

Animal Production Systems Group

MSc Thesis

Manure management and nutrient cycling in smallholder crop-livestock systems in Nyando, Kenya

Author: Flavia A.M. Casu

Registration number: 91 05 14 156 110

Supervisor: Dr. ir. Simon J. Oosting

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Flavia A.M. Casu | 91 05 14 156 110

Animal Production Systems | APS-80436

Supervisors

Dr. ir. Simon J. Oosting | Wageningen University

Dr. Julie M.K. Ojango | International Livestock Research Institute

Examiners

Dr. ir. Simon J. Oosting

Prof. dr. ir. Imke J.M. de Boer

Abstract

An essential aspect for smallholder crop-livestock farmers in sub-Saharan Africa is productive soils in order to maintain animal and crop productivity. Often, these systems are heavily dependent on local resources for their input and as a result, manure forms an important by-product to serve as fertiliser for their land. As part of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), research on manure management in smallholder farmers in Nyando, western Kenya was done. The aim of this research was to assess manure management practices and current nutrient losses that occur through the manure management cycle. Based on these results, novel management activities were described that could improve current manure management and reduce nutrient losses. A questionnaire was used to acquire data on farm characteristics, manure management and farmers' perceptions of 20 farms in the Nyando district. Fresh and stored manure samples were taken on-farm and analysed on nutrient content. Based on these results, nutrient losses between fresh and stored manure were calculated. The FARMSIM simulation model was used to calculate herd dynamics and production, especially production of manure. Results showed that between fresh and stored manure, dry matter loss was on average 75% and carbon, nitrogen and phosphorus showed an average loss of 80, 74 and 45%, respectively. On average, 82 kg N ha⁻¹ year⁻¹ was produced, whereas 42 kg N ha⁻¹ year⁻¹ was collected and only 17 kg N ha⁻¹ year⁻¹ was applied on farm.

The results indicated that between manure excretion, collection and application large losses occur. Particularly manure collection and method of storage (i.e. manure stored on a heap or in a pit, and uncovered or covered with a shed or tree) play an important role. Furthermore, current manure management practices do not provide the farm with sufficient amounts of nutrients needed for a stable crop production. Improvement of manure management practices could reduce nutrient losses and increase overall manure quality. Novel practices include more frequent collection of manure, decreasing the period of storage, covering the manure with a plastic sheet and altering the storage unit in order to reduce nutrient losses through leaching and evaporation.

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Chapter 1: Introduction

1.1 General Introduction

Most farmers in sub-Saharan Africa are smallholders, who often live on mixed crop-livestock farms and spread their income over both the production of crops and animal products (Dixon et al., 2001). Crop production plays an important role in many rural livelihoods, as its outputs are used to sustain families and are thus directly linked with food security (Kraaijvanger and Veldkamp, 2015). Often, smallholder farmers do not have access to technological inputs, which makes them heavily dependent on land resources for their outputs. An essential aspect of these systems are productive soils that support a steady production of crops. However, poor soil fertility has been widely accepted as a major factor limiting productivity of smallholder farms in Africa (Tittonell et al., 2005a) and numerous studies about soil fertility management underline its importance for the productivity and livelihoods of smallholders (Smaling et al., 1997; Shepherd and Soule, 1998; Tittonell et al., 2005a; Bekunda et al., 2010).

The area under study in this thesis is the Nyando basin, situated in western Kenya around Lake Victoria. Western Kenya has been studied by numerous researchers as soil fertility depletion is seen as one of the most important causes of low productivity and decreased livelihoods of mixed crop-livestock farmers (Shepherd et al., 1997; Tittonell et al., 2005a, 2005b; Giller et al., 2011). At regional level, low soil fertility is linked to nitrogen and phosphorus deficiencies, however low levels of soil organic matter form an issue at local level (Shepherd et al., 1997; Tittonell, 2005a). As farmers often do not have the means to purchase external resources for inputs to their farms, they are dependent on local resources as farm inputs. Manure forms an essential source of nutrients for soils in order to sustain crop productivity for the majority of smallholder farming systems in Africa (Giller et al., 2002) and the efficient management of manure is a key to support sustainable crop production and livelihoods (Rufino et al., 2007).

The integration of crops and livestock in mixed systems forms an effective means of nutrient cycling within and between farms that benefit plant nutrient uptake and crop production (Thornton and Herrero, 2001). Crop-livestock systems can be divided in several sub-systems in which nutrients are cycled and with each step, losses of nutrients occur which decreases the overall amount of useful output. This describes the nutrient cycling efficiency (NCE) of a farm and can be defined as the ratio of useful output to input in any system or system component (Powell et al., 1996). A main component of a mixed system is livestock and this forms an important factor within nutrient cycling. Nutrients are gathered from the surroundings through grazing and are converted to milk and meat for human consumption, while the remaining nutrients are excreted through faeces and can be incorporated in the farm (Rufino et al., 2006). Therefore, only nutrients from excreta are returned to the soil from the total amount of nutrients that are taken up by the livestock sub-system. Nutrients in excreta can be partitioned in the

faecal fraction and the urinary fraction, and the quality of the feed partly determines the concentration of nutrients in the urine and faeces (Rufino et al., 2006). Overall, collection and handling of manure are critical steps where nutrients may get lost that could otherwise be used as fertiliser. After collection, manure can be stored or composted before incorporation on the farm, which is another step where nutrient losses occur through leaching and volatilisation (Rufino et al., 2006). Despite the fact that significant losses of nutrients can occur during these critical steps, rendering manure management less efficient, manure is still considered a valuable output of livestock. If the quality of manure can be improved through managing these steps more effectively, this will result in more nutrients for crops, which has a positive effect on maintaining soil organic matter and thus increases the overall productivity of the farm (Turner, 2016). Rufino et al. (2007) evaluated the effect of manure management activities at different stages (before and during collection, and during storage) on overall nutrient cycling efficiency, with a focus on nitrogen (N), for different wealth classes in western Kenya. It was found that substantial losses of urinary N were common in all wealth classes, which accounts for significant losses as urinary N can contain 50% of the total excreted nitrogen. Furthermore, results showed that collection and storage activities have a large effect on nutrient retention. Within the farms, specific manure management activities can increase nutrient retention by 30%.

All in all, smallholder farmers with limited possibilities to acquire external inputs for their farms can benefit from optimally re-using the output of their sub-systems. Efficient use of local resources can promote efficient nutrient cycling, resulting in nutrient-rich soils which are necessary for stable crop production and resilient farming systems.

1.2 ILRI's Climate-Smart Agriculture Project

In 2011, the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) facilitated a partnership with different actors to test various climate change adaptation, mitigation and risk management interventions in the Nyando district. As such, the resilience of farmers against the effects of climate change can be increased (i.e. climate-smart agriculture). The International Livestock Research Institute (ILRI) led such an intervention, which was aimed at the introduction of improved strains of indigenous sheep and goats to improve the productivity of small ruminants in smallholder farms within Nyando (Ojango et al., 2016). The focus on genetic improvement of small ruminants was to enhance their adaptability to the harsh climatic conditions while improving the productivity of livestock within the systems. However, climate-smart agriculture encompasses a broad area of interventions that could render a farming system or community more resilient to the effects of climate change such as long droughts and intense, variable rainfall. Different approaches to climate change adaptation exist, and three pillars of climate-smart agriculture are described as (1) risk management, (2) diversification, and (3) sustainable intensification (Descheemaeker et al., 2016). Within these three categories, different agricultural practices can contribute to a more resilient farming system and the focus can be on livestock, crops or the whole integrated farming system. For this research, the options of an integrated approach to

climate-smart agriculture have been evaluated by looking at manure management. Manure is produced by livestock that consume either on-farm feed (e.g. crop residues or cultivated Napier grass) or from common rangelands. In the latter case, nutrients are brought into the farming system, whereas nutrients taken from the farm can be (partly) brought back to the soil through manure. As manure is incorporated in the farm, the contained nutrients can be made available to plants, which can result in increased crop production, while the contained carbon enhances soil organic matter and nutrient cycling through microorganisms (Sanchez et al., 2001). Hence, manure management impacts multiple components of a farming system. As such, evaluation of possibilities to improve manure quality through specific management activities should include an integrated approach and be analysed on a systems level in order to understand the effects it has on different scales. Improving manure management contributes to sustainable intensification of farms (Descheemaeker et al., 2016), as an increased crop production can be achieved on the same plot of land. Together with an improved soil quality, better adaptation to climate change can be achieved.

1.3 Overall Objective and Research Questions

The use of manure as fertiliser is seen as a promising and economically viable way to increase soil fertility and crop production and through this, develop a farming system that is more resilient against the effects of climate change. In order to effectively use manure as fertiliser, different management options exist to decrease the risk of nutrient losses and consequently increase the quality of the end product. The overall objective of this study is (1) to outline current manure management performance of farmers in the Nyando district and (2) assess which key activities can improve overall manure management. In order to reach the overall objective, the following research questions need to be answered:

1. What are the general household and farm characteristics of farmers in Nyando?
2. What are current manure management activities of farmers and what are their perceptions on the importance of manure for their farm?
3. What is the quality of fresh and stored manure and the magnitude of nutrient cycling and losses through the farming system?
4. What manure management activities can increase manure quality and nutrient cycling on farm?

Chapter 2: Materials and Methods

This chapter will give an outline of the study area, the scientific methods used to carry out this research and how both on-farm and laboratory results were acquired. Furthermore, it will give information on the computer simulation model developed by Wageningen University that was used for this study to evaluate current farm performance.

2.1 Study Area

The project area lays in the Nyando Basin and consists of seven villages, spread over two different counties: Kisumu and Kericho (see figure 1).



Figure 1 Map of western part of Kenya highlighting the Nyando Basin. Stars on map indicate all farmers that took part in ILRI's project (own picture)

The majority of villages are located in Kisumu county, namely Kamango, Kobiero, Obinju, and Kamuana, whereas Chemildagey, Kapsorok and Tabet B are located in Kericho county. These two counties are located between the coordinates 35.068E 0.269S, 35.068E 0.361S, 34.978E 0.361S and 34.978E 0.269S. Agriculture is the primary source of income and farmers mainly own mixed crop-livestock systems (Macoloo et al., 2013). The area is one of the highest populated rural localities of East Africa with a population density of over 400 persons per square kilometre (Ojango et al., 2016).

2.2 Farm Selection

For each of the seven villages included in this research, three farms were selected in each village through a transect walk (Bunning et al., 2016). This was done through selection of an area and its boundaries based on the farmers that participated in each village. As a result, rectangular areas for each village were created and the transect walk was performed on the diagonal of the area. This area was characterised by different gradients of altitudes in order to represent the variability of biophysical characteristics of each village, and the selected farms represent these variables. Besides biophysical attributes, farms needed to represent the baseline characteristics of the area, taking into

account different levels of resource endowment, focussing specifically on farm size and number of livestock owned. As this information was acquired at the start of activities integrating improved sheep and goat management in 2014, the baseline data were used to ensure the selected farms represented the area based on the above characteristics.

For this study, a farm typology was used to categorise farmers into different wealth categories and classification was done by looking at different factors such as land size, types of livestock owned, number of TLUs (tropical livestock units) owned, market orientation and off-farm income (for a complete overview of factors included see appendix 1). TLUs were calculated for cattle and small ruminants and 1 TLU was set for a local zebu cow of 300 kg. Crossbred and pure dairy cows were valued as 1.3 and 1.6 TLUs, respectively, whereas small ruminants were considered 0.1 TLU (ILCA, 1990). Three categories of farm typologies were designed and data between these groups were analysed in order to detect differences in farm performance.

2.3 Data Collection

Data collection took place during a three month period of both field and laboratory work. Farmers were interviewed through a questionnaire on household and farm characteristics, market orientation, livestock composition and manure management perceptions and practices. The questionnaire was developed with the Open Data Kit tool (ODK) which is designed to upload a survey on a device (e.g. mobile phone) which stores the data directly and transfers it to an excel database. Triangulation was used through combining already existing data on farmers with data from the new questionnaire. After asking questions on farm characteristics and management activities, a walk through the farms was done in order to verify whether the given information corresponded with the farm observations. Besides the survey, manure samples from cattle and, if possible, small ruminants were taken on each farm. For both stored and fresh manure, 300 grams were stored in plastic zip lock bags and transported in cooling boxes to ILRI laboratories for further analysis.

2.4 Laboratory Analysis

Laboratory analysis on the manure samples was done for macro nutrient concentrations (i.e. potassium, phosphorus, carbon and nitrogen) as well as organic matter content, pH, dry matter content and crude ash.

2.4.1 Determination of carbon and nitrogen

Total carbon and nitrogen content was analysed with a C-N combustion analyser. All manure samples were prepared in duplicates and the procedure was done as follows (Wanyama, 2016): 20 g of solid representative samples were transferred into 50 ml glass beakers and mixed with 10 ml of 25% hydrochloric acid. The samples were then oven dried at 38 °C for 72 hours and ground with a soil mill until a particle size of 5 µm. From these dry samples, 10 mg were weighted into tin capsules and moulded into

spherical balls, which was performed in duplicate for all samples. The tin balls were stored in 96-well micro plates and transferred into a desiccator prior to analysis.

2.4.2 Determination of potassium and phosphorus

The amounts of potassium and phosphorus present in both the fresh and stored manure samples were analysed using atomic absorption spectroscopy and UV-visible spectrophotometer, respectively. All samples were prepared in triplicates and the procedure was done as follows: 1 g of solid representative samples were transferred into 50 ml glass beakers and mixed with 5 ml concentrated nitric acid (HNO₃) and 1 ml 30% hydrogen peroxide (H₂O₂). After leaving samples to stand overnight, they were digested by heating up to 100 °C until formation of a clear residue. Samples were then cooled and transferred to 50 ml volumetric flasks and diluted to the 50 ml mark with distilled water. The last step consisted of filtering the solution through Whatman filter paper (no. 41) and transferred to 50 ml plastic centrifuge tubes, ready for analysis.

2.4.3 Dry matter and organic matter determination

In order to determine the dry matter and organic matter content of the manure samples, 25 g of manure was heated in a moisture analyser. The analyser measures the percentage of moisture content (MC) of the sample, after which the dry matter content (DMC) could be calculated by subtracting the percentage of moisture content from 100 percent: $\% DMC = 100 - \% MC$

Organic matter content was calculated through determination of the ash content of the manure. Samples were placed in crucibles, weighted in duplicates and gradually heated for 8 hours to 580 °C. The final ash content of the samples was calculated as: $\% ash = (weight\ ash \cdot 100) / weight\ original\ sample$

From the ash content, the organic matter content could be calculated through the following formula: $organic\ matter\ (g/kg\ DM) = 1000 - ash\ (g/kg\ DM)$

2.4.4 Determination of pH

The pH of the manure samples was determined using a bench top pH meter. Before measuring the pH, all samples were diluted with distilled water and mixed for 30 minutes using a tube roller. The samples were then put to rest for 10 minutes before starting the analysis.

2.5 Nutrient Loss Calculations

After analysis of nutrient content and organic matter and ash content of both the fresh and stored manure samples, losses of nutrients and dry matter could be calculated in order to determine the current farm performance on manure management and what the magnitude of losses were. Within a farming systems, nutrients cycle through different sub-systems and in every step, losses occur (see figure 2 for an outline of different steps of nutrient cycling). As the analysis of manure described in paragraph 2.4 resulted in percentages of nutrients, dry matter losses were calculated based on the ash content of

the samples (i.e. losses between step 3 and 5 of figure 2). Percentages of ash content in fresh and stored manure were analysed and for dry matter loss calculations two assumptions were made: (1) quantity of ash stayed the same after storing manure, and (2) initial quantity of fresh dry matter was 1000 grams. Through this, differences in quantity of fresh and stored dry matter could be calculated, thus quantifying the absolute dry matter and nutrient losses. These calculations were done as follows:

Formula 1: $(\text{quantity ash} / \text{quantity DM}) * 100 = \text{ash content of DM (for both fresh and stored manure)}$

Formula 2: $\text{quantity stored dry matter (kg)} = (\text{quantity stored ash} * 100) / \text{ash content of dry matter in stored manure}$

Based on the decrease of dry matter from fresh to stored manure, the percentage of losses during storage could be calculated in order to quantify the nutrient losses.

Step 3 in figure 2 shows collection of manure, and the amount of dry matter and nitrogen collected was calculated using the losses described above. As the quantity of stored dry matter and nitrogen were calculated (formula 2), quantity of manure (dry matter and nitrogen) collected could be calculated as follows:

Formula 3: $\text{quantity collected (kg)} = \text{quantity stored} / (1 - \% \text{ losses})$ (for both dry matter and nitrogen)

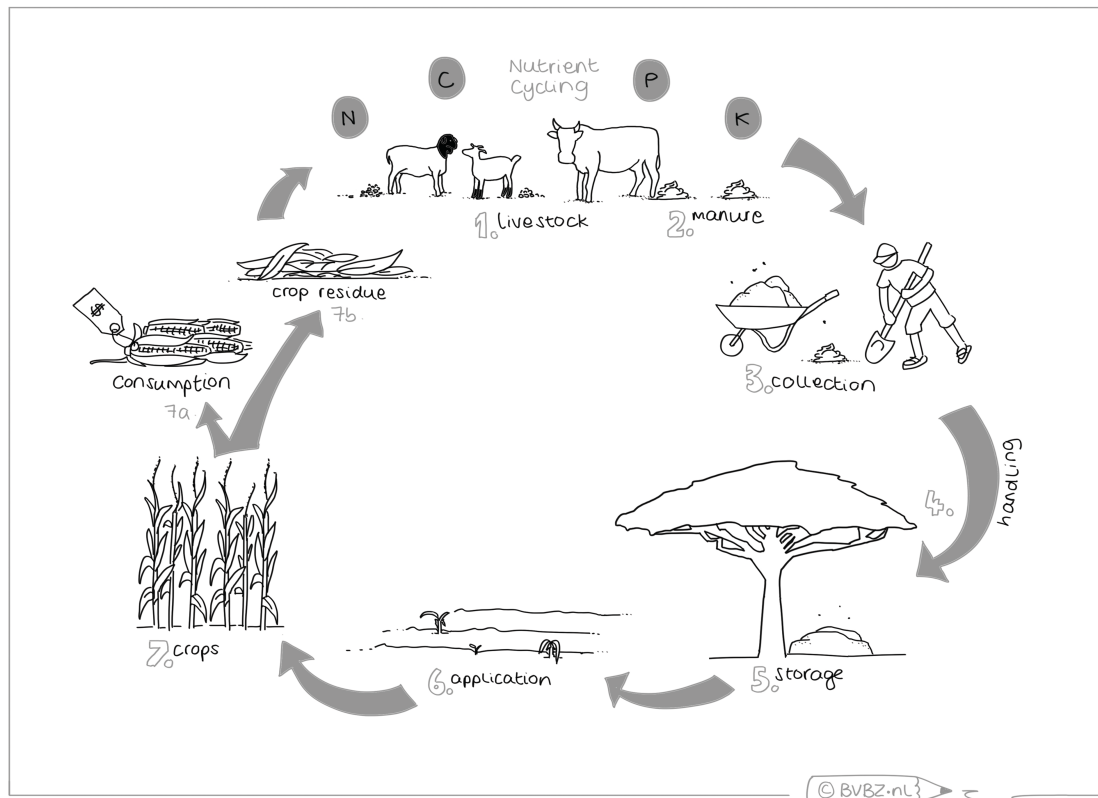


Figure 2 Nutrient cycling through a farming system (Bureau voor Beeldzaken, 2017)

2.6 Farm Analysis Through FARMSIM

In order to simulate herd productivity and quantity of manure produce (step 2 of figure 2) the simulation model NUANCES-FARMSIM was used. This model is based on the NUANCES (Nutrient Use in Animal and Cropping systems – Efficiencies and Scales) framework, that combines systems analysis and experimentation with detailed field observations and surveys, and expert knowledge (both local knowledge and results of research).

The NUANCES-FARMSIM model simulates the effects of farm management decisions on livestock, crop production and manure quality by dividing a farming system into different interacting components, all of which have their own sub-models within the FARMSIM model. Analysis of a farming systems through this simulation model gives information on the current performance of a farm, as well as options where to improve management decisions in order to increase production efficiency of the farm as a whole. The sub-models of NUANCES-FARMSIM are: (1) *FIELD*, that calculates crop dry matter production per season and consists of two sub-models, *SOILSIM* and *CROPSIM-QUEFTS*, (2) *LIVSIM*, that simulates individual animals in a herd and calculates monthly production (i.e. meat, milk, progeny and manure), and (3) *HEAPSIM*, the sub-model that simulates the dynamics of manure produced by the livestock sub-systems and keeps track of collection and storage (see figure 3 for a schematic representation of the NUANCES-FARMSIM model and how its sub-models interact).

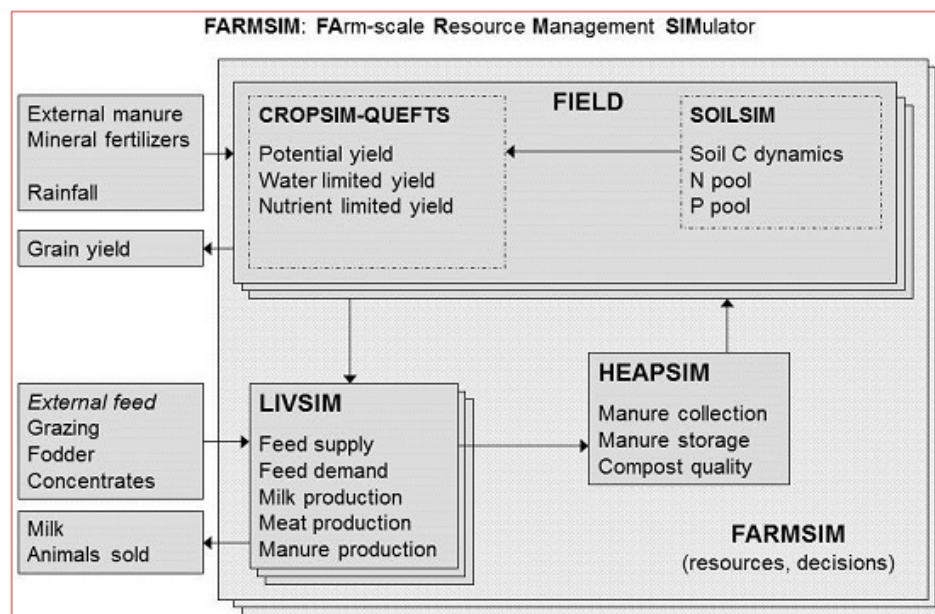


Figure 3 Schematic representation of the NUANCES-FARMSIM model (Rufino et al., 2007)

In order to run the model and analyse the farm-scale interactions, the data acquired on-farm were used as input for the *CROPSIM* and *LIVSIM* sub-models (see figure 3). Input data for the *SOILSIM* sub-model on carbon dynamics and the nitrogen and phosphorus pool in the soil were derived from previous research in western Kenya, where soil types are similar to those of Nyando district (Tiftonell et al., 2010b). For this study, results on

herd dynamics and production (especially manure production) were used. With these data, overall nutrient cycling through the farming system could be calculated through quality and quantity of (1) manure produced by the herd, (2) manure collected for storage and (3) manure that finally ends up on the land.

Tittonell et al. (2010b) used the FARMSIM simulation model for scenario studies on improvement of manure management and analysis of key points of manure collection, handling and storage where large amounts of nutrients get lost. Results from this study were used to evaluate how farm performance could be improved and to what extent specific manure management activities decrease nutrient losses through manure management.

2.7 Statistical Analysis

Statistical data analysis was carried out using the SPSS package version 24.0.0.0.

Descriptive statistics were used to summarise all data collected through interviews and results from the laboratory analyses. Normality of the data was determined through evaluation of QQ-plots. As these plots showed relatively consistent patterns, normality of all data could be assumed. T-tests were run to detect significant differences between fresh and stored manure quality. Analysis for differences between resource endowment groups was done through analysis of variance (ANOVA). Subsequently, a Tukey's HSD post hoc test was done for all significant between-group differences. Furthermore, regression analysis was done in order to determine the correlation between amount of nutrients and manure used on farm and farm size. Lastly, the correlation between number of TLUs and amount of nutrients and manure used on farm was analysed.

Chapter 3: Results

In this chapter results from the farm interviews and laboratory analyses will be presented. Based on interviews with farmers and on-farm observations, general characteristics on farm and household structures and livestock and crop subsystems are described in paragraph 3.1. Following the general farm description, detailed results on livestock and manure management are given in paragraph 3.2 and 3.3, respectively. Detailed results on calculations and analyses of manure quality are described in paragraph 3.4. Lastly, paragraph 3.5 presents the results derived from FARMSIM on manure excreted and collected.

3.1 General Farm Characterisation

The homestead of farmers was generally surrounded by the livestock facilities and home gardens. Grazing fields and forest land were the areas mostly found further away from the homestead. Cropping fields were situated in areas where the land was flat and preferably close to the home garden. Table 1 shows an outline of the main farm characteristics per resource endowment group (see appendix 2 for a detailed outline of farm characteristics per farm). Low resource endowment farmers owned on average 8.4 TLUs and 0.6 ha of land, of which over 85% consisted of arable land. None of the farmers owned forest land. Even though most crop produced were used for home consumption, crops were considered the main source of on-farm income, together with poultry. Food self sufficiency was relatively high, with an average of 10.2 months per year. The medium resource endowment farmers owned on average 7.2 TLUs and 2.3 ha of land. Land use was mostly allocated to arable and grazing land, however several farmers owned forested grassland as well. In a few cases, unutilised land was present but had been unused for not more than two cropping seasons. The main source of on-farm income were cash crops. For both low and medium resource endowment farmers, the main crops produced were maize and sorghum. The high resource endowment farmers owned on average 9.4 TLUs and 4.0 ha of land. The farm size was significantly higher than poorer farmers ($p < 0.05$). Most farming land was allocated to arable and grazing land and the main crops produced were maize, sorghum and millet. Cattle were considered the most important livestock as dairy and beef production were the main sources of on-farm income. Food self-sufficiency was high, with an average of 10.8 months. Even though differences between resource endowment categories were present (e.g. farm size, number and types of animals), all farmers had a relatively high food self-sufficiency.

Only in a few cases farmers indicated the use of artificial fertilisers and in all these cases, fertilisers were used only on crop fields. Non of the poorer farmers used artificial fertilisers. The most common fertiliser used are DAP (diammonium phosphate) and NPK (nitrogen phosphorus potassium). Farmers indicated to apply fertilisers together with manure prior to planting time during both the long and short rains.

Table 1 Mean scores of general farm characteristics: number of tropical livestock units (TLUs), farm size, land use, main crops produced on farm and food self-sufficiency over the year. Standard deviation is given between brackets

Resource endowment	Low n = 5	Medium n = 7	High n = 8
TLU	8.4 (2.7)	7.2 (3.9)	9.4 (4.1)
Farm size (ha)	0.6 ^a (0.28)	2.3 (1.4)	4.0 ^b (3.4)
Land use (%)			
Arable	85.3 ^a (20.2)	63.5 (7.2)	59.1 ^b (16.4)
Forested grassland	0	3.3 (3.9)	0.64 (1.4)
Grazing	14.7 (20.2)	31.3 (8.1)	32.1 (9.7)
Unutilised	0	7.5 (19.9)	8.1 (23.1)
Main crops produced	maize, sorghum, cowpeas	maize, sorghum, sweet potato	maize, sorghum, millet
Main source of on-farm income	crops, poultry	crops	dairy, beef
Food self-sufficiency (months year ⁻¹)	10.2 (2.1)	9.57 (1.1)	10.8 (0.7)
^{a-b} Values within a row with different superscripts differ significantly at p<0.05			

3.2 Livestock Management

All farmers but one owned small ruminants (sheep, goats or both) and these were considered the most important components of the livestock subsystem. The value of small ruminants has increased after introduction of the improved breeding programme by ILRI and more labour has been allocated to small ruminants since then. Table 2 shows the number and types of livestock kept per resource endowment group (for a detailed outline of livestock composition per farmer see appendix 3). Poor farmers owned on average 7.6 cattle, 2.2 goats and 3.4 sheep. Chickens were kept by most farmers, with an average of 6.6 chickens per farmer, and none of the poorer farmers owned a donkey. Medium resource endowment farmers owned less cattle than poor farmers (average of 5.3 cattle), however they owned significantly more goats ($p < 0.05$). The average number of sheep and chickens was 2.4 and 12.7, respectively and several farmers owned a donkey (average of 1.4 donkeys per farm). High resource endowment farmers owned on average 8.3 cattle, 7.1 goats, 4.1 sheep and 24.6 chickens. Only a few farmers owned a donkey, with an average of 0.88 per farm.

For all wealth categories, the function of small ruminants was similar. Farmers indicated that the main production purpose was meat and animals were primarily sold as live animals through animal markets or middle men. Sheep and goats mainly served as a security asset and were sold when cash was needed. Cattle were kept as a security asset as well, however the production of milk was seen as the primary asset. Although wealthier farmers perceived dairy production as their main source of on-farm income, all farmers only sold a relatively small part of the milk produced to the market. The majority was kept for home consumption.

Table 2 Mean scores of livestock composition: types and number of livestock, main income from agricultural activities and whether livestock generates income. Standard deviation is given between brackets

Resource endowment	Low n = 5	Medium n = 7	High n = 8
Cattle	7.6 (2.70)	5.3 (3.09)	8.3 (2.14)
Goats	2.2 (1.64)	9.4 (7.30)	7.1 (7.02)
Sheep	3.4 (2.19)	2.4 (2.07)	4.1 (5.11)
Chicken	6.6 (5.55)	12.7 (15.59)	24.6 (21.54)
Donkey	-	1.4 (0.98)	0.88 (0.99)
Income generated from livestock	yes	yes	yes

With the exception of one farmer, all farms owned cattle. Besides milk production and financial security asset, cattle were kept for draught power. Farmers also indicated that owning cattle was a sign of good wealth but only few farmers stated this to be a main purpose to keep cattle. Table 3 outlines the number and breeds of cattle kept per resource endowment category and what type of housing and feeding systems are used during the dry and rainy season (see appendix 4 for details on the cattle subsystem per farmer).

Table 3 Mean scores of cattle subsystem: number of animals per breed, housing system throughout the year and feeding system. Standard deviation is given between brackets

Resource endowment	Low n = 5	Medium n = 7	High n = 8
Number of cattle			
Zebu	6.2 ^a (3.4)	2.0 ^{bc} (1.6)	2.6 ^{bc} (1.8)
Crossbred	1.4 (2.6)	2.9 (2.8)	4.1 (3.3)
Dairy breed	-	0.4 (0.8)	0.5 (0.9)
Housing system			
Dry season	free range	free range	free range
Rainy season	mainly grazing, some stall feeding	free range	mainly grazing, some stall feeding
Feeding system			
Dry season	communal grazing crop residues	crop residues communal grazing	crop residues communal grazing
Rainy season	communal grazing cut & carry fodder	cut & carry fodder communal grazing	(own) grazing land concentrates

^{a-c} Values within a row with different superscripts differ significantly at $p < 0.05$

The low resource endowment farmers owned a relatively large number of cattle, of which on average 6.2 were zebus and 1.4 were crossbreds. These farmers owned significantly more zebus than the medium and high wealth categories ($p < 0.05$). None of the poorer farmers owned pure dairy breeds. In general, cattle were kept in a confinement overnight and grazed freely during the day. During rainy season, stall feeding increased and animals were fed primarily with cut and carry fodder. Medium

resource endowment farmers owned on average 2.0 zebus, 2.9 crossbreds and 0.4 pure dairy breeds. Cattle were kept in a free range system, but farmers indicated to feed cattle some crop residues and cut and carry fodder. High resource endowment farmers owned on average 2.6 zebus, 4.1 crossbreds and 0.5 pure dairy breeds. Cattle were mostly kept in a free range system as well, however crop residues played an important role during the dry season and several farmers fed cattle with some concentrates. In most farms, of all wealth categories, animals would graze freely on fallow land and roadsides. Several farmers kept their livestock tethered, which was mostly done during the rainy season. Among farmers of the three wealth categories, housing and feeding systems were similar even though function and production purposes of cattle differed between these groups. However, cattle breeds differed significantly between these groups.

3.3 Manure Management

Manure was considered an important input to the farm by 19 out of the 20 interviewed farmers and was collected on a regular basis (i.e. daily, weekly or seasonally). As small ruminants often were an important part of the livestock subsystem, and thus produced a considerable amount of manure, both cattle, sheep and goat manure was collected. Farmers indicated that all manure from the livestock confinement areas would be collected and stored, as well as manure found in the direct area of the farm when animals were tethered. During the day, when livestock would graze further away from the farm, manure was usually not collected. A common reason was the lack of labour that could be allocated to livestock and manure activities, but farmers also indicated that manure collected on-farm was perceived sufficient in quantity for use as fertiliser. Table 4 outlines the current manure management practices per resource endowment group (for details on manure management per farmer see appendix 5).

Table 4 Mean scores of manure management: storage, manure cover and type of added materials, time of collection, storage and application, and quantity of manure added as fertiliser. Standard deviation given between brackets

Resource endowment	Low n = 5	Medium n = 7	High n = 8
Type of storage	heap	heap/pit	heap
Cover	open space	shed/tree shade	tree shade
Organic materials added	tree leaves	tree leaves, kitchen waste	tree leaves; crop residues
Manure collected	daily	weekly	daily
Storage period (months)	10.4 (3.6)	7.7 (4.1)	5.4 (3.2)
Added to soil (times year ⁻¹)	5.8 (3.6)	7.4 (4.3)	5.4 (3.2)
Quantity added to soil (kg ha cultivated land ⁻¹)	3015 (2936.7)	2489 (3163.7)	1163 (1482.8)

Between the resource endowment groups, farmers had some overlapping management activities. Farmers either stored their manure on a heap or in a pit. The main organic components added to manure were tree leaves. The medium and high resource

endowment farmers indicated to add kitchen waste and some crop residues, respectively. Poorer farmers stored their manure in an open space, whereas farmers from the medium and high wealth category indicated to either store their manure under a shed or tree. Low and high resource endowments farmers collected their manure on a daily basis and added manure to the soil on average 5.8 and 5.4 times per year, respectively (table 4). Most medium resource endowment farmers collected their manure on a weekly basis, but did add manure to the soil more frequently (on average 7.4 times per year). With increasing resource endowment, the storage period of manure decreased. Large variability was seen between farmers on the quantity of manure that was added yearly to the soil (hence the large standard deviations shown in table 4). The general pattern showed that poorer farmers added most manure to their farms per hectares, whereas the high resource endowment group added the least manure.

In general, farmers did not perceive a difference in quality between manure stored in a heap or pit. However, farmers did confirm the use of a fence and roof system would be beneficial for the quality of manure. This was largely due to protection from rain, sunlight and foraging chicken (the latter was explained by animals eating the added crop residues and household wastes). Farmers indicated that the use of manure was important for crop production and that they would invest in manure management activities to improve quality of manure. All farmers viewed increased crop production as main result of application of manure to their fields. Several farmers also indicated the importance of manure for the soil itself, describing it as more fertile soils with an increased resistant to droughts. When providing information about manure quality and whether quality could be improved via management, farmers confirmed that interventions would help increase manure quality. However, knowledge on how to improve quality was the main constraint. There was a general consensus that the type of storage place influenced nutrient loss, but further knowledge on collecting and handling of the manure, and how this would influence quality, was not present. When informing about the main constraints to improve manure management, most farmers indicated that storage capacity, treatment capacity and lack of information were the main restrictions. Storage capacity was an important constraint as most farmers thought a construction needed to be build in order to have an effect on manure quality. Mostly, to prevent the effects of heat and sunlight, but also to more effectively separate manure from different animals and keep away animals that forage on added organic materials. Treatment capacity refers to different processes for manure prior to application to fields that preserves nutrients or increases overall quality. A basic manure treatment is adding of organic materials but more complex, high-tech treatments exist that require machinery and therefore, a relatively high energy input. For this reason, farmers view treatment capacity as a major constraint, as only household wastes and tree leaves are a relatively steady supply of materials that can be added to the manure heap. Crop residues are occasionally added, however, this is also an important livestock feed thus farmers must consider trade-offs when using crop residues for composting. As farmers consider more complex manure treatments difficult to implement on their smallholder

systems, it is viewed as an important point that inhibits them to move towards more efficient manure management practices. Lack of information on how to improve manure management was an important point for the majority of the farmers. First, general knowledge was indicated to be limited as in the area no advanced manure management activities were known to be present. Farmers could thus not pass on knowledge and information. Second, lack of access to information was viewed as a limitation as well, as villages in Nyando district are linked with Community Based Organisations that often provide information on improving farming practices. As these organisations have not provided information on manure management, farmers perceived this as a reason for not having the right information to improve their manure management practices. Access to information from external sources was thus viewed as an important aspect when farming practices are to be improved.

Specific questions on how farmers perceived the effect of covering manure were asked, as this has shown to be an effective and economic way of improving manure quality (Rufino et al., 2006). None of the farmers covered their manure with a plastic sheet, but the majority of farmers confirmed that this would improve its quality, as nutrients would not get lost through evaporation and the plastic layer would prevent the manure heap from drying.

3.4 Manure Quality

From each farm, fresh and stored manure was collected and analysed on overall quality and macro-nutrient content. In table 5, a summary of the chemical analysis is shown (see appendix 6 for results per farmer). A significant difference was shown in quality between fresh and stored manure for carbon, nitrogen, phosphorus and potassium content, as well as pH ($p < 0.05$). The carbon content of fresh manure was on average higher than in stored manure, whereas phosphorus and potassium content showed higher percentages in stored manure.

Table 5 Summary of chemical analysis of fresh and stored manure. Standard deviation given between brackets

Content (%)	Fresh n = 20	Stored n = 20
Organic matter	89.5 (11.7)	67.6 (12.1)
Ash	10.5 (11.4)	32.4 (12.1)
Carbon	33.2 (6.2)	24.7 (6.0)
Nitrogen	1.02 (0.4)	1.05 (0.5)
Phosphorus	0.36 (0.1)	0.58 (0.1)
Potassium	0.33 (0.3)	0.96 (0.5)
pH	8.5 (0.5)	9.1 (0.4)

Between resource endowment categories, significant differences were found for organic matter, carbon, nitrogen, phosphorus and potassium content in fresh manure ($p < 0.05$). Except for potassium, all components were lower in the low resource endowment

group. A significant difference in ash content was found as well, as farmers from the low wealth category had a higher ash content in fresh manure. For stored manure, no significant differences were found, as nutrient content was similar between wealth categories.

Based on the nutrient content of the fresh and stored manure samples, losses were calculated for dry matter, and carbon, nitrogen, phosphorus and potassium. Table 6 shows these results for the three wealth categories (results per farmers are outlined in appendix 7). No significant differences in losses between categories were found, however large losses of nutrients occurred in all farms. In particular losses of dry matter (on average 75 percent) and carbon and nitrogen (80 and 74 percent, respectively) were large when storing manure for, on average, 6 months.

Table 6 Mean percentages of dry matter and macro-nutrient losses from fresh to stored manure per resource endowment category. Standard deviation given between brackets

Losses (%)	Low n = 5	Medium n = 7	High n = 8
Dry matter	62.9 (31.4)	79.6 (11.8)	76.8 (11.2)
Carbon	87.2 (12.1)	85.3 (8.0)	83.7 (10.1)
Nitrogen	84.5 (17.3)	84.1 (9.9)	72.6 (18.4)
Phosphorus	17.2 (53.0)	63.3 (26.0)	54.5 (18.9)
Potassium	28.8 (29.7)	-24.3 (110.5)	-26.1 (99.6)

Phosphorus and potassium showed a decrease as well, however over a quarter of farmers had a higher potassium content after storing manure, thus rendering the overall decreasing trend less consistent. No significant differences were found between the three resource endowment groups on dry matter and macro-nutrient losses.

Based on the results presented in table 6, calculations were made on the amount of dry matter and the four macro-nutrients that were added to the soil per hectare cultivated land per year. Figures 3, 4 and 5 show the relation between these quantities and the farm size per resource endowment category. All figures show a similar trend in quantities of nutrients added to the soil per farm. Most farmers of the low resource endowment category add small quantities of nutrients on relatively small land sizes. However, several medium and high resource endowment farmers add similar quantities of manure to their farm while having a larger farm size. As the number of livestock between wealth categories do not differ significantly, a similar amount of manure is produced which results in less manure added to the farm per hectare of cultivated land. Only few farmers added larger quantities of nutrients to their land, while having relatively small farm sizes of 1.5 hectares or less.

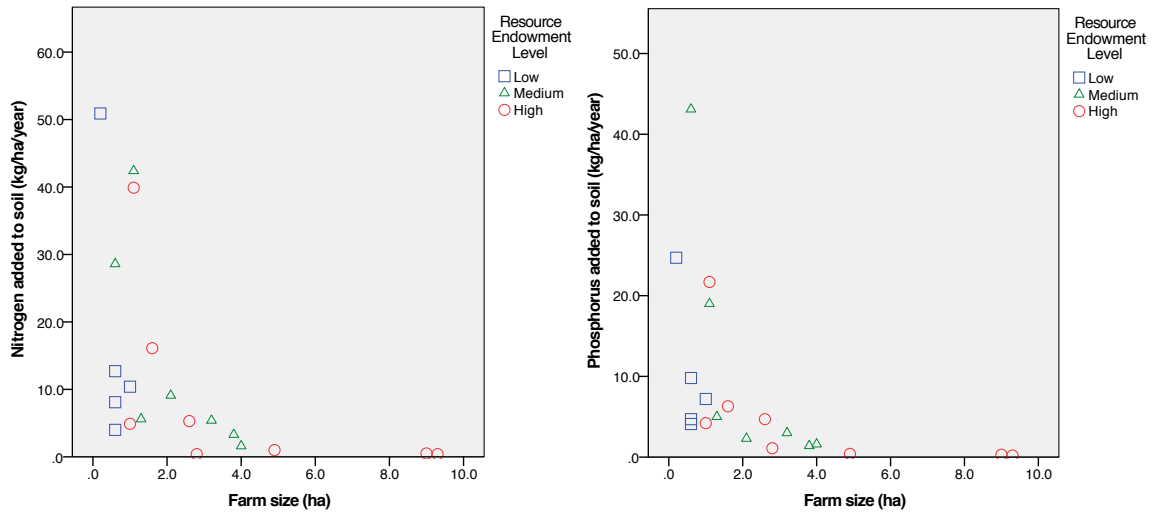


Figure 3 Relation between total dry matter/carbon added to soil ($\text{kg ha}^{-1} \text{yr}^{-1}$) and farm size (ha) for different resource endowment groups: blue = low; green = medium; red = high

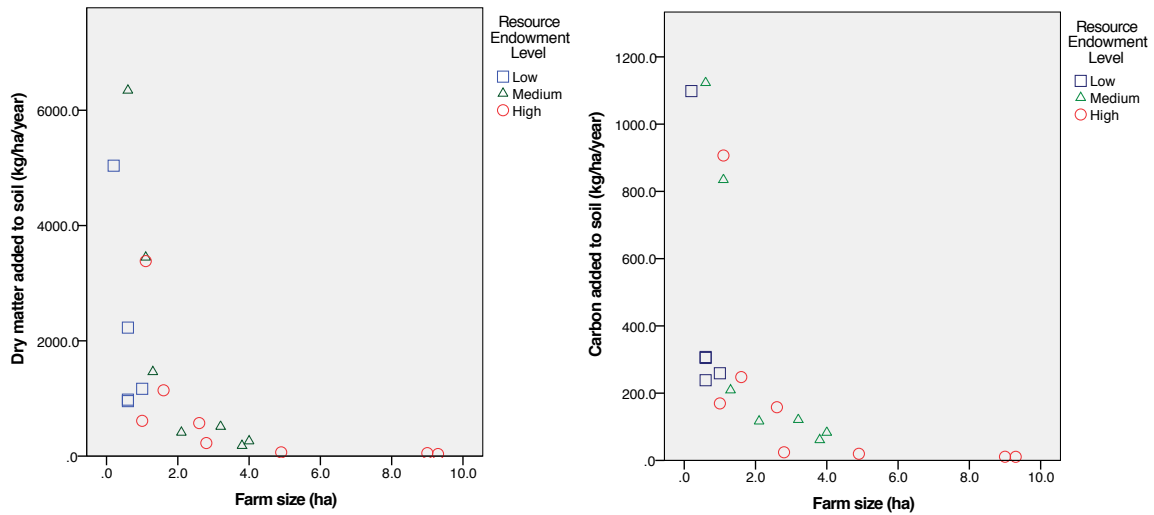


Figure 4 Relation between total nitrogen/phosphorus added to soil ($\text{kg ha}^{-1} \text{yr}^{-1}$) and farm size (ha) for different resource endowment groups: blue = low; green = medium; red = high

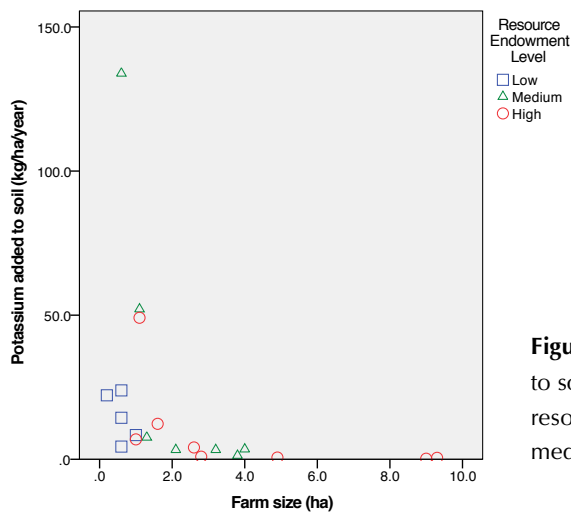


Figure 5 Relation between total potassium added to soil ($\text{kg ha}^{-1} \text{yr}^{-1}$) and farm size (ha) for different resource endowment groups: blue = low; green = medium; red = high

3.5 FARMSIM model simulations

Through the FARMSIM simulation model, data was acquired on the amount of manure (expressed in *kg dry matter year⁻¹* and *kg nitrogen year⁻¹*) excreted by the herd. Calculations were done in order to determine the amount of manure collected on every farm. Table 8 and 9 show these amounts, as well as the amount of manure and nitrogen that was eventually added (see appendix 8 for details on manure excreted and collected per farmer).

Table 8 Quantity of manure (*kg dry matter ha⁻¹ year⁻¹*) excreted, collected and added to the farm per resource endowment group. Standard deviation given between brackets

	Low n = 5	Medium n = 7	High n = 8
Excreted	5698.1 (5075.8)	2848.2 (3257.6)	1755.9 (1391.8)
Collected	6510.3 (8975.6)	9652.2 (11147.5)	2983.1 (4205.6)
Added	2073.8 (1738.0)	1831.9 (2289.3)	770.0 (1119.9)

For the low resource endowment farmers, large losses occur between collection and adding the manure to the soil, hence during the months of storage. A similar pattern can be seen in the high resource endowment group, however a discrepancy occurred as the amount of manure collected is higher than the amount excreted (which was calculated through FARMSIM). This is also the case for medium resource endowment farmers. However, the results generally show that losses occur from excretion to application and that most losses occur during storage period (see figure 6). For all wealth categories, the standard deviation shows large values which can be appointed to the large within-group variability of manure production and collection.

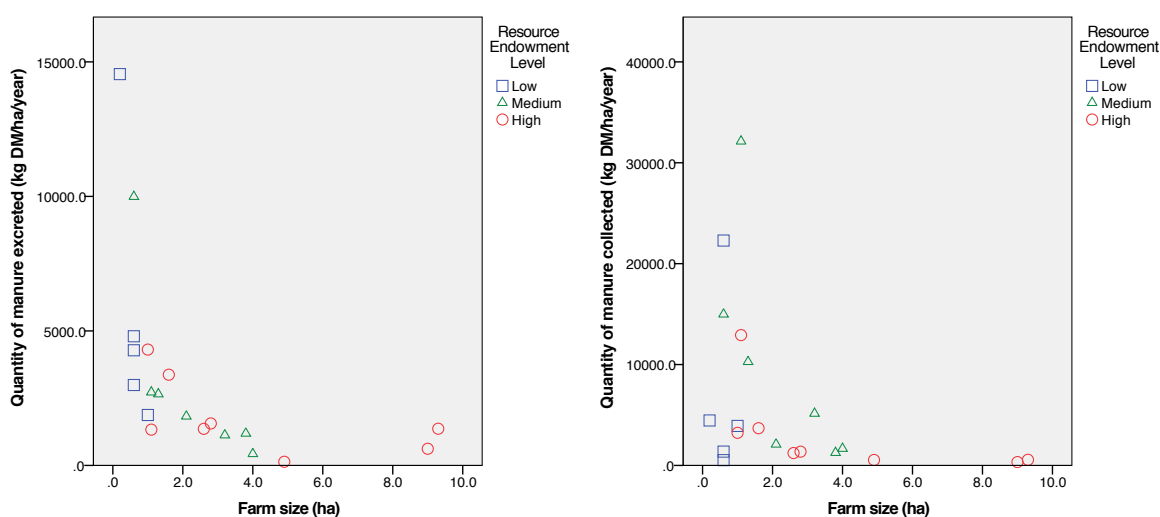


Figure 6 Relation between quantity of manure excreted and collected (*kg DM ha⁻¹ year⁻¹*) and farm size (ha) for different resource endowment groups: blue = low; green = medium; red = high

The FARMSIM simulation model could not calculate excretion of all macro-nutrients, thus table 9 and figure 7 show the results for nitrogen specifically. Again, most losses occur between collection and application of manure for all three wealth categories. No significant differences were found between resource endowment groups. For the medium resource endowment group, the amount of nitrogen collected is higher than the amount excreted indicating a discrepancy between calculations of FARMSIM and farmers' estimations of manure.

Table 9 Quantity of nitrogen ($\text{kg ha}^{-1} \text{ year}^{-1}$) excreted, collected and added to the farm per resource endowment group. Standard deviation given between brackets

	Low n = 5	Medium n = 7	High n = 8
Excreted	148.6 (137.5)	70.7 (78.2)	51.1 (41.0)
Collected	41.9 (47.5)	116.8 (175.9)	23.6 (26.7)
Added	17.2 (19.1)	14.2 (15.2)	8.7 (13.7)

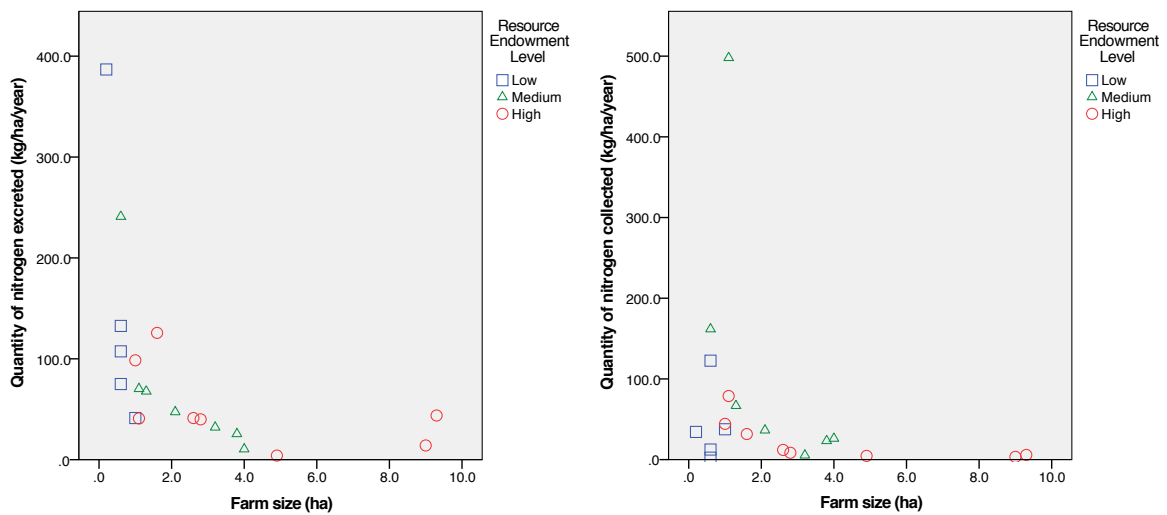


Figure 7 Relation between quantity of nitrogen excreted and collected ($\text{kg ha}^{-1} \text{ year}^{-1}$) and farm size (ha) for different resource endowment groups: blue = low; green = medium; red = high

Chapter 4: Discussion

4.1 Current Manure Management and Farm Performance

Farmers were grouped into three different wealth categories in order to determine whether differences were present in livestock and manure management, market orientation and farm investments. Furthermore, perspectives on the importance of cattle and small ruminants, as well as the use of manure as fertiliser were assessed. All farmers but one invested time in manure management and stored manure from cattle and small ruminants for later use as fertiliser. Manure was thus seen as an important by-product and it was believed that manure was beneficial for crop production. Medium and high resource endowment farmers generally stored their manure under a tree or shed as they believed this would prevent nutrients from getting lost. This reasoning was less present in poor farmers, hence the difference in storage method. This could be explained by rich farmers often having more knowledge on agricultural practices (Kebebe et al., 2015) and implementing farm practices that are aimed at long-term effects. Furthermore, high resource endowment farmers stored their manure together with tree leaves, kitchen waste and crop residues, whereas poorer farmers indicated to not add any kitchen waste or crop residues. Another clear difference between wealth categories was the length of the storage period, which was shorter for wealthier farmers. Several farmers in the higher resource endowment categories indicated that the effectiveness of manure as fertiliser would decline if stored for over 6 months, hence their storage period would not exceed 7 months. This points out wealthier farmers allocate more labour to manure management. These results indicate that richer farmers invest in activities that increase the quality of manure. However, the quantity of manure that is added to the soil per hectare is greater for poor farmers compared to medium and high resource endowment farmers. Despite the fact that wealthier farmers with more land generally own more livestock, they do not collect a greater amount of manure per hectare. However, the number of livestock per hectare is lower for high resource endowment farmers, which results in less manure produced per hectare. Additionally, farmers with bigger herds graze their cattle on owned or communal pastures for most of the time. As a result, a large amount of manure produced during grazing will not be collected. Poor farmers often have their cattle tethered near their homestead during the day, which enables them to collect more manure.

The laboratory results showed a difference in nutrient content between fresh and stored manure. The carbon content was higher in fresh manure, which can be explained by the storage period of manure after collection, which is on average between 6 and 12 months. During storage, carbon losses occur through conversion by microbes and fungi to gaseous compounds (i.e. CO₂ and CH₄), and a large percentage of losses takes place in the first 3 months of storage (Tittonell et al., 2010b). As storage period of all farmers exceeded this period, carbon losses can be ascribed to this. Phosphorus and potassium contents of stored manure were higher than fresh manure, which was not in line with

the expectations as nutrients in manure decline after several months of storage. The higher P and K content in stored manure can be explained by the method of storage and sample collection. In most cases, stored manure was mixed with soil, which would accumulate over time when manure was added to the heap. Especially in farms with a larger number of small ruminants, contamination with soil increased as goat and sheep manure is difficult to collect without soil (due to size and composition of excreta). Studies have shown that this can result in manure containing up to 90% soil (Mugwira and Murwira, 1997). As a result, nutrients present in the soil are included in the laboratory analysis of the manure samples, which could explain the results. Taking this into account, it could be assumed that phosphorus and potassium contents are higher in fresh manure or at least stay relatively constant after storage.

The nutrient content of both fresh and stored manure samples have been statistically analysed between the three resource endowment groups. Nutrient content of fresh manure differed significantly between resource endowment categories for carbon, nitrogen and potassium. The low C and N content of manure for low resource endowment farmers could be due to differences in feed availability between resource endowment categories. Poor farmers had a higher dependence on cut and carry fodder (from outside the farm) and the quality and quantity of feed available declines around the dry seasons. The feed available to wealthier farmers (i.e. own pasture and crop residues) can differ in quality from poor farmers which has an effect on the nutrient content (Rufino et al., 2007).

Stored manure did not show a difference in nutrient content between farmers. Thus, N, C, P and K content between wealth categories were similar, indicating the quality of manure after several months of storage is the same, regardless of initial fresh manure quality (i.e. nutrient content). This could be explained by the storage methods of farmers that showed few differences between resource endowment categories. Although higher resource endowment farmers did place their manure heap under a shed or tree, instead of in the open air, this has proved to not have significant effects on quality of stored manure (Rufino et al., 2007; Tittonell et al., 2010b). It can thus be concluded that for the 'end product' (i.e. de manure that will be used as fertiliser), all farmers show a similar performance and large losses of nutrients resulted in a low nutrient content of stored manure. The decrease in nutrient content between fresh and stored manure was used to calculate losses during excretion and application of manure, which will be discussed in the next section.

4.2 Excretion, Application and Collection of Manure

Nutrient losses from manure can occur during different phases of the manure management cycle (figure 2) and estimates of the amount of manure collected, as well as the magnitude of losses during storage were made. Additionally, the amount of manure excreted by the herd was calculated using the computer simulation model FARMSIM. These will be discussed below.

The FARMSIM model gave an estimation on the amount of manure excreted by cattle (both dry matter quantity and nitrogen quantity) which was compared with the amount collected by farmers. Results on amounts of excreted manure and data on collected manure were not consistent. More manure was collected than was estimated by FARMSIM to have been excreted. There are several reasons that could be ascribed to this and could all explain the discrepancy of these results. First, the quantity of manure added yearly to the farm was estimated by the farmers and expressed in either number of wheelbarrows, bags or buckets. This amount of manure could have been overestimated by the farmers or the configuration factor to express the amount of manure in kilograms did not represent the quantities estimated. Second, the assumption that ash quantity stayed constant during storage of manure could have resulted in overestimation of the nutrient losses. Theoretically, this assumption is viable as ash content is the fraction that will not undergo losses through, for example, evaporation (Matthiessen et al., 2005). However, during the period of storage ash quantity could decline through leaching (e.g. after rainfall) or increase through mixing with soil. In the latter, total ash content in the stored fraction will increase as the ash fraction from soil is added as well. As in this study, soil could have mixed with manure during collection and storage, the total ash quantity could be higher. If this would be taken into account, results of nutrient losses would be lower than the current outcomes. Five farmers indicated that sometimes ash is added to the manure heap which would make the assumption stated above unreliable. These farmers were thus excluded from the calculations. Third, FARMSIM only calculates the amount of manure excreted by cattle and does not take other livestock into account. As all farmers owned small ruminants and in several cases, manure of these animals made up a significant proportion of total manure collected, the results from FARMSIM are an underestimate of the amount of manure available on farm. Lastly, the results from FARMSIM in general could be an overestimation. Excreted manure is based on feed intake, feed quality and body weight of the animal. Feed quality was based on data available from the Vihiga district of western Kenya and could possibly not represent the quality of feed available in Nyando. Furthermore, feed intake and body weight of the animals were based on estimates given by the farmers and on data of previous research in western Kenya (Rufino et al., 2007; Tiftonell et al., 2010b; Diogo et al., 2013). When taking these factors into account, amount of manure collected could be higher than the values presented in the results and would be proportionate with the amount of manure excreted by the herd.

The nutrient content of fresh and stored manure was used to calculate losses from collection to end of storage. For carbon this resulted in losses from 60 to 89% for all resource endowments categories, whereas nitrogen showed losses from 50 to 85%. Also dry matter losses were high (60 to 80%), with no significant differences between wealth categories. Previous studies have shown large losses of nutrients in similar farming systems as well. Shah et al. (2012) found carbon and nitrogen losses up to 67 and 46%, respectively which was comparable with a previous study by Tiftonell et al. (2010b) who found carbon and nitrogen losses of 70 and 38%, respectively. Although results of

this study were on average higher, it does show that in the process from manure excretion to several months of storage, large losses occur on farm. This is also underlined by the quantities of nitrogen that were excreted, collected and applied on farm. Most farmers applied on average 17 kg N ha⁻¹, whereas the average amount of N excreted by cattle was 82 kg ha⁻¹. The applied amount is far below the average amount of 67 kg N ha⁻¹ needed for maize production (FAO, 2006), which was the dominant crop produced by all farmers.

Most farmers collected their manure on a daily or weekly basis and between wealth categories, differences were present on the length of the storage period. Based on the losses from fresh to stored manure, calculations were done on the amount of manure and nitrogen collected per farm. Even though, as described earlier, discrepancies were present the results show that on average farmers collected 42 kg N ha⁻¹.

These results show that from excretion to application, large losses occur and that most farmers have far less manure (and thus nutrients) available than on average required per hectare. However, if collection and application of manure would increase farmers could potentially reach the required level of, at least, nitrogen. Current manure management practices do not prevent large nutrients losses from manure. This can be appointed to several aspects and could differ between resource endowment group and individual farm performance. First, wealthier farmers, with a larger farm size and generally more livestock, add similar or lower amounts of manure to their farm per hectare compared to poorer farmers. Thus, more land or livestock did not result in a better performance in terms of amount of manure collected. As such, for wealthy farmers large losses of manure occur during collection and it can be concluded that most manure is not collected (table 8). Previous studies have shown that in general, most manure will not be collected by farmers in a smallholder system without a zero grazing unit (Rufino et al., 2006; Tittonell, 2010a). As in this study no zero grazing units were present and livestock spend a large part of the day outside the farm, it is likely that large proportions of manure are not collected at all. Second, all low resource endowment farmers had similar handling and storage practices with manure stored in the open air on a heap, with limited addition of organic materials, and storage periods close to one year. This indicates that losses of nutrients occur due to storage methods as these practices contribute to a decrease in manure quality (Rufino et al., 2007; Shah, 2013). However, methods of handling and storage in higher wealth categories did not differ considerably from the low resource endowment farmers when looking at the extent to which nutrient loss is prevented. Limited shade was provided and manure was still stored in the open and exposed to external factors. This indicates that for wealthier farmers as well, losses occur during storage. Together with limited collection of manure, wealthy farmers can improve their activities along the different steps of the manure management cycle (figure 2).

4.3 Options to Improve Manure Management

The critical steps where nutrient losses occurred are in line with previous studies done in western Kenya (Rufino et al., 2007; Tiftonnell et al., 2010b; Shah et al., 2012, Diogo et al., 2013). As such, improved manure management activities that have shown to be successful and economically viable to implement could be promising for these farmers as well. First of all, different components of the storage place play a critical role in the prevention of nutrient losses. Studies by Tiftonnell et al. (2010b) and Shah et al. (2012) both showed that covering manure with a plastic sheet could reduce carbon and nitrogen losses up to 50 and 80%, respectively. As this would only require the purchase of such a plastic sheet, implementation on smallholder farms is a viable option. Additionally, providing the storage place from a roof and floor prevents nutrients from getting lost as well (Rufino et al., 2007). However, reduction of nutrient losses can only be established when using materials such as iron sheets or wood (for roofing material) and concrete (for floor material) which could be unattractive economically. If farmers have the resources to invest in an improved storage place, reduction of nutrient losses could be up to 40% compared to manure stored in the open (Rufino et al., 2007). Second, the storage period can influence the quality of manure considerably. A study by Tiftonnell et al. (2010b) has shown that the majority of nutrient losses occur in the first 3 months of storage. After 6 months, the rate of nutrient loss decreased and between 10 to 12 months of storage, no considerable differences occurred. As most farmers in this study stored their manure over 6 months, nutrient losses could be reduced by reducing the storage period. This would mean that farmers should apply manure more frequently to their plots, which would increase the labour allocation to manure management. Third, adding organic materials to manure increases the total mass of the compost and has shown to decrease mass losses over 20% (Rufino et al., 2007). However, significant trade-offs occur when implementing this activity, as organic materials mostly derive from crop residues. Often, smallholder farmers rely on crop residues as feed for their livestock and alternatives are often lacking. Furthermore, crop residues are valuable to directly enhance soil quality as well. When leaving residues on the field after harvesting, it benefits the soil through water retention and enhancing soil organic matter (Giller et al., 2002). These two functions of crop residues already form trade-offs within a smallholder system and often pose a challenge for farmers to decide whether to leave residues on the field or use them as livestock feed. Introducing a third function (i.e. as component for manure composting) could make decision making and trade-off assessment too complex and unattractive for farmers. A fourth activity to improve manure management could be to increase the frequency at which manure is collected (Diogo et al., 2013). Especially for wealthier farmers, this should significantly increase the amount of manure that is available per hectare. This would increase labour allocated to manure management as well. In order to determine whether more time can be invested in manure management, further research should be carried out. Lastly, the stalls where livestock is kept during the night could be altered in a way that allows for a better collection of manure, including urine (Rufino et al., 2007). As urine contains a

large fraction of the total nitrogen excreted, collection of urine could increase the total collected N considerably.

The above manure management activities all play a role in the efficient retention of nutrients in manure. However, interrelation between these activities is present and a decrease in nutrient losses could possibly only be successful when combining different management strategies. Whether implementation of these novel practices is viable differs between farmers and there is not one generic solution available. Consequently, further assessment whether farmers have the necessary resources to shift their manure management practices should be conducted to secure successful results.

Chapter 5: Conclusion

Between resource endowment categories, differences in management, decision making and perspectives on manure management were present. However, all farmers included a basic form of manure management and confirmed the importance to collect manure from their livestock and use it as fertiliser. Higher resource endowment farmers did show more knowledge on manure management and invested more time and resources in order to increase the quality of the manure.

The methods used in this study to calculate nutrient losses and overall manure quantities were limiting in order to accurately outline current farm performance. However, results did show that major nutrient losses took place and that different steps in the manure management cycle account for large mass losses of manure as well. Stored manure lost between 60 to 89% of carbon and 50 to 85% of nitrogen. Dry matter losses were on average 60 to 80%. Consequently, current management practices do not provide sufficient nutrients, in particular nitrogen, that is needed to replenish soils after harvest. On average, 82 kg N ha⁻¹ year⁻¹ was produced, whereas 42 kg N ha⁻¹ year⁻¹ was collected and only 17 kg N ha⁻¹ year⁻¹ was applied on farm. Between resource endowment categories, differences were present where losses occurred but focus should be both on manure losses between excretion and collection, and collection and application.

Novel manure management activities that have proven to be viable strategies to increase overall manure quality could be implemented: (1) covering manure with a plastic sheet; (2) improving floor and roof of the storage unit; (3) decreasing the storage period; (4) adding organic materials to the manure heap; (5) increase the frequency of manure collection, and (6) improve flooring of stalls where livestock is kept overnight.

Further research is needed to determine whether farmers have access to these resources and whether more labour can be allocated to manure management. Additionally, knowledge on how to implement novel activities should be provided in order to create a sustainable system.

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Appendices

Appendix 1: Indicators included in resource endowment categorisation

Primary indicators	Secondary indicators
Cattle breeds	Educational level
Farm size (ha) <i>low: 0 – 1.0 ha</i> <i>medium: 1.1 – 2.5 ha</i> <i>high: > 2.5 ha</i>	Hired labour (Y/N)
Food self-sufficiency (months year ⁻¹) <i>low: < 6 months</i> <i>medium: 6 – 9 months</i> <i>high: 10 – 12 months</i>	Housing type
Off-farm employment (Y/N)	Land status
Total number of livestock <i>low: 0 – 10 animals</i> <i>medium: 11 – 20 animals</i> <i>high: > 20 animals</i>	Milk sold (Y/N)
Cash crops (Y/N)	Rented land (ha)

Appendix 2: Detailed outline of general farm characteristics per farmer

Farm	Farm size (ha)	TLU	Land use (%)				Main crops produced ^a	Main on-farm income	Food self sufficiency (months year ⁻¹)
			Arable land	Forest land	Grazing land	Un-utilized			
BO	0.2	8.6	100	0	0	0	MZ, S, CP	poultry	12
FAO	0.6	6.7	100	0	0	0	MZ, S	crop	10
AAO	0.6	11.5	100	0	0	0	MZ, S, CP	poultry	12
EA	4.0	4.7	60	0	40	0	MS, S,	crops	11
MO	0.6	10.5	66.7	0	33.3	0	MZ, S, SP	crops	10
PO	1.0	11.7	60	0	40	0	MZ, S, M	crops	10
JOO	1.1	7.6	57.7	3.8	38.5	0	MZ, S, M	crops, dairy	11
JPA	2.6	6.6	61.5	0	38.5	0	MZ, S	beef	12
JO	1.1	6.9	53.6	10.7	35.7	0	MZ, S, SP	crops	9
EO	0.6	13.7	66.7	0	33.3	0	MZ, SP	crops	9
HO	1.0	4.9	60	0	40	0	MZ, S, M	poultry	7
DL	2.1	10.9	76.9	3.8	19.2	0	MZ, S, CP	crops	11
CK	1.6	13.3	75	0	25	0	MZ, S	beef	10
JK	9.3	12.2	21.7	0	13	65.2	MZ, S	dairy, beef	11
WM	1.3	7.0	64.5	3.2	32.3	0	MZ, S, SP	dairy	9
EM	2.8	12.8	71.4	0	28.6	0	MZ, S	beef	10
LS	3.2	3.6	62.5	0	37.5	0	MZ,S	crops	8
KM	9.0	9.4	67.3	1.3	31.4	0	MZ, S, M	dairy, beef	11
SK	4.9	1.2	58.3	0	41.7	0	MZ, S, CP	dairy	11
AN	3.8	3.4	21.1	5.3	21.1	52.6	MZ, S	crops	10

^a MZ = maize, M = millet, S = sorghum, SP = sweet potato, CP = cowpeas

Appendix 3: Detailed outline of livestock composition per farmer

Farm	Livestock					Income generated from livestock (yes/no)
	Cattle	Goats	Sheep	Chicken	Donkey	
BO	8		6	12		Y
FAO	6	4	3	2		N
AAO	11	1	4			Y
EA	3	17		47	3	Y
MO	9	3		7		Y
PO	9	3	12	51		Y
JOO	6	12	2	37	1	Y
JPA	5	1	11	5		N
JO	5	12	2	5	1	Y
EO	11	6	5	3		Y
HO	4	3	4	12		Y
DL	7	20	5	14	1	Y
CK	11		7	14	1	Y
JK	9	20		12	3	N
WM	6			10	1	N
EM	10	7	1	10	1	Y
LS	3	3	3	5	2	N
KM	8	2		8		Y
SK		12		60	1	N
AN	2	8	2	5	2	Y

Appendix 4: Detailed outline of cattle subsystem per farmer

Farm	Number of cattle			Housing system ^a		Feeding system ^b	
	Zebu	Cross-breed	Pure breed	Rainy season	Dry season	Rainy Season	Dry Season
BO	8			FR	MG, SS	CG, C&C	CG, CR
FAO	6			MG, SS	MG, SS	CG, C&C	CG, CR
AAO	11			FR	MG, SS	CG, CR	CG, CR
EA	3			FR	FR	C&C, CG	CR, CG
MO	3	6		T	FR	CG, C&C	CG
PO	3	6		MG, SS	FR	CC, CR	CR, CG
JOO	5	1		T	MG, SS	CC, GL	CG, CR
JPA	3	2		MG, SS	FR	CC, C&C	CR, CG
JO	3	1	1	T	MG, SS	C&C, CC	CR, CG
EO	4	5	2	MG, SS	FR	C&C, CC	CG, CR
HO	3	1		FR	FR	CG, C&C	CG, CR
DL		7		FR	MG, SS	C&C, CG	CR, CG
CK	4	5	2	FR	MG, SS	GL, C	CR, CG
JK	3	6		FR	FR	GL, C&C	CG, CR
WM	1	5		FR	MG, SS	GL, C	GL, CR
EM		10		FR	FR	GL, C	GL, CR
LS	3			FR	FR	GL, C&C	CG, CR
KM	3	3	2	FR	FR	GL, C	GL, CR
SK				MG, SS	MG	CG	CG, CR
AN		2		FR	FR	CG, C	CG, CR

^aFR = free range, MG = mostly grazing, SS = some stall feeding, T = tethered

^bCG = communal grazing, C&C = cut & carry fodder, CR = crop residues, C = concentrates, GL = grazing land

Appendix 5: Detailed outline of manure management per farmer

Farm	Type of storage	Cover	Materials added	Manure collected	Storage (months)	Added to soil (times yr⁻¹)	Added to soil (kg year⁻¹)
BO	heap	tree shade		daily	12	3	1620
FAO	heap	open space	ash; tree leaves	daily	4	4	900
AAO	pit	tree shade	tree leaves	weekly	12	5	1800
EA	heap	shed		seasonally	6	4	1350
MO	heap	open space	ash; tree leaves	daily	12	5	675
PO	heap	tree shade	tree leaves	yearly	12	5	900
JOO	heap	open space		monthly	6	5	4500
JPA	heap	tree shade		daily	6	3	1800
JO	pit	soil	kitchen waste	monthly	12	5	4500
EO	heap	tree shade		monthly	12	1	5400
HO	pit	open space		yearly	12	5	1350
DL	heap	tree shade	kitchen waste	seasonally	4	4	1500
CK	heap	open space	kitchen waste	seasonally	4	3	4500
JK	heap	tree shade		seasonally	4	4	600
WM	heap	shed		seasonally	4	4	2700
EM	pit	soil	tree leaves	daily	6	4	1350
LS	pit	open space		seasonally	12	5	2250
KM	heap	tree shade	crop residues; leaves	daily	4	4	600
SK	heap	shed	tree leaves	weekly	1	3	360
AN	heap	tree shade	tree leaves	seasonally	4	4	900

Appendix 6: Chemical analysis of fresh and stored manure samples per farmer (Organic matter (OM), ash and macro nutrients given in percentages)

Farm	OM		Ash		C		N		P		K		pH	
	F	S	F	S	F	S	F	S	F	S	F	S	F	S
BO	52.4	57.9	47.6	42.1	18.7	21.8	0.77	1.01	0.63	0.49	0.82	0.44	9.0	8.6
FAO	64.7	80.7	35.3	19.3	19.5	25.0	0.46	0.85	0.61	0.43	0.92	0.46	9.3	9.0
AAO	93.6	36.0	6.4	64.0	32.2	13.8	0.55	0.18	0.32	0.44	0.27	1.07	8.8	8.9
EA	93.6	59.0	6.4	41.0	35.7	31.8	1.57	0.61	0.35	0.60	0.10	1.33	8.4	9.3
MO	81.4	74.0	18.6	26.0	22.2	31.1	0.91	1.30	0.25	0.48	0.94	1.47	8.9	8.7
PO	93.9	67.8	6.1	32.2	36.6	27.7	1.37	0.80	0.23	0.68	0.25	1.13	8.9	9.1
JOO	92.3	70.6	7.7	29.4	36.2	26.8	0.61	1.18	0.46	0.64	0.26	1.45	8.1	9.4
JPA	90.7	80.1	9.3	19.9	34.0	27.6	0.98	0.93	0.47	0.82	0.41	0.71	8.6	9.4
JO	95.9	61.8	4.1	38.2	38.8	24.2	1.55	1.23	0.30	0.55	0.17	1.51	8.3	8.8
EO	88.1	71.9	11.9	28.1	38.8	17.7	1.08	0.45	0.35	0.68	0.27	2.11	8.5	9.3
HO	87.5	58.1	12.5	41.9	30.9	22.2	0.96	0.89	0.40	0.62	0.41	0.72	8.8	8.4
DL	94.6	72.5	5.4	27.5	36.7	28.4	1.74	2.22	0.43	0.57	0.55	0.80	8.7	9.4
CK	96.1	87.4	3.9	12.6	36.3	21.7	0.86	1.41	0.28	0.55	0.11	1.08	8.0	9.7
JK	94.1	68.7	5.9	31.3	34.5	29.5	1.03	1.04	0.29	0.54	0.11	1.42	8.4	9.8
WM	92.8	49.4	7.2	50.6	33.3	14.3	0.65	0.38	0.35	0.34	0.24	0.52	8.5	8.7
EM	96.2	77.1	3.8	22.9	38.5	10.7	0.62	0.19	0.29	0.47	0.17	0.38	8.5	9.1
LS	96.7	66.9	3.3	33.1		23.6		1.05	0.25	0.59	0.12	0.65	8.6	9.1
KM	94.5	65.4	5.4	34.6	34.1	20.9	1.02	1.00	0.34	0.62	0.27	0.40	7.3	8.9
SK	95.6	63.5	4.4	36.5	36.6	30.1	0.84	1.60	0.21	0.68	0.12	0.88	7.9	9.1
AN	95.1	83.8	4.9	16.2	37.5	33.7	1.84	1.82	0.35	0.75	0.18	0.73	8.1	9.4

Appendix 7: Losses of dry matter and nutrients per farmers given in percentages

Farm	Dry matter	Carbon	Nitrogen	Phosphorus	Potassium
BO	-13.1	-31.8	-48.3	12.1	39.3
FAO	-82.9	-134.5	-238.0	-28.9	8.5
AAO	90.0	95.7	96.7	86.3	60.4
EA	84.4	86.1	93.9	-37.4	-107.6
MO	28.5	-0.2	-2.2	-37.4	-11.9
PO	81.1	85.7	88.9	44.0	14.4
JOO	73.8	80.6	49.3	63.6	-46.1
JPA	53.3	62.1	55.7	18.5	19.1
JO	89.3	93.3	91.5	80.3	4.7
EO	57.7	80.7	82.4	17.7	-230.9
HO	70.2	78.6	72.3	53.8	47.6
DL	80.4	84.8	74.9	74.0	71.4
CK	69.0	81.5	49.3	39.2	-203.9
JK	81.2	83.9	81.0	64.9	-143.3
WM	85.8	93.9	91.7	86.2	69.2
EM	83.4	95.4	94.9	73.1	62.9
LS	90.0			76.5	46.0
KM	84.4	90.4	84.7	71.5	76.9
SK	87.9	90.1	77.0	61.0	11.6
AN	69.8	72.8	70.1	35.2	-22.7

Appendix 8: Results of FARMSIM output per farmer: amount of dry matter and nitrogen excreted, collected and added to the soil (kg ha⁻¹ year⁻¹)

Farm	Dry matter			Nitrogen		
	Excreted	Collected	Added	Excreted	Collected	Added
BO	14545.7	4456.1	5038.2	386.8	34.3	50.9
FAO	2988.8	521.6	954.0	75.0	2.4	8.1
AAO	4801.3	22290.0	2229.0	132.6	122.6	4.0
EA	431.2	1671.3	260.9	10.5	26.2	1.6
MO	4280.1	1369.7	979.9	107.4	12.5	12.7
PO	4305.9	3230.6	612.0	98.5	44.3	4.9
JOO	1330.4	12917.6	3383.2	40.9	78.8	39.9
JPA	1360.2	1226.6	573.2	41.3	12.0	5.4
JO	2721.2	32131.2	3448.6	70.3	498.0	42.4
EO	9990.7	14982.7	6345.0	241.0	161.8	28.6
HO	1874.4	3914.3	1167.8	41.3	37.6	10.4
DL	1826.3	2091.6	410.7	47.3	36.4	9.1
CK	3371.7	3689.1	1141.9	125.7	31.7	16.1
JK	1364.2	560.0	105.6	43.8	5.8	1.1
WM	2651.7	10275.7	1462.2	67.8	66.8	5.6
EM	1560.3	1365.6	226.6	40.0	8.5	0.4
LS	1126.2	5148.4	513.3	32.1	5.4	5.4
KM	618.8	332.8	51.9	14.1	3.4	0.5
SK	135.8	542.4	65.4	4.1	4.6	1.0
AN	1190.2	1264.6	382.5	25.6	23.3	7.0