704	LH1
125	35.21311	0.26909	LH1
126	35.21595	0.26815	LH1
127	35.19104	0.24767	LH1
128	35.13054	0.37654	LH1
129	35.12578	0.37354	LH1

130	35.13323	0.3762	LH1	153	35.21176	0.26888	LH1
131	35.09227	0.48952	LH1	154	35.23916	0.21565	LH1
132	35.08852	0.48696	LH1	155	35.23602	0.21766	LH1
133	35.09056	0.4889	LH1	156	35.23903	0.21823	LH1
134	35.08456	0.47139	LH1	157	35.23925	0.21742	LH1
135	35.09189	0.48756	LH1	158	35.23579	0.21518	LH1
136	35.12606	0.50383	LH1	159	35.21439	0.26657	LH1
137	35.1325	0.41766	LH1	160	35.25623	0.24039	LH1
138	35.18716	0.3346	LH1	161	35.26045	0.23886	LH1
139	35.2825	0.19243	LH1	162	35.26054	0.23894	LH1
140	35.28695	0.19537	LH1	163	35.26196	0.23835	LH1
141	35.2911	0.19834	LH1	164	35.2359	0.2155	LH1
142	35.29029	0.19816	LH1	165	35.23374	0.216	LH1
143	35.28612	0.19674	LH1	166	35.13602	0.41464	LH1
144	35.28811	0.19935	LH1	167	35.10719	0.37098	LH1
145	35.28947	0.19751	LH1	168	35.105	0.37165	LH1
146	35.28728	0.19642	LH1	169	35.10424	0.37132	LH1
147	35.28855	0.20011	LH1	170	35.10664	0.37023	LH1
148	35.28798	0.19705	LH1	171	35.13657	0.41464	LH1
149	35.12819	0.41815	LH1	172	35.10683	0.37206	LH1
150	35.12553	0.41674	LH1	173	35.13036	0.41714	LH1
151	35.23861	0.21583	LH1	174	35.10867	0.37552	LH1
152	35.19506	0.24551	LH1	175	35.10851	0.3741	LH1

176	35.18745	0.24605	LH1	199	34.95951	0.0087	LH2
177	35.19018	0.24531	LH1	200	34.89676	0.11557	LH2
178	35.2106	0.26945	LH1	201	34.99771	0.03495	LH2
179	35.21215	0.26875	LH1	202	34.89845	0.11822	LH2
180	35.19578	0.24486	LH1	203	34.95556	0.00967	LH2
181	35.21455	0.26893	LH1	204	34.90102	0.11968	LH2
182	35.22932	0.21567	LH1	205	34.95846	0.00927	LH2
183	35.23532	0.21976	LH1	206	34.95795	0.00985	LH2
184	35.21105	0.26929	LH1	207	34.9577	0.00875	LH2
185	35.21539	0.26937	LH1	208	34.95792	0.00854	LH2
186	34.94769	0.1366	LH2	209	34.87593	0.07512	LH2
187	34.95049	0.13253	LH2	210	34.87332	0.07363	LH2
188	34.94206	0.13494	LH2	211	34.87405	0.07431	LH2
189	34.95108	0.13179	LH2	212	34.87285	0.07413	LH2
190	34.94851	0.13704	LH2	213	34.8749	0.07501	LH2
191	34.94928	0.1302	LH2	214	34.87434	0.07702	LH2
192	35.07999	0.21019	LH2	215	34.87332	0.07503	LH2
193	35.07435	0.39349	LH2	216	34.86798	0.07105	LH2
194	35.07498	0.39278	LH2	217	34.87416	0.07616	LH2
195	35.07845	0.38802	LH2	218	34.8762	0.07509	LH2
196	34.90386	0.12246	LH2	219	34.87432	0.074	LH2
197	34.90277	0.12092	LH2	220	34.95908	0.20375	LH2
198	34.89917	0.11727	LH2	221	34.94513	0.13809	LH2

222	34.94467	0.13816	LH2	245	35.10697	0.1303	LH2
223	34.94519	0.13355	LH2	246	35.0288	0.06748	LH2
224	34.95833	0.20251	LH2	247	35.02802	0.06738	LH2
225	34.96135	0.20201	LH2	248	35.10379	0.13166	LH2
226	35.12677	0.19316	LH2	249	35.03058	0.06997	LH2
227	34.94679	0.13518	LH2	250	35.14854	0.05044	LH2
228	34.94358	0.13581	LH2	251	35.14862	0.05237	LH2
229	35.02739	0.06726	LH2	252	35.13678	0.05278	LH2
230	34.95904	0.00834	LH2	253	35.15155	0.04862	LH2
231	35.02857	0.06871	LH2	254	35.13855	0.05053	LH2
232	34.95941	0.00745	LH2	255	35.13925	0.05079	LH2
233	34.95885	0.00859	LH2	256	35.13733	0.0533	LH2
234	34.95928	0.00784	LH2	257	35.14406	0.05563	LH2
235	35.02848	0.06653	LH2	258	35.13921	0.05053	LH2
236	34.95534	0.01131	LH2	259	35.13878	0.05166	LH2
237	34.95484	0.01132	LH2	260	35.13994	0.05251	LH2
238	35.02715	0.0706	LH2	261	35.17184	0.08329	LH2
239	35.10998	0.12989	LH2	262	35.16191	0.08982	LH2
240	35.02926	0.06777	LH2	263	35.16904	0.08443	LH2
241	35.10577	0.13234	LH2	264	35.16842	0.08395	LH2
242	35.0289	0.06894	LH2	265	35.17038	0.08502	LH2
243	35.02768	0.06731	LH2	266	35.17238	0.08504	LH2
244	35.10606	0.13048	LH2	267	35.16812	0.08527	LH2

268	35.1626	0.08922	LH2	291	34.96073	0.20088	LH2
269	35.17025	0.08552	LH2	292	34.95986	0.20699	LH2
270	35.17419	0.08351	LH2	293	35.12749	0.19313	LH2
271	35.17083	0.08741	LH2	294	34.9825	0.20106	LH2
272	35.02586	0.06543	LH2	295	35.06003	0.2268	LH2
273	35.10652	0.12993	LH2	296	35.05958	0.23076	LH2
274	35.09886	0.13337	LH2	297	35.05883	0.22759	LH2
275	35.09904	0.13351	LH2	298	35.06005	0.22831	LH2
276	35.09853	0.13291	LH2	299	35.06009	0.22906	LH2
277	35.10055	0.13272	LH2	300	35.06005	0.22719	LH2
278	34.98354	0.20002	LH2	301	35.0605	0.22731	LH2
279	34.96468	0.20335	LH2	302	35.05959	0.22996	LH2
280	34.96095	0.20912	LH2	303	35.05942	0.22898	LH2
281	34.96142	0.2071	LH2	304	35.05923	0.23041	LH2
282	34.96121	0.20442	LH2	305	35.12757	0.1898	LH2
283	34.98402	0.20023	LH2	306	35.12715	0.1929	LH2
284	34.98078	0.19242	LH2	307	35.12731	0.19321	LH2
285	34.98018	0.19322	LH2	308	35.1283	0.19451	LH2
286	34.97966	0.18919	LH2	309	35.1288	0.19287	LH2
287	35.12842	0.19381	LH2	310	35.06312	0.31732	LH2
288	35.12469	0.19233	LH2	311	35.14228	0.16621	LH2
289	34.97883	0.19214	LH2	312	35.143	0.16767	LH2
290	34.98181	0.20009	LH2	313	35.14187	0.16928	LH2

314	35.14245	0.16683	LH2	325	35.04416	0.27148	LH2
315	35.06191	0.31813	LH2	326	35.04849	0.27415	LH2
316	35.13986	0.16603	LH2	327	35.06324	0.30728	LH2
317	35.06114	0.31849	LH2	328	35.04474	0.27229	LH2
318	35.05964	0.3203	LH2	329	35.04711	0.27225	LH2
319	35.05066	0.27345	LH2	330	35.06321	0.30766	LH2
320	35.06224	0.31782	LH2	331	35.14151	0.16443	LH2
321	35.03748	0.27895	LH2	332	35.14268	0.1641	LH2
322	35.04684	0.27325	LH2	333	35.14143	0.16448	LH2
323	35.04794	0.27594	LH2	334	34.96029	0.2071	LH2
324	35.04579	0.27295	LH2	335	35.14202	0.1655	LH2

7. **Mean acreage for various farmland uses by smallholder dairy farmers by Agro-ecological zones (LH1, LH2 and UM), Gender, Income Category and by Education Level (± Standard error of the mean)**

AEZ	Gender	Income category	Education Level	Household area (Acres)	Cash crop (Acres)	Horticulture area (Acres)	Grazing area (Acres)	Trees area (Acres)	Total Acreage (Acres)
LH2	Male	Crops	No formal and Illiterate	0.4±0.10	2.1±0.88	0.2±0.05	1.6±0.55	0.1±0.13	4.3±1.47
UM	Male	Crops	No formal and Illiterate	0.2	3±1.00	0.3±0.20	2.3±1.70	0.2±0.08	6.0±2.98
LH2	Female	Crops	No formal and Illiterate	0.1	8.0	0.5	0.3	0.2	9.1
UM	Female	Crops	No formal and Illiterate	0.1	1.7	0.1	0.2	0.1	2.2
LH1	Female	Dairy	No formal and Illiterate	0.2	2.0	0.5	1.0	0.0	3.7
LH2	Female	Dairy	No formal and Illiterate	0.1	0.8	0.1	0.1	0.1	1.2
LH1	Female	Other	No formal and Illiterate	0.5	3.0	0.2	0.5	0.1	4.3
LH2	Female	Crops	No formal but literate	0.2	1.8	0.1	1.5	0.2	3.8
LH1	Male	Dairy	No formal but literate	0.6±0.40	1.6±1.40	0.6±0.43	6±4.00	0.6±0.40	9.4±6.63
LH1	Female	Dairy	No formal but literate	1.1±0.56	1.8±0.55	0.9±0.59	2.6±0.56	0.8±0.61	7.3±2.59
LH2	Female	Dairy	No formal but literate	0.3±0.20	0.7±0.35	0.3±0.05	1.3±0.25	0.2±0.05	2.6±0.90
LH2	Female	Other	No formal but literate	0.3	0.5	0.1	0.2	0.1	1.2

LH1	Male	Crops	Primary School	0.8±0.17	13.3±3.33	0.3±0.03	11±4.51	0.3±0.17	25.8±4.07
LH2	Male	Crops	Primary School	0.3±0.05	3±0.73	0.2±0.03	1.1±0.33	0.3±0.16	4.8±1.05
UM	Male	Crops	Primary School	0.4±0.09	6.0±1.56	0.3±0.08	1.6±0.69	0.2±0.14	8.5±1.73
LH1	Female	Crops	Primary School	0.6±0.20	2.8±0.20	0.6±0.75	2.9±0.29	0.8±0.29	7.7±2.04
LH2	Female	Crops	Primary School	0.3±0.09	1.7±0.40	0.6±0.27	1.6±0.45	0.1±0.04	4.4±0.94
UM	Female	Crops	Primary School	0.8±0.16	22.2±19.46	0.3±0.19	3.1±1.85	0.1±0.05	26.5±21.51
UM	Male	Poultry	Primary School	0.2	0.3	0.1	0.2	0.3	1.1
LH1	Male	Dairy	Primary School	0.4±0.06	1.8±0.39	0.3±0.10	3.2±1.36	0.2±0.04	5.9±1.53
LH2	Male	Dairy	Primary School	0.3±0.06	2.3±0.88	0.3±0.09	2.5±1.22	0.2±0.08	5.6±2.19
UM	Male	Dairy	Primary School	0.5±0.11	3.4±1.06	0.3±0.14	4.2±2.67	0.2±0.07	8.6±3.69
LH1	Female	Dairy	Primary School	2.0±1.45	1.0±0.44	0.2±0.09	3.7±1.09	0.3±0.19	7.2±1.74
LH2	Female	Dairy	Primary School	0.2±0.04	0.8±0.18	0.3±0.10	1.5±0.50	0.2±0.07	3.0±0.79
UM	Female	Dairy	Primary School	0.4±0.15	6.4±5.65	1.5±1.50	2.8±2.25	0.3	11.2±9.25
LH1	Male	Other	Primary School	0.1±0.08	1±1.00	0.1±0.03	0.6±0.45	0.1±0.13	1.9±1.68
LH2	Male	Other	Primary School	0.1	1.0	0.3	0.2	0.2	1.8
UM	Male	Other	Primary School	0.4	1.2	0.1	0.3	0.3	2.3
LH1	Female	Other	Primary School	0.2	0.2	0.2	0.2	0.1	0.9
LH2	Female	Other	Primary School	0.7±0.39	1.5±0.44	0.2±0.06	0.5±0.13	0.3±0.12	3.1±0.82

LH1	Male	Crops	High School	1.8±0.85	4.4±1.27	0.1±0.08	1.8±0.50	0.6±0.31	8.7±1.42
LH2	Male	Crops	High School	0.3±0.05	3.2±0.62	0.6±0.31	1.5±0.25	0.3±0.09	5.9±0.81
UM	Male	Crops	High School	0.4±0.04	3.4±0.57	0.4±0.13	0.7±0.16	0.1±0.04	5.0±0.82
LH1	Female	Crops	High School	0.3±0.06	2.3±0.78	0.5±0.20	2.5±0.87	0.03	5.6±1.74
LH2	Female	Crops	High School	0.3±0.10	3.6±1.52	0.2±0.06	2.2±1.05	0.2±0.06	6.6±2.05
UM	Female	Crops	High School	0.3±0.03	3.0	0.3	2.0	0.3	5.8±0.23
LH2	Female	Poultry	High School	0.2			0.1		0.3
LH1	Male	Dairy	High School	0.9±0.32	4.5±2.41	0.2±0.04	6.3±2.86	0.6±0.19	12.6±5.25
LH2	Male	Dairy	High School	0.4±0.11	1.4±0.44	0.2±0.02	1.8±0.39	0.3±0.09	4.0±0.78
UM	Male	Dairy	High School	0.2	2.0	0.2	0.4	0.1	2.9
LH1	Female	Dairy	High School	0.4±0.15	2.9±0.86	0.2±0.04	2.6±0.62	0.4±0.10	6.5±1.17
LH2	Female	Dairy	High School	0.1	1.1	0.2	1.2	0.1	2.7
UM	Female	Dairy	High School	0.1	1.5	0.1	1.0	0.0	2.7
LH1	Male	Other	High School	1.3±0.75	4.5±3.50	0.3±0.25	0.4±0.13	0.4±0.15	6.7±3.03
LH2	Male	Other	High School	0.3±0.06	1.1±0.19	0.15±0.05	0.4±0.06	0.3±0.06	2.2±0.24
LH2	Female	Other	High School	0.1	1.0	0.0	0.5	0.2	1.8

LH1	Male	Crops	College	0.9±0.38	2.5±0.65	0.5±0.18	4.3±1.11	0.7±0.21	8.8±1.53
LH2	Male	Crops	College	0.6±0.18	6.5±2.86	0.3±0.07	1.2±0.47	0.7±0.37	9.2±3.34
UM	Male	Crops	College	1.2±0.85	4.4±2.65	0.6±0.10	3.5±2.50	0.3	9.9±0.80
LH1	Female	Crops	College	0.2±0.08	2.3±1.75	0.1±0.10	1.1±0.95	0.2±0.08	3.8±2.75
LH2	Female	Crops	College	0.2	1.8±0.25	0.2	0.8±0.25	0.1±0.10	3±0.60
UM	Female	Crops	College	0.7±0.35	0.9±0.63	0.3±0.25	0.1±0.05	0.3	2.1±0.03
LH1	Male	Dairy	College	0.65±0.11	3.9±0.61	0.2±0.08	5.2±1.62	0.9±0.28	10.9±1.84
LH2	Male	Dairy	College	0.4±0.14	3.2±2.4	0.3±0.15	1.9±0.84	0.1±0.05	5.9±3.07
UM	Male	Dairy	College	1.6±1.40	3.3±2.75	2.4±2.15	12±10.00	90.25±89.75	109.45±100.55
LH1	Female	Dairy	College	0.5±0.16	2±1.23	0.4±0.14	3.3±0.80	0.6±0.49	6.8±2.41
LH2	Female	Dairy	College	0.4±0.21	1.3±0.32	0.3±0.09	2.1±0.72	0.2±0.03	4.2±1.21
LH2	Male	Other	College	0.3	2.0	0.1	0.5	0.1	3.0
LH1	Female	Other	College	0.4	6.5±3.50	0.3±0.20	1.1±0.40	0.4±0.15	8.7±4.25
LH2	Male	Crops	University	0.4±0.06	8.9±2.32	0.2±0.01	2.5±0.41	1.2±0.57	13.3±2.68
UM	Male	Crops	University	1.0	3.8	0.2	0.0	0.0	5.0
LH1	Female	Crops	University	0.3	0.5	0.0	0.5	0.3	1.5
LH2	Female	Crops	University	0.4±0.15	2±1.00	1.8±1.25	2.3±0.75	0.5±0.50	6.9±0.65
LH1	Male	Dairy	University	0.7±0.63	5±4.50	0.4±0.30	15±13.30	8.4±8.30	29.5±27.23
LH2	Male	Dairy	University	1.0	11.0	0.5	17.0	5.0	34.5
UM	Male	Dairy	University	1.0	2.0	1.0	1.5	0.5	6.0
LH1	Male	Other	University	0.4	1±1.00	0.4±0.30	16±14.00	0.5	18.3±13.30
LH2	Male	Other	University	0.9±0.60	0.75±0.25	0.6±0.40	0.6±0.10	0.1±0.08	3.0±1.08
LH2	Female	Other	University	0.5	10.0	0.4	10.0	1.0	21.9

NB: Cash crop for LH1- Tea, LH2- Maize and UM- Sugarcane

8. Percentage of smallholder dairy farmers on cleaning frequency of their livestock confinement in each Agro-ecological zone (LH1, LH2 and UM) by gender, education level, income category and also whether water is used during cleaning and livestock bedding is added to the manure after cleaning. (Each frequency of cleaning totals to 100% as well as the total below for the frequencies total to 100%)

AEZ	Gender	Education level	Income category	No-water use, no-bedding use				No water use, yes bedding use	Yes-water use, no-bedding use			Yes-water use, yes bedding use
				daily	<1month	1-3 months	>1 year	<1month	<1month	1-3 months	3-12 months	<1month
LH1	Male	No formal but literate	Dairy	0.6%								
LH1	Male	Primary School	Crops	1.0%								
LH1	Male	Primary School	Dairy	9.4%								
LH1	Male	Primary School	Other	0.6%								
LH1	Male	High School	Crops	1.9%								
LH1	Male	High School	Dairy	4.8%					9.1%			
LH1	Male	High School	Other	0.3%				10				
LH1	Male	College	Crops	1.0%								33.3%
LH1	Male	College	Dairy	1.6%						5		
LH1	Male	University	Dairy	1.0%								
LH1	Male	University	Other	0.6%								

LH1	Female	No formal and Illiterate	Dairy	0.3%							
LH1	Female	No formal and Illiterate	Other	0.3%							
LH1	Female	No formal but literate	Dairy	2.6%							
LH1	Female	Primary School	Crops	1.9%							
LH1	Female	Primary School	Dairy	2.9%			10				
LH1	Female	Primary School	Other	0.3%							
LH1	Female	High School	Crops	1.3%							
LH1	Female	High School	Dairy	3.5%	25.0%					10	
LH1	Female	College	Crops	0.6%							
LH1	Female	College	Dairy	2.3%					5		
LH1	Female	College	Other	0.3%		10					
LH1	Female	University	Crops	0.3%							
LH2	Male	No formal and Illiterate	Crops	1.3%							
LH2	Male	Primary School	Crops	4.2%							
LH2	Male	Primary School	Dairy	4.8%	25.0%						
LH2	Male	Primary School	Other	0.3%							
LH2	Male	High School	Crops	7.1%				18.2%			33.3%
LH2	Male	High School	Dairy	3.9%							
LH2	Male	High School	Other	1.0%				9.1%			

LH2	Male	College	Crops	1.3%			33.3%
LH2	Male	College	Dairy	1.6%		9.1%	
LH2	Male	College	Other	0.3%			
LH2	Male	University	Crops	1.0%		18.2%	
LH2	Male	University	Dairy	0.3%			
LH2	Male	University	Other	0.6%			
LH2	Female	No formal and Illiterate	Crops	0.3%			
LH2	Female	No formal and Illiterate	Dairy	0.3%			
LH2	Female	No formal but literate	Crops	0.3%			
LH2	Female	No formal but literate	Dairy	0.6%			
LH2	Female	No formal but literate	Other	0.3%			
LH2	Female	Primary School	Crops	2.9%			
LH2	Female	Primary School	Dairy	2.9%			
LH2	Female	Primary School	Other	2.3%			
LH2	Female	High School	Crops	2.6%		9.1%	
LH2	Female	High School	Poultry	0.3%			
LH2	Female	High School	Dairy	1.3%			
LH2	Female	High School	Other	0.3%			
LH2	Female	College	Crops	0.3%	25.0%		
LH2	Female	College	Dairy	1.3%			
LH2	Female	University	Crops	0.3%		9.1%	

LH2	Female	University	Other		25.0%							
UM	Male	No formal and Illiterate	Crops	0.6%								
UM	Male	Primary School	Crops	4.5%								
UM	Male	Primary School	Poultry	0.6%								
UM	Male	Primary School	Dairy	2.3%								
UM	Male	Primary School	Other	0.3%								
UM	Male	High School	Crops	1.9%								
UM	Male	High School	Dairy	0.3%								
UM	Male	College	Crops	0.6%								
UM	Male	College	Dairy	0.6%								
UM	Male	University	Crops	0.3%								
UM	Male	University	Dairy						9.1%			
UM	Female	No formal and Illiterate	Crops	0.3%								
UM	Female	Primary School	Crops	1.6%								
UM	Female	Primary School	Dairy	0.6%								
UM	Female	High School	Crops	0.6%								
UM	Female	High School	Dairy	0.3%								
UM	Female	College	Crops	0.3%					9.1%			
Total				92.8%	1.2%	0.3%	0.3%	0.3%	3.3%	0.6%	0.3%	0.9%

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Faculty/School/Institute Institute for Climate Change and Adaptation

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