DEVELOPMENT OF NUTRIENT MANAGEMENT STRATEGIES ALONG A CONTINUUM OF DAIRY PRODUCTION INTENSIFICATION IN UGANDA

BY

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A THESIS SUBMITTED TO MAKERERE UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY

JANUARY 2008

DECLARATION

I declare that the work presented in this thesis is my own and has not been published or submitted in any form for any other award to any other university. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

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DEDICATION

I dedicate this work to my parents Ezekiel, H. B. Lubanga and Anne Nakato, D. Lubanga who laboured tirelessly to ensure that I receive a good education. I also wish to dedicate this work to my husband Dr Jackson, F. Mubiru, whose love, care, support, patience and encouragement eased the burden of this task.

Finally I dedicate this work to my children Miriam, E. Namubiru and Mark, W. Nkugwa who had to endure long periods of my absence.

You are all special people and are a part of this achievement, may the good Lord bless you.

ACKNOWLEDGEMENT

I am indebted to numerous people without whose support this work would not have been possible. I thank Drs J. S. Tenywa of Makerere University, D. Romney of the International Livestock Research Institute (ILRI) and N. Halberg of the Danish Institute of Agricultural Sciences (DIAS) who supervised this work and greatly enriched it with their experience. My thanks to Drs I. Baltenweck and S. Staal for contributions at all stages of the study, Dr. M. Herrero towards proposal development and to Dr. R. Fawcett for assistance with deriving nutrient management improvement strategies.

I am grateful to P. Wanjohi for assistance with data management, M. Nakabiri, R. Magambo, A. Ssali and J. Kigongo for data entry work they did and to all the field enumerators who collected data in Mbarara, Masaka and Jinja. I acknowledge the contribution of S. Nagda and D. Njubi for the statistical analysis, P. Ochungo towards the Geographic Information Systems (GIS) work, L. Njoroge and E. Karuiki towards data processing, and John Hermansen and the Agricultural Systems Department of DIAS for support towards the methodologies for calculation of nutrient balances. I appreciate the efforts of all the laboratory technicians in Namulonge Agricultural and Animal Production Research Institute (NAARI) and at Makerere University. I am indebted to Dr. C. Ebong for the collaboration fostered between, the National Agricultural Research Organisation (NARO) and ILRI leading to the initiation of this study and to W. Nanyeenya and all my colleagues of the Animal Production Programme. I acknowledge the immense contribution of the farmers in the districts of Mbarara, Masaka and Jinja who were involved in the studies.

I am indebted to NARO of Uganda and the Diretor of Research, NAARI, for the logistical support. The "Danish International Development Assistance" (DANIDA) is heartily appreciated for funding the study. Dr. A. Percy Smith was instrumental in initiating collaboration between DIAS, ILRI and NARO. Finally, I thank God who granted wisdom and knowledge and sustained me during the period of this study.

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DEFINITIONS

Arable land (Land)	Land used specifically for crop production. It includes pastures.
Crop pattern	Dominant crop or crops in a mixture occupying a patch.
DM	Dry Matter
Farm	All the land owned by a household and the livestock components. The land may include more than one land parcel/plot.
Farmer controlled flows (FC)	Flows that the farmers have substantial control over through their activities
Nutrient balances	Nutrients in minus Nutrients out *(kg DM* ha^{-1} *season*$^{-1}$*)*
Patch	The subdivisions within arable land (Land) representing a different crop or crop mixture grown thereon.
Plot	A single piece of land which is connected. Pieces of land not connected are considered separate plots.
Total Livestock Units (TLU)	A scoring system for livestock types based on average animal size. In this study it is only used in relation to cattle as follows: Adult male = 1 unit, Adult female = 0.7 units, Weaners = 0.5 units, Pre-weaners = 0.2 units
Uncontrolled flows	Flows that farmer have limited control over and are mainly controlled by environmental forces
Ushs	Uganda Shillings

ABSTRACT

Soil fertility decline is a leading form of land productivity degradation in Sub-Saharan Africa. Colossal quantities of nutrients are removed annually from soils, especially through crop harvests, unreciprocated by nutrient inputs. This is true for both crop and livestock centred production systems in the region. Moreover, with prudent management, the integrated crop-livestock system offers better opportunities for nutrient management particularly within the low resource endowed small scale farmer production framework.

Livestock plays a critical role in the socio-economic setting of the region. In Uganda, livestock contributes 20% of Agricultural Gross Domestic Product (AGDP), and is a principal sector in income generation and food security for the population. Of the livestock sector contribution to the economy, the dairy sub-sector accounts for 40–50%. Within the sub-sector exists a spectrum of production practices along with a diversity of levels of production. Furthermore, the gap between production and the demand for dairy products is spiraling, owing to the increasingly low levels of system productivity. Among the major causes is soil fertility decline, likely due to negative nutrient balance sheets. As such, efforts to develop appropriate interventions ought to hold this as the critical entry-point. In this case, the starting point is the need for a clear understanding of the dairy systems across the country, particularly in terms of management and levels of intensification. On the basis of such efforts, a systematic layout of the dairy systems structure will be achievable within which a critical trail for nutrient flow can be traced, mapped and realistic interventions mounted. It was within this framework that this research was conducted.

The objectives of the study were to: (i) Establish farm categories on the basis of dairy intensification in Uganda for targeting nutrient management interventions; (ii) Evaluate the effect of dairy intensification on major plant nutrient balances as a mechanism for identifying entry-points for intervention and subsequent contribution to sustainable productivity of dairy systems; (iii) Identify indicators of nutrient status for assessment of dairy production systems;

and (iv) Identify options for improving nutrient balances at various levels of intensification of dairy production in Uganda.

Studies were conducted in the districts of Jinja, Masaka and Mbarara in Uganda in two parts, namely (i) a cross-sectional characterisation of dairy systems; and (ii) a longitudinal study of nutrient flows and their management. The characterisation study, which lasted three months, involved three sub-counties per district and these were selected based on agro-ecology, human population and intensity of transport network. Within each sub-county, 37 households were selected from two villages. A semi-structured questionnaire was then administered to one adult per household. Key elements of the questionnaire were household structure, land size, crops and their yields; livestock types, numbers and productivity; livestock management systems and household incomes.

From this study, 4 major dairy categories were identified, namely, Herding (HD), Tethering (TE), Fenced (FE) and Zero grazing (ZG), in order of increasing intensification of production. The HD category was characterised by (i) low herd content of improved cattle breeds (21%), (ii) low expenditure on veterinary services (Ushs 71,368 year^{-1}), (iii) moderate use of long term hired labour (1.1 persons farm^{-1}), and (iv) very low off-farm income (Ushs 5,846 year^{-1}). The TE category was similar to the HD in improved cattle breed content but was moderate in expenditure on veterinary services and long term labour. Off-farm income which was very high (Ushs 65,111 month^{-1}) was the exception in this category. On the other hand, the FE category was outstanding in long term labour use (1.6 persons farm^{-1}) and off-farm income (Ushs 200,667 month^{-1}). Contrastingly, ZG was exceptionally high in improved breeds and expenditure on veterinary services, but very low (0.5 persons farm^{-1}) long term labour use.

From the characterisation study part, 19 farms were drawn and used in the longitudinal study. Farm selection ensured representation of the four categories described above. However, out of the ZG category, a new category named Semi-Intensive (SI) was created to cater for the unique features that were evident in the interphase between ZG and FE. Overall, each category was represented by at least three farmers as replicates. Each Farm was examined in terms of arable land (hereafter referred to as Land) and the livestock component with focus on dairy production. The Land was considered to have a variety of Patches. A Patch in this context is a subdivision within arable land (Land) representing a different crop or crop mixture grown thereon. The farms selected varied in total land area, ranging from 0.4 to 28 ha, with 1 to 30 heads of cattle. The study was ran for three cropping seasons during 2003-2004. The main study parameters included herd dynamics, milk yields, livestock feeds, land allocation to crops, fodder and pasture, crop harvests, soil fertility management practices and generally all farm imports and exports.

From this study, the largest nutrient influxes into the Farms were those into the ZG category and least into FE, with differences between the two amounting to 35, 200 and 320-folds for N, P and K, respectively. Off-farm feeds were responsible for the large nutrient influxes into the farms and in the case of N, biological N fixation (BNF) made a substantial contribution. Nutrient inflows to the farms through direct applications from off-farm were negligible in all categories. The major channel for N, P and K outflows from the Farms was through crop harvests, with the largest values in the ZG category, and lowest in HD. The outflows from the ZG category amounted to 10, 11 and 5-folds those in the HD category for N, P and K, respectively.

From the Land standpoint, the highest N influx was in the TE category, and was 7-folds that in the HD category, which was the lowest. The greatest contributor to N inflows to the Land was BNF. Phosphorus and K entries into the Land were again highest in TE, but lowest in the SI category. The P inflow value for TE was 20-folds that for the SI category, but 19-folds in the case of K. Outflow values for Land N, P and K were highest in ZG category with a range of 7 13-folds those in the HD category which had the lowest values.

Farm N, P and K inflow to outflow ratios were greater than unity, with the exception of those in the FE category, and for K in HD, which had less than unity values. The highest Farm N inflow to outflow ratio (3.2) was in the TE category, yet for P it was in ZG (4.2). In contrast, the highest K Farm inflow to outflow ratio (5.2) was in the SI category. Land inflow to outflow ratios were all <1, with highest ratios in N (0.7) and P (0.5) occurring in TE, while the FE category had the highest Land K inflow to outflow ratio of 0.2. Differences between values of

Farm N, P and K balances and their Land counterparts were persistently highest in ZG and lowest in HD and FE.

Dairy intensification, to an extent, had a positive effect on Farm N, P and K balances, while the contrary was true for Land balances. With respect to Farm nutrient balance sheets, ZG category had the largest positive N, P and K values. On the other hand, FE presented the poorest scenario, with all consistently negative net balances. At arable land (Land) level, TE category presented the highest positive N balance (1.1 kg ha^{-1} season^{-1}), while HD had the highest but negative P and K balances (-0.6 and -4.1, respectively).

At Land level, on basis of crop patterns, Fodder crops presented the lowest and negative N, P and K net balances, and these were -54.7, -8.6 and -85.9 kg ha^{-1}season^{-1}, respectively. Contrastingly, the Beans-Maize crop pattern had the highest positive N balance (8.7 kg ha^{-1} season^{-1}), while Banana-Beans had the highest P balance (1.5). The highest K balance (-2.6) was in the Pasture crop pattern.

Factors related to land size, crop patterns, harvests, grazing and inputs to the land were identified as major indicators for N, P and K balances. Among these indicators, manure use was identified as the major option for improving nutrient management. Quantities of manure required to offset N imbalances on the Land were established using the indicators identified and Patch balances. The largest quantities of manure required for offsetting land N imbalances were among the more intensive farm categories with the highest value (1665 kg (DM) ha^{-1} season^{-1}) in the ZG category and least in the less intensive categories with the lowest value (298 kg (DM) ha^{-1} season^{-1}) in the HD category. Manure available on farms in FE and TE was adequate to offset N imbalances on the Land; however, additional external nutrient inputs would have to be obtained in the HD (367 kg (DM) of manure), SI (410 kg (DM) of manure) and ZG (17 410 kg (DM) of manure) categories. Biological N fixation (BNF), with the ability to raise N balances, was also identified as a viable option for improving nutrient management.

Basing on yield response functions developed from regression models, manure application of [illegible]0 kg (DM) ha^{-1} season^{-1} to the Land, could predictably increase yields of banana by 13%, mounting to Ushs 331,850; and elephant grass by 48% also amounting to Ushs 717,210, *Ceteris Paribas.*

n a nutshell, this study has demonstrated that:

a) dairy systems productivity improvement is better tackled on basis of dairy intensification categories;

b) the most intensified systems attract more nutrient inflow but this is not translated into proportionate inflow of nutrients into the arable land (Land), which is a situation that signals inefficient management of nutrients within the Farm. Among the bottlenecks to nutrient transfer into the Land was the non-utilisation of cattle manure as a fertility input for crop and fodder production;

c) biological N fixation contributes a significant *in-situ* N input though the level of contribution is far less than the external feed inflow in the more intensive categories (ZG and SI). Therefore, focal attention on enhancement of BNF, particularly for the small scale farmers, offers a window of opportunity for elevating productivity of the crop-dairy system;

d) key factors that influence nutrient management provide inference on nutrient balances and are relevant for development of options for nutrient balance improvement; and

e) improved utilisation of manure could potentially improve crop and fodder yields.

CHAPTER ONE

INTRODUCTION

Jutrient management is a key aspect in agricultural production globally and presents divergent hallenges in different parts of the world. While the developing countries are faced with utrient deficits, the developed countries have problems of nutrient surpluses (De Haan *et al.*, 996). Strategies to address these problems are unrelated, hence, the discussion in this thesis vill focus on aspects related with nutrient deficits which are the major nutrient problem in the reas where the studies were undertaken. Nutrient loss from agricultural production systems is he cause of these deficits and should be addressed to avert deterioration of production nvironments. Nutrients are transported all over the world through trade in agricultural produce nd fertilisers, and at local level, they are lost through crop harvests and livestock products, rosion, deposition, volatilisation and leaching. As a result, nutrient flows at farm level over ime become unbalanced (De Jager *et al.*, 1999). This has largely been caused by rapid rise in uman population (Pretty *et al.*, 2003) which has led to rising demand for food, fibre and other uman needs. In developing countries, human needs have greatly exceeded the supplying apacity to the extent that food insecurity is the norm in most countries. Annual increases in ood production in Africa, for instance, are largely attributed to exploitation of marginal areas or agricultural production with ensuing land degradation effects. This trend, if uninterrupted is ikely to fuel food insecurity in the continent (World bank, 1993).

On the African continent, average annual losses of nitrogen (N), phosphorus (P) and potassium K) are estimated to be 22, 2.5 and 15 kg ha^{-1} yr^{-1} of arable land, respectively (Stoorvogel and maling, 1990). Losses for sub-Saharan Africa by the year 2000 were projected at 27, 8 and 25 g ha^{-1} yr^{-1} for N, P and K, respectively (Stoorvogel and Smaling, 1990). On the contrary, large eas of western Europe, north eastern United States, coastal south eastern Asia and large areas China have nutrient surpluses ranging from 200 to over 1000 kg N ha^{-1} $year^{-1}$ (De Haan *et* ., 1996). Existing farming systems in sub-Saharan Africa are of low or no input in nature, eaning inadequate replacement of lost nutrients. On a per *capita* scale, Africa reportedly used

9 million metric tonnes (MT) of fertiliser in the year 2001 (Sasakawa Global, 2002). This is in ɔntrast with 22.6 million MT in Europe, 73.2 million MT in Asia and 22 million MT in North merica in the same year. Moreover, the African figure is exaggerated by inclusion of South ıd North Africa, which are more advanced in soil fertility management. Otherwise, fertiliser ;e in sub-Saharan Africa is reportedly less than 1 kg ha^{-1} $year^{-1}$ (Sasakawa Global, 2002; AOSTAT, Online: http:faostat.fao.org). Therefore, agricultural systems in Africa are lopsided wards nutrient mining and scientific reports exist to attest to this situation. Nutrient mining ıs been estimated at 660 kg ha^{-1} $year^{-1}$ for nitrogen (N), 75 for phosphorus (P) and 450 for ɔtassium (K) for the last 30 years from about 200m million ha of cultivated land from 37 ɔuntries in Africa (Stoorvogel and Smaling, 1990; Sanchez *et al.*, 1997; Smaling *et al.*, 1997). Uganda specifically, seasonal N losses in the eastern region reportedly range from 22 to 40 g ha^{-1} $year^{-1}$ (Wortmann and Kaizzi, 1998).

ıtensification of agricultural production with minimal or no nutrient additions is one of the ıuses of nutrient imbalances. Intensification has occurred in response to increasing population, ı the sub-humid areas of Africa (McIntire *et al.*, 1992; Delgado *et al.*, 1999; Baltenweck *et al.*,)04). Intensive agriculture provides a source of livelihood for many peri-urban households and ı Uganda this is largely evident in the dairy sector where zero-grazing and semi zero-grazing ırms are now common in peri-urban areas (DENIVA, 1995; Livestock Systems Research rogramme (LSRP), 1999, unpublished). The intensive systems, together with the already kisting less intensive and more extensive dairy systems create a continuum with regards to the vel of intensification of dairy production. This raises concern regarding the quality of nutrient anagement within the production systems along this continuum and motivates the exploration opportunities for improved nutrient management. With insufficient or no addition of ıtrients to replace those lost through harvested products and other losses, nutrient mining and bsequently land degradation will occur (Stoorvogel and Smaling, 1990; Smaling *et al.*, 1997). this trend is left unaddressed there are great national socio-economic and biophysical ıplications. The socio-economic phenomenon is in terms of food security and poverty enarios, while the biophysical is in terms of climatic changes, resource degradation and odiversity disruption. Interventions to address this problem must be sought first through rnessing the existing resources within the production systems.

gricultural production systems in Africa are largely small-scale and typically mixed. Crop and vestock production are key components of the farm, and both are largely interdependent perationally (Powell and Williams, 1995). It is, therefore, imperative that efforts geared owards improving productivity with consideration of nutrient management must logically onsider the synergy between and among these components. In the generally low or no input ystems in Africa, crops could depend directly or otherwise on livestock manure inputs; owever, these are often not fully utilised by farmers (Krauss, 2001). The livestock sector epends almost entirely on crops for feeds, shelter, and bedding materials. Owing to the limited eographical coverage of research done so far in Africa and Uganda in particular, there is bvious need for a systematic research scheme to explore unique agricultural systems such as hose involving dairy and other livestock, which allow resource interactions with potential utrient benefits. It would be interesting to explore nutrient stocks in such systems, especially long the perceived dairy intensification transformation line. Such a study will permit lentification of gaps and suitable nutrient management methods within these production ystems. Potential methods to respond to the inadequacies observed can also be identified.

)airy production globally is tending towards intensification (CEAS and EFNCP, 2000; Warren nd Harold, 2000; Anderson *et al.*, 2004; Baltenweck *et al.*, 2004). In Uganda and other eveloping countries, dairy production is undergoing a slow but steady transformation largely n response to the growing shortage of pastureland due to human population pressure, and to the apid rise in the demand for livestock, particularly milk products (McIntire *et al.*, 1992; elgado *et al.*, 1999). For instance *per capita* consumption of milk is higher in urban areas here it is 17 litres person^{-1} year^{-1} higher than in rural areas (www.ugandainvest.com., 2001). he transformation transect is evidently towards production intensification, whereby the aditionally pastoral systems involving open and long distance grazing are quickly phasing wards agro-pastoral, and the latter into paddocking and zero grazing. Along this line of ansformation, there is increased but supposedly more efficient use of inputs per unit output. is includes use of high milk yielding cattle breeds, high value and early maturing pastures ecies, use of relevant agro-chemicals including fertilsers, among other practices. It also plies increased superiority in general management of the systems (UN/WFP, 1993; ENIVA, 1995). Unfortunately, to-date, this transformation lacks recognition in most of the country, yet it's clear understanding could provide logical entry points for research and development of the various stages along the transformation line. The nutrient dynamics involved at the different levels of intensification are a key area that requires attention. This will yield knowledge crucial in improvement of nutrient management at each of these levels.

In an integrated agricultural production system it is important that status of nutrient management is evaluated to enable monitoring of sustainable land use. Assessment of nutrient management in production systems requires the use of parameters for indication of the nutrient status within the system. Nutrient balances, which are the difference between the sums of nutrients inputs and nutrient outputs, are an effective means of assessing the nutrient status of production systems (Mohamed Saleem., 1998; Geurts *et al.*, 1999). Positive nutrient balances are desirable indicating that more nutrients are brought into the production systems than those lost. Negative ones are undesirable indicating that more nutrients are leaving the system than are brought in. A zero balance is fair and means that all nutrients lost from the system are replaced. Nutrient balances can also be integrated with analyses simulating dynamics of nitrogen, phosphorus and carbon in soils over time (Shepherd and Soule, 1998). This would enable the study of changes in quantities of N and P over time in the production system. Use of nutrient balances, delineates the risks a system is exposed to and provides entry points for technological interventions. This is because these balances are estimated from the flows of each of the elements critical in the production system. In this way, beneficial and detrimental flows can be identified and means sought to minimize the latter and enhance the former. Beneficial, non-existing flows can also be introduced into the system to raise nutrient balances. Previous studies carried out on assessment of nutrient management in Uganda (Wortmann and Kaizzi, 1998; Walaga *et al.*, 2000; Esilaba *et al.*, 2005) have been discrete in nature and those targeting dairying in particular and in detail are clearly lacking. Agricultural production in Uganda has broad categories, which need to be considered in nutrient management studies. Nutrient management in crop production systems for instance, will differ from that in livestock and mixed crop–livestock production systems. Analyses of nutrient management that separates such broad production categories are still lacking and need to be undertaken. Most nutrient studies in Uganda have concentrated on crop production systems and more attention now needs to be channelled to mixed crop-livestock systems.

The more prudent way to respond to inadequacies in natural resource management is to reconcile ecological management and traditional agricultural knowledge. In fact current production systems could benefit from integration of those features to yield ecologically sound production systems, which will meet the challenge of nutrient management. These features may include development of well integrated mixed crop-livestock systems. Efficiency of use of added nutrients is also very crucial and practices employed in the production processes need to be capable of enhancing nutrient supply to the plants in time of need and retaining excess nutrients. Such strategies require less advanced technology but are extremely sensitive (Woomer and Swift, 1994; Powell *et al.*, 1996; Matson *et al.*,1977) for instance, operations need to be timely, nutrients should be added in appropriate quantities, handling of some of materials such as crop residues and manure determines the quantities of nutrients that will be retained. One of the current challenges is to understand how the ecosystems are altered by intensive agriculture and in turn develop strategies that take advantage of the ecological interactions within the production systems to enhance nutrient management (Matson *et al.*, 1997). The approaches towards nutrient management may vary with the level of intensification, available resources, climate, existing enterprises and infrastructure, however, it is important to identify those relevant to the different systems. Development of appropriate approaches requires knowledge of nutrient management status of a system.

A clear understanding of the nutrient status, nutrient flows and quantitative balances in a farming system is a prerequisite to laying strategies for system productivity (Smaling *et al.*, 1996; De Jager *et al.*, 1998; Van den Bosch *et al.*, 1998). Proper nutrient management of the system is possible through knowledge and use of this information. Nutrients are key in the functioning of plants and ultimately animals with the most critical ones being nitrogen (N), phosphorus (P) and potassium (K). Information on nutrient management may be of little use if provided generally for production systems. It is imperative therefore, to target such information specifically for instance, to farm categories using nutrient balances as the basis for decision making. This enables development of specific interventions for specific farm types applicable in their unique settings and environments.

Nutrient balance computations are complicated and can not be easily done at farm level therefore it is necessary to identify simpler methods to ensure sustainable capacity at grass root levels. It is therefore, imperative that indicators of farm nutrient status are identified which can be used to make a rapid assessment of expected nutrient status according to observed management practices in any dairy production system. This presents a useful tool that can be used for by farmers, extension agents, policy makers, researchers and students in assessing nutrient status of the systems. Output from such an assessment will be critical in identifying areas where significant nutrient losses are occurring, where interventions to improve nutrient management can be made and appropriate management practices to do so.

This study was therefore designed to contribute to the improvement of dairy production in Uganda through understanding the dairy systems and their resource transformation and identifying means for efficient resource use. The specific objectives included:

i. Establish farm categories on the basis of dairy intensification in Uganda for targeting nutrient management interventions;
ii. Evaluate the effect of dairy intensification on major plant and systems nutrient balances as a mechanism for identifying entry points for intervention and subsequent contribution to sustainable productivity of dairy systems;
iii. Identify indicators of nutrient status for assessment of dairy production systems; and
iv. Identify options for improving nutrient balances at various levels of intensification of dairy production in Uganda.

CHAPTER TWO

LITERATURE REVIEW

2.1 Dairy Production

The dairy sector constitutes a significant component of the livestock sector globally. Consumption of dairy products is estimated at 539 million tonnes and is expected to grow at an annual rate of 1 – 2% by 2005 (Promar International, 2000, Online: just-food.com). In Uganda, dairy production is increasingly gaining importance with current national annual milk production at 900,000 tonnes from 365,000 tonnes in 1991 (DDA, 2001/2002). Growth of output from the livestock sector is reported to be 2.8% per annum since 1995, with most of the growth resulting from dairy production (Online: ugandainvest.com, 2001). The sector reportedly contributes 20% towards the food processing industry which in turn contributes 4.3% to the National Gross Domestic Product (GDP) (Staal and Kaguongo, 2003). The dairy herd; exotic and cross breeds, increased from 220,000 in 1995 to 285,000 in 2000. The *per capita* milk consumption also increased from 16 L $person^{-1}$ $year^{-1}$ in 1985 to 40 L $person^{-1}$ $year^{-1}$ in 2001 (DDA, 2001/2002). Cattle rearing on smallholder farms is purposely for milk production to benefit the family directly as food and for household income. This contrasts with the commercial livestock sector, which almost balances the dairy and the beef production interests (Okwenye, 1994, Online: http://www.fao.org/docrep/x5661e00.htm). The Ugandan dairy sector has experienced transformations over the years in response to changes in biological and socio-economic factors. These should be considered in research efforts to address needs of the sector.

2.1.1 Trends within the Dairy Production Systems in Uganda

Prior to the mid-1980s, commercial dairy production in Uganda was mainly on fenced farms with natural or improved pastures demarcated into paddocks. Desired animal breeds then were exotic and cross-breeds (UN/WFP, 1993). These farms were few and most of them were government owned. Sufficient milk production was also realised from the pastoral areas, where indigenous cattle breeds, particularly the long horn Ankole cattle (Sanga breed), were kept in large numbers by pastoralists and agro-pastoralists (Mwebaze, 2000). Households with few heads (1-5) of indigenous cattle breeds, particularly *Zebu* did not contribute substantially to the bulk of milk in the market, owing to low milk yields ranging from 1-3 litres cow^{-1} day^{-1} (Mwebaze, 2000, Online: www.fao.org/ag/AGP/doc/Counprof/Uganda).

A shift in policy emphasis in Uganda in 1986 sparked off a number of initiatives in the dairy sector through the National Rehabilitation and Development Plan (RDP) (UN/WFP, 1993). These included introduction of zero grazing in dairy production. This is a system of management where cattle are housed in stalls and fed and watered therein. This system was promoted by the Ministry of Agriculture and non–Governmental organisations (NGOs). The most prominent NGOs included Heifer Project International (HPI), Heifer Project for Women Farmers, European Development Fund (EDF) micro-projects, Send-a-Cow and Heifer Projects in the Uganda Catholic Secretariat, Young Women Christian Association (YWCA) and the Anglican Church (Fonteh *et al.*, 1998). Development Network of Indigenous Voluntary Associations (DENIVA), in a study they undertook in 1995 indicate that 57% of NGOs in Western Uganda, 50% in the central region and 23% in the eastern part of the country, promoted zero grazing (DENIVA, 1995). Most of the NGOs' beneficiaries received an in-calf heifer, which they repaid by returning the first female calf to the organisation to be passed on to another beneficiary. Beneficiaries of some of the projects, such as those of the EDF micro-project, received in-calf heifers as loans, which were paid back in cash over long periods of time. Also, some projects provided construction materials for cattle stalls and these were part of the heifer loan and were often subsidised. All projects obliged beneficiaries to establish at least one acre of *Pennisetum purpureum* (elephant grass) and in some cases also, a smaller field of a forage legume; *Lablab purpureus* (Lablab) for feeding the cattle. The beneficiaries were given the relevant training on the management of the animals and received regular follow up by the project management (Besiime, 1995; Kasirye, 1995).

Introduction of the zero grazing management system was aimed at improving food security and livelihood of households in the country. The cow received through the project was expected to be the nucleus for a household herd that would provide milk for the household as well as income through milk and animal sales. The latter was expected to be done when the herd became too large for the household, or through culling. It was also anticipated that the households would utilise manure to maintain soil fertility, and hence, sustain crop and fodder productivity. Production of biogas for cheap household energy was also seen as an opportunity, which was adopted by a number of households with zero grazing units (DENIVA, 1995; Fonteh *et al.*, 1998). Many of these undertakings were successful from narration of several farmers who listed the numerous benefits they had realised from the zero-grazing cows (Livestock Systems Research Programme (LSRP), 1999, unpublished).

In the light of the above scenario, a number of other households with and without dairy cattle decided to emulate the project beneficiaries using their own resources. Some households with local animals decided to upgrade them gradually through artificial insemination or through use of village bull schemes. Some of the farmers who shifted their dairy farming method retained part of their grazing pastures, converted some paddocks to fodder fields and constructed stalls in strategic sites on their farms to allow both zero grazing and open-grazing. This is normally referred to as the "semi-intensive" management system. Other semi-intensive dairy farmers retained a few paddocks and within the paddocks constructed feed troughs, where chopped fodder was placed for the animals (Mwebaze, 2000, Online: www.fao.org/ag/AGP/doc/Counprof/Uganda).

Dairy production in Uganda, therefore, has a spectrum of systems ranging from extensive to intensive. Considering that the intensification trend is widespread in Uganda, it is critical that the merits and demerits of the different production systems with regards to nutrient management are assessed. This analysis should be targeted at specific production systems to avoid generalisation of inferences. Such analyses will enable identification of entry points for research and development and subsequently options for improvement within the production systems. To achieve this, dairy production systems should be categorised based on key factors related with level of intensification of production.

2.1.2 Categorisation of Dairy Production Systems in Uganda

Types of dairy production systems in Uganda are largely influenced by biophysical factors and socio-economic setting of the location of the holdings. These systems can also be classified on basis of the objectives of the farmers. In this case, farmers who produce milk for subsistence purposes and those who do so opportunistically are considered in different systems from those who do so commercially to maximize profits (Staal and Kaguongo, 2003). Major dairy production systems in Uganda according to UN/WFP (1993) and FAO (2000) are zero grazing, semi-intensive, fenced dairy farms, tethering and communal, agro-pastoral and pastoral grazing. Zero grazing systems are prevalent within vicinity of urban areas where land is scarce and the milk market is good. Semi-intensive systems are commonly found in peri-urban areas mainly in south western, central and south eastern parts of Uganda. The fenced dairy farms are also common in the same areas, however, they are not necessarily close to urban centres. Communal and pastoral systems are found in the south west, central, north and north eastern parts of the country. Tethering system in not confined to any particular area but is common where crop production is a prime activity and cattle numbers are very few.

The existing systems, therefore, form a continuum with the semi-nomadic pastoralism at one end and the stall-feeding (zero grazing) system at the other (UN/WFP, 1993). In between these two extremes there are systems that draw management practices from each end of the continuum to varying degrees. The semi-nomadic pastoralists are oriented towards subsistence, accumulation of capital in cattle and cultural prestige. Though some produce and market milk, this is not their primary objective. The zero grazers are largely market oriented and operate systems with high external inputs, more efficient use of resources and often on small land holdings close to urban areas (Staal and Kaguongo, 2003). The dairy production systems can broadly be categorized into four classes namely communal grazing, free range grazing, fenced grazing and zero grazing (Kasirye, 2003).

(i) Communal grazing systems

These are grazing systems where cattle owners graze their animals on land they do not own. This is often land owned by individuals who do not use it and is therefore left fallow. The cattle could be herded or tethered. In instances where the cattle are herded a herdsman is employed.

Vhere households are in close proximity and cattle numbers are not very large the herdsman ould take care of cattle belonging to as many as six households. Cattle grazed communally are ften indigenous Zebu and Ankole (Sanga) breeds. Where households have large numbers of attle managed communally the cattle exclusively depend on the materials grazed from the ommunal lands. However, where households have 1-3 cattle grazed communally some ouseholds supplement grazing with crop residues or fodder obtained off or on the farm Fonteh *et al.*, 1998). Communal grazing systems with large numbers of cattle are found in outh western Uganda, central and north eastern Uganda in areas where there are large grazing reas referred to as the cattle corridor (Mugasi *et al.*, 2002, Online: www.ossrea.net/dhp). Communal grazing systems with few cattle numbers are found in all parts of the country. Communal grazing households may have other livestock and grow crops which could be for ubsistence, commercial or both. Sale of crop produce is often at a very small scale and only one after fulfilling subsistence requirements. This system is found in areas where human opulation pressure is relatively low to the extent that there still exists communal land that can e used for grazing (Mwebaze, 2000, Online: www.fao.org/ag/AGP/doc/Counprof/Uganda). his is a low input system which presents opportunities for nutrient importation into the farms. he animals make dung deposits in the night kraals which contain nutrients sourced from utside the farm and can later be applied to the crop fields. Nutrient losses from the farm are lso minimal because they are limited only to food crop harvests as the livestock feed tends to e sourced from outside the farm. Opportunities also exist for use of crop residues as livestock eed and then returning manure to the field. One constraint they would have in relation with utrient management is that they can not improve the nutrient status of the grazing fields ecause they have no ownership over them.

***i)* Free range grazing**

his system involves grazing cattle on unfenced land owned by the farm household. It is acticed in areas where there is plenty of land and a single household can own over 100 ha of tural pasture with an average of 80 head of cattle (Mugasi *et al.*, 2002, Online: ww.ossrea.net/dhp). Cattle reared in this system are often local Zebu or Ankole cattle and y depend purely on the pasture for their nutrition and get no supplementation from other urces. The cattle are often herded by a herdsman and in the evening may be returned close to he homestead to spend the night in a kraal. These cattle may or may not be milked with milk yields of 2.4 – 3.8 litres cow^{-1} day^{-1} (Mugasi *et al*., 2002, Online: www.ossrea.net/dhp). Farmers who practice this system may sell milk but are also often largely driven by accumulation of wealth in cattle. These systems are found distanced from urban areas in less populated areas of western, central and north eastern Uganda. These holdings may or may not have other livestock, however, most also have crop fields with both annual and perennial crops to varying extents. Crops may be for subsistence or commercial purposes or both. Opportunities with regards to nutrient management include utilisation of crop residues as livestock feed and then returning the manure to the fields. All dung and urine deposits from the animals will be made on the farm meaning that if, for instance, they were to obtain feed from outside the farm such as concentrates or crop residues from neighbours they would get the full benefit from the manure. In addition, they have ownership over the land they use so they can improve it's nutrient status.

iii) Fenced grazing

This is a system where cattle are grazed on fenced land owned by the household. Fencing may be perimeter fencing only or perimeter with paddock fencing. These are often farms with large investment targeting dairy production. They tend to have improved pastures and may range from 2 – 10 ha in size. Cattle breeds kept are exotic and cross breeds with 1 - 20 and more heads of cattle. Many of the holdings tend to be located on the periphery of or within peri-urban areas targeting the milk market. Cattle are often supplemented with concentrates, fodder, crop residues or agro-industrial by products in addition to the grazing pastures. These systems are found in southwestern, central and southeastern Uganda (Mwebaze, 2000, Online: www.fao.org/ag/AGP/doc/Counprof/Uganda). These holdings may or may not have other livestock, however, most also have crop fields with both annual and perennial crops to varying extents. Some for instance in Mbarara tend to have banana plantations for commercial purposes. Others may have crops largely grown for subsistence purposes (Mugisha, 1998). Opportunities with regards to nutrient management are similar to those expressed for the free range grazing system.

(iv) Zero grazing

Within the zero-grazing system cattle are kept and fed in stalls. The stalls vary from permanent well built stalls with concrete floors to temporary stalls with grass thatched roofs and mud floors. Cattle kept in this system are exotic and cross breeds and few numbers are kept per household rarely exceeding 3 head. This is because this system is practiced in highly populated urban and peri-urban areas where land is largely limiting. It is a high input system targeted at maximizing milk yields for commercial purposes. Cattle are fed on chopped fodder, crop residues, concentrates and agro-industrial by-products. Opportunities with regards to nutrient management in this system include the ability of the farmer to collect all the manure from the livestock (Mwebaze, 2000, Online: www.fao.org/ag/AGP/doc/Counprof/Uganda; Twinamasiko, 2001). This offers the opportunity for proper storage, management and enrichment. In addition, it enables fair apportioning among crop fields and development of a systematic programme for its application.

Research to address constraints of dairy production systems have largely focussed on parasites, diseases, breeding and feeding. However, improved nutrient management enabling improved soil fertility is fundamental in improvement of feeding, breeding and disease resistance. Hence the need to address nutrient management aspects in dairy production

2.2 Nutrient Management in Dairy Production Systems in Uganda

Proper management of nutrients in a production system ensures the presence of nutrient resources for continued production. Dairy production systems incur large nutrient losses through harvests of crops and fodder and milk which occur on a daily basis. Such nutrient losses need to be countered by nutrient replacements. However, this is not always done leading to soil nutrient depletion. For instance soil samples collected from 24 farms in Masaka district 16 of which were dairy farms showed that 91.4, 60.3 and 53.4% of the samples were deficient in N, P and K respectively (Mubiru *et al.*, 2003). Nutrient management in dairy production largely depends on the management system used as this affects nutrient in and out flows and nutrient recycling. The management system in turn is closely related to the level of intensification of production along which the dairy production continuum is structured. These aspects within dairy farms have been addressed scantily and quantitative information available is minimal. Wortmann and Kaizzi (1998), showed negative N, P and K balances for elephant grass fields and similarly negative P and K balances for pastures but positive N balance. In previous studies (Fonteh *et al.*, 1998) dairy farmers when drawing resource flow maps for their farms included many crop-livestock interactions inferring efficient use of nutrient resources. These included, Bean haulms used in mulching banana plantations, crop residues such as sweet potato vines and banana peels fed to livestock and dung and urine used for improving soil fertility in banana plantations, maize, beans and other crops. These reports, however, do not indicate to what extent these practices are done nor the proportion of farmers who implement them. This leaves an information gap in relation to nutrient management in dairy production systems which must be addressed if dairy production is to be practiced in a sustainable manner. To do this there is a dire need to identify constraints within the dairy sector related with nutrient management.

2.2.1 Nutrient Management Constraints in Dairy Production Systems

Poor nutrient status on a farm will be expressed in various ways which will include primary and secondary symptoms. Primary symptoms will include poor crop growth and yields which may ignorantly be attributed to other factors such as diseases and pests, unfavourable climate and poor planting material. Secondary symptoms may include poor reproductive performance of livestock resulting from poor feeding of livestock which also may be attributed to poor breeds and diseases. Nutrient deficiencies within a production system, therefore, are difficult to identify particularly by farmers and hence may not feature often in diagnostic studies. However, farmers in Mbarara and Masaka identified soil degradation as one of the major causes of shortage of pastures during development of problem trees for major constraints (Livestock Systems Research Programme (LSRP), unpublished). This merits the need for studies to address this constraint which cannot be isolated from the dairy production systems with their inbuilt intensification continuum created by the transformation described in Section 2.1.1.

2.2.2 Nutrient Management and the Dairy Production Intensification Continuum

Information on nutrient management in relation with the dairy production intensification in Uganda is lacking. This is because the thrust of nutrient management studies has targeted crops and pastures are remotely perceived as crops. However, where crop-livestock systems have been included in detail nutrient management studies such as in Europe, nutrient status has been assessed and nutrient balances are used to monitor nutrient deficits and surpluses (De Haan *et al.*, 1996). An understanding of existing and potential synergies in the crop-livestock systems creates a knowledge resource that can be utilised in management of the nutrients within the systems. This enables development of methods to control undesirable conditions and avert land degradation or nutrient toxicity. Therefore there is need to study nutrient management aspects in dairy systems in Uganda to enable understanding of nutrient management and assess nutrient stock in the light of dairy production transformations.

There exists different opportunities for nutrient management at different points of the intensification continuum. The intensive zero grazing system may obtain influx of nutrients through importation of feeds into the farm. These feeds include crop residues, fodder, agro-industrial by-products and concentrates. The semi-intensive systems may import nutrients into the farm through channels similar to those for the zero-grazing system as well as grazing in communal lands. The extensive systems may import nutrients through grazing in communal lands. Where on-farm grazing is involved the animals tend to put back some of the nutrient removed through grazing by dropping some of manure back to the pastures during grazing. These dynamics and others need to be studied and understood and harnessed as well as include others to improve nutrient management.

Such studies need initial assessment of nutrient status along the dairy intensification continuum which could be done through soil analysis or calculation of nutrient balances. However, the latter method is more appropriate because unlike soil analysis it is not influenced by circumstances beyond the farmers' control. Soil chemical composition is largely controlled by the parent rock.

2.2.3 Significance of Nutrient Balances

A nutrient balance of a production system, as indicated previously is the difference between the sums of nutrients inputs and nutrient outputs (Mohamed Saleem, 1998; Geurts *et al.*, 1999). Nutrient balances assessed on basis of countries, production systems or enterprises are useful sources of information that will give indications on whether there is nutrient mining or oversupply of certain nutrients in agro-ecosystems. They will therefore provide a guide to farmers, researchers and policy makers on issues related to nutrient management (Mutert, 1995). They provide information on the channels through which largest quantities of nutrients are entering and leaving a production unit. This information provides basis for devising interventions for nutrient management through increasing or reducing nutrient acquisition and nutrient losses depending on the prevailing nutrient status of the production unit. The information they provide therefore can be used to maintain and optimize productivity while remaining protective of the environment (Magdof *et al.*, 1997). Such nutrient management decisions are deemed to be more crucial for higher input, intensive systems of land use.

Nutrient balances may be positive, neutral or negative and they vary significantly between agricultural land uses (NLWRA, 2001). A neutral nutrient balance is considered a sustainable target provided nutrient losses are minimal. A consistent negative balance for a specific nutrient means the production system is progressively depleting the soil nutrient reserves. Such a system, however, may not always respond to nutrient additions particularly if the soils have a high level of natural fertility such that it exceeds the amount of nutrient removed regularly in harvested products (NLWRA, 2001). Negative balances for some nutrients may in turn affect the efficiency of use of other nutrients. For instance long term studies in Asia have shown that negative P and K balances, may reduce nitrogen use efficiency (Mutert, 1995). A positive nutrient balance is desirable until a certain extent to which the quantity of the nutrient in the system may become toxic. A highly positive nutrient balance therefore, may mean that nutrient efficiencies may be obtained by reducing levels of nutrient addition which in turn may limit off-site nutrient losses (NLWRA, 2001). However, this situation is rare in most countries of sub-Saharan Africa.

Different crops and crop mixtures will have different effects on balances of specific nutrients. Presence of legumes in a production system for instance will present large concentrations of nutrient losses in harvested seeds and pods in comparison to cereal grain crops. Increased frequency of crop legumes in rotations may enhance the decline in soil potassium and magnesium especially if yields are high (NLWRA, 2001).

2.2.4 Calculation of Nutrient Balances

Nutrient balances can be obtained through calculation of flows of different nutrients into and out of a production system. The difference of the nutrient inflows and the outflows is the nutrient balance. This can be done using known values of the different nutrients in the various materials, results from soil and plant chemical analyses and quantities of nutrients within materials already documented in literature. There are 2 major methods of calculating nutrient balances. Method 1 uses only those dynamics of the production system that occur above the ground (Stoorvogel and Smaling, 1990; Smaling *et al.*, 1993; Stoovogel *et al.*, 1993; Smaling *et al.*, 1996; De Jager *et al.*, 1998; Van den Bosch *et al.*, 1998). This takes into account the nutrient flows into and out of the unit of analysis. Method 2 includes both above the ground and soil nutrient dynamics (Shepherd and Soule, 1998). This in addition to the flows described under Method 1 will also include nutrient gains to and losses from the soil as a result of biological, chemical and physical activity. Method 1 is quite straight forward and simple to perceive but is nevertheless time consuming. The below ground component added in Method 2 makes the method quite complex and adds to the time requirement for the procedure. The method selected for use needs to fit the purpose for which the balances are being obtained. Method 1 is sufficient where the unit of production is being considered as a whole to assess the nutrient resource availability. Method 2 is most appropriate for use where aspects related with details of soil fertility are required. The purpose of this study is largely hinged on production system nutrient management and, therefore, Method 1 was selected for use. Method 1 can also be sub-divided into 2 approaches. Sub-method 1(a), calculates balances that only consider those flows that can be controlled by the farmers (partial balances) such as harvests and purchased inputs. Sub-method 1(b), uses both flows that the farmers can control and those over which they have little control. The latter include flows such as atmospheric deposition and leaching. In this study both Sub-methods 1(a) and 1(b) were used. Nutrient balances obtained from Sub-method 1(a) were used in identifying predictors of nutrient balances and options for improvement of nutrient management. Those from 1(b) were obtained to assess the proportion of the balance figure that the farmer had minimal control over.

Most critical nutrients in agricultural production systems are N, P and K. Nitrogen, P and K balances, for instance, would be computed as shown in Equations 1 – 3.

Equation 1: N balance = N In – N Out
Equation 2: P balance = P In – P Out
Equation 3: K balance = K In – K Out

Where: N In, P In and K In = Quantity of N, P and K entering the study unit, respectively;
N Out, P Out and K Out = Quantity of N, P and K leaving the study unit, respectively.

Nutrient inflows calculated include: organic fertilisers, imported food, feeds (concentrates), external fodder, biological nitrogen fixation, atmospheric deposition and sedimentation. Outflows include: exported farm produce, burning of crop residues, exported animal products, erosion, gaseous losses and leaching. The N, P and K within each of these movements will be quantified and included in the calculation for the nutrient balances.

Information related to inflows of mineral fertilisers, imported food, organic fertilisers and feeds obtained from outside the farm as well as outflows of crop and animal produce, crop residues and manure are extracted from data collected from the farm households. Amounts of N, P and K are calculated using the nutrient contents of the various materials. Inflows of atmospheric deposition and biological N fixation and outflows of leaching and gaseous losses are estimated using transfer functions.

Equations for estimation of atmospheric deposition, biological N fixation, leaching and gaseous losses are shown below:

Equation 4: $AD_N = 0.14p^{1/2}$

Equation 5: $AD_p = 0.023p^{1/2}$

Equation 6: $AD_K = 0.092p^{1/2}$

(Vlaming *et al.*, 2001)

Where: AD_N, AD_p and AD_k are the N, P and K input into the farm unit through wet and dry atmospheric deposition in kg $ha^{-1}yr^{-1}$ and p is the mean annual precipitation in mm yr^{-1}.

Equation 7: $NS_N = 2 + (p-1350) \times 0.005$

Where: NS_N is non-symbiotic N fixation

Equation 8: $L_N = (\text{soil N} + \text{Fertiliser N}) \times (2.1 \times 10^{-2} \times p + 3.9)$ [clay < 35%]

Equation 9: $L_N = (\text{soil N} + \text{Fertiliser N}) \times (1.4 \times 10^{-2} \times p + 0.71)$ [35% < clay < 55%]

Equation 10: $L_N = (\text{soil N} + \text{Fertiliser N}) \times (7.1 \times 10^{-2} \times p + 5.4)$ [clay > 55%]

Equation 11: $L_k = (\text{Exch.K} + \text{Fertiliser K}) \times (2.9 \times 10^{-4} \times p + 0.41)$ [clay < 35%]

Equation 12: $L_k = (\text{Exch.K} + \text{Fertiliser K}) \times (2.9 \times 10^{-4} \times p + 0.26)$ [35% < clay < 55%]

Equation 13: $L_k = (\text{Exch.K} + \text{Fertiliser K}) \times (2.9 \times 10^{-4} \times p + 0.11)$ [clay > 55%]

(Vlaming *et al.*, 2001)

Where: L_N and L_k are amount of N and K leached in kg ha^{-1} yr^{-1}, soil N is mineral soil N, and Exch. K is exchangeable K in Cmoles kg^{-1}.

Equation 14: $G_N = (\text{Soil N} + \text{Fertliser N}) \times (-9.4 + 0.13 \times \text{clay} + 0.01p)$
(Vlaming *et al.*, 2001)

Where: G_N is the quantity of N lost through gaseous losses in kg ha^{-1} yr^{-1} and clay the percentage of clay in the soil.

Leaching of P is assumed to be zero because it is immobile. Symbiotic nitrogen fixation is estimated as a percentage of the N uptake in the legume crop fields. This may be obtained through summing of the N in the harvested crop and N in the crop residues. It could also be calculated through the use of expected N quantities fixed by different crops in the given environment per ha covered with the legume (Wortmann and Kaizzi, 1998). Losses through burning are estimated by fractions of the residues burnt. In instances where animals are grazed off the farm periodically, estimation of the percentage of feed obtained from the grazing fields is estimated depending on the quantity of feed eaten when the animals return to the farm. In this case it is assumed that the daily feed intake meets the daily feed requirement of the animals.

Equation 15: Grazing DMI as a percentage of body weight = $\frac{120}{\%NDF}$

(Grant *et al.*, 1997)

Losses through erosion are often estimated using the "universal soil loss equation" (USLE) developed by Wischmeier and Smith, (1965) as applied by Nisar *et al.* (2000) shown in Equation 16.

Equation 16: $A = RKLSCP$

where: A is the average soil loss per unit of area (tons ha^{-1} $year^{-1}$), R is rainfall and run off erosivity (joules m^{-2}), K is erodibility (tons-sec m^{-2}), L is the slope length (m), S is the slope steepness (%), C represents the cover & management practices and P the supporting conservation practices. Area estimates from previous erosion studies such as presented by Lufafa *et al.* (2003) can also be used.

Some flows may be absent in some systems and some systems may have some additional flows. For instance sedimentation tends to occur in valley bottoms and will be irrelevant to include in other circumstances.

2.2.5 Nutrient Balance Studies and Related Improvement Strategies

Nutrient balance values can be presented at different levels of assessment depending on the purpose of the assessment. They can be presented for continents, regions, countries, farms, fields and crops. Henao and Baanante (1999) for instance reported negative nutrient balances for N, P and K for all African countries ranging from -14 to -136. Uganda was among the countries in East Africa with highest annual losses of N and K.

The largest unit this study is addressing is the farm level and hence focus will remain at the smaller units. Information on nutrient balances in dairy production systems in Uganda is very limited (ODI, 1999). Available information mainly focuses on crop production and even where livestock production is included, approaches used are in form of generalities. Walaga *et al.* (2000), for instance, undertook studies and estimated farm level nutrient balances in Kabarole and Pallisa districts of Uganda. Balances for N, P and K were -173.8, -60.8, and -41.3 kg ha^{-1}, respectively for Kabarole, and +2.3, +1.5 and 15 kg ha^{-1}, respectively for Pallisa district.

Assessment of nutrient balances in their study combined different types of farms with different enterprises within the districts. For instance, nutrient balances from farms with (i) crop production only, (ii) crop production and small ruminants, and (iii) crop production and cattle were assessed in one group. This approach could be improved by partitioning the data and assigning contributions for different components in the farm sample group. This study, however, briefly described some of the livestock management practices in the areas. In Pallisa. for instance, livestock were reportedly substantially dependent on crop residues and off-farm grazing. In Kabarole, cattle were mainly managed under the zero-grazing system. They were fed on *Pennisetum purpureum* (elephant grass) grown on the farms as well as feed resources obtained from off-farm. These additional feed resources included elephant grass, maize (*Zea mays)* stover, banana (*Musa spp.*) pseudostems and banana peels. The information from Pallisa refers to livestock in general which could include a number of species, while that for Kabarole refers to cattle without disaggregating into dairy and other categories. Such information gives an overview of nutrient status on farms within the districts. Again, details with regards to particular production systems cannot be inferred. Recommendations from such information will be broad and cannot be targeted at particular production systems.

Farmers in the study areas were already using some nutrient management methods some learnt through interaction with NGOs. These included traditional fallow followed by slash and burn, mixed cropping, crop rotation, manuring, traditional agro-forestry, grass bands, composting, terracing and green manuring (Walaga *et al.*, 2000).

Wortmann and Kaizzi, (1998) also conducted an assessment of nutrient balances for four districts in Uganda, namely, Pallisa, Kamuli and Iganga in the eastern region; and Mpigi in the central region. The study incorporated more detail than those in previous discussions because in this case nutrient balances were calculated for, commodities on the land referred to as "land use types" (LUT) and the farm unit. Data for Kamuli, Iganga and Mpigi districts were combined due to high similarity and the 3 districts were referred to as region 2 and Pallisa as region 1. The nutrient balances by LUTs included pasture and elephant grass bringing in an aspect of livestock production. The nutrient balances in terms of kg ha^{-1} $year^{-1}$ and kg $farm^{-1}$ $year^{-1}$ for pasture LUT were positive for N and negative for P and K. Nutrient balances for N, P and K for elephant grass LUT were negative. Table 1 presents the N, P and K balances of pasture and elephant grass in the 2 regions.

Table 1. Nitrogen, P and K balances for pasture and elephant grass "land use types" (LUTs) in Pallisa, Kamuli, Iganga and Mpigi districts in Uganda

Attribute	Nutrient	Region 1 (Pallisa district)	Region 2 (Kamuli, Iganga and Mpigi)
Nutrient balances for	N	19.2	-
Pasture LUT	P	-3.3	-
(kg ha^{-1} $year^{-1}$)	K	-30.7	-
Nutrient balances for	N	53.5	0.4
Pasture LUT	P	-11.6	-0.1
(kg $farm^{-1}$ $year^{-1}$)	K	-108.8	-1.3
Nutrient balances for	N	-	-4.4
elephant grass	P	-	-0.8
(kg $farm^{-1}$ $year^{-1}$)	K	-	-8.1

Source: Wortmann and Kaizzi (1998).

The results show that within these regions and under the prevailing circumstances, nutrient management for the pasture LUT is beneficial for N but not for P and K in both regions. Nutrient management for the elephant grass LUT is not beneficial for any of the nutrients. In this study, the dairy system was remotely considered. Here also, farm level assessment combined livestock and non-livestock farms in one group. Although data on different livestock on the farms and their numbers were obtained, there was no classification of farms based on livestock parameters. Consideration of LUTs of pastures and elephant grass was useful as an aspect related to livestock production. However, in many areas these are not the only livestock feed resources used and species occurring in pastures vary.

The study provides valuable information in relation to possible interventions for improvement of nutrient management and their expected effects on nutrient flows as well as crop yields in some instances. Interventions identified include soil erosion control measures which were estimated to make nutrient savings of 7.9, 2.7 and 14.5 kg ha^{-1} $year^{-1}$ of N, P and K respectively in Pallisa and 5.5, 1.4 and 7.2 kg ha^{-1} $year^{-1}$ of the same nutrients in Iganga. Application of soybean, bean and household wastes to bananas rather than burning them was estimated to add 25.5, 2.9 and 32.6 kg ha^{-1} $year^{-1}$ of N, P and K, respectively. It was also estimated to increase yield of bananas by 3000 kg ha^{-1} $year^{-1}$. Farmyard manure left unused was sufficient to add 22.6, 9.3 and 33.7 kg ha^{-1} $year^{-1}$ of N, P and K respectively. If this manure was added to maize sole or intercrops it was estimated to provide yield increase of 700 kg ha^{-1} in a season. Inoculation of soybean with bradyrhizobia strains was estimated to result in additional fixation of 35 kg ha^{-1} of N in a season. Application of 20 kg ha^{-1} of P to beans would increase yield by 350 kg ha^{-1} in a season and increase N fixation by 20 kg ha^{-1} also in a season. Application of 30 kg $ha^{-1}season^{-1}$ was estimated to increase yield of maize by 1000 kg $ha^{-1}season^{-1}$ in Pallisa, Kamuli and Mpigi. In Iganga, 10 kg ha^{-1} would be required in addition.

Short-term fallows of leguminous cover crops were estimated to add 40 kg N ha^{-1} $year^{-1}$ and reduce erosion losses by 10%. Use of legume cover crops in bananas would add approximately 25 kg N $ha^{-1}year^{-1}$ and reduce erosion losses by 16.5% (Wortmann and Kaizzi, 1998).

Esilaba *et al.* (2005) also studied aspects of nutrient balances in Mayuge district in eastern Uganda. This was done with farms classified by the farmers on basis of extent of use of nutrient management methods and wealth status. The balances were calculated from resource flow maps developed by the farmers with assistance of researchers. They particularly included an aspect of the livestock through calculation of "animal production system" balances. These were separated from the crop balances despite their co-existence on farms. The approach used focused more on making comparisons in nutrient balances between classes of farms using more and those using less nutrient management practices. Table 2 presents some of the findings. There were more negative balances in the long rains than in the short rains. However, the balances are not largely negative. The findings show that the animal production system balances in the area were marginal or zero since none or minimal nutrients entered or left the system. The approach used in the study was specifically tailored to addressing concerns of impact of soil fertility management on nutrient balances and, hence, these results cannot be used to address nutrient management issues in dairy production systems. Also, separate calculation of the "animal production systems" balances departs from the concept of crop-livestock interactions which is key in dairy production systems.

Table 2. Nitrogen, P and K balances for crop fields in good soil fertility managed and poor soil fertility managed farms in the long and short rain seasons in Mayuge district, eastern Uganda

Season	Good soil fertility managed farms			Poor soil fertility managed farms		
	N	P	K	N	P	K
Long Rains	-7.3	-1.3	-10.0	-4.0	-1.5	-8.5
Short rains	-0.6	-0.6	-4.3	-3.0	-0.5	-6.0

Source: Esilaba *et al.* (2005).

Recommendations for improvement of nutrient management are given generally and are not targeted to any of the farm classes in particular. Also, the recommendations lack quantities of use or expected effects. There is still, therefore, need to address nutrient management aspects of dairy production systems in particular as well as categorise dairy farms for more effective assessment and relevant targeting of recommendations. A number of practices have been evaluated in different environments and established as useful methods for improving nutrient status. Ability of the methods for improving nutrient status is mainly demonstrated by yield increase realised and improvement in crop product quality. The common methods are described in the following section.

2.2.6 Methods for Improving Nutrient Balances

(i) Farmyard manure

To improve nutrient balances in production systems in developing countries, local resources have to be used efficiently. Smallholder farmers can rely on manure from their animals to augment and sustain production (ILRI, 1997). Farmers could mitigate consequences of continuous cropping by effectively integrating livestock into intensive cropping systems as well as devise systems for rearing livestock that recycle nutrients effectively and economically efficiently. Ruminants collect, transport, convert and deposit nutrients and are, therefore, key in improving nutrient management in resource scarce farming systems. Up to 80% of the nitrogen and phosphorus consumed by livestock are excreted (Wells and Dougherty, 1997). Nitrogen is voided in both urine and faeces and phosphorus predominantly in faeces. The value of animal manures was shown in numerous studies (Murwira *et al.*, 1995; Reynolds and De Leeuw, 1995; Williams *et al.*, 1995; Madiagne *et al.*, 1999; Rufino *et al.*, 2006).

In long term-trials carried out in West Africa (Williams *et al.*, 1995) strategic combinations of manure with small quantities of NPK sustained steady increases in sorghum yield, which exceeded that obtained with use of NPK alone and where no input was used. After a period of 30 years, yield where manure was mixed with NPK was about 2500 kg ha^{-1}, where NPK was used alone was about 900 kg ha^{-1} and where no input was used was about 300 kg ha^{-1} (Williams *et al.*, 1995). Also exclusive use of inorganic fertilisers was seen to create dangers of reducing carbon levels and decreasing the cation exchange capacity of the soil. However, manure influenced these parameters positively. As a result of residual benefits of manure on soil fertility, applications do not have to be on every field every year. Application can be by rotation, for instance, rotating tethering sites of animals among fields. Utilisation of animal faeces in combination with urine also showed dramatic impacts on millet yields in Niger. The presence of urine also increased availability of phosphorus and this in turn raised soil pH. The residual effects significantly increased millet production upto 3 years after application (Williams *et al.*, 1995). In studies by Esilaba *et al.* (2002) on integrated nutrient management carried out in eastern Uganda, application of manure at a rate of 10 tonnes ha^{-1} fresh weight on maize in 6 sites, caused increase in yield in five of the sites ranging from 100 – 800 kg ha^{-1}. However, these increases were not significant.

(ii) Green Manure

Green manures and cover crops are useful for maintaining soil fertility, suppressing weeds, controlling soil erosion, improving soil moisture retention, providing appropriate preparatory strategy for zero tillage and controlling plant diseases and nematodes. Plants used as green manures or cover crops include *Lablab purpureus*, *Crotalaria mucronata*, *Tephrosia candida*. and *Stizolobium niveum* (white mucuna) and *Stizolobium atterrimum* (black mucuna) . These plants can be grown in mixtures with food crops. They can be grown in relays with other crops ie as in a crop rotation and they can be grown on wastelands or on fields under fallow. They can also be grown under fruit trees, forest trees and any other perennial crop particularly if shade tolerant species such as *Centrosema pubescens* are used. An additional advantage for the leguminous species is that they have the potential to fix N in the soil (Bunch, Online: www.green-seeds.com/green_manure.html). Use of *Canavalia sp.* and Lablab sp. as green manures in maize in eastern Uganda produced increases in yield of 160 and 43 kg ha^{-1} (Esilaba *et al.*, 2002).

(iii) Mulching

Mulching is the covering of the top soil with dry plant material which could be obtained from non-crop materials or from crop residues. This is useful in conserving soil moisture, increasing organic matter in the soil, reducing leaching and suppressing weeds. At Ikulwe District Farm Institute (DFI), in eastern Uganda, yield for a mulched banana plantation was 18,300 kg ha^{-1} fresh weight, higher than that from the unmulched plantation (Esilaba *et al.*, 2002).

(iv) Inorganic fertilisers

There is a wide variety of inorganic fertilisers that can be used to add nutrients to the soil. Most common fertilisers have N, P and K in combination or separately as these are the 3 most critical nutrients in crop production. Common inorganic fertilisers are NPK, urea, single super phosphate (SSP), triple super phosphate (TSP) and potassium chloride (European Fertilisers Manufacturers Association (EFMA), Online:www.powercrop.com/statistics.asp). They tend to be applied to soils depending on the crop planted or to be planted and the deficiencies identified in the soil through chemical analyses of soil samples. They are costly and not commonly used in sub-Saharan Africa, however numerous studies done in the region show increases of upto 50% in maize yields with application of nitrogen and phosphate fertilisers (Simpkins *et al.*, 1989; Tittonell *et al.*, 2007; Thorne *et al.*, 2002). Inorganic and organic fertilisers can be used in combination. Yield from inorganic fertiliser N in Nepal produced at least 25 – 30 kg increase in maize per kg of N applied when use was at low moderate rates (LEISA, 2002).

(v) Hedgerows

These consist of vegetation established along contours at intervals along slopes for controlling soil erosion. Different types of grass species as well as agro forestry shrubs are used for this purpose. These include vetiver grass, elephant grass and multi-purpose trees such as Calliandra. Hedgerows are also often planted in flat areas using multi-purpose trees species for purposes of leguminous N fixation (Oluka-Akileng *et al.*, 2000; Wambugu *et al.*, 2006). In the Kenya highlands, studies on use of Calliandra-elephant grass contour hedgerows for soil conservation was effective on both slopes with gradients of 20% and 40% (Angima *et al.*, 2002). The hedgerows conserved 15% more soil on the 20% than on the 40% slopes. Similarly, total biomass yield for livestock feed from the hedgerows was 33% higher from the 20% than 40% slopes (Angima *et al.*, 2002).

(vi) Agro-forestry

This involves establishment of trees with desirable characteristics in crop fields for soil fertility improvement, soil moisture enhancement and soil erosion control. Leguminous multi-purpose shrubs such as *Calliandra calythorsus* are commonly used for this purpose (Wambugu *et al.*, 2006). Alley cropping is one of the nutrient management strategy that involves agro forestry species. It is establishment of rows of trees or shrubs at intervals within a crop field. The trees serve as soil erosion barriers and nutrient retention enhancers through their influence on the supply and availability of nutrients in the soil through N fixation and retrieval of nutrients from below the rooting zone of crops. In addition, the trees reduce nutrient losses from soil through controlling erosion and leaching (Szott *et al.*, 1999; Oluka-Akileng *et al.*, 2000). Also, studies done in Rwanda (Niang *et al.*, 1998) reported improved crude protein (CP) levels of grasses when grown in association with leguminous shrubs. Crude protein in elephant grass grown with leguminous shrubs increased by 58% and by 20% in *Setaria sp.*.

(vii) Terracing

This is one of the methods used in hilly areas for controlling soil erosion by rain. There are different types of terraces in different parts of the world depending on the agricultural production systems, the government policies and available resources. In Kabale district in southwestern Uganda for instance forward sloping terraces have evolved as a result of elephant grass strips established at intervals across the slope. In India, forward-sloping terraces have been transformed into bench terraces to create a slight back slope allowing excess runoff to drain away. In the Limpopo province of South Africa, terraces have well constructed costly stone-faced walls. More than 60% of farmers interviewed in Africa and Asia indicated that terraces were effective at reducing soil erosion (Critchley and Brommer, 2003).

(viii) Grass strips

Rows of a selected grass specie are established at intervals in crop fields to control soil erosion. This method is sometimes combined with trenches in which case the grass row is established on one side of the trench. Elephant grass (*Pennisetum purpureum*) is often used for this purpose. In such a case the grass is also sometimes used for feeding ruminant livestock (Oluka-Akileng *et al.*, 2000).

(ix) Trash lines

Dry crop material, branches and twigs are heaped in rows at intervals in the crop fields. This serves mainly to control soil erosion. The dry plant materials used decompose over time and increase soil organic matter and hence also contribute towards soil fertility enhancement (IRRI, 1998).

(x) Trenches

These are deep furrows dug in gardens along contours to reduce the speed of runoff and control soil erosion. Elephant grass or multi-purpose leguminous trees are often established on the side of the trench on the lower end of the slope to increase the strength of the trench. The species used to stabilise the trenches are also often used for feeding livestock and may also have the ability to fix N in the soil (Oluka-Akileng *et al.*, 2000).

(xi) Compost making

Compost making is a process where all available organic waste from the farm and kitchen is collected and allowed to decompose before being applied to the crop fields. The collected materials are often decomposed in pits or in heaps and are turned in the process to allow uniform decomposition. Compost is a source of organic matter for the soil and improves soil physical properties in particular soil porosity, structure and water holding capacity (Misra *et al.*, 2003). Studies on use of compost in Burkina Faso showed 45% increase in sorghum grain yield (Ouedraogo *et al.*, 2001).

Use of nutrient management improvement methods would require continuous assessment of their effect on the production systems. This would infer regular evaluation through nutrient balance values. The results from such a study therefore, would be even more valuable if an assessment tool permitting repetition of nutrient balance calculations by less complex and rigorous means was produced. Such a tool could be used by a wider scope of stakeholders in decision-making. Such stakeholders would include farmers, extension advisors, policy makers and researchers. A set of predictors identified as key in influencing nutrient balances can be used to achieve this.

2.2.7 Indicators of Nutrient Management

Indicators of nutrient management are factors that can be used to give inference on the status of nutrient management of a production unit and are key in monitoring, decision making and policy development. Some useful models such as the NUTBAL (Online: http://cnrit.tamu.edu/aflews), NUTMON (Smaling *et al.*, 1996; De Jager *et al.*, 1998; Van den Bosch *et al.*, 1998; Vlaming *et al.*, 2001) and IMPACT (Herrero *et al.*, 2005) have been developed for calculating nutrient balances. However, they require rigorous data collection, creating the need for a simpler and faster tool that can be used to calculate nutrient balances to certain precision levels with less rigour.

Nkonya *et al.* (2005), identified socio-economic and bio-physical determinants of nutrient balances in maize farming systems in eastern Uganda. Bio-physical factors with significant ($p<0.05$) effects on N, P and K balances for individual land parcels on the farms were "tropical livestock units" (TLU) with a positive effect on all balances, "agricultural potential" with a positive effect on N and negative on P and K balances, "number of crops grown" with negative effect on N and K and positive effect on P balances and "farm size" with positive effect on N and negative on P and K balances. Effort made towards this result is commendable and provides a basis for related studies. However, although the study included aspects of livestock it was not particularly targeted at dairy production systems but rather at maize based production systems and no effort was made to classify farms. The strategy of including both socio-economic and bio-physical factors as determinants was novel, however, bio-physical factors are largely related with farm management practices. As a result, they will not only be used as predictors but may as well offer viable options for improvement of nutrient management and subsequently balances.

There is a need therefore to include more bio-physical factors in such analyses to develop a set of predictors which can be used to provide inference on balances and also be transformed into nutrient management improvement strategies. Such tools need to be used with a lot of caution and are more reliably used within the limits of the production systems that were used in their development.

2.3 SUMMARY

Dairy production in Uganda contributes significantly to the national economy and the nutrition of the population. The tendency towards intensification observed globally in dairy production also exists in Uganda. The intensification trend has presented a continuum of dairy production intensification yet the quality of nutrient management within the production systems along this continuum is not clear. This is a key aspect for concern if sustainability is to be ensured. Although the impact of this trend on nutrient availability in production systems may be known in some countries very little to this effect is known in Uganda. This creates the necessity to study the effect on nutrient balances of dairy production systems at different levels of intensification of production. This kind of study can borrow strategies from one system to improve another.

This approach requires first and foremost categorisation of the existing dairy production systems through a characterisation study. This would take into account various factors of production. As well as grazing and feeding management systems which are largely governed by the agro-ecological zones. Characterisation of production systems is vital in studies to address problems more specifically through targeting the issues of each category more precisely. Categories described in Section 2.1.2 of this thesis are rather broad, need updating and require quantification for some key factors. Studies on nutrient management in dairy production systems should be addressed within farm categories. The nutrient status of each system would then be assessed, strengths and weaknesses of the system identified and options for improvement developed.

Nutrient balances have been used effectively as a way of assessing the nutrient management of agricultural production systems and obtaining options of improvement. Examples of studies that have included use of nutrient balances have been discussed in Section 2.2.5 of this thesis. Nutrient balances directly related with aspects of dairy production have been addressed scantily leaving research gaps. Methods of calculating nutrient balances are complex and time consuming and can not be done whenever nutrient balances are required. This creates the necessity for developing tools for predicting nutrient balances with a given degree of precision rather simply and quickly for short duration tasks where the whole process of calculating the balances can not be undertaken. The identification of predictors of nutrient balances also allows identification of options for improving nutrient management.

The issues discussed in this chapter provide a background to the aspects to be addressed in the studies undertaken and described in the following chapters.

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 STUDY SITES

This study involved 3 districts, namely, Mbarara, Masaka and Jinja. The location of these districts in Uganda is shown in Map 1. The districts were selected as appropriate sites for the study based on information obtained from a report by MAAIF/ILRI (1996) in which major areas supplying milk to Kampala were mapped out and referred to as the "Kampala milk shed". The selection was also based on cattle numbers, agro-ecological zones and management practices. The 3 districts were viewed to be representative of the different scenarios within the milk shed. Masaka and Jinja had similar cattle management systems but with slightly better market opportunities observed in Jinja compared to Masaka. Relevant profiles of fair detail on the districts are presented in Sections 3.1.1 – 3.1.3.

3.1.1 Mbarara District

Mbarara district lies in south-western Uganda. It shares a border with Tanzania in the south, with Ntungamo and Bushenyi districts in the west, Kabarole district in the north and Masaka and Rakai districts in the east. The major cattle production systems in the district are commercial dairy, traditional dairy in transition, traditional dairy, traditional ranching, commercial ranching and zero-grazing (Okwenye, 1994; MAAIF/ILRI, 1996; Mugisha, 1998; Twinamasiko, 2001; Staal and Kaguongo, 2003). The size of the landholdings varies tremendously: within the urban areas, land holdings are 0.2 - 2 ha, while in the pastoral areas 13 –38 ha. In between these two categories, land sizes of holdings lie in the range of 0.8 - 8 ha (Okwenye, 1994; MAAIF/ILRI, 1996; Mugisha, 1998; Twinamasiko, 2001; Staal and Kaguongo, 2003).

Map 1. Map of Uganda showing the districts including Mbarara, Masaka and Jinja.
= Study Districts

Table 3 presents the differences between Mbarara, Masaka and Jinja districts with regards to cattle and human populations, area and number of sub-counties. In comparison to Masaka and Jinja, Mbarara has the largest cattle numbers and highest cattle density. Cattle production systems are largely extensive with most cattle being the long horned Ankole type. Most of the households in the district are involved in both crop and livestock production. The district also has the largest number of sub-counties and human population. A district map with the sub-counties is presented in Map 2. Both annual and perennial crops are grown with bananas and coffee covering the largest area. Different types of livestock are reared with cattle existing in the largest numbers. Twelve percent of the cattle population is exotic and cross breeds and the rest are indigenous breeds (Okwenye, 1994; MAAIF/ILRI, 1996; Mugisha, 1998; Twinamasiko, 2001; Staal and Kaguongo, 2003).

Mbarara generally has sandy loam soils of fair productivity. They are of low nutrient status with top soils being less acidic having a pH of about 6 (MNR, 1998). Fairly high rainfall of 1000 - 1250 mm and relief of 1140 - 1260 m.a.s.l (metres above seas level) (MNR, 1998), render these areas prone to substantial quantities of soil loss through erosion. Long fallow periods are recommended for this soil class to maintain productivity; however, this may not be done due to increasing population pressure.

Generally nutrient management is largely non-existent except in a few instances where manure is applied and agro-forestry is established. Trenches are used in some instances to control soil erosion (Livestock Systems Research Programme (LSRP), unpublished). Mulching is widely practiced particularly done under banana plantations (MNR, 1998).

Table 3. Human and cattle populations, district sizes, number of sub-counties in each district and sub-county average sizes for Mbarara, Masaka and Jinja districts

District	Area (km^2)	Cattle population (000)	Cattle population density (cattle km^{-2})	Human Population (000)	Human population density (people km^{-2})	Sub-counties	Sub-county size (km^2)
Mbarara	10154	607	60	931	92	34	299
Masaka	10611	528	50	839	79	16	663
Jinja	734	14	19	289	394	8	92

Source: Mugisha (1998).

3.1.2 Masaka District

Masaka district is in the southern part of Uganda, bordered by the districts of Mbarara in the west, Rakai in the south, Mpigi in the north-east, Mubende in the north and Lake Victoria in the south-east. The district has the lowest human population density in comparison to Mbarara and Jinja and the largest sub-county sizes (Table 3). A map of the district and its sub-counties is shown in Map 3. The main farming system is the "banana-coffee-livestock" system, with agro-pastoralism in some areas. Coffee is the major cash crop and bananas the staple food. However, alongside this there is intensive dairy cattle keeping in peri-urban areas and extensive communal grazing in the semi-arid areas of the district. Land holdings per household in peri-urban areas lie in the ranges of 0.2 - 2 ha and 0.4 - 100 ha in rural areas (Mugisha, 1998).

Poultry, among the livestock, constitute the largest number, followed by goats then cattle. Eleven percent of the cattle breeds in the district are exotic and cross dairy breeds (Livestock Systems Research Programme (LSRP), unpublished) the rest being local.

Parts of Masaka district, have soils associated with volcanic activity, pre-Cambrian rock and recent alluvials (MNR, 1998). They are high in humus and exchangeable bases and posses pH $\leq$ 6 (MNR, 1998) especially in the top soil. Other soils in the district are largely composed of the yellow loam and are of low nutrient status (MNR, 1998). More than 50% of soils in Masaka are deficient in N (Mubiru *et al.*, 2003). Like in Mbarara, nutrient management is insignificant except in high value cropping systems and some intensive cattle management systems (Livestock Systems Research Programme (LSRP), unpublished).

3.1.3 Jinja District

Jinja district (Map 4) borders with districts of Iganga in the east, Mukono in the south-west, Kamuli in the north and Lake Victoria in the south. Generally, it is the smallest of the 3 districts and has the lowest of all parameters presented in Table 3 except human population density which is the highest in comparison to Mbarara and Masaka (Mugisha, 1998).

Jinja is an agro-industrial district comprising of agricultural activities such as livestock, fishing, crop cultivation (mainly subsistence and large commercial sugar-farms and maize). Furthermore this was historically the most industrialised town in Uganda creating access to agro-industrial by-products by livestock keepers in the locality.

There is considerable land fragmentation due to population pressure. Land size ranges from 0.4–2 ha, with the majority of farmers owning 0.8 – 1.3 ha (Fonteh *et al.*, 1998). Most of the land is under crops with an approximate land allocation ratio of livestock to crops of 1:3. Major livestock reared are cattle, goats, sheep, pigs and poultry. Eighteen percent of cattle kept are exotic and cross breeds (Fonteh *et al.*, 1998).

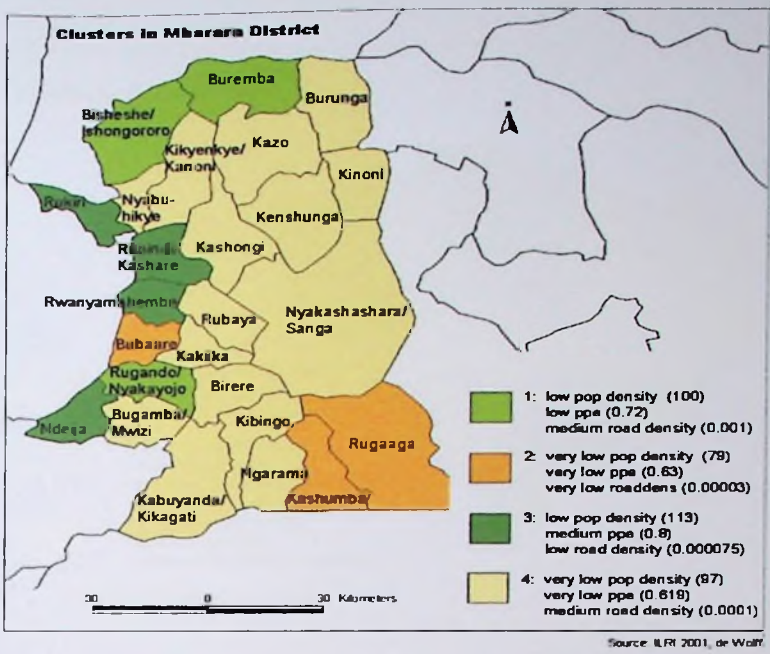
Soils in Jinja like those of Mbarara are sandy loams of fair productivity (MNR, 1994). Nutrient management methods are not widely practiced, however, a few households apply manure in banana plantations, maize, beans and other crops (Fonteh *et al.*, 1998).

3.2 SELECTION OF SUB-COUNTIES

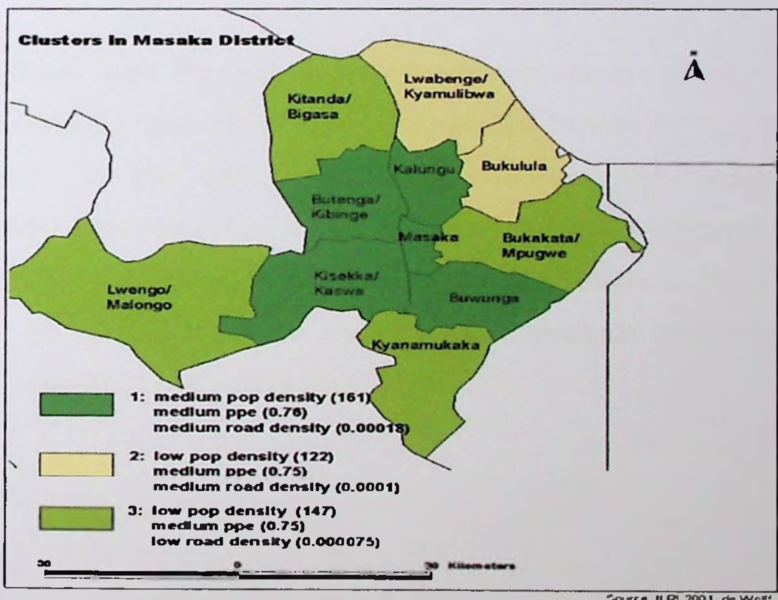
Reconnaissance visits were made to the three districts in order to select sub-counties for the study. During the visits, discussions were held with extension staff before a number of farms were visited to get acquainted with the prevailing circumstances in these areas. Information was obtained on the diversity of dairy production systems and their distribution. This information was used in combination with maps (Maps 2 – 4) developed using Geographic Information Systems (GIS) methodologies to select sub-counties within the districts.

A map for each district (Maps 2 - 4) representing human population density (people km^{-2}), density of road networks (km length of roads km^{-2}) and a climatic index, precipitation/potential evapotranspiration (PPE) were used in selection of sub-counties. These factors were selected due to their influence on patterns of agricultural activities. Human population density affects agricultural production patterns through effects on land, labour and markets. Road density inferences to markets which is key to agricultural production. The climatic index, PPE, provides indication of precipitation moisture retained for agricultural production (Luseno *et al.*, 2003).

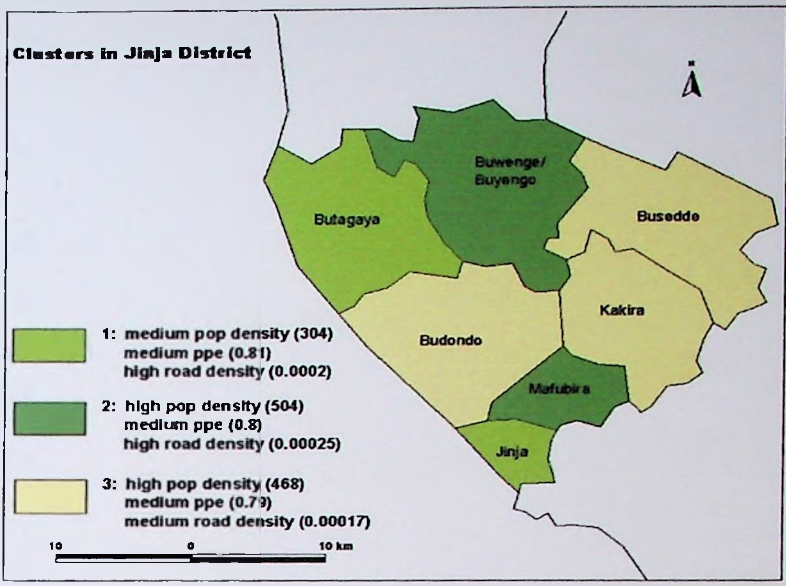
Sub-counties in each of the districts were grouped and allocated a colour shade depending on the combination of human population density, PPE and road density (Maps 2 – 4). This was done with the aim of selecting a sub-county from each group in a district to obtain representation of the wide range of conditions in each district. However, in Mbarara, it was not possible to select from groups 2 and 4 (Map 2) as these were largely pastoral areas. In Masaka, it was not possible to select from group 2 (Map 3) because the required sample size for cattle households in a sub-county could not be obtained in these areas. In Jinja, a sub-county was selected from each of the sub-county groups. Sub-counties selected were Bisheshe, Buremba and Rwanyamahemebe in Mbarara; Kalungu, Kyanamukaka and Kisekka in Masaka; and Budondo, Butagaya and Mafubira in Jinja.



Map 2. Map of Mbarara district showing sub-counties and their human population densities, PPE (precipitation/potential evapotranspiration) and road densities.



Map 3. Map of Masaka district showing sub-counties and their human population densities, PPE (precipitation/potential evapotranspiration) and road densities.



Map 4. Map of Jinja district showing sub-counties and their human population densities, PPE (precipitation/potential evapotranspiration) and road densities.

Two villages were then selected randomly from each sub-county using lists of parishes and villages obtained from sub-county headquarters. Within the selected sub-counties, villages that were small in size and population (particularly considering number of cattle owning households) were merged to create what were termed as 'villages' for the purpose of the survey. Villages that were selected are shown in Table 4, details of which are in Appendix 1. Chapters Four to Six present specific materials and methods and results addressing the different objectives outlined in Chapter One.

Table 4. Districts, sub-counties and villages where study farms were located

District	Sub-county	Village
Masaka	Kalungu	Mirembe Byaana
	Kisekka	Kyanangaazi Bunyere
	Kyanamukaka	Bukunda Katikamu & Nabitaka
Mbarara	Buremba	Kakoni Mushambya
	Bisheshe	Kakatsi Rwebikoona
	Rwanyamahembe	Nyakayojo A & B, Kakyerere &Rweishaka Rutooma I & V, Owengoma, Bugatsi
Jinja	Budondo	Buwairama Ibungu –West
	Mafubira	Musima Kayunga
	Butagaya	Kiwagama North & South Mpumwire Nawaguma B

CHAPTER FOUR

CHARACTERISATION OF DAIRY PRODUCTION IN UGANDA BASED ON LEVEL OF INTENSIFICATION

4.1 INTRODUCTION

Categorisation of production systems is vital in targeting research and development, and customising recommendations specifically for a particular production system. This is precautionary to development of generalised interventions which do not work for diverse production systems. Targeted recommendations tend to be realistic and are, therefore, likely to be more acceptable and adopted by end-users.

Categorisation of dairy production systems in Uganda has been done numerously in the past; however, each categorisation exercise is for different purposes (MAAIF/ILRI, 1996; Fonteh *et al.*, 1998; Kasirye, 2003). Most common among previous efforts is that, the categories developed bear characteristics that are non-quantitative (Fonteh *et al.*, 1998). Aspects of nutrient management, which are crucial, particularly in sub-Saharan African dairy systems, require targeting based on resources and managerial capacity. In light of this, it was found necessary to characterise the dairy production systems and on the basis of this delineate categories based on levels of dairy production intensification

Previous categorisation efforts have concluded that cattle production systems in Uganda form a continuum, with semi-nomadic pastoralism at one end and zero-grazing on the other (MAAIF/ILRI, 1996; Fonteh *et al.*, 1998; Kasirye, 2003). They categorised dairying into intensive, semi-intensive and extensive systems based on the level of capital investment and dairy cattle management (MAAIF/ILRI, 1996). Dairy production in Uganda has also been categorised into communal grazing, free range grazing, fenced grazing and zero grazing based on the size of the holding (Kasirye, 2003). More detailed characterisation within the smallholder dairy system aimed at targeting research, categorised it into urban, peri-urban and rural; and each of these was further sub-divided into 4 – 10 sub-categories based on grazing and feeding management, major limiting resource, sources of cash income and wealth assessment (Fonteh *et al.*, 1998).

Categorisation, therefore, can be done in many different ways to suit the purpose for which it is required. The purpose in this study was to categorise dairy production systems in order to target pertinent management for sustainable dairy production in Uganda, which hitherto has not been done.

4.2 MATERIALS AND METHODS

4.2.1 Selection of Study Households and Study Design

A cross-sectional survey was conducted in the study districts during 2002. The survey involved 300 households with 100 each from the districts of Mbarara, Masaka and Jinja. Seventy percent of these were cattle owning households, and 30% were households with no cattle, the latter were included for purposes of comparison. Thirty four households were selected from each sub-county drawn from 2 villages. The number of households from each village was allocated in proportion to the village population.

In each village, 2 transects were used for sampling. Village maps were developed together with key informants from the sub-counties; key sites were marked and 2 pairs of key sites were selected randomly. A sample of one of the maps drawn is shown in Appendix 2. All households along the most direct route between the paired sites were marked. Each of these households was visited and a record of their family name and whether they had cattle or not was taken. This information was later used in selecting the households for interview ensuring that the sample sizes required were obtained with the required numbers of cattle and non-cattle households.

Selection of farms along either side of the route was alternated at specific intervals to ensure that much of the 'route' was covered and with more less equal number of farms on either side of the route. The sampling interval along the routes depended on household density. Two and four households were skipped on either side of the transect in low household and high household concentration areas respectively. Each of the selected households was visited to agree on the interview schedule.

4.2.2 Study Instruments and Data Collection

A semi-structured questionnaire was developed and pre-tested in each of the three districts and, thereafter, appropriate adjustments were made to respond to unforeseen features and issues encountered during the pre-testing exercise. The questionnaire was administered in the 3 districts. Selected households were visited and interviewed, data were collected over a period of 3 months (May to July 2002).

The main data collected included information on the following: household composition, farm activities, labour and facilities, land tenure, size and details on land use, objectives for farming, constraints to production, soil fertility enhancement practices, pests and disease management, cattle management systems including feeding strategies, cattle herd changes in past year, milk production and marketing, use of extension services, credit and household farm and non-farm income and expenditure.

The Geographic Positioning System (GPS) location readings (waypoints) were also taken for each of the households. These data were downloaded into a computer package "MapSource" (Version 3.02, GARMIN, Copyright © 1999, GARMIN Corporation) and were later transferred and plotted using "Arch view" (ArcView GIS 3.2a, Copyright © 1992 – 2000, ESRI, Inc). The waypoints, consisting of values for the latitude, longitude and altitude, were used to generate data for each household on annual rainfall and population density.

4.2.3 Data Analysis

All the data from the characterisation survey were entered into "Microsoft Access" (Microsoft Access, 2002, Copyright Microsoft Corporation 1992 - 2001) and translated to Excel sheets before transfer to SPSS (SPSS 12.0 for windows, Release 12.0.0, 2003) for cluster analysis. A cluster analysis is a statistical tool used for grouping items with similar tendencies based on a set of variables. The K-means cluster analysis method was used on basis of the advantage of generating distances between cluster centres as well as distances between each case and the cluster centre. This provides interference on the intensity of relationship between the clusters and cohesion within the individual clusters. The analysis was done with no iterations and cases were excluded listwise rather than pairwise. Distances between the centres of different clusters and between cases and their cluster centres were obtained using the simple Euclidean distance procedure. The selection for the number of clusters to be generated was altered systematically by inputting different figures in turn and comparing the cohesion within each cluster for the different outputs. As such, the analysis producing the most cohesive clusters was selected as the most appropriate. On the other hand, cases in scarcely populated clusters with less than 15 members were considered outliers. Cluster analysis has also been used successfully in other studies, for characterising production systems (Hassan and Njoroge, 1996; Srairi and Lyoubi, 2003; Mburu *et al.*, 2007).

Characteristics used in the cluster analysis included the following: proximity to the main road, number of persons employed as permanent hired labourers on the farm, monthly household income, proportion of cattle herd comprising of improved breeds, rating of the farm in terms of intensification, total farm land, annual expenditure on artificial insemination (AI) and veterinary services per TLU (TLU = Total Livestock Units), cattle TLU ha^{-1} and monthly off-farm income. Monthly household income was represented by a class variable with 1 $\leq$ 10,000; 2 = 10,000 to 30,000; 3 = 30,000 to 60,000; 4 = 60,000 to 100,000; 5 = 100,000 to 200,000; 6 $\geq$ 200,000 (all values in Ushs). Intensification scores were assigned to farms based on the feeding management systems ranging from 0 – 10, with 0 being the least intensive in terms of cattle management system represented by the free range grazing systems and 10 being the most intensive represented by the exclusively zero-grazing management system. The scale for cattle

TLUs used was as follows: adult male = 1, adult female = 0.7, weaner = 0.5 and pre-weaner = 0.2 (ILRI, 1998). Analysis outputs included cluster means, analysis of variance information (ANOVA) for the cluster variables and distances between cluster centres.

4.3 RESULTS

4.3.1 Major Clusters Identified

The cluster analysis divided the data used into 16 different groups shown in Table 5. Clusters with very few members were ignored and such members were considered as outliers from the data set. These clusters with few members are, henceforth, excluded from the discussion. Clusters with prominent membership; 6, 8, 10 and 16, were considered as the major groups from which the dairy farm categories were to be developed.

Table 5. Number of Cases in each Cluster

Cluster	Number of cases
1	3
2	1
3	2
4	2
5	1
6	15
7	1
8	98
9	3
10	32
11	1
12	1
13	2
14	2
15	5
16	45
Total	214

A scatter diagram with the farms and their distances from their cluster means (Figure 1) shows that cluster 8 had the largest proportion of farms close to the cluster mean, while cluster 6 had a large proportion of farms relatively distanced from the cluster mean. Clusters 10 and 16, despite having large proportions of farms close to their cluster means, also had a few outlier farms which were located very far from the cluster means.

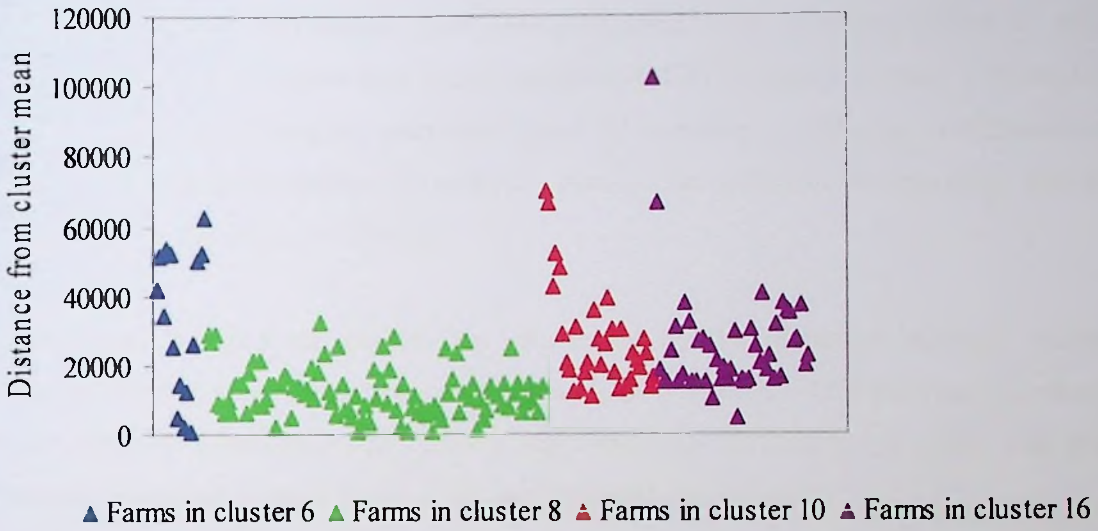


Figure 1. Distance of farms from the cluster means in clusters 6, 8, 10 and 16. (The distance between the x-axis and each point represents the distance between the cluster mean and the farm represented by the point).

Cluster means in Table 6 show that proportion of improved cattle breeds and annual expenditure on artificial insemination (AI) and veterinary services were highest in cluster 10 and lowest in cluster 8. Expenditure on AI and veterinary Services in cluster 10 was 5 times that in cluster 8. The intensification score was highest in cluster 10 and lowest in cluster 6. Farms in cluster 10 were closest to the main road and those in cluster 8 were the furthest. Cattle TLU ha^{-1} in cluster 16 was about twice as much as that on farms in cluster 10. Total land and use of long term labour were highest in cluster 6 and lowest in cluster 10 with total land in cluster 6 being over 5 times that in cluster 10. Monthly off-farm income and total monthly household income score were highest in cluster 6 and lowest in cluster 8.

Level of variation between cluster variables was obtained from the cluster ANOVA results which were summarised in the last column of Table 6 (significance column). Details of the ANOVA results are presented in Appendix 3. The highest variation between clusters was observed in the total household and off-farm income, proportion of improved cattle breeds on the farm and annual expenditure on AI and veterinary services. The least variation was observed for the variable indicating proximity to the main road.

Although significant differences have been presented in these results (Table 6), according to SPSS, significant differences in a cluster analysis ANOVA should be used with caution as they are only meant for descriptive purposes rather than testing hypotheses of differences between means. This is because during the analysis, clusters are allocated to maximize the differences among cases in the different clusters.

Relationships between the clusters are illustrated by the distances between cluster centres shown in Table 7. Most related cluster pairs were 8 - 10 and 8 – 16 which had the shortest inter-cluster distance. Most un-related cluster pairs were 6 - 10 and 6 - 8 which had inter-cluster distances more than 3 times those of the most related cluster pairs.

Table 6. Cluster means for variables used in the cluster analysis

Variables	Major clusters				Significance Level
	6	8	10	16	
Proportion of improved breeds in cattle herd	0.37 (0.12)	0.21 (0.04)	0.63 (0.08)	0.22 (0.06)	***
Expenditure on AI and vet services (Ushs TLU^{-1} $year^{-1}$)	16,086 (4,003)	13,252 (1,125)	71,368 (4,379)	20,641 (2,952)	***
Intensification score	1.80 (0.65)	2.64 (0.27)	4.75 (0.57)	3.49 (0.42)	**
Proximity to the main road (Km)	1.19 (0.55)	1.78 (0.29)	1.03 (0.23)	1.57 (0.40)	NS
Cattle TLU ha^{-1}	1.51 (0.17)	1.85 (0.30)	1.01 (0.18)	2.45 (0.20)	NS
Total farm land (ha)	11.69 (5.8)	5.08 (0.76)	2.08 (0.33)	3.04 (0.72)	NS
Long term hired labour (No. of persons)	1.60 (0.34)	1.05 (0.12)	0.50 (0.16)	1.36 (0.19)	**
Off-farm income (Ushs $month^{-1}$)	200,667 (9,384)	5,846 (880)	11,078 (3,375)	65,111 (3,391)	***
Household income (Class)	5.40 (0.24)	2.48 (0.15)	3.03 (0.27)	3.96 (0.18)	***

± = the 4 major clusters derived from Table 5; Cattle TLUs: Adult male = 1, Adult female = 0.7, Weaners = 0.5, Pre-weaners = 0.2; Intensification score was assigned to farms based on the feeding management systems ranging from 0 – 10; *** = P<0.001; ** = P<0.05; NS = Not Significant; numbers in parenthesis are standard errors.

1), cluster 16 with cattle tethered (Plate 2), cluster 6 with fenced farms (Plate 3) and cluster 10 with semi-intensive (Plate 4) and zero grazing (Plate 5) farms. Farms at the interface between zero grazing and fenced management systems, which were mainly placed in the zero grazing group were regrouped in another separate group namely semi-intensive.

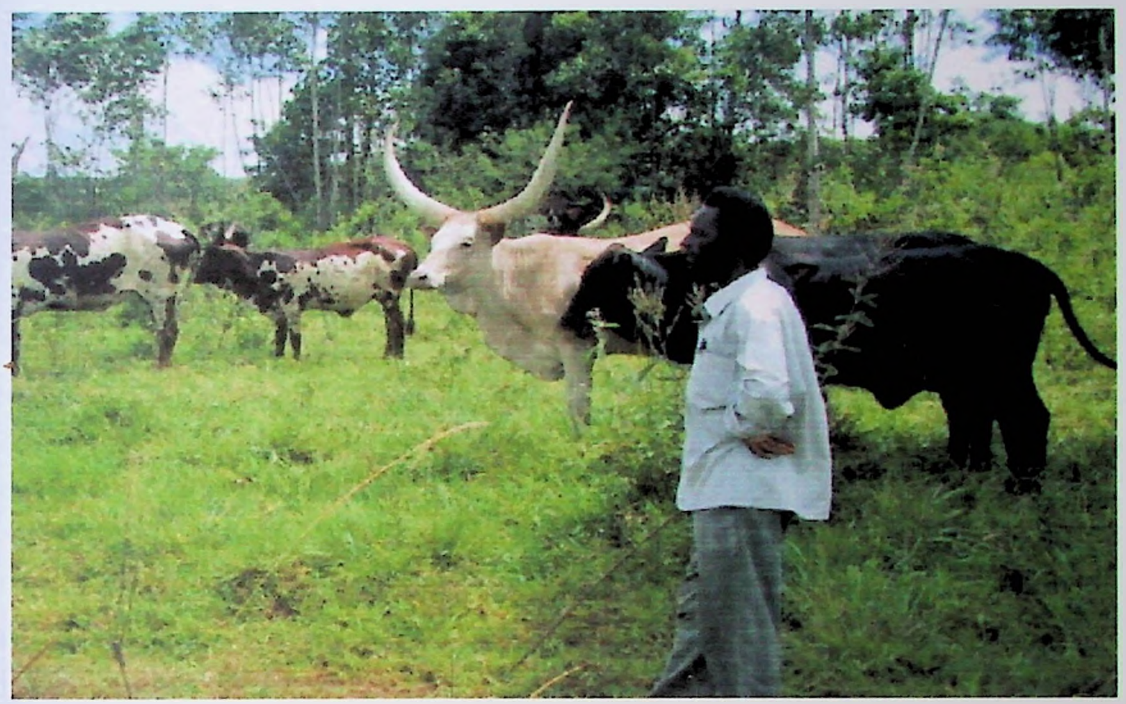


Plate 1. Setting in the Herding (HD) category. Long horned Ankole cattle and Ankole-Zebu crosses grazing on open pastures.

Plate 2. Setting in the Tethering (TE) category. The rope around the neck is a typical feature of the tethering system in Uganda.

Plate 3. Setting in the Fenced (FE) category. Notice the paddock fencing line in the background.

Plate 4. Setting in the Semi-intensive (SI) category.

Plate 5. Setting in the Zero grazing (ZG) category.

CHAPTER FIVE

EFFECT OF DAIRY INTENSIFICATION AND CROP PATTERNS ON NUTRIENT FLOWS AND BALANCES AND INDICATORS OF N, P AND K BALANCES IN DAIRY SYSTEMS IN UGANDA

5.1 INTRODUCTION

Nutrient inputs versus outputs have been used to address nutrient management concerns in different types of production systems in previous studies (De Haan *et al.*, 1996; Baijukya and De Steenhuijsen, 1998; De Jager *et al.*, 1998; Wortmann and Kaizzi, 1998; Halberg, 1999; Esilaba *et al.*, 2005). Studies of nutrient flows, their quantities and nutrient balances within the dairy farm categories identified in the previous chapter, was deemed as a strategic approach to assessment of levels of nutrient management within dairy production systems in the country. This is so because quantities of nutrient inputs and outputs from farms largely depend on the cattle management system. For instance, quantities of nutrient inflows into a Zero grazing (ZG) farm where cattle feed is mainly sourced from neighbours, markets and restaurants will be much higher than a farm in the Fenced (FE) category where cattle graze exclusively on farm pastures. The assessment of nutrient balances would then expose the strengths and weaknesses in nutrient management within the different farm categories.

Nutrient management within the different farm categories is also influenced by the cropping activities present on the farms (Baijukya and De Steenhuijsen, 1998; Wortmann and Kaizzi, 1998). These activities, therefore, should also be included in the nutrient balance assessments. Crop fields within all the farm categories tend to have crop mixtures rather than pure crop stands. The differences in the crops agronomy and purposes for which the different crops are grown are likely to influence nutrient flow quantities and balances on the farms. For instance, tomatoes, citrus fruits and banana are known to remove large quantities of K from the soil (Imas, 1999), while leafy vegetables remove large quantities of N (Wortmann and Kaizzi, 1998). Purposes for which specific crops are grown influence nutrient flows through management. Banana, for instance, tends to be mulched more than any other crop in Uganda (Karugaba and Kimaru, 1999). Farmers also tend to put manure on crops that fetch substantial income. These tendencies affect nutrient balances and as such, a systematic study of the effect of dairy intensification on nutrient management requires that in addition to the livestock component, the crops and crop mixtures associated with the farm categories be identified and their nutrient dynamics analysed. The crop mixtures unique to a farm category will to an extent provide inference on the nutrient balances for that farm category.

The nutrient balances and flows within the dairy farm categories, together with crop patterns create a set of information that can be used in identifying systems beneficial in proper nutrient management of dairy production systems. To achieve this, classification of the dairy production systems has to be followed by classification of the crop activities therein. Knowledge of the quantities of the nutrient inputs and outputs for the different crop patterns would enable computation of their nutrient balances which are useful in assessment of nutrient management within farm categories where the crop patterns are dominant.

Computations for nutrient balances can be done at different levels of production ranging from global, regional, national, farming system, farm, crop field, crop and livestock unit (Stoorvogel and Smaling, 1990; Smaling *et al.*, 1993; Stoorvogel *et al.*, 1993; Smaling *et al.*, 1996; Baijukya and De Steenhuijsen, 1998; De Jager *et al.*, 1998; Shepherd and Soule, 1998; Van den Bosch *et al.*, 1998; Wortmann and Kaizzi, 1998; Bekunda and Manzi, 2003; Esilaba *et al.*, 2005; Nkonya *et al.*, 2005).

The value of nutrient balances as means of evaluation of quality of nutrient management is better realised under farmer conditions with simpler methods for assessment. Simple indicators of nutrient balances would be ideal for this purpose. Currently, processes for computation of nutrient balances require comprehensive studies. Previous studies to establish indicators of N, P and K balances in Uganda have been done (Nkonya *et al.*, 2005). These, however, were addressed to maize-based farming systems. In the current study, indicators of N, P and K balances were identified at Patch level and they are particularly targeted at dairy production systems.

The major purpose of this study, therefore, was to (i) evaluate the effect of dairy Farm Categories and Crop Patterns on major plant nutrient balances; and (ii) identify indicators of N, P and K balances for use in smallholder level nutrient management assessment and as a mechanism for identifying entry points for intervention and subsequent contribution to sustainable productivity of dairy systems.

5.2 MATERIALS AND METHODS

The procedure to address the major objective of this study involved a longitudinal survey. This involved collection of the same type of data over a prolonged period in this case seasons. This was done to enable capture of events on the farms during different periods of the growing season. These data reveal the changes that occur on farms in the factors of interest across the seasons. This was done to enable tracking of quantities of nutrient related materials leaving and entering the farms and the land throughout the season.

5.2.1 Selection of Farm Households

Nineteen out of the 300 farms in the characterisation survey (Chapter 4) were selected for the longitudinal survey. This was done strategically to obtain representation from each of the Farm Categories identified in Chapter 4. To this effect, all the farms in the characterisation survey were allocated to each of the farm categories, HD, TE, FE, SI or ZG. This was first done in SPSS 12.0 for Windows (2003) using the automatic allocation function in the cluster analysis options. The SI category, included in the list above, was obtained from ZG category for all farms using a mixture of stall feeding and on-farm grazing. All farms where cattle were exclusively stall fed were retained in the ZG category.

The major characteristics used in the cluster analysis (Table 6) were considered when selecting farms for the longitudinal survey. Farms with values for these major characteristics close to the cluster means were selected for that survey. This was done to ensure the highest degree of homogeneity possible among factors of interest in the farm category. However, it was difficult to get this homogeneity maintained for all the characteristics. Although 19 farms were required for the survey, 40 potential farms were selected. Each of the potential farms was visited to check for conformity with major Category characteristics, as such, the most appropriate farms were selected. Larger numbers of farms were selected from farm categories with large variability in characteristics. Such categories included TE, FE and SI. Hence, 5 farms were selected in the SI category, 4 farms each in the TE and FE categories, and three each in the HD and ZG categories. Names of household heads and locations for the selected households are presented in Appendix 4. The farm categories were considered the treatments and data for each season from the farms within a category were considered replicates.

5.2.2 Longitudinal Data Collection

Two sets of coded data collection schemes were developed, namely, (i) the "Production data scheme" (Appendix 5a and b) and (ii) the "Inventory data scheme". The Production data scheme was used to collect all data related with the farm activities carried out in a season. The Inventory data scheme was used to collect information on available resources on the farm at the beginning of each season and their quantities.

(i) Data collected by the Production Data Scheme

Data collected by the Production Data Schemes included aspects of milk production, consumption and sale, other livestock products; mainly eggs and manure, and their utilisation channels. Data were collected on grazing aspects including both on- and off-farm grazing, types of pastures, herd combinations and lengths of time spent grazing. Data collected also included livestock feeds, particularly the cut and carry types, and their sources (on- or off-farm sources). In addition, data were collected on harvests, inputs to the land Patches, including mulch, manure, compost and inorganic fertilizers. These data were collected on a fortnightly basis with the data for milk, feeds and grazing being daily records and that on other livestock products, inputs to the land and harvests depended on the farmers narration of occurrences in the past 2 weeks prior to the date of data collection.

Milk data were included because milk consumption and sale provides channels of nutrient outflows from the livestock unit and the Farm with the exception of the portion going to the calves. Similarly, other livestock products and their utilisation were included in the data to account for nutrient outputs from the farm through these products. However, manure moved to the crop fields was not considered a Farm output but an input to the Land.

Grazing aspects were included in the data because of their contribution towards quantities of nutrients taken up by the animals and the proportions deposited as manure. These data enabled calculation of nutrients moving from the Land to the livestock and nutrients being brought to the Farm from off-farm grazing. Livestock feeds data were critical in establishing quantities of fodder harvested from the garden and related nutrient movements as well as quantities of nutrients in the resulting manure. The data were also important in obtaining the quantities of nutrients that were imported into the Farm through off-farm feeds and the quantities deposited on the Farms as manure.

Inputs to the Land such as mulch, manure, compost or inorganic fertilizers are direct addition of nutrients and hence, the significance for their quantification. It was also useful to obtain information on the source of the inputs because those obtained from off-farm were considered nutrient inputs to both the Farm and the Land. However, inputs to the Land from on-farm livestock e.g. manure, were considered inputs to the Land only. Similarly, inputs from one Patch of the Land to another were considered nutrient inputs into the destination Patch and outputs from the source Patch.

Harvest data included food products and residues of which proportions consumed by the household or livestock, sold, given away or transferred to other Patches on the Land were quantified. Nutrients in harvests consumed, sold and given away were considered outputs from the Farm and the Land. Nutrients in harvests fed to livestock were considered outputs only from Land. but still present on the Farm. Nutrients transferred to other Patches on the Farm were considered outputs from the source Patch and inputs into the destination Patch. However, all forms of planting material were not considered inputs whether to the Farm or Land because nutrient resources in these are simply recycled within the system.

(ii) The Inventory Data Scheme

Information was on household characteristics and facilities, land tenure, land use and land sizes and all farm livestock at the beginning of each growing season using this scheme. This was done to keep track of changes in Farm, Plot and Patch sizes, crops grown, herd sizes and structures and household sizes. Data on changes in land sizes across seasons was important for scaling harvests, inputs and nutrient balances to unit area. Record of crops grown was crucial for computation of the nutrients leaving the Land at harvest. Herd sizes and structures were key to estimating quantities of pastures removed in grazing and estimating manure produced. Cattle weights for all cattle on the farms were obtained using heart girth measurements, which were taken using appropriate tapes. Cattle weights were important in estimating grazing feed intake from pastures. Household sizes were also necessary for making inference on labour availability and food consumption.

Codes to assist entry of data both into the schemes and the database were developed. The codes included all possible options expected to be present on the study farms with regards to each issue addressed. The options for entry were, therefore, allocated numbers i.e. 1, 2, 3 to the last option. In the case of data reported in quantities such as milk produced in a day and harvests obtained from a Patch, actual numbers for these quantities were recorded.

Weights were required for certain data such as harvests and feeds offered to livestock and here data were recorded in terms of the farmer's own measurement. This measurement was then ascertained using a weighing scale. Such measurements were done for bunches of bananas, bundles of elephant grass, sacks of beans and livestock fed crop residues including sacks of banana peels.

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The schemes were pre-tested in the three study districts in areas other than those of the survey (Chapter 4) but with similar farming systems. Pre-testing was done on three farms in each district after which codes omitted from the code lists were included.

Each of the farms selected for the longitudinal survey was visited and farm maps were sketched. This was done by measuring and sketching the Plots within the Farm and the Patches in the Plots (Appendix 6). The sketches were used for calculation of the areas of each Plot and Patch for estimation of balances based on unit areas. Proportion of land cover for each crop in the Patches was also estimated to provide a basis for classification of the different crop mixtures and, hence, enable comparison of nutrient management between different crop patterns. Mapping of Farms and recording of crops in Patches and their proportions was repeated at the beginning of each growing season. This was done to monitor changes in Plot and Patch sizes as well as crop combinations.

Administration of the data schemes involved visiting of each of the study farms fortnightly to fill the Production Data Scheme, for a period of 3 growing seasons (May 2003 – August 2004). All members of the household familiar with the farming activities would contribute towards the required data; however, this was often done by the household heads and spouses of male household heads. At the beginning of each season, the Inventory Data Scheme was also filled in for each study farm. These were filled in thrice for each farm throughout the study period.

Soil samples were also obtained from each Plot using an auger with samples taken from 2 depths; the top layer of 0-15 cm and sub-soil layer of 15–30 cm. These were analysed according to routine procedures as described by Okalebo *et al.* (2003). Analysis was done to provide pH, N, P, K, OM and texture of the soils. Soil characteristics were required for inclusion in transfer functions (Chapter 2, Section 2.2.4) for calculation of quantities of N, P and K movements in leaching and gaseous losses. Soil data were also required for assessment of soils N, P and K in relation to the critical N, P and K levels for agricultural production. These were used in providing inference on nutrients that were most depleted in the soils.

Laboratory analysis was done on milk and manure samples using the NIRS method (Lyons and Stuth, 1992) to establish the N, P and K contents. Analysis was specifically done for these because they are key products in dairy systems. These were used in obtaining quantities of N, P and K in flows in the study involving milk and manure.

Data on annual rainfall for each of the three districts were obtained from the Meteorological Department (Ministry of Environment) database. These were used in transfer functions to calculate atmospheric deposition, non-symbiotic N fixation, leaching and gaseous losses.

Data collected were entered in "Microsoft Access" and cleaned before transfer to MS Excel and then to SPSS 12.0 for Windows (2003) and "GenStat" (for Windows Discovery Edition) for statistical analysis. Data cleaning involved identification of entries that seemed incorrect and cross checking them with information in the data schemes. In some cases, unclear data had to be checked with the farm households during later visits. Necessary revisions were made in the database when clarity on incorrect data was obtained.

5.2.3 Classification of Crop Patterns

The purpose of classifying the crop patterns has been discussed in Section 5.1 of this thesis. This was done based on the proportion of each crop in each Patch. "StatTransfer 6" (Stat/Transfer, Copyright 1986 – 2001, Circles Systems, Inc.) was used for this purpose because of its unique functions. This was done by first arranging the Patch crop data for all the seasons in 3 columns with the Patch identification number, crop and crop proportion. This means that each Patch had data in as many rows as the number of crops that were recorded. The data were then sorted by Patch identification and crop proportion to enable ranking of the crops in each Patch in order of land cover.

The columns with the crop and the proportion were merged to show both the crop and its proportion side by side in a single cell. The data were subsequently transposed and data for each Patch were placed in a single row with 2 columns. The first column had the Patch identification while, the second column had all the crops in the Patch with their proportions ranked from the highest to the lowest in a single cell. The data were sorted basing on the column with the crops enabling patches with the same dominant crop to be grouped together. Names for crop patterns were then allocated depending on the dominant crops, their proportions and the number of crops in the Patch, e.g., a Patch covered with banana (*Musa spp*) 40% Fruit tree crops 25%, Coffee (*Coffea spp.*) 20%, Lablab (*Lablab purpureus*) 5%, Yam (*Dioscorea spp.*) 5% was placed in "Intercropped Banana" and one with bean (*Phaseolus vulgaris*) 90%, maize (*Zea mays*) 40% and banana 10% was placed in "Beans-Maize" crop pattern.

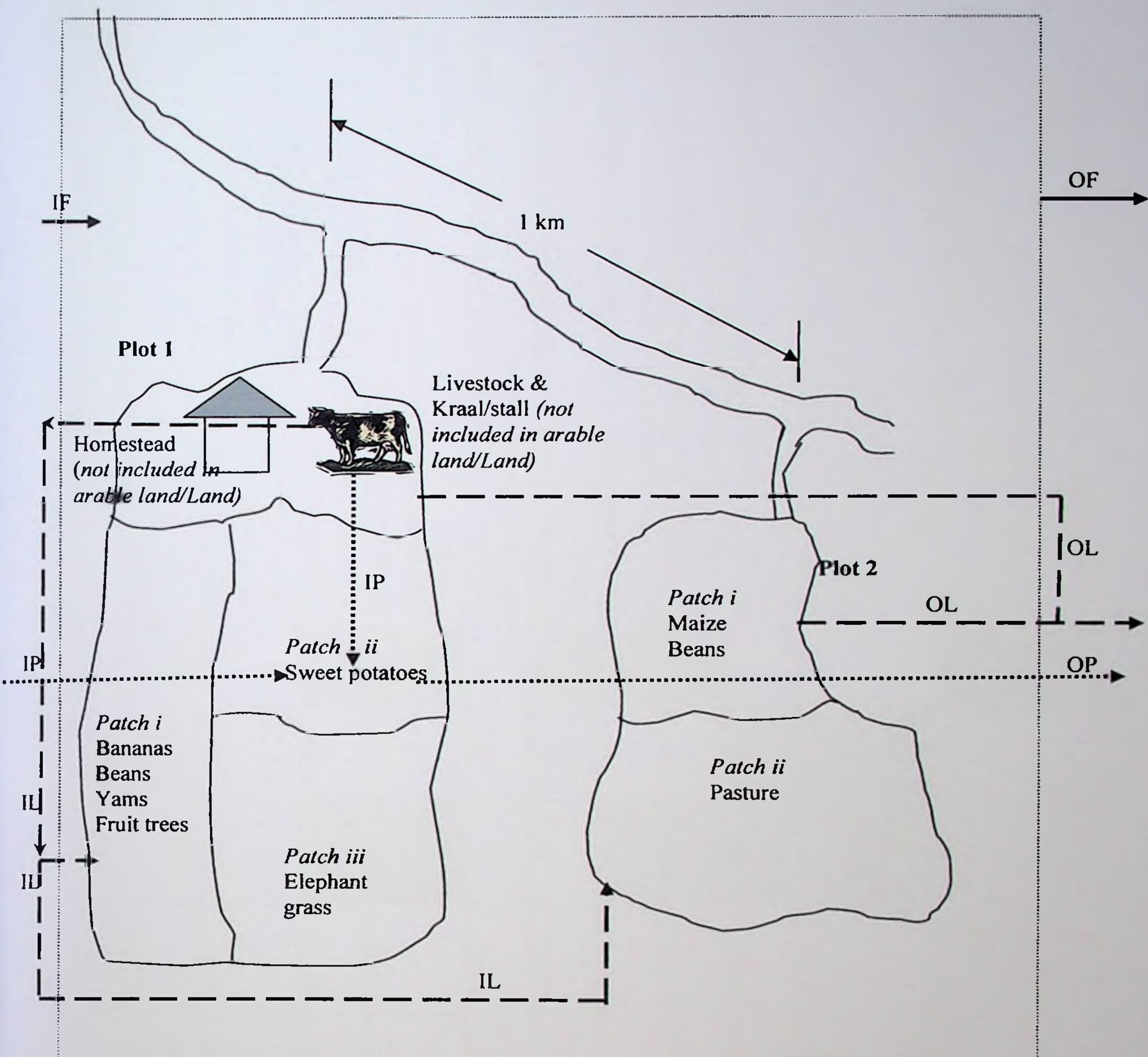
5.2.4 Calculation of N, P and K Balances and N Stocks

Farm, Land and Patch N, P and K balances were calculated by establishing the quantities of N, P and K in the inflows and outflows, and obtaining their differences. First, concentrations of N, P and K for all materials included in the data as inputs or outputs and their dry matter proportions (%DM) were obtained from available literature and from laboratory analyses (Appendix 7). Calculation of N, P and K quantities involved in the different flows namely, harvest, patch inputs, livestock feeds, grazing and milk, was done by first establishing the quantities of the flows in fresh weight. The fresh weight quantities were then transformed to dry matter using the DM proportions and the N, P and K quantities in the different materials were calculated using the N, P and K concentrations.

Farm balances were calculated by obtaining the difference between total quantities of N, P and K in the inflows to the Farms and total quantities of N, P and K in the outflows from the Farms (Figure 2). Similarly, Land balances were calculated by obtaining the difference between total quantities of N, P and K in the inflows to and outflows from the Land. Patch balances were calculated by obtaining the difference between total quantities of N, P and K involved in the inflows to and outflows from each patch.

Flows whose quantities were derived directly from the data; harvest, patch inputs, livestock feeds, grazing and milk, have been referred to as the "farmer controlled" (FC) flows since the farmer can make choices that would be certain to control them to a large extent. Other flows were estimated from already established transfer functions (Vlaming *et al*., 2001) and these included soil erosion, deposition, gaseous losses and non-symbiotic N fixation. These, in this study, have been termed as the "uncontrolled" (UC) flows because their control is largely determined by environmental forces (Vlaming *et al*., 2001). Biological N fixation (BNF), although often presented as an uncontrolled flows was considered among the farmer controlled flows because this can be controlled on the farm to a large extent through choice by including or excluding legumes from Crop Patterns.

The different flows calculated and used in estimation of N, P and K balances as well as their symbols are shown in the following sections and described further in Table 8. An illustration of the flows is also shown in Figure 3.



IF = Nutrient inflows to the Farm; OF = Nutrient outflows from the Farm; IL = Nutrient inflows to the Land; OL = Nutrient outflows from the Land; IP = Nutrient inflows to a Patch; OP = Nutrient outflows from a Patch. Farm Balance = IF – OF; Land Balance = IL – OL; Patch Balance = IP – OP

Figure 2. Hypothetical representation of a Farm to demonstrate Farm, Land and Patch/crop pattern balances.

Table 8. Definitions of nutrient inflows and outflows used in calculation of N, P and K balances for Farms, Land and Patches within the HD, TE, FE, SI and ZG farm categories

Flows (kg DM of N, P and K)	Flow code	Type of flow	In/Out flow			Definition
			Land	Patch	Farm	
Outflows from Farm in harvests	H1	EXT/FC	Out	Out	Out	Nutrients that have left the Farm in harvests that have been consumed by the households, sold and given away. Does not include the harvests consumed by the livestock. These are outflows at Land and Patch levels.
Transfers to other Patches on the same Plot	H3	INT/FC		Out		Nutrients that are moved from one Patch to another Patch on the same Plot/Parcel within the same Farm. These are outflows from the Patch.
Transfers to other Patches on different Plots	H4	INT/FC		Out		Nutrients that are moved from one Patch in a Plot/Parcel to another Patch in another Plot/Parcel within the same Farm at harvest mainly crop residues. These are outflows from the Patch.
Applications from off-farm	P1	EXT/FC	In	In	In	Nutrients applied to the Land from off-farm sources which are mainly mulches. These are inflows at Land, Patch and Farm levels.
Applications from own livestock through manure	P2	INT/FC	In	In		Nutrients applied to the Patches through manure from farm livestock. These are inflows at Land, and Patch levels.
Applications from other Patches on the same Plot	P3	INT/FC		In		Nutrients that are brought into a Patch from another Patch in the same Plot/Parcel within the same Farm. These are inflows to the Patch only.
Applications from other Patches on different Plots	P4	INT/FC		In		Nutrients brought into a Patch from another Patch in another Plot/Parcel within the same Farm mainly crop residues. These are inflows to the Patch.
Inflows to livestock from off-farm feed	F11	EXT/FC			In	Nutrients obtained by the livestock from off-farm feeds excluding the quantities excreted. These are inflows to the Farm.
Inflows to farm through manure deposits from off-farm feeds	F12	EXT/FC			In	Nutrients obtained on the Farm through off-farm feeds in terms of manure and urine deposits. These are inflows at the Farm level. Cannot be used as inflows at Patch and Land level because at this point it is not clear exactly which Plot/Parcel and Patch they end up until application is done.
Feed transfers from on-farm to livestock	F4	INT/FC	Out	Out		Nutrients transferred from on-farm feeds obtained from the Land and Patches to livestock mainly fodder and crop residues. These are outflows from the Land and Patches. This excludes the portion deposited as manure and urine.
Manure deposits in kraals from on-farm feeds	F5	INT/FC	Out	Out		Nutrients deposited in manure and urine from on-farm feeds. These remain on the Farm but are considered outflows from Patches and Land. Cannot be used as inflows at patch and

Flows (kg DM of N, P and K)	Flow code	Type of flow	In/Out flow			Definition
			Land	Patch	Farm	
						land level because at this point it is not clear exactly which plot and patch they end up until the y are applied.
Losses from manure deposits in kraals from on-farm feeds	F6	EXT/FC			Out	Nutrients lost from feaces and urine deposited on-the Farm originating from on-farm feeds. These nutrients are lost through volatalisation, leaching and erosion. They are losses at Farm level.
Inflows to farm from off-farm grazing through manure deposits	G12	EXT/FC			In	Nutrients obtained on the Farm from off-farm grazing in terms of manure and urine deposits. These are inflows at Farm level. Cannot be used as inflows at Patch and Land levels because at this point it is not clear exactly which plot and patch they end up until they are applied.
Transfers from patch to livestock from on-farm grazing	G21	INT/FC	Out	Out		Nutrients transferred to the livestock from the Land; Plots/Parcels and Patches through grazing. These are outflows at Land and Patch levels.
Inflows to livestock from off-farm grazing	G11	EXT/FC			In	Nutrients obtained by the livestock from off-farm grazing excluding the quantities excreted. These are inflows at Farm level.
Manure deposits in kraals from on-farm grazing	G22	INT/FC	Out	Out		Nutrients deposited in manure and urine from on-farm grazing. These remain on the Farm but are considered outflows from the Land and Patches. Cannot be used as inflows at patch and land level because at this point it is not clear exactly which Plot/Parcel and Patch they end up until they are applied.
Losses from manure deposits in kraals from on-farm grazing	G3	EXT/FC			Out	Nutrients lost from faeces and urine deposited in the kraals originating from on-farm grazing. These losses occur through volatalisation, leaching and erosion. They are losses at Farm level.
Losses from manure deposits in farm grazing paddocks (only applies for N)	G4	EXT/UC	Out	Out	Out	These are N gaseous losses that occur specifically from faeces and urine deposited in the farm paddocks during the grazing period. These are losses from the Farm. Land and Patches with grazing pastures.
Outflows through milk sales and consumption	M1	EXT/FC			Out	Nutrients leaving the farm in milk through milk consumed by the household, sold and given away. Does not include milk given to calves because this remains accessible on the farm. These are outflows from the Farm.
Leguminous N fixation (kg sn $^{-1}$)	NF	EXT/FC	In	In	In	Quantities of N assumed to be fixed in the soil from atmosphere by rhizobia inhabiting roots of legumes. Inflow to Farm, Land and Patch.
Atmospheric deposition (kg sn $^{-1}$)	AD	EXT/UC	In	In	In	Nutrient inflows into the soil through rain and dew which they acquire from the atmosphere as they drop to the ground. Also includes nutrient inflows through dust. Inflow to Farm,

Flows (kg DM of N, P and K)	Flow code	Type of flow	In/Out flow			Definition
			Land	Patch	Farm	
						Land and Patch.
Leached (kg sn $^{-1}$)	L	EXT/UC	Out	Out	Out	Nutrient lost from the soil through movement to lower depths of the soil profile where they cannot be accessed by plant roots. This mainly applies for N and K but does not apply for P because it is immobile. Loss from Farm, Land and Patch.
Gaseous losses (kg sn $^{-1}$)	GS	EXT/UC	Out	Out	Out	Nitrogen lost from farm materials and soil through denitrification and volatalisation. Loss from Farm, Land and Patch.
Non-symbiotic N fixation (kg sn $^{-1}$)	NS	EXT/UC	In	In	In	Nitrogen fixed in the soil from the atmosphere by free living, non-photosynthetic, aerobic and non-aerobic bacteria. Inflow to Farm, Land and Patch.
Erosion (kg sn $^{-1}$)	E	EXT/UC	Out	Out	Out	Nutrient losses from the soil through removal of top soil particularly from slopes through running water and wind. Loss from Farm, Land and Patch.

Flow codes: Codes used to refer to the respective flows within the thesis; IN: Inflows, Out: Outflows; N, P and K losses from the manure are deducted in the cases of F12, G12 and P2; INT: Internal flow[1]; EXT: External flow[2]; FC: Farmer controlled flow[3]; UC: Uncontrolled flow[4].

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[1] = Internal flow: Flow limited within the Farm with nutrients moving between farm entities (intra-farm flows)
[2] = External flow: Flow moving materials into or out of the Farm
[3] = Farmer controlled flow: Flows that the farmers have substantial control over through their activities
[4] = Uncontrolled flow: Flows that farmer have limited control over and are mainly controlled by environmental forces

(i) ***Flows included in calculation of balances***

(a) Harvest flows (H) (Figure 3)

- N, P and K outflows from the farm (includes quantities sold, consumed and given away) – H1
- N, P and K transfers to other patches on the same plot – H3
- N, P and K transfers to other patches on different plots –H4

(b) Patch input flows (P) (Figure 3)

- N, P and K applications from off-farm – P1
- N, P and K applications from own livestock through manure – P2
- N, P and K applications from other patches on the same plot – P3
- N, P and K applications from other patches on different plots – P4

(c) Feed flows (F) (Figure 3)

- N, P and K obtained from off-farm sources – F1
    - N, P, K inflows to livestock from off-farm feed – F11
    - N, P and K inflows to farm through manure deposits from off-farm feeds (less anticipated N, P and K losses) – F12
- 2. N, P and K feed transfers from on-farm to livestock – F4
- 3. N, P and K in manure deposits in kraals from on-farm feeds – F5
- N, P and K losses from manure deposits in the kraal from on-farm feeds – F6

To obtain the proportion of N, P and K excreted by the livestock, estimates were obtained for percentages of N, P and K ingested that is excreted in manure and urine. It was assumed that 75%, 80% and 85% of ingested N, P and K respectively is excreted (Wells and Dougherty, 1997). This was used in the feed and grazing flows.

(d) Grazing flows (G) (Figure 3)

- N, P and K obtained from off-farm grazing – G1
  - N, P and K inflows to livestock from off-farm grazing – G11
  - N, P and K inflows to farm from off-farm grazing through manure deposits (less anticipated N, P and K losses) – G12
- N, P and K obtained from on-farm grazing – G2
  - N, P and K transfers from patch to livestock from on-farm grazing – G21
  - N, P and K in manure deposits in kraals from on-farm grazing – G22
- N, P and K losses from manure deposits in the kraal from on-farm grazing – G3
- N losses from manure deposits in farm grazing paddocks (only applies for N) – G4

To estimate daily dry matter feed intake (DMI) during grazing cattle liveweight (which was obtained from the heart girth measurements taken) and percent Neutral Detergent Fibre (%NDF – should be used as a percentage value and not converted to a fraction) of the pasture were used in the method adopted from Grant *et al.* (1997) and described in Equation 15, Section 2.2.4 of this thesis.

It was also assumed that grazing animals often only manage to obtain approximately two thirds of the expected DMI (Wortmann and Kaizzi, 1998). Calculation of N, P and K deposited in manure and urine was done as previously in the feeds calculations. It was assumed that for off-farm grazing 50% of the manure and urine deposits were made during grazing off-farm and 50% made on the farm (Wortmann and Kaizzi, 1998).

(e) Milk flows (M) (Figure 3)

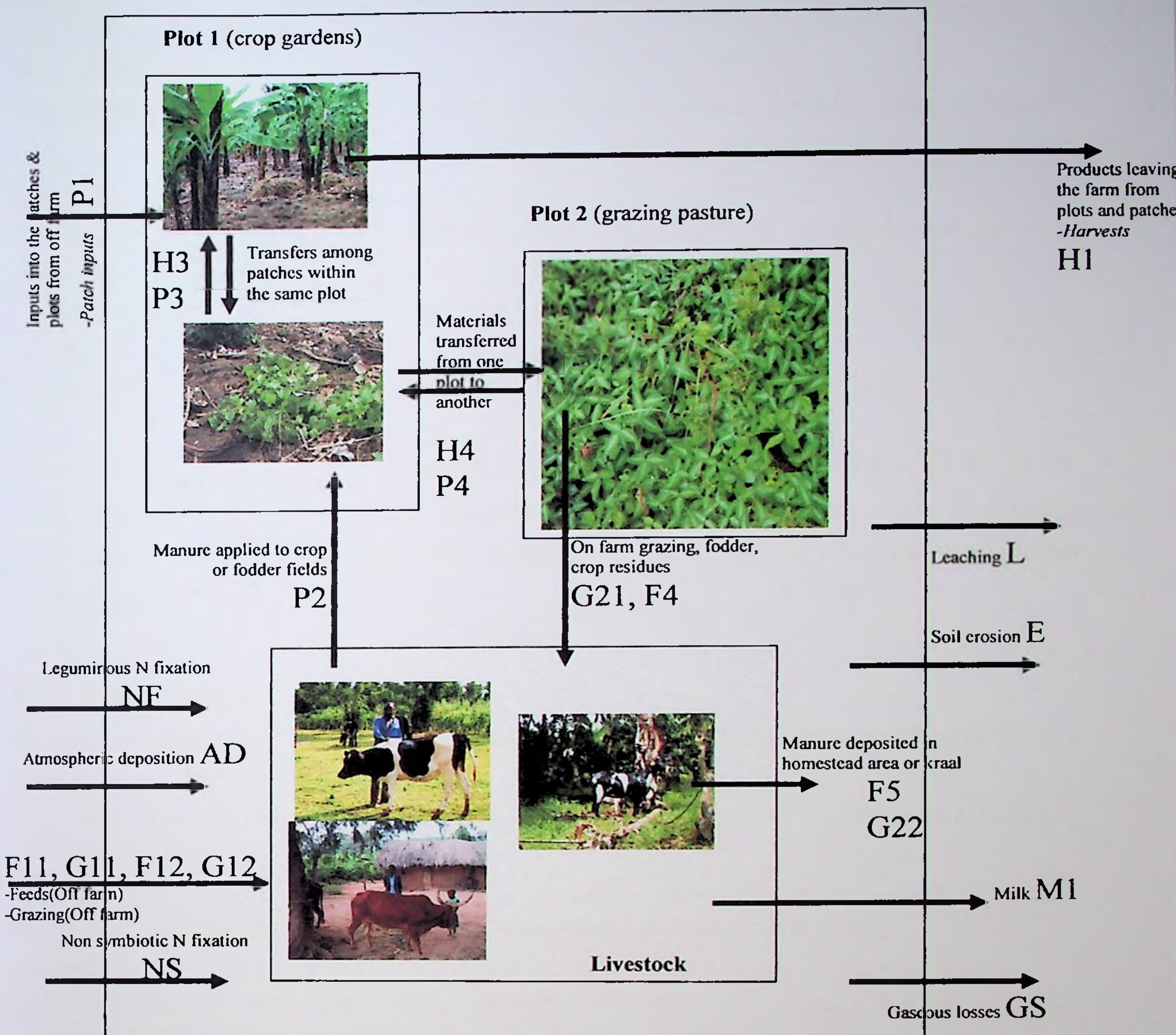
- N, P and K outflows through milk sales and consumption – M1

(f) Uncontrolled flows

These flows were quantified using established transfer functions and were not derived directly from the data collected in the longitudinal survey. Equations for estimation of atmospheric deposition, BNF, leaching and gaseous losses used were adopted from Vlaming *et al.* (2001). Biological N fixation (BNF) was estimated using the total acreage covered by legumes and their mixtures. Legumes in pure stand were assumed to fix 30 kg N ha^{-1} $season^{-1}$, legumes in crop mixtures 10 kg N ha^{-1} $season^{-1}$ and in grass/legume pasture mixtures approximately 25 kg N ha^{-1} $season^{-1}$ (Abaidoo *et al.*, 2001).

Estimation of losses through soil erosion was done using values adopted from predictions by Lufafa *et al.* (2003) assessed in areas within the Lake Victoria basin catchment using a GIS-based Universal Soil Loss Model. All Plots on each Farm were grouped as summits, back slopes or valley bottoms. All the Plots were grouped among those with over 60% crop cover. Soil erosion losses for the summits, back slopes and valley bottoms were estimated at 15, 39.5 and 0 tons ha^{-1} yr^{-1}, respectively.

Seeds and planting materials such as banana stems, sweet potato vines and banana suckers were not considered as nutrient inputs because their nutrient reserves are used in supporting growing plants. Nutrients in food purchases by the households were also not included in the calculations.



AD = Atmospheric deposition (kg sn $^{-1}$); E = Erosion (kg sn $^{-1}$); F11 = Inflows to livestock from off-farm feed; F12 = Inflows to farm through manure deposits from off-farm feeds; F4 = Feed transfers from on-farm to livestock; F5 = Manure deposits in kraals from on-farm feeds; F6 = Losses from manure deposits in kraals from on-farm feeds; G11 = Inflows to livestock from off-farm grazing; G12 = Inflows to farm from off-farm grazing through manure deposits; G21 = Transfers from patch to livestock from on-farm grazing ; G22 = Manure deposits in kraals from on-farm grazing; G3 = Losses from manure deposits in kraals from on-farm grazing; G4 = Losses from manure deposits in farm grazing paddocks (only applies for N); GS = Gaseous losses (kg sn $^{-1}$); H1 = Outflows from Farm in harvests; H3 = Transfers to other Patches on the same Plot; H4 = Transfers to other Patches on different Plots; L = Leached (kg sn $^{-1}$); M1 = Outflows through milk sales and consumption; NF = Leguminous N fixation (kg sn $^{-1}$); NS = Non-symbiotic N fixation (kg sn $^{-1}$); P1 = Applications from off-farm; P2 = Applications from own livestock through manure; P3 = Applications from other Patches on the same Plot; P4 = Applications from other Patches on different Plots

Figure 3. Representation of a farm and the nutrients flows in and out of the Farm, Plots, Patches and the livestock component.

(ii) Balance computations

(a) Farm balances

Farm balance (kg ha^{-1} season^{-1}) = Nutrient inputs into the Farm – Nutrient outputs from the Farm

Equation 17:

$$\mathrm{FB_N} = [\mathrm{P1_N} + \mathrm{F11_N} + \mathrm{F12_N} + \mathrm{G11_N} + \mathrm{G12_N} + \mathrm{NF} + AD_N + NS] - [\mathrm{H1_N} + \mathrm{F6_N} + \mathrm{G3_N} + \mathrm{G4_N} + \mathrm{M1_N} + E_N + L_N + GS]$$

Equation 18:

$$\mathrm{FB_P} = [\mathrm{P1_P} + \mathrm{F11_P} + \mathrm{F12_P} + \mathrm{G11_P} + \mathrm{G12_P} + \mathrm{NF} + AD_P] - [\mathrm{H1_P} + \mathrm{F6_P} + \mathrm{G3_P} + \mathrm{M1_P} + E_P]$$

Equation 19:

$$\mathrm{FB_K} = [\mathrm{P1_K} + \mathrm{F11_K} + \mathrm{F12_K} + \mathrm{G11_K} + \mathrm{G12_K} + \mathrm{NF} + AD_K] - [\mathrm{H1_K} + \mathrm{F6_K} + \mathrm{G3_K} + \mathrm{M1_K} + E_K + L_K]$$

Where: $\mathrm{FB_N}$, $\mathrm{FB_P}$ and $\mathrm{FB_K}$ are N, P and K farm balances, respectively. See 5.2.3 (c) for the meaning of the other codes. Codes denoted by a subscript N, P and K refer to nitrogen, phosphorus and potassium flows, respectively. Codes in italics are the uncontrolled flows.

(b) Patch balances

Patch balance (kg ha^{-1} season^{-1}) = Nutrient inputs into a Patch – Nutrient outputs from a Patch

Equation 20:

$$\mathrm{PAB_N} = [\mathrm{P1_N} + \mathrm{P2_N} + \mathrm{P3_N} + \mathrm{P4_N} + \mathrm{NF} + AD_N + NS] - [\mathrm{H1_N} + \mathrm{H3_N} + \mathrm{H4_N} + \mathrm{F4_N} + \mathrm{F5_N} + \mathrm{G21_N} + \mathrm{G22_N} + \mathrm{G4} + E_N + L_N + GS]$$

Equation 21:

$$\mathrm{PAB_P} = [\mathrm{P1_P} + \mathrm{P2_P} + \mathrm{P3_P} + \mathrm{P4_P} + AD_P] - [\mathrm{H1_P} + \mathrm{H3_P} + \mathrm{H4_P} + \mathrm{F4_P} + \mathrm{F5_P} + \mathrm{G21_P} + \mathrm{G22_P} + E_P]$$

Equation 22:

$$\mathrm{PAB_K} = [\mathrm{P1_K} + \mathrm{P2_K} + \mathrm{P3_K} + \mathrm{P4_K} + AD_K] - [\mathrm{H1_K} + \mathrm{H3_K} + \mathrm{H4_K} + \mathrm{F4_K} + \mathrm{F5_K} + \mathrm{G21_K} + \mathrm{G22_K} + E_K + L_K]$$

Where: $\mathrm{PAB_N}$, $\mathrm{PAB_P}$ and $\mathrm{PAB_K}$ are N, P and K patch balances, respectively.

(c) Land balances

Land balances (kg ha^{-1} $season^{-1}$) = Nutrient inputs into the total farm arable land (Land)– Nutrient outputs from the total farm arable land (Land)

Equation 23:

$$LB_N = [P1_N + P2_N + NF + AD_N + NS] - [H1_N + F4_N + F5_N + G21_N + G4_N + G22_N + L_N + GS + E_N)]$$

Equation 24:

$$LB_P = [P1_P + P2_P + AD_P] - [H1_P + F4_P + F5_P + G21_P + G4_P + G22_P + E_P)]$$

Equation 25:

$$LB_K = [P1_K + P2_K + AD_K] - [H1_K + F4_K + F5_K + G21_K + G4_K + G22_K + L_K + E_K)]$$

Where: LB_N, LB_P and LB_K are N, P and K land balances, respectively.

(d) Nitrogen (N) Stocks

Nitrogen stocks were derived from the concentrations of N in the soil deterimined by techniques described in Section 5.2.2 (ii). The concentration values were multiplied by the top soil (0 – 20 cm) a hectare approximated as 2 million kg. Mineral N was presumed to be negligible (Geurts *et al.*, 1999). Assuming constant seasonal Land N balances, years to total depletion of N stocks were calculated for each of the dairy Farm Categories with negative Land N balances (Walaga *et al.*, 2000). Nitrogen being the nutrient required in largest quantities by plants, priority focus for assessment of stocks was on the same.

(iii) Statistical analysis

Nutrient balance computations were done in MS Excel and the outputs were fed into "GenStat" (for Windows Discovery Edition). Analysis was done to compare quantities of N, P and K inflows, outflows and balances between HD, TE, FE, SI and ZG farm categories. Two sets of balances were used, these were, the balances obtained from the farmer controlled (FC) flows alone and those from the farmer controlled and uncontrolled (UC) flows combined.

Comparison of means was done in "GenStat" using the Least Significance Difference (LSD) multivariate comparison of main effects at a probability level of 5%. This was done to compare quantities of N, P and K involved in the different types of inflows and outflows between farm categories and between flow types within the farm categories. In this case, the quantities of N, P and K were considered the dependent variables and the flow types the fixed factors. Similar analysis was also done to compare quantities of N, P and K balances between the different farm categories. The balances were considered the dependent variables and the farm categories the fixed factors.

To obtain indicators of N, P and K, Linear Mixed Models analysis in "GenStat" was used with patch N, P and K balances (using only FC balances) each treated separately as the response variates (dependent variables) and the factors influencing the balances as the "fixed model". The "Farm" and the "Plot" within the Farm were included as the "random model" to eliminate any variation that could be resulting from them. The variables included in the fixed model were done so manually, one by one and those that showed no significant influence (significance level = 0.1) were eliminated from the model. This process was repeated several times because some variables were significant when in combination with a specific group and not significant in another. Major aim was to obtain coefficients that provide logical explanations and models with an acceptable "goodness of fit". The latter was tested using a composite check which displays the residuals, fixed values, normal and half normal curves. The variables included in the model were subjected to correlation tests to eliminate collinearity. In the event that a pair of variables had correlation coefficient of 0.5 and above one of the variables would be eliminated from the model. Crop patterns were included in the analysis as logical variables (1 or 0) were used for presence or absence of the specific Crop Pattern.

5.3 RESULTS

5.3.1 Nitrogen, P and K Inflows and Outflows

(i) Farm N, P and K inflows and outflows

(a) Farm N inflows and outflows

Overall, ZG was superior in N inflow quantitatively (Table 9); this was followed by the TE category; while FE had the lowest. Considering the inflows across farm categories, the feed channels clearly emerged superior to their non-feed N inflow counterparts. In between the two feed channels, N inflow through manure resulting from off-farm feed ($F12_i$) tended to contribute the most Farm N input. In some cases, the differences ranged between 33 and 50%.

Among the N inflow channels, the applied N inflow from off-farm ($P1_i$) ranked the poorest contributor to Farm N stocks (Table 9). In fact, the differences between the feed channel with the highest values and $P1_i$ were as wide as 100% in some cases. However, there were a few cases where there were no statistically detectable differences ($p>0.05$) between the channels.

Generally, there were two main channels of N outflow identified across the five farm categories namely, crop harvests ($H1_o$) and milk ($M1_o$) (Table 9). Clearly, the crop harvests channel ($H1_o$) had an edge over its counterpart. The outflow differences ranged from 25 to 55%.

By way of comparison, the N inflow values for several channels were generally greater than their outflow counterparts. This was particularly evident in the ZG and FE categories, most especially in the feed channels. The inflow to outflow ratio was highest in the TE category amounting to 7 times that in the FE where the ratio was the lowest.

Table 9. Farm N inflows and outflows in kg ha^{-1} season^{-1} in dairy farm categories in Uganda

Flow	Farm category					$LSD_{0.05}$
	HD	TE	FE	SI	ZG	
$P1_i$	0.00	0.31	0.01	0.04	0.00	0.19
$F12_i$	0.27	4.33	0.00	5.62	28.59	3.19
$F11_i$	0.18	2.89	0.00	3.75	19.06	2,12
NF_i	0.89	6.71	0.89	3.12	4.70	2.30
$G12_i$	0.42	2.06	0.25	1.59	0	1.20
$G11_i$	0.56	2.75	0.34	2.11	0	1.61
$LSD_{0.05}$ (inflows)	0.55	3.54	0.55	2.60	2.92	
$H1_o$	1.22	4.09	1.46	6.20	9.65	3.22
$M1_o$	0.51	1.84	1.95	5.15	7.39	1.89
$LSD_{0.05}$ (outflows)	1.23	2.48	0.80	3.63	15.53	
LSD $_{0.05}$ (Overall)	0.72	3.21	0.61	2.84	5.51	
Inflow/Outflow ratio	1.34	3.21	0.44	1.43	3.07	

P1 = nutrients applied from off-farm; F12 = inflows to farm through manure deposits from off-farm feeds; F11 = inflows to livestock from off-farm feeds; H1 = outflows from farm in harvests; NF = Leguminous N fixation; M1 = outflows through milk sales and consumption; G12 = inflows to farm from off-farm grazing through manure deposits; G11 = inflows to livestock from off-farm grazing; i = inflow; o = outflow; HD = herding; TE = tethering; FE = fenced; SI = semi-intensive; ZG = zero grazing.

(b) <u>Farm P inflows and outflows</u>

Values for P inflows and outflows (Table 10) were much lower than those for N (Table 9). The ZG category, as in the Farm N inflows, maintained the highest overall value for Farm P inflows, amounting to 200-folds of the lowest value in the FE category. The off-farm feeds ($F11_i$ and $F12_i$) inflow channels were generally responsible for largest influx of P into the farms, while the least P importation was through inputs applied from off-farm ($P1_i$).

Table 10. Farm P inflows and outflows in kg ha^{-1} $season^{-1}$ in dairy farm categories in Uganda

Flow	Farm category					$LSD_{0.05}$
	HD	TE	FE	SI	ZG	
$P1_i$	0.00	0.06	0.01	0.01	0.00	0.04
$F12_i$	0.06	1.36	0.00	1.62	9.58	0.92
$F11_i$	0.02	0.42	0.00	0.51	2.99	0.29
$G12_i$	0.15	0.72	0.02	0.47	0.00	0.35
$G11_i$	0.09	0.45	0.03	0.29	0	0.22
$LSD_{0.05}$ (inflows)	0.11	0.49	0.04	0.60	0.60	
$H1_o$	0.19	0.68	0.20	0.97	1.65	0.55
$M1_o$	0.09	0.33	0.33	0.92	1.32	0.34
$LSD_{0.05}$ (outflows)	0.19	0.45	0.14	0.62	2.78	
$LSD_{0.05}$ (Overall)	0.13	0.46	0.08	0.60	1.02	
Inflow/Outflow ratio	1.14	2.98	0.11	1.53	4.23	

P1 = nutrients applied from off-farm; F12 = inflows to farm through manure deposits from off-farm feeds; F11 = inflows to livestock from off-farm feeds; H1 = outflows from farm in harvests; NF = Leguminous N fixation; M1 = outflows through milk sales and consumption; G12 = inflows to farm from off-farm grazing through manure deposits; G11 = inflows to livestock from off-farm grazing; i = inflow; o = outflow, HD = herding; TE = tethering; FE = fenced; SI = semi-intensive; ZG = zero grazing.

Overall, P outflows from the Farms were again highest in the ZG category, amounting to approximately 10-folds those in the HD category, which had the least outflow quantities.

Quantities of P outflows through the crop harvests channel tended to be higher than those through milk in all categories, except in the FE where the contrast was true; however, all were not statistically significant (P>0.05). On the other hand, the highest inflow to outflow ratio was in the ZG category, where the value was approximately 40 times that in the FE, which was the lowest. This was quite different from N where the highest ratio was obtained in the TE category.

(c) Farm K inflows and outflows

A similar pattern of inflows into the Farms by N and P was exhibited by K (Table 11), with values comparable to those of N. The highest K inflows into the Farms were registered in the ZG category, amounting to about 300-folds those in the FE category, which had the lowest value. As observed previously in the N and P flows (Section 5.3.1.(i) a and b), largest quantities of inflows were registered through the off-farm feeds channels ($F12_i$ and $F11_i$), and the lowest through nutrients applied to the from off-farm ($P1_i$).

Table 11. Farm K inflows and outflows in kg ha^{-1} $season^{-1}$ in dairy farm categories in Uganda

Flow	Farm category					$LSD_{0.05}$
	HD	TE	FE	SI	ZG	
$P1_i$	0.00	0.04	0.02	0.03	0.00	0.06
$F12_i$	0.95	5.97	0.01	19.67	31.60	11.34
$F11_i$	0.21	1.32	0.00	4.34	6.97	2.50
$G12_i$	0.11	0.51	0.06	0.33	0	0.26
$G11_i$	0.05	0.23	0.03	0.15	0	0.12
$LSD_{0.05}$ (inflows)	0.56	2.15	0.07	6.55	17.84	
$H1_o$	2.47	5.77	2.35	3.63	11.99	2.20
$M1_o$	0.11	0.40	0.43	1.13	1.61	0.42
$LSD_{0.05}$ (outflows)	2.07	3.62	0.85	1.79	6.66	
$LSD_{0.05}$ (Overall)	1.03	2.43	0.41	5.71	14.94	
Inflow/Outflow ratio	0.51	1.31	0.04	5.15	2.84	

P1 = nutrients applied from off-farm; F12 = inflows to farm through manure deposits from off-farm feeds; F11 = inflows to livestock from off-farm feeds; H1 = outflows from farm in harvests; NF = Leguminous N fixation; M1 = outflows through milk sales and consumption; G12 = inflows to farm from off-farm grazing through manure deposits; G11 = inflows to livestock from off-farm grazing; i = inflow; o = outflow; HD = herding; TE = tethering; FE = fenced; SI = semi-intensive; ZG = zero grazing.

Generally, as in N and P, the highest K outflow was in the ZG category, amounting to 5 times that in the HD, which ranked the lowest (Table 11). Overall, largest quantities of K outflows overall were again through the harvests channel. The highest inflow to outflow ratio was in the

SI category, amounting 130-folds that for the FE, which was the lowest. This was rather different from N and P where the highest values were in the TE and ZG categories respectively.

Values for Farm K flows were in most cases a little less than those for N; however, much higher than those for P. Farm K inflow to outflow ratios for HD, TE and FE categories were lower than those for N and P. In the SI category Farm K ratio was higher than that for N and P while in the ZG its value was intermediate lying between those for N and P.

(ii) Land N, P and K inflows and outflows

(a) Land N inflows and outflows

Nitrogen inflows to the Land were generally greatest in the TE category (Table 12). Overall, the HD and FE categories consistently had the lowest values in this respect. Among the N inflows to the Land across the farm categories, BNF represented as NF_i (Table 12) contributed the largest N input into the Land. Differences between quantities of N inflow into the Land through BNF and applications of on-farm manure ($P2_i$) ranged from 20 to 80%, and were mostly significant ($p<0.05$). Largest values were observed in the TE and ZG categories and the lowest in the HD and FE. The off-farm N application channel ($P1_i$) maintained least quantities of inflows as observed at the farm level (Table 9). Overall, the HD, FE and ZG categories presented hardly any traceable values in this respect.

Table 12. Land N inflows and outflows (kg ha^{-1} $season^{-1}$) in dairy farm categories in Uganda

Flows	Farm categories					$LSD_{0.05}$
	HD	TE	FE	SI	ZG	
$P1_i$	0.00	0.31	0.01	0.04	0.00	0.31
$P2_i$	0.24	1.27	0.72	0.06	1.14	1.58
NF_i	0.89	6.71	0.89	3.11	4.67	3.75
$LSD_{0.05}$ (inflows)	0.57	4.82	1.05	1.11	2.18	
$G21_o$	0.84	0.62	4.55	4.56	0.00	4.28
$G22_o$	1.25	0.94	6.82	6.85	0.00	6.42
$H1_o$	1.22	4.09	1.45	6.19	9.58	5.24
$F4_o$	0.18	0.38	0.19	3.97	6.35	3.86
$F5_o$	0.55	1.14	0.57	11.92	19.04	11.57
$LSD_{0.05}$ (outflows)	1.11	1.70	1.22	5.92	11.57	
$LSD_{0.05}$ (Overall)	0.92	3.05	1.14	4.69	8.51	
Inflow/Outflow ratio	0.25	0.69	0.11	0.09	0.16	

P1 = Applications from off-farm; P2 = Applications from own livestock through manure; G21 = Transfers from the land to livestock from on-farm grazing; G22 = Manure deposits in kraals from on-farm grazing; H1 = Outflows from farm in harvests; F4 = Feed transfers from on farm to livestock; F5 = Manure deposited outside farm land from on-farm feeds; i = inflow; o = outflow; HD = herding; TE = tethering; FE = fenced; SI = semi-intensive; ZG = zero grazing.

Nitrogen in the outflow channels from the Land was generally greatest in the ZG and SI categories (Table 12), though there were two cases in the ZG where zero outflow values, in the grazing channels (G21 and G22) were realised. Generally, the HD and TE categories presented the lowest outflow values with only a few significant differences ($p<0.05$) among these channels. On-farm grazing channels for N removal from the land ($G21_o$ and $G22_o$) presented highest N outflow values in FE and SI. Zero values were obtained for N through these channels in the ZG category.

Evidently, the feed outflows leaving the Land and deposited in kraals across farm categories led among the N outflow channels. These were followed by crop harvests. The poorest N export channel was what was transferred to the animals and retained in their bodies for maintenance and production.

In terms of inflow to outflow ratios, the TE category had a greater value than the rest and was in the magnitude of eight folds that of the SI category which had the lowest ratio. Detailed scrutiny of the N balance scenario for the study categories are presented in Section 5.3.2.

(b) Land P inflows and outflows

Phosphorus inflow values into the Land (Table 13) were again relatively smaller than those of N (Table 12). Unlike the case of N which had three inflow channels, P maintained only two, namely those involving application of (i) off-farm materials ($P1_i$); and (ii) on-farm manure ($P2_i$). The largest quantities of P inflows into the Land in the TE category and was 20-folds that in the SI category, which was the lowest.

Table 13. Land P inflows and outflows (kg ha^{-1} $season^{-1}$) in dairy farm categories in Uganda

Flows	Farm categories					$LSD_{0.05}$
	HD	TE	FE	SI	ZG	
$P1_i$	0.00	0.06	0.01	0.01	0.00	0.07
$P2_i$	0.10	0.53	0.47	0.02	0.41	0.98
$LSD_{0.05}$ (Inflows)	0.12	0.46	0.62	0.04	0.79	
$G21_o$	0.14	0.10	0.75	0.63	0.00	0.56
$G22_o$	0.28	0.21	1.50	1.25	0.00	1.11
$H1_o$	0.19	0.68	0.21	0.97	1.63	0.89
$F4_o$	0.02	0.06	0.02	0.48	0.73	0.44
$F5_o$	0.09	0.23	0.09	1.90	2.93	1.77
$LSD_{0.05}$ (Outflows)	0.20	0.31	0.24	0.90	1.87	
$LSD_{0.05}$ (Overall)	0.17	0.36	0.42	0.71	1.42	
Inflow/Outflow ratio	0.14	0.46	0.19	0.01	0.08	

P1 = Applications from off-farm; P2 = Applications from own livestock through manure; G21 = Transfers from the land to livestock from on-farm grazing; G22 = Manure deposits in kraals from on-farm grazing; H1 = Outflows from farm in harvests; F4 = Feed transfers from on farm to livestock; F5 Manure deposited outside farm land from on-farm feeds; i = inflow; o = outflow; HD = herding; TE = tethering; FE = fenced; SI = semi-intensive; ZG = zero grazing.

Despite the absence of significant differences (p>0.05), values for the FE and ZG categories were close to those of the TE category, while the HD and SI categories also tended to be close to each other in magnitude. Generally, P inflows into the Land were greater within the on-farm manure application channel ($P2_i$) than for applications from off-farm ($P1_i$). This difference, however, was only recognised within the TE category.

Quantities of P outflows from the Land were generally highest in the ZG category where they were approximately 5 times higher than in the HD category, which had the lowest value (Table 14). Phosphorus losses from the Land were largely through on-farm feeds ($F4_o$ and $F5_o$), followed by on-farm grazing ($G21_o$ and $G22_o$) and crop harvests ($H1_o$).

Movement of P along the outflow channels was relatively higher than observed in the inflow channels. This was, especially so in the ZG and SI categories, where the differences between the highest outflow and inflow were as high as 99% compared to 22% in the TE category. The difference between the highest and lowest inflow to outflow ratio in the case of Land P flows, was much greater than that in N. In this respect, the ratio for the TE category, which was the highest, was 45-folds that of the lowest in SI.

(c) <u>Land K inflows and outflows</u>

Potassium Land flows (Table 14), were quantitatively larger than those of N and P (Tables 12 and 13). Inflow channels for K were similar to those of P, in terms of the highest inflow value, again, in TE approximately 20-folds that of the lowest also in the SI category. Inflows into the Land were greater through on-farm manure ($P2_i$) than applications of inputs from off-farm ($P1_i$) with the exception of the SI category where the two were the same.

Largest quantities of K outflows from the Land were again in the ZG and SI categories (Table 15) and least in the HD categories. The feed flows ($F4_o$ and $F5_o$) were generally the dominant channels through which K left the Land, particularly in the ZG and SI categories. Crop harvests ($H1_o$) also removed fairly large quantities of K from the Land across all categories. Dismal quantities of K were removed through the grazing channels ($G21_o$ and $G22_o$). Differences in K quantities between feed and grazing outflows ranged from 82 to 100%, all with significant values ($P<0.05$).

Potassium outflows exceeded inflows by 5 to 500 times. Furthermore, the inflow to outflow ratios were remarkably greater than their corresponding N and P values. The ratio for the TE category, which was the highest overall, was 90 folds that of the SI category, which was the lowest.

Table 14. Land K inflows and outflows (kg ha^{-1} season^{-1}) in dairy farm categories in Uganda

Flows	Farm categories					$LSD_{0.05}$
	HD	TE	FE	SI	ZG	
$P1_i$	0.00	0.04	0.02	0.03	0.00	0.10
$P2_i$	0.16	1.07	0.95	0.03	0.61	1.95
$LSD_{0.05}$ (Inflows)	0.18	0.95	1.25	0.07	1.16	
$G21_o$	0.07	0.05	0.38	0.31	0.00	0.28
$G22_o$	0.20	0.15	1.06	0.89	0.00	0.79
$H1_o$	2.47	5.76	2.34	3.62	11.90	3.57
$F4_o$	0.23	0.45	0.21	3.91	6.45	3.71
$F5_o$	1.30	2.55	1.21	22.15	36.54	21.04
$LSD_{0.05}$ (Outflows)	1.46	2.17	0.99	8.4	17.81	
LSD0.05 (Overall)	1.13	1.76	1.07	6.59	13.0	
Inflow/Outflow ratio	0.04	0.12	0.19	0.00	0.01	

P1 = Applications from off-farm; P2 = Applications from own livestock through manure; G21 = Transfers from the land to livestock from on-farm grazing; G22 = Manure deposits in kraals from on-farm grazing, H1 = Outflows from farm in harvests; F4 = Feed transfers from on farm to livestock; F5 = Manure deposited outside farm land from on-farm feeds; i = inflow; o = outflow; HD = herding; TE = tethering; FE = fenced; SI = semi-intensive; ZG = zero grazing.

5.3.2 Nitrogen, P and K Balances

(i) Farm and Land N balances

The ZG category emerged outstanding overall with fairly large positive balance values in the two Farm balance cases (Table 15). This was remotely followed by the TE category which had positive values in the FC Farm and Land cases. Fenced and SI categories trailed with negative balances throughout.

$Land_{FC+UC}$ N balances ranked highest in the net negative balances overall. Land N balance was only positive in the TE category (Table 15). The highest negative balance values were obtained in SI and ZG. In this case, the highest Land N balance (TE category) was approximately 50 times that of the lowest (SI category). Generally, $Land_{FC}$ N balances were higher than their combined $Land_{FC+UC}$ counterparts.

Table 15. Farm and Land N balances (kg ha^{-1} $season^{-1}$) for dairy farm categories in Uganda

Balance type	Farm categories					$LSD_{0.05}$
	HD	TE	FE	SI	ZG	
Farm $_{FC}$	-0.45	12.00	-06.27	-05.18	25.58	12.49
Farm $_{FC+UC}$	-15.51	-08.11	-16.67	-24.80	15.75	12.93
Land $_{FC}$	-2.92	1.12	-11.96	-30.28	-29.15	16.14
Land $_{FC+UC}$	-18.1	-19.63	-22.72	-49.93	-39.56	16.68
$LSD_{0.05}$ overall	1.86	12.0	6.65	20.36	33.58	

HD = herding; TE = tethering, FE = fenced; SI = semi-intensive; ZG = zero grazing; FC = Farmer controlled flows; UC = Uncontrolled flows.

(ii) Farm and Land P balances

Farm P balances were largely positive (Table 16) with only one negative value for the FE category. Highest Farm P balances occurred in the ZG category, yet the lowest was in the FE category. The $Farm_{FC+UC}$ P balances tended to be slightly higher than the $Farm_{FC}$ balances.

Land P balances were higher than their Land N counterparts with the exception of the $Land_{FC}$ P balance in TE. The highest $Land_{FC}$ P balance value was in HD, while that for $Land_{FC+UC}$ P balance was in the TE category. The SI farm category had the lowest P balances. Land P balances for the HD, TE and FE categories were generally similar as were those of SI and ZG categories.

$Land_{FC+UC}$ P balances were again higher than their FC counterparts in all farm categories. Detailed scrutiny of the differences between Farm and Land balances is presented in Section 5.3.2 (iv.) of this thesis.

Table 16. Farm and Land P balances (kg ha^{-1} season^{-1}) for dairy farm categories in Uganda

Balance type	Farm categories					$LSD_{0.05}$
	HD	TE	FE	SI	ZG	
Farm $_{FC}$	0.03	2.44	-0.70	0.91	11.34	2.29
Farm $_{FC+UC}$	1.61	4.25	0.39	1.98	11.99	2.41
Land $_{FC}$	-0.61	-0.69	-2.1	-5.19	-4.89	2.48
Land $_{FC+UC}$	1.13	1.17	-0.35	-2.62	-2.35	2.44
$LSD_{0.05}$ overall	0.40	1.39	1.28	3.35	4.30	

HD = herding; TE = tethering; FE = fenced; SI = semi-intensive; ZG = zero grazing; FC = Farmer controlled flows; UC = Uncontrolled flows.

(iii) Farm and Land K balances

Generally, Farm K balances (Table 17) were constituted by both positive and negative values with the former being slightly more. The highest Farm K balance values were in the ZG category. The lowest values were below zero and were in FE for the Farm$_{FC}$ balances and in HD for the Farm$_{FC+UC}$ balances. The highest value being approximately five times that of the lowest. Farm$_{FC}$ K balances were in some cases higher than their FC+UC counterparts. This was evident in the HD, TE and SI categories, while the contrary was true for other categories.

On the whole, Land K balances were negative with the largest values observed in the HD and FE categories, and the lowest in the ZG and SI. The highest value was approximately thirteen times that of the lowest. Land$_{FC}$ K balances were higher than their Land$_{FC+UC}$ counterparts in all categories except the ZG category where the contrary was true but to a negligible extent. Farm K balances were higher than the Land balances in all categories and detailed scrutiny of these differences is presented in Section 5.3.2 of this thesis.

Table 17. Farm and Land K balances (kg ha^{-1} season^{-1}) for dairy farm categories in Uganda

Balance type	Farm categories					$LSD_{0.05}$
	HD	TE	FE	SI	ZG	
Farm $_{FC}$	-1.57	1.36	-3.10	15.12	17.45	15.29
Farm $_{FC+UC}$	-3.43	0.86	-2.96	13.34	18.93	15.72
Land $_{FC}$	-4.1	-7.84	-4.24	-30.82	-54.28	16.65
Land $_{FC+UC}$	-6.14	-9.63	-5.24	-32.64	-53.53	17.00
$LSD_{0.05}$ overall	3.45	5.76	4.22	23.0	47.68	

HD = herding; TE = tethering; FE = fenced; SI = semi-intensive; ZG = zero grazing; FC = Farmer controlled flows; UC = Uncontrolled flows.

(iv) Differences between Farm $_{FC}$ and Land $_{FC}$ balances

Differences between Farm and Land balances were all positive (Table 18) with the highest values accruing from the ZG and lowest in the HD and FE categories. Generally, differences between Farm and Land P balances were the lowest in magnitude, while those of N and K were high and maintained comparable values.

Zero grazing presented the highest differences between Farm and Land balances for N, P and K. This was followed by SI, and then HD had the least overall. Generally, N differences were the largest in magnitude with the exception of ZG and SI where K differences were outstanding. It is also important to note that K differences in HD, TE and FE were relatively dismal compared to the SI and ZG cases.

Table 18. Differences between Farm and Land N, P and K balances (kg ha^{-1} season^{1}) for dairy farm categories in Uganda (Farm balances – Land balances)

Nutrient	Farm categories					$LSD_{0.05}$
	HD	TE	FE	SI	ZG	
N	2.47	10.88	5.69	25.10	54.73	12.30
P	0.63	3.13	1.96	6.10	16.23	3.01
K	2.53	9.2	2.30	45.94	71.73	25.11

HD = herding; TE = tethering; FE = fenced; SI = semi-intensive; ZG = zero grazing.

(v) Dominant crop patterns across dairy farm categories

Twenty seven crop patterns were identified from the spectrum of crop mixtures found on the farms (Table 19, Appendix 8). Evidently, the banana based cropping systems (Plates 6 and 7) dominate across farm categories. Most prominently, the Banana-Beans crop pattern is represented in all the farm categories, with the highest number of patches in the HD category. The Banana-Beans crop pattern was followed closely by the bean, cassava and coffee based crop patterns. Among the farm categories, the SI had the greatest diversity of crop patterns. This was followed by the FE category; while ZG had least diversity overall with only three crop patterns. The SI category had the highest frequency of fodder based crop patterns and the ZG had none.

Table 19. Number of Patches per farm with specified crop patterns in the dairy farm categories

Crop pattern	Farm Categories				
	HD	TE	FE	SI	ZG
Banana-beans	2.5 (0.58)	1.5 (1.73)	1.5 (0.93)	0.1 (0.32)	1.0 (0)
Banana-cassava	NA	NA	NA	0.2 (0.42)	NA
Banana-fodder crop	0.75 (0.96)	NA	0.13 (0.35)	0.1 (0.32)	NA
Beans-cassava	NA	0.5 (1)	0.5 (0.54)	0.3 (0.48)	NA
Beans-maize	NA	1.5 (1.73)	0.63 (0.74)	0.5 (0.85)	NA
Coffee-banana	0.75 (0.96)	NA	0.13 (0.35)	0.1 (0.32)	0.5 (0.71)
Coffee-beans	0.25 (0.5)	NA	0.38 (0.74)	NA	NA
Coffee-fodder crop	NA	NA	NA	0.4 (0.52)	NA
Fallow	0.25 (0.5)	NA	0.75 (0.17)	0.1 (0.32)	NA
Finger millet/sorghum	NA	NA	0.38 (0.52)	NA	NA
Fodder crop	NA	NA	NA	1.6 (1.58)	NA
Fruit trees	NA	0.25 (0.5)	0.13 (0.35)	NA	NA
Ground nuts	NA	NA	0.38 (1.06)	NA	NA
Intercropped banana	0.5 (0.58)	NA	0.25 (0.46)	0.2 (0.42)	NA
Intercropped cassava	NA	0.5 (0.58)	NA	0.7 (0.82)	NA
Intercropped maize	0.25 (0.5)	1 (1.16)	NA	0.3 (0.68)	NA
Banana based intercrops	1 (1.16)	0.5 (0.58)	0.63 (0.74)	NA	NA
Cassava based intercrops	NA	0.5 (0.58)	0.13 (0.35)	0.3 (0.48)	NA
Coffee based intercrops	NA	0.25 (0.5)	NA	0.2 (0.42)	0.5 (0.71)
Maize based intercrops	0.25 (0.5)	0.5 (0.58)	NA	0.1 (0.32)	NA
Multiple crop mixtures	NA	NA	NA	0.2 (0.42)	NA
Pasture¥	1.25 (0.25)	NA	2 (1.51)	0.9 (0.99)	NA
Pineapples¥	NA	NA	0.25 (0.71)	NA	NA
Sugarcane¥	NA	NA	0.25 (0.46)	NA	NA
Sweet potatoes¥	0.5 (0.58)	3.5 (1)	NA	1.2 (1.14)	NA
Vegetables¥	NA	NA	NA	0.1 (0.32)	NA
Yams¥	NA	NA	NA	0.2 (0.42)	NA

HD = Herding; TE = Tethering; FE = Fenced; SI = Semi-intensive; ZG = Zero grazing. Patch = a subdivision within the land on which different crops or crop mixtures are planted ; The crop pattern name represents the most dominant crops; traces of other crops including fodder could have been present but not considered; ¥ = All except those marked were intercrops at different levels; Values in parenthesis are standard deviations; NA = crop pattern was non-existent in the category.

Plate 6. Banana-Beans Crop Pattern.

Plate 7. Mainly Bananas Crop Pattern.

(vi) Crop pattern N and K balances

Tables 20 and 21 show integrated crop pattern balances (Patch level balances presented on basis of crop patterns) for N and K, specifically selected because they emerged most frequent across the farm categories.

Among the crop pattern N balances, Beans-Maize, and Banana-Beans (Plate 6) presented positive balances overall, and these were generally higher than the rest (Table 20). However, the positive balances were only restricted within TE, FE and SI categories; the other categories had negative balance values. Among the major crop patterns across the farm categories, the Beans-Maize by and large had the highest N balance with the highest value in the FE category. On the other hand, Fodder had the lowest value in the SI category.

From the stand point of K, all crop patterns presented negative balances across the farm categories; however, the crop pattern with the lowest negative values was Pasture in the HD category (Table 21). The most severely affected crop pattern was Fodder which was found only in the SI category.

Table 20. Crop pattern N balances (kg ha^{-1} $season^{-1}$) across dairy farm categories in Uganda (Selected Crop Patterns only)

Crop pattern	Farm categories					$LDS_{0.05}$
	HD	TE	FE	SI	ZG	
Banana-beans	-13.8	4.3	0.63	7.6	-25.2	30.32
Banana-fodder$^{\Psi}$	-14.1	NA	-34.67	-1.8	NA	
Mainly bananas	-39.6	-69.1	-13.46	NA	NA	45.54
Coffee-bananas$^{\Psi}$	-12.6	NA	-1.39	-13.0	-89.1	
Beans-maize	NA	5.64	14.35	6.8	NA	16.5
Mainly cassava$^{\Psi}$	NA	-29.2	-0.5	-4.0	NA	
Fodder crops*	NA	NA	NA	-54.7	NA	
Pasture	-2.8	NA	-16.93	-38.8	NA	24.01
Fallow	-13.4	NA	-20.04	-30.1	NA	
$LDS_{0.05}$	34.54	29.0	11.83	30.02	NS#	

$^{\Psi}$ = LSDs between farm category balances for these crop patterns could not be calculated due to few cases, * = Crop pattern was in only one farm category; # = T-test used to test for significance difference rather than LSD; NA = crop pattern was non-existent in the category; HD = herding; TE = tethering; FE = fenced; SI = semi-intensive; ZG = zero grazing.

Table 21. Crop Pattern K balances (kg ha^{-1} season^{-1}) across dairy farm categories in Uganda

Crop pattern	Farm Categories					$LDS_{0.05}$
	HD	TE	FE	SI	ZG	
Banana-beans	-39.8	-10.6	-15.57	-7.0	-65.3	39.18
Banana-fodder$^{\Psi}$	-52.9	NA	-73.35	-5.2	NA	
Mainly bananas	-71.7	-194.2	-34.02	NA	NA	77.82
Coffee-bananas$^{\Psi}$	-34.2	NA	-2.19	-35.5	-115.8	
Beans-maize	NA	-12.1	-4.9	-2.3	NA	18.26
Mainly cassava$^{\Psi}$	NA	-48.6	-0.43	-4.4	NA	
Fodder crops*	NA	NA	NA	-85.9	NA	
Pasture	-0.3	NA	-2.19	-4.5	NA	2.36
Fallow	-1.6-	NA	-17.36	-9.4	NA	
$LDS_{0.05}$	53.06	34.61	14.42	39.08	247.9	

$^{\Psi}$ = LSDs between farm category balances for these crop patterns could not be calculated due to few cases, * = Crop pattern was in only one farm category; NA = crop pattern was non-existent in the category; HD = herding; TE = tethering; FE = fenced; SI = semi-intensive; ZG = zero grazing.

Table 22 presents pooled mean nutrient balances for the crop patterns across farm categories. Evidently, K had the largest net negative balance values, while P presented the lowest and in some cases positive values. Nitrogen was intermediate, but surprisingly had one case in Beans-Maize with the largest positive balance. Like in the farm category based data (Tables 20 and 21), Beans-Maize maintained the lowest negative balances across the major nutrients, while Fodder again maintained the most negative values.

Table 22. Pooled N, P and K balances (kg ha^{-1} $season^{-1}$) for selected crop patterns across dairy farm categories in Uganda (used farmer controlled (FC) flows only)

Crop pattern	Nutrients		
	N	P	K
Banana-beans	-4.76	1.46	-25.36
Banana-fodder	-15.74	-0.05	-47.47
Mainly bananas	-33.08	-4.92	-76.85
Coffee-bananas	-23.55	-3.78	-42.71
Beans-maize	8.71	-1.15	-6.8
Mainly cassava	-11.84	-2.64	-18.47
Fodder crops	-54.69	-8.61	-85.87
Pasture	-21.14	-3.57	-2.58
Fallow	-20.47	-3.21	-14.4
$LSD_{0.05}$	15.41	3.47	20.67

Data represent pooled means across dairy farm categories for the study areas.

5.3.3 Soil Fertility Status in the Farm Categories

Soil analytical data for the farm categories considered in this study are presented in Table 23. When compared with the critical values advanced by Okalebo *et al.* (1993), N is severely deficient, while P is deficient in SI and ZG categories. In contrast, K values were above the critical level for all farm categories.

Nitrogen stocks were highest in the TE and SI categories both containing the same quantity (2800 kg ha^{-1}) of N. This was followed by ZG (2000 kg ha^{-1}) and HD (1800 kg ha^{-1}); and least in FE (1600 kg ha^{-1}). The Zero grazing (ZG) category presented the lowest value for the projected number of years (34 years) within which N stocks could be depleted if the Land N balance (Table 15) remained constant. In contrast, HD had a value of 310 years which was the highest despite its N stocks being next to the lowest. Years to depletion of N stocks for FE and SI were 67 and 46 years, respectively.

Table 23. Concentrations available N, P and K in soil within dairy farm categories in Uganda

Soil property	Farm categories					Critical levels[¥]
	HD	TE	FE	SI	ZG	
N (%)	0.09	0.14	0.08	0.14	0.10	0.2
P (mg kg^{-1})	20.95	25.45	12.04	6.72	4.48	15.0
K (cmol. kg^{-1})	0.77	0.97	0.68	0.87	0.70	0.4

HD = herding; TE = tethering; FE = fenced/paddock; SI = semi-intensive; ZG = zero grazing. [¥] According to Okalebo *et al.* (1993).

5.3.4 Indicators of N, P and K Balances

Overall, there were nine recognised indicators of N, P and K balances (Table 24), namely, Banana-Beans (BB), Pasture (Pa), Coffee-Fodder (CF), Legume Intercrops (LI), Sweet Potato (SP) and Fodder (FC) crop patterns, quantities of materials leaving the patch in harvests and grazing as a proportion of the total from the Farm in the season (HvGz), proportion of the Patch in the Plot (PP) and quantity of manure applied to the Patch as a proportion of total manure produced on the Farm in the season (Mn). Potassium balances had the largest number of indicators (7), while P had the smallest number (5).

By way of magnitude of influence, coefficients for the K balance had the largest values amounting to 4-folds those for P, which had the lowest values. More than half of the coefficients for indicators of N and P balances were positive while, the contrast was true for K.

Table 24. Indicators of Patch N, P and K balances and their coefficients

Indicators	Nutrients		
	N	P	K
Constant	-20.40	-1.83	-18.66
BB	2.33	0.65**	-29.73
CC	-3.88	-1.25	-14.94
Pa	8.38	1.14	16.40**
CF	-33.71*	-6.26*	-72.08*
BI	-1.35	-2.41	-28.75
LI	13.58*	0.27[a]	-15.88
SP	4.28**	-2.03	-20.27*
FC	-27.77	-5.03	-63.87*
HvGz	-93.07***	-16.01***	-120.2***
PP	20.77*	2.71	40.79*
CR	6.82	-0.81	-1.58
Mn	78.36*	59.31***	120.0**

BB = Banana-beans; CC = Cereals, cassava and general intercrops; Pa = Pasture; CF = Coffee-fodder intercrops; BI = Banana intercrops; LI = Legume based intercrops; SP = Sweet potatoes; FC = Fodder crops; HvGz = Quantity of material leaving the patch in harvests and grazing as a proportion of total from farm; PP = Patch area as a proportion of the plot; CR = Quantity of crop residues applied to the patch as a proportion of total crop residues applied on the farm (square root); Mn = Quantity of manure applied to the patch as a proportion of total manure produced on the farm (square root).

The indicators which demonstrated strongest influence over all balances; N, P and K, were the quantities of materials leaving the Patch in harvests and grazing (HvGz) with negative influence on the balances and quantity of manure applied to the Patch (Mn) with positive effects. In contrast, the indicator with the weakest influence was the "Legume based intercrop" Crop pattern (LI) with a positive effect on P balance.

The indicators tended to maintain uniformity of tendency of effect for all three balances. For instance an indicator with a positive effect on N also had a positive effect on P and K. The only exception was observed with the "Sweet potato" Crop Pattern, which had a positive effect on N and negative on K balance.

5.4 Discussion

5.4.1 Nitrogen, P and K Inflows and Outflows

(i) Farm N, P and K inflows and outflows

(a) Farm N inflows and outflows

The superiority of zero grazing (ZG) dairy category into N inflow to the farm, is attributed to the large quantities of nutrient-rich feed materials imported from off-farm (Table 9); which contrasts with the herding (HD) and fenced (FE) categories, where feed supply is almost entirely sourced from within the farm. In typical ZG farms, a variety of feed materials were reportedly imported on a daily basis in the study areas. Such materials included elephant grass (Napier grass), banana peels, maize stover and sweet potato vines. Furthermore, within the ZG category, imported feed was approximately 2,600 kg (DM) per total livestock units (TLU) per season, compared to 0.7 kg TLU^{-1} season $^{-1}$ in the FE category (data from the longitudinal survey). Generally, 9 – 19 kg (DM) of elephant grass was fed to each TLU daily across the study districts. Elephant grass is known to carry large quantities of nutrients especially K and N. According to Lekasi *et al.* (2001), proportion of N in elephant grass, this brings the level of N exiting the fodder patches at the level of 0.1 to 0.3 kg TLU^{-1} day^{-1}.

The critical issue in this case, with respect to the smallholder dairy producers, is judicious utilisation of the positive N stocks to ensure sustainable productivity of the system and less dependence on external input supply. Otherwise, it becomes inevitable that the flux of nutrients into the farm, if unparalleled by proper redistribution within the Land and the Patches, will lead to environmental degradation through pollution particularly of water systems, with its (degradation) attendant effects on human and animal health (De Haan *et al.*, 1996; Schiere *et al.*, 2002).

The dismal inflow through off-farm N application is expected of these smallholder farmers who rarely invest in soil fertility inputs particularly from external sources. This is often explained in light of the high costs of fetiliser materials and the lack of awareness of their value and use in the production process (Sasakawa Global, 2002; Nkonya *et al.*, 2005). The most affected categories are likely to be the HD and FE which do not benefit significantly from the feed channels of N input, and yet lack alternative nutrient inflows. These categories stand to suffer from depletion of N stocks faster than the ZG and tethering (TE) categories. Under the circumstances, N recycling and redistribution within the farm to minimise excessive leakages into the environment would be vital.

From the N outflow stand point, the relatively higher outflow values in the crop harvests than in the milk channel is attributed to over-emphasis on crop production for subsistence purposes. This study has revealed that, quantities of crop produce from the farms are much higher than milk produced in a given season with crop quantities as much as 25 times the milk quantities, and as a result, N outflows through crop harvests are high in all categories. Considerable contribution of crop harvests to nutrient losses was also observed also by Wortmann and Kaizzi (1998) and Nkonya *et al.* (2005).

The greatest disequilibrium in the N outflow through crop harvests relative to the milk channel was realised in the HD and TE categories with a ratio of 2-folds. On the other hand, the lowest value of 1.3-folds was obtained in the ZG and SI categories. These values clearly show that there is greater dependence on crop production in HD and TE in contrast with the ZG and SI, whose thrust is on milk production with a commercial orientation. Earlier studies have also demonstrated considerable N losses through crop harvests (Wortmann and Kaizzi, 1998; Nkonya *et al.*, 2005), though relativity with milk N losses were not considered.

(b) <u>Farm P inflows and outflows</u>

The similarity of N and P Farm inflow and outflow pattern is expected from the imported feeds that surged in ZG and semi-intensive (SI) categories also delivered P. In contrast, the HD and FE categories in which feed inflow channels were dismal also displayed low P values. The highest inflows to outflow ratios were in ZG and to some extent TE implying accumulation of P stock in these categories. This scenario implies superiority of these categories in terms of sustainable land productivity assuming that the stocks are put to rational use up to the Land level.

The lower magnitudes of P than N values in corresponding flow channels is a natural phenomenon and has also been observed in other studies in and outside Uganda (Guerts *et al.*, 1999; Baijukya and De Steenhuijsen, 1999; Walaga *et al.*, 2000; Zake *et al.*, 2002; Bekunda and Manzi, 2003). Clearly, plant materials invariably contain limited quantities of P, and hence are not dependable sources of the nutrient for cropping systems. Nevertheless, the high inflow to outflow ratio in ZG signals sequential accumulation, hence contrasting with the FE and HD categories both of which had the lowest ratios.

Clearly, P management in all categories is important to achieve the desired sustainable productivity within the dairy systems. While rational management of the growing P stocks in ZG and TE is necessary, strategic sourcing and use of P inputs is imperative for the other categories. Unfortunately, P cannot be sourced from *in-situ* natural systems such as, is he case in biological nitrogen fixation (BNF) for N. Externally sourced P inputs are inevitable, with the exception of the ZG and TE categories. One of the best sources of organic P is *Tithonia diversifolia*, a wild sunflower plant widely spread in EastAfrica (Nziguheba *et al.*, 2004). This plant is known for accumulation of P in circumstances where other plants lack access to P (Nziguheba *et al.*, 2004). Smallscale dairy communities in the disadvantaged categories could benefit from this source of P. The harvest channel ($H1_o$) remained the major outlet for P, demonstrating a clear need for regular nutrient replacement in Farms.

(c) Farm K inflows and outflows

The similarity in trends for the Farm K inflow and outflow channels with those for N and P above again demonstrates that movement of the nutrients was concurrent. The off-farm feed channels ($F11_o$ and $F12_o$) still remained the gateways for K into the Farms, with the greatest enrichment (high inflow to outflow ratio) in the SI category. This implies a consequential build up of K stocks in this category. Like in the case of N, rationalised use of the stocks within the Farm is necessary to avoid waste and contamination of the environment. Potassium, like N, is highly soluble and mobile, especially in the tropical CEC-limited oxisols and ultisols (Sanchez *et al.*, 1997).

For the non-K-endowed dairy categories (FE and HD), which are less dependent on off-farm imported materials such as feeds, use of external K resources is definitely inevitable to avoid K depletion from the Land. Again unlike N, K has no known natural *in-situ* sources. It has to be imported into the Farm through organic or inorganic inputs, or intercepted by deep rooted plants from the leached stocks, where they exist. Coffee husks, tobacco leaves and wood ash are known sources of K (University of Rhode Island GreenShare Factsheets, Online: www.uri.edu/ce/factsheets/prints/nutorgprint.html), and most of these are residues available in the study areas. Multi-purpose trees such as *Calliandra calythorsus* are known to draw nutrients from soil depths and avail them to companion crops (Oluka-Akileng *et al*., 2000). These could be utilised as well.

(ii) Land N, P and K inflows and outflows

(a) <u>Land N inflows and outflows</u>

The relatively higher levels of N flow into the Land in both the TE and ZG categories than others are due to restrictive Farm sizes (Table 6) from which major inputs such as mulch could not be obtained in adequate quantities. This left the farmers of these categories with no alternative option but to source the materials from outside the Farms and, consequently, the Land. Under the circumstances, it is clear that nutrient input into the Land will for sometime remain from external sources. However, the eventual build up in the Land needs to be monitored and the stocks utilised wisely for sustainable productivity with the overall aim of curtailing the need for further imports.

The superiority of BNF as a N input channel into the Land is clear (Table 12) and merits management focus. This is because enhancement of this natural channel is noble in light of the subsistence nature of the farmers who invariably lack capacity to purchase and utilise externally sourced traditional fertilisers ($P1_i$ in Table 12). This channel can be enhanced through strategic inclusion of high potential BNF legumes, with high fodder quantity within the pastures. Further enhancement of this N import channel could be through targeted use of inexpensive legume species specific Rhizobia inoculants currently available in the country (Makerere University). For the HD and FE categories, this BNF strategy is often difficult to draw capital from. This is so especially for the HD category in which the communal approach to utilising pasture resources provides no incentives for practice of nutrient management. For the FE category, inclusion of self-seeding stress resilient legumes in pastures is the best option.

In the ZG category, a variety of legumes were used; the major ones were Lablab, Calliandra and Mucuna. These are renowned high level N fixers, ranging from 30 to 50 kg N ha^{-1} $year^{-1}$ (AABNF, 2001). A similar significant BNF contribution to N input (22%) on small-scale farms in Uganda was reported by Nkonya *et al.* (2005).

The large quantities of fodder removed from the Land in the ZG and SI categories are responsible for the observed high N outflows from these categories. Fodder harvests from the ZG and SI study farms amounted to 2120 and 1490 kg (DM) $ha^{-1}season^{-1}$ of total farm land compared to 60 and 180 in the HD and TE categories. The higher values for N removals from the Land through grazing in the FE and SI categories relative to other categories occurred because there is profound dependence on on-farm pastures within these categories. In contrast, there was no record of on-farm grazing within the ZG category, where livestock are exclusively fed on "cut and carry" feeds hence, the zero values within this category for outflows through grazing.

The large quantities of N in the crop harvests outflow channel from the Land in the ZG and SI categories, fit into the Farm level explanation advanced earlier in this thesis (Section 5.4.1 (i) (a)). Low quantities of N outflows in crop harvests from the Land in the HD, TE and FE categories are attributed to lower numbers of crops in Patches with approximately 2 in comparison to 3 crops per Patch in the ZG category. Furthermore, use of crop residues for livestock feed in the HD, TE and FE categories is relatively low and amounted to 334 kg (DM) $season^{-1}$ compared to 1313 kg (DM) $season^{-1}$ in the ZG and SI categories. This implies that large quantities of crop residues are left in the fields in the HD, TE and FE categories while, the contrary occurs for the ZG and SI categories. It is critical that in the categories where crop residues are removed from the Land, alternative materials to replace lost nutrients be sought and put on the Land to prevent soil fertility degradation. Manure, mulch obtained from forests, bushes and swamps and inorganic fertilisers can be used for this purpose.

Among the outflow channels, large quantities of N from cattle feed deposited as manure in kraals ($F5_0$ in Table 12) are expected as livestock only use a proportion of the nutrients in the feed. As such, if manure is left un-utilised large quantities of N are wasted. This also presents dangers of pollution when manure is allowed to accumulate. Overall removal of substantial quantities of N from the Land through crop harvests occurs because, within all the farm categories, household food needs are met primarily through home grown food. Sales of crop produce are also made when harvests are in excess of the household needs, a practice which supplements the often insufficient household incomes. On the longitudinal study farms quantities of seasonal food crop harvests were high ranging from 1800 to 4200 kg (DM) household^{-1} season^{-1} across the farm categories. This infers that an appreciable extent of crop cultivation is required to meet both household food needs and additional household income resulting in substantial N outflows from the Land. Nitrogen removal from the Land, therefore, through crop harvests is inevitable and the only way to counter this is through replacement of lost N to avoid land degradation. Manure and compost application, use of legumes and inorganic nitrogenous fertilisers can be used for this purpose.

The high N inflow to outflow ratio in the TE category is quite commendable in that this system promotes N build up at Land level. This is in direct resonance with the Farm level (Table 9) in which TE led the other categories in this respect. At Land level, however, ZG was third in ranking hence, contrasting with the Farm level where it was second. The direct link between Farm and Land N enrichment in terms of the ratios for TE, implies that the gains in N stocks at Farm level are, to some extent, transferred to Land level, suggesting some level of nutrient management efficiency in the TE compared to other categories.

On the other hand, for the ZG category, the lowest Land inflow to outflow ratio (Table 12) deriving from a very large ratio at Farm level (Table 9) suggests a hold up of N on the Farm. This also implies that the ZG category is more dependent on external N sources and less on BNF. It also points to high potential for pollution resulting from continuous N accumulation without appropriate utilisation or disposal mechanism. Clearly, although ZG attracts plenty of nutrients from external sources, their management is sub-optimal and leads to unsustainable productivity of land resources. In contrast, the SI category with a very low ratio of N inflow to outflow depends greatly on on-farm grazing and feed resources. This is aggravated by minimal recycling of farm nutrients particularly the return of manure to the fodder and crop fields. Evidently, it is necessary that practices in the SI and ZG categories be adjusted to enhance management of N. This could be through, returning manure to fodder and crop fields; increasing off-farm inputs to the Land and systematic inclusion of legumes in crop mixtures.

(b) Land P inflows and outflows

The smaller overall quantities of P within flows, relative to N, is a natural phenomenon owing to the low P quantities in plant and other organic materials which are the main conduits for nutrient flow on the study farms. In general, while N concentration may exist in proportions as high as 2.9% in organic materials, P is only known to be highest at 0.35% (Appendix 7).

Like in the case of N, Land P inflows were greatest in the TE category. As such, similar explanations presented for N (Sections 5.4.1.(ii) a of this thesis) could be advanced in this case as well. The explanation for the larger quantities of P inflows within the channel for on-farm manure application ($P2_i$) rather than applications from off-farm ($P1_i$) is that, P concentration in manure of approximately 0.6% (Snijders and Wouters., 2003), is higher than in most mulch materials of about 0.3% (Appendix 6). Moreover, mulch was the main input to the Land and materials used for this purpose on the study farms tended to be crop residues. In addition, quantities of on-farm manure applied to the Land (4 – 80 kg (DM) ha^{-1} of farm Land) were higher than the off-farm inputs (0 – 19 kg (DM) ha^{-1} of farm Land).

Large quantities of crop harvests, including residues in ZG, remains the reason for highest value for Land P outflows as was observed in N (Section 5.4.1 (ii.) (a.)). In contrast, but also similar to N, the presence of the lowest Land P outflows in the HD category could be attributed to low quantities of crop harvests. Large quantities of fodder harvested for livestock feed elevate the quantities of P in the feed outflow channels ($F21_o$ and $F22_o$). In addition, P concentrations are higher in the major fodder types grown, namely elephant grass (0.22%) and Lablab (0.3%), than overall in the major non-fodder crops grown on the study farms (0.18%) (Van den Bosch, *et al.*, 1998; Wortmann and Kaizzi, 1998; Lekasi *et al.*, 2001; Mugerwa, 2001).

Again, as in N, the TE category, shows highest level of P management through possession of the highest inflow to outflow ratio. This is attributed to less harvests of fodder from the Land in TE than in other categories, while input values are the highest among all categories. On the other hand, SI, had the lowest Land P inflow to outflow ratio indicating poor management of P, mainly resulting from large quantities of P removals from the Land through fodder harvests and grazing, and minimal inputs. Evidently, there is minimal purposive effort to replace P lost from the Land, particularly, in the SI category. Continued poor management of P will eventually lead to its depletion in the soil. To prevent this, manure should be returned to fodder fields and a proportion put on the crop fields where crop residues are obtained for livestock feed. Also use of plants such as *Tithonia diversifolia* with the potential to build up stocks of available P in the soil is a valuable practice (Nziguheba *et al.*, 2004). Other inputs from off-farm include inorganic fertilisers, additional manure and compost.

(c) Land K inflows and outflows

Quantitative superiority of K Land flows over N and P is attributed to general concentrations of K in the flow materials (1.9%) being largest in comparison to N (1.6%) and P (0.3%). Land K inflows were highest in the TE category as in N and P cases with the largest contribution from application of on-farm manure. Hence, the reason advanced for this in the case of N (5.4.1 (ii.) (a.)) is also relevant here. The general tendency for superiority of on-farm manure application inflows over off-farm inputs applications is attributed to the relative ease of accessing on-farm manure compared to off-farm inputs. Sourcing off-farm inputs such as, mulch, manure and inorganic fertilisers requires time and in most cases financial resources which many smallholder resource poor farmers lack. It is, therefore, most practical to depend more on available on-farm than off-farm nutrient resources. Also, as with the case of P, the concentration of K in manure is higher than in most mulching materials, which were the major component of the off-farm inputs (Section 5.4.1 (ii) (b.)).

Among the Land K outflows, the large quantities of K exiting through the feed channels was a tendency observed also in the case of P and has been discussed in Section 5.4.1 (ii) b. However, grazing flows being the lowest among the Land K outflows is attributed to the subsequent replacement of K through manure dropped by the grazing animals. This is in view of the fact that approximately 85% of ingested K is excreted in manure compared to 75 and 80% in N and

P (Wells *et al.*, 1997). Furthermore, unlike N lost from the manure dropped in grazing areas through volatilisation when exposed K losses are insignificant (Wortmann and Kaizzi, 1998). Clearly, categories with a component of grazing inevitably have substantial nutrient recycling on their farms, with minimal effort, through the livestock. This reduces on labour that would have been committed to returning manure to the grazing areas. In this respect, the FE category offers a sustainable option which could be adopted to an extent by the other categories. However, land limitation is a critical problem, particularly, in the ZG and TE categories where land for grazing pastures is unavailable. In this case, a feasible strategy involves grazing of livestock in crop fields in the dry season after harvest of crops. The livestock feed on the crop residues and drop manure on the fields. This practice is commonly used in West Africa (De Ridder *et al.*, 2004; Powell *et al.*, 2004). Another option for harnessing manure with minimal labour input, is through regular relocation of the livestock kraal or night boma and using the previous kraal site for cultivation. This practice referred to as "mobile cattle pens" (Walaga *et al.*, 2000) is said to be common in Pallisa and Kumi districts in eastern Uganda.

Large disparity existing between the highest Land K inflow to outflow ratio in TE and the lowest in SI could be attributed to harvests of large quantities of elephant grass from the Land for feeding cattle on SI farms. Concentration of K in elephant grass (2.4%) (Lekasi *et al.*, 2001) is high compared to the overall mean (1.9%) for the plant materials harvested on the farms. Elephant grass was harvested on a daily basis on farms within the SI category to feed livestock in quantities of approximately 8 kg (DM) farm^{-1} day^{-1}. This based on Lekasi *et al.* (2001), contained approximately 0.2 kg N farm^{-1}day^{-1}. Unfortunately, the quantities of inflows to the Land reflect insignificant amounts of manure returned from the livestock to the fodder fields, yet this should be done to avoid depletion of K from the soil.

5.4.2 Farm and Land Nutrient Balances

(i) Farm and Land N balances

Extremely large N influxes into farms in the ZG category through off-farm feeds, accompanied by unmatched N removals from the farm are responsible for the high Farm N balances (Table 15). This situation could potentially endanger the environment as possible leakages into resources are prone to occur. However, positive balances do not necessarily infer nutrient excesses unless the soil has reached saturation levels. Continuous nutrient assessments would provide information on quantities of available N that should be applied and amounts that should be transferred to other areas with deficits. Knowledge of how much manure, for instance, is in excess and could thus be passed on to neighbours would be obtained from these kinds of assessments.

The negative Farm N balance values within the FE and SI categories could be rooted in the management systems used, which include minimal use of off-farm nutrient endowed inputs. These farm categories, therefore, are prone to N depletion and if this trend is not halted, system productivity will diminish gradually. In this case, a nutrient management assessment framework would be vital for informing farmers the quantities of N that would be required on their farms from external sources to, at least, off-set the observed imbalance.

Large negative values among the $Land_{FC+UC}$ N balances indicate that the UC outflow channels are responsible for removal of large quantities of N from the Land. Large N losses through UC outflow channels were observed also in previous studies amounting to 25 kg ha^{-1} year^{-1} through leaching, 6.2 kg ha^{-1} year^{-1} through denitrification and volatilisation (Wortmann and Kaizzi, 1998) and 4.6 kg ha^{-1} year $^{-1}$ (Zake *et al.*, 2002) through erosion. It is important that N losses through various channels is minimised in order to benefit the dairy systems in Uganda.

With regard to the TE category, the maintenance of a positive Farm and Land N balances could be attributed to substantial use of off-farm inputs and comparatively less removals from the Land (Tables 9 and 12). This suggests that the management practices used within the TE category are noble for nutrient management. However, the fact that the Land N balance is still lower than the Farm balance is an indication of inefficient utilisation of the N stocks that build up in the farms from external sources. In contrast, the high negative Land balances in the SI and ZG categories are linked to large fodder harvests from the fields as shown by the feed flows (Table 12).

The lower values for the Land N balances than Farm N balances (Table 15) is again an indication of inefficient utilisation of available N stocks on the farms. This tendency was, in fact, evident in all the farm categories; though most prominent in the ZG category where the largely positive Farm N balance was turned into a largely negative value at Land level. This could be linked to neglect of manure application on the Land yet large quantities of manure within this category result from imported off-farm feed. Furthermore, continuous harvesting of fodder from the Land with minimal return of nutrients to the fields also contributed to the negative net N balances. This situation, was consistent with that observed in previous studies (Walaga *et al.*, 2000) in Kabarole district in Uganda, where livestock fodder was mainly grown on-farm and only small quantities of feed materials were obtained from off-farm.

(ii) Farm and Land P balances

The modest positive values among the Farm P balances (Table 16) are not very surprising because, unlike N, P from external sources builds stocks since it does not leach from the soil system. This is consistent with previous studies by Wortmann and Kaizzi (1998) and Nkonya *et al.* (2005), where P balances were characterised by more positive values than N and K. Hence, there is less risk of P depletion in the dairy systems. Management of P among the dairy farm categories, therefore, appears to be less demanding than management of N.

The superior Farm P values in ZG (Table 16) appear to be a result of the sequential quantities of P imported through off-farm feeds. Contrastingly, small quantities of off-farm feeds as well as off-farm inputs in FE are responsible for presentation of the lowest Farm P balance values. In this case, like in N, off-farm feeds are a dual purpose resource meeting livestock feed requirements and providing a source of soil nutrients. Like in N, there is a need for proper utilisation of imported P. Fortunately, unlike N, dangers of pollution from accumulated P are less due to lower concentrations of P compared to N in most of the plant materials moved on the Farms.

The higher $Farm_{FC+UC}$ P balances than their $Farm_{FC}$ counterparts (Table 16) is a result of immobility of P which, unlike N, is not lost from the soil through leaching. This renders P more manageable than N. Nevertheless, P management within the production systems is still essential particularly where soils are already deficient in the nutrient.

The highest $Land_{FC}$ P balance in the HD category (Table 16) is owed to generally low quantities of P outflows. Obviously, from the Land inflows and outflows (Table 13), HD appears less demanding on P than the other categories. Nevertheless, like all the other categories, its $Land_{FC}$ P balance is negative and additional effort is required in use of farm and external nutrient resources to off-set these imbalances.

$Land_{FC+UC}$ P balances, as at Farm level, were again higher than their $Land_{FC}$ counterparts. This continues to demonstrate inefficient use of Farm P as was the case with N.

(iii) Farm and Land K balances

Potassium influxes through the off-farm feed channel, as in N and P, continued to account for highest values of Farm K balances in the ZG category (Table 17). Again FE had the lowest Farm K balance due to low quantities of K imports in feeds as well as off-farm inputs. Superiority of the $Farm_{FC}$ K balances over the $Farm_{FC+UC}$ in the HD, TE and SI categories and the contrast in the FE and ZG categories was likely a result of differences in environmental factors particularly rainfall, terrain and soil texture. These influence the UC flows causing an overall reduction or increase in the computed balance. It is imperative, therefore, that farmers get substantial knowledge on the effect such environmental factors can have on nutrient stocks and how to offset the causative factors.

The highest Land K balances in the HD and FE categories (Table 17) resulted from low quantities of both K inflows and outflows in these 2 categories compared to the rest. This is because both of these farm categories use grazing management systems for their livestock, which comparison to the "cut and carry" systems remove less K per unit area. Furthermore, the grazing systems have provision for return of nutrients to the grazing fields through dung and urine deposited as the animals graze. In contrast, large quantities of on-farm feed removed from the Land (Table 15) suppress Land K balances in the ZG category. On-farm feeds removed from the Land amounted to approximately 9 kg (DM) farm^{-1} day^{-1} of which approximately 67% was elephant grass of which 2.4% (Lekasi *et al.*, 2001) was K. Previous studies in Iganga in Uganda, also obtained negative K balances for all farm types (Esilaba *et al.*, 2005) which is consistent with the Land K balances in the current study. Clearly, there is a high risk of K depletion particularly in ZG and SI dairy farm categories. To prevent this, a proportion of manure from livestock must be returned to the fodder fields. In addition, mulching with coffee husks and tobacco leaves releases substantial quantities of K into the soil and can therefore be used to build K stocks in the soil. (University of Rhode Island GreenShare Factsheets, 2005, Online: www.uri.edu/ce/factsheets/prints/nutorgprint.html).

(iv) ***Differences between Farm$_{FC}$ and Land$_{FC}$ balances***

The ZG category, demonstrated the most inefficient use of nutrients obtained from off-farm sources. Hence, the highest values for the differences between N, P and K Farm and Land balances were in this category. The ZG category had large quantities of nutrient inflows into the Farms, through off-farm feeds, which resulted into large quantities of manure. However according to the Farm and Land inflows (Tables 9 - 14), only 2% of total farm manure in ZG was transferred to the Land.

In contrast, the lowest values for the difference between Farm and Land balances in the HD category are owed to minimal off-farm feeds. In addition, livestock, in this category graze in open pastures, hence reducing instances of manure deposits in kraals. Moreover, approximately 16% of the total manure deposited in the kraals is applied to the Land (Tables 9 and 12). The HD dairy farm category, therefore, shows highest efficiency in terms of nutrient management in comparison to the rest. Nevertheless, even the nutrient management situation in the HD category is still sub-standard. Poor utilisation of N and K were more rampant than that of P because N and K exist in larger concentrations in the study farm materials in comparison to P. Outstanding differences in K Farm and Land balances in the ZG and SI categories are attributed to dependence on elephant grass for livestock feed in comparison to the other categories. The elephant grass results in large quantities of K in manure deposits, which are apparently underutilised.

Definitely, utilisation of N, P and K within each of the dairy farm categories is inefficient. Similar observations were made by Wortmann and Kaizzi (1998) in previous studies in which manure management in all study locations was poor with infrequent removal from kraals and poor application methods. Systematic recycling of nutrients, particularly manure, will contribute significantly towards reducing or offsetting the N, P and K Land imbalances observed in this study. However, effort towards manure utilisation should be mindful of the potential pollution that can result from excessive application of nutrients to the land. Therefore, nutrient management programmes for assessment of farm status and options for improving nutrient balances and stocks, should also include strategies that provide inference on ceiling levels for the nutrients within various circumstances. Furthermore, proper methods of application should be emphasised to minimise nutrient losses and leakages into water bodies.

(v) Dominant crop patterns across dairy farm categories

Prominent presence of banana based crop patterns on Patches within all categories is attributed to the fact that bananas are generally staple food in most of study areas. In addition, bananas are a source of income and, because of their perennial nature, provide for extensive intercropping. The Banana-Beans crop pattern in particular, provides basic household food requirements and therefore, it is not surprising that it was present in all farm categories.

The greatest diversity of crop patterns present in SI compared to other categories, is attributed to the cattle management system used which includes both grazing and utilisation of "cut and carry" feeds. The presence of fodder based crop patterns established to, simultaneously, provide feed for the livestock and food for human consumption as well as pastures for grazing contribute to the existing wealth of crop patterns within the SI category. Unlike SI, the ZG category was composed of the fewest number of crop patterns due to limited farm sizes. However, it should be noted that, the absence of any fodder based crop pattern within the ZG category (Table 19) does not mean that fodder was absent on the farms. In fact, the patches within the ZG category had fodder, but the patches were excessively intercropped with many different crop types and only the major crops in the mixtures were used in naming the crop patterns. For details on all crop types within the different crop patterns refer to Appendix 8.

(vi) Crop pattern N and K balances (FC balances only)

Positive N balances for Beans-Maize and Bananas-Beans are a result of N fixation by the beans. Wortmann and Kaizzi (1998) and Zake *et al.* (2002) also obtained positive N balances for some of the bean and groundnut fields in previous studies in Uganda. The superiority of the Beans-Maize crop pattern in N balance is attributed to both BNF and the generally low quantity of N removed from the patches by maize compared to, for instance, bananas. Lowest N balance for the Fodder crop pattern within the SI category results from excessive fodder harvests which involved removal of the whole plant shoot and leaves from the fields and in this case with minimal nutrient replacements.

The occurrence of the highest K balance in the Pasture crop pattern, largely associated with the less intensive systems, is due to the in-built mechanism of nutrient replacement whereby grazing animals deposit dung and urine in pastures. Moreover, these deposits may include nutrients from off-farm feeds and grazing allowing increase of nutrient stocks in the pastures. The explanation for the most negative K balance being that for the Fodder crop pattern is similar to that advanced in the case of N balance. Large negative K balances for fodder match results obtained by Esilaba *et al.* (2005) in Iganga in eastern Uganda.

Clearly, crop patterns have a bearing on nutrient fluxes and balances. As such, there is a need for farmers to have knowledge of nutrient management concerns and benefits related with different crop patterns in order to make feasible decisions. The practice of crop rotation, for instance, when organised strategically may lead to control of excesses of inflows or outflows of specific nutrients. This would otherwise go unchecked where the same crop is grown continuously on the same piece of land.

The nutrient mining situation in the Fodder crop pattern, which is associated with intensive systems, demonstrates imprudent use of nutrient resources which could lead to nutrient depletion. Nutrient replacements could be in terms of manure, crop residues, compost or inorganic fertilisers. Including legumes in crop mixtures is one strategy that can be used to build N stocks. However, this is likely to be achieved on soils where N is not excessively deficient and rhizobia compatible with the planted legume are present.

5.4.3 Soil Fertility Status within Farm Categories

Severe deficiency of N in the soils is clear indication of the effect of the generally negative Land balances observed (Tables 15). The Land P balance values (Table 16) are generally the highest compared to N and K and again P is not limiting in three farm categories hence suggesting a certain degree of sustainable maintenance of P stocks in the soil. Similarly, P in the soils is below the critical level in the ZG and SI categories where Land P balances were most negative (Table 17). Although soil values showed K to have higher values than the critical limit, the negative Land balance values obtained in the study (Table 17) suggest long term lack of sustainable supply for the nutrient.

The K situation here is consistent with comments indicating that K in Sub-Saharan African soils is the least limiting in comparison to N and P (Sanchez *et al.*, 1997; Smaling *et al.*, 1997). However, continued removals of K through cultivation of, particularly, root crops and bananas, with high K off-take can result in K depletion (Sanchez *et al.*, 1997) especially when inputs to the land are lacking. There are indications therefore that nutrient balances could provide inference on available soil nutrient levels. However, of critical importance, is the need to improve management of N through nutrient recycling, BNF and soil organic and inorganic inputs to prevent further depletion and rather begin increasing N stocks in the soil. To ensure this, specific tools with the ability to provide inference on nutrient status as a baseline for intervention, are required. Indicators of nutrient balances provide an appropriate tool for this purpose; hence, they were accorded precedence in this study.

Clearly, the values obtained for the years to depletion indicate that Farm Categories with the largest negative land N balances are not necessarily at highest risk of depletion. For instance, although SI has the most negative Land N balance, ZG required a shorter period to depletion than SI. This is attributed to the higher N stocks in SI than ZG and conforms to the discussion advanced by Walaga *et al.* (2000). High risk of depletion in ZG can be averted by efficient use of manure in crop and fodder fields, exploit the BNF channel and application of inorganic fertilisers.

5.4.4 Indicators of N, P and K Balances

The number of indicators influencing a balance was directly related to the balance values (irrespective of the positive or negative sign) at Land level; for instance, K balances with largest number of indicators also had the largest Land balance values (Table 17). In contrast, P balances had the lowest number of indicators as well as the lowest Land balance values (Table 16). Similarly, the values for the indicator coefficients were related to the values of the Land balances. As such, the indicator coefficients for K balances had the highest values, while those for P had the lowest.

The presence of more negative than positive effects among indicator coefficients for K was the ultimate reason for the large negative K balance values. On the other hand, N and P; which had smaller negative values than K, had more positive than negative effects among their indicator coefficients.

The demonstration of very strong negative influence of HvGz on N, P and K balances is evidence that harvesting of crops and fodder and grazing are major channels for nutrient losses from the Land. In contrast, the strong positive effect of Mn on the Land balances clearly indicates the high value of manure as a source of nutrient input to the Land.

The reason for the small positive effect of LI on P balance is not clear, however, it could be attributed to lower P content in legumes compared to other crops. This is based on the P composition in the legume grains and the residues of average 0.19% compared to the general crops average of 0.28% (Appendix 7b).

The positive and negative influence of SP crop on N and K balances respectively could result from a number of factors. The positive influence on N balances is suspected to be a result of the low quantities of N in most of the components of the sweet potatoes (Appendix 7b) apart from the vines which are sometimes left in the fields once the tubers are harvested. The negative influence of this crop pattern on patch K balances could result from the large K requirement for sweet potatoes with K concentrations of up to 11% in some of its components (Appendix 7b).

5.5 CONCLUSIONS

In conclusion, the dairy farm categories developed and, therefore, intensification have inference on Farm and Land N, P and K balances. Dairy intensification has a positive effect on Farm nutrient balances. This is demonstrated by the consistent superiority of Farm balances in the most intensive categories; ZG and SI, and the lowest in the less intensive dairy farm categories; FE, HD and TE. High Farm balances in the more intensive categories occur as a result of sizeable quantities of nutrient influxes through off-farm feeds, which was not the case in the less intensive categories.

Dairy intensification has a negative effect on Land N, P and K balances, which is in contrast with the situation at Farm level. This is shown by the consistently lower Land N, P and K balances in the more intensive categories; SI and ZG, in comparison to those in the less intensive categories; TE, HD and FE. The low Land balances in the more intensive categories occur as a result of substantial nutrient removal through fodder harvests from the Land, without replacements. On the other hand, the less intensive HD and TE categories, partly, depend on off-farm feed resources. More farm Land in these categories is committed to food crops, which remove less nutrients from the Land than fodder. Furthermore, where on-farm grazing is done in HD and TE, nutrients are replaced through dung and urine deposited by the grazing animals.

Utilisation of manure in all the farm categories is inefficient as demonstrated by the higher Farm balance values than those for Land balances. This situation is most severe in the more intensive categories (SI and ZG), where there is failure to redistribute large quantities of manure from the kraals to the Land.

The Fodder Crop Pattern, depletes N, P and K from the soil while, the Beans-Maize and Banana-Beans raise N balances due to BNF.

Indicators of N, P and K balances are Banana-Beans (BB), Pasture (Pa), Coffee-Fodder (CF), Legume Intercrops (LI), Sweet Potato (SP) and Fodder (FC) crop patterns, quantities of materials leaving the Patch in harvests and grazing as a proportion of the total from the Farm in the season (HvGz), proportion of the Patch in the Plot (PP) and quantity of manure applied to the Patch as a proportion of total manure produced on the Farm in the season (Mn). These indicators can be used to obtain inference on Patch N, P and K balances. The indicators are also valuable for deriving options for improving nutrient management. These options would seek to maximise those indicators with positive effects on the balances and minimise, where possible, indicators with negative effects.

One limitation with regard to the indicators, however, is that they can only include those factors among the activities and management practices of the study farms. Hence, methods scantily used or absent on the study farms cannot feature among the set of indicators, notwithstanding, common knowledge of their value in nutrient management. In this study, for instance, there was no recorded use of inorganic fertilisers; therefore, it can not feature as an indicator of nutrient management. Also instances of use of crop residues for mulching were too few and possibly as a result had no significant effect on the nutrient balances.

Finally, it is recommended that improvement of nutrient balances within the dairy farm categories be enhanced through two major approaches, (i) efficient use of existing farm nutrients, particularly manure, and (ii) biological N fixation (BNF). However, appropriate utilisation of farm nutrients demands the ability to estimate nutrient input requirements. The indicators identified in this Chapter and their coefficients are suitable tools for achieving this as demonstrated in Chapter Six of this thesis.

CHAPTER SIX

CATTLE MANURE UTILISATION FOR MAINTENANCE OF N BALANCE AND ENHANCEMENT OF ELEPHANT GRASS AND BANANA PRODUCTION

6.1 INTRODUCTION

The nutrient balance indicators described in Chapter Five are of value not only for assessing nutrient balances, but also in identifying strategies for obtaining desired nutrient stocks. This is possible through assembling the indicators and their coefficients into a mathematical function which predicts the nutrient balance. Different nutrient management scenarios can be tested by shifting the levels of the indicators to identify those scenarios that present viable options. This approach provides a valuable tool, particularly, where a wide variety of indicators are included in the function given that each indicator may provide a set of options for improving nutrient balances.

The use of such tools in identifying suitable nutrient management options will be instrumental in preventing land degradation and pollution of natural resources. Furthermore, it is critical to relate options for improvement of nutrient management with expected effects on crop and fodder yields. This provides a complete scenario of the implications of defined nutrient management improvement strategies. This type of approach was used by Wortmann and Kaizzi (1998) where expected changes in crop yields with implementation of specific nutrient management methods were presented. In that study, however, fodder crops were not included in the final yield analyses. The current study focuses on fodder crops considering that among all the crop patterns, they had the lowest N, P and K balances (Tables 20 - 22) and yet, fodder is a major source of livestock feed in intensive systems.

Establishment of relationships between nutrient balances, nutrient management improvement options and crop and fodder yields in form of a decision support tool, will be very useful to farmers, policy makers and extension advisors (Mutert, 1995). Furthermore, such tools provide opportunity for researchers to test suggested research strategies in aspect of production system sustainability.

In this study, emphasis on nutrient balance improvement was placed on N as it was found to be the most lacking in the soil (Table 23). Similarly, major options for N balance improvement were limited to manure use because manure emerged as a major indicator with positive influence on all nutrients; N, P and K (Table 24). Moreover, manure was the most available nutrient resource in all categories and was not efficiently used. In this respect, it was seen as critical, that efforts should, at least, be made to maintain a zero net balance as a starting point towards improving nutrient management. Definitely, maintaining a zero net balance is not adequate for sustaining productivity in the systems and, as such, in the long term strategies for building nutrient stocks have to be developed. This study, therefore, deemed it necessary to provide strategies within the different dairy Farm categories for maintaining zero net N balances using available manure.

Effect of nutrient management improvement on yield was focussed on bananas, a major food and cash crop within all the farm categories (Table 19), and elephant grass (Napier grass), an important source of feed within the more intensive farm categories. The purpose of this study, therefore, was to provide approaches to restoration of N in the negative N balance using cattle manure which was a major by-product in the dairy systems for which there was no immediate alternative use on Farms; and the subsequent effects on yields of bananas and elephant grass.

6.2 Materials and Methods

The data generated in Chapter Five on indicators of nutrient balances constituted the inputs towards this particular study. In order to achieve the objectives of this study, three major equations were developed. The following sections describe the structures of the equations as well as their respective functions and outputs.

6.2.1 Prediction of Manure Requirement to Remove N Deficits

The quantities of manure required to offset the N imbalances for different scenarios were predicted using Equation 26 developed from the indicators identified and their coefficients obtained from the mixed models analysis (Table 24). The basis for prediction of the quantity of manure requirement was the elimination of N imbalance, that is, attainment of 0 $kgha^{-1}season^{-1}$ net N balance. This prediction was done at Patch level within each farm category and subsequently extrapolated to the Land level.

Equation 26:

$$\sqrt{Mn} = (NB + 20.4 - 2.33\ BB + 3.88\ CC - 8.38\ Pa + 33.71\ CF + 1.35\ BI - 13.58\ LI - 4.28\ SP + 27.77\ FC + 93.07\ HvGz - 20.77\ PP - 6.82\ \sqrt{CR}) / 78.36$$

Where: NB = N patch balance (kg ha^{-1} $season^{-1}$) DM basis; BB = Banana-beans; CC = Cereals, cassava and general intercrops; Pa = Pasture; CF = Coffee-fodder intercrops; BI = Banana intercrops; LI = Legume based intercrops; SP = Sweet potatoes; FC = Fodder crops; HvGz = Quantity of material leaving the patch in harvests and grazing as a proportion of total from farm; PP = Patch area as a proportion of the plot; CR = Quantity of crop residues applied to the patch as a proportion of total crop residues applied on the farm (square root); Mn = Quantity of manure applied to the patch as a proportion of total manure produced on the farm (square root).

The value of manure input required to offset N imbalances obtained from Equation 26 is a proportion of the total manure produced on the Farm in a season. This value was generated for each study Farm. Category means were computed from the values obtained from the equation for the farms in each category. The manure proportion required at Land level in each category (TMn) was obtained by first establishing the number of Patches per Farm per season in each category (Pc) and then multiplying this with the proportion (Mn) obtained from Equation 26. Total manure quantity (kg (DM)) produced on the Farms in a season for the different categories was obtained using manure production rates from Haileslassie *et al.* (2005), which put daily manure production of a cattle TLU at 3.3 kg (DM) (Equation 27).

Equation 27: $TMq = TLU \times 3.3 \times Ds$

Where: TMq = total manure quantity in kg (DM) produced on the farm in a season; TLU are the total cattle TLUs on the farm; and Ds = Number of days in the season (180 days in this case).

The product of TMq and TMn provided the total manure quantity required on the Land (TMreq) in each Farm within the different categories to offset N imbalances. Farm categories where available farm manure was not adequate to eliminate N imbalances were identified. Quantities required to add to the existing farm manure resources to offset the imbalance were obtained through the difference between TMreq and TMq.

6.2.2 Prediction of Yield Response to Manure Application for Banana and Elephant grass

Yield response analyses for bananas and elephant grass were done using multiple linear regression using "GenStat" statistical package. The crop/fodder yields were treated as the response variates (dependent variables) and the management and environmental factors expected to influence yield as the explanatory variables (independent variables). Separate analyses were done for each crop/fodder. Each independent variable, was included in the regression model in turn eliminating those which had no significant effect on yield ($P>0.1$). Correlation tests between the independent variables was used to avoid colinearity. In this respect, only one member of a pair of variables which were highly correlated was included in the model. The most appropriate model was selected on basis of resemblance to normality of the distribution of the residuals. The major factors influencing yield were used to develop yield response equations for both bananas and elephant grass in separate analyses.

Yield response curves for each crop/fodder were developed by including different manure application levels in the yield response equations, in turn, within the limits of 0 to 1000 kg (DM) ha^{-1} $season^{-1}$. The expected incomes from the yields were also calculated. The manure levels and the yields for both bananas and elephant grass were plotted to produce the curves. Similarly, curves were plotted for the manure levels and expected income (Ushs) from bananas and elephant grass.

Conversion of the banana yields kg (DM) to Ushs was done using the %DM value for bananas, estimated at 20.9% (Appendix 7b) to convert the kg (DM) to fresh weight and assuming that a 30 kg bunch would be sold at approximately Ushs 4000. This was based on information from the study areas. Parameters used to estimate the expected income for elephant grass yield were %DM value for milk (12%), concentration of N in milk (4.1%), concentration of N in elephant grass (1.5%) and the proportion of N in feed converted to milk which was estimated from the study data at approximately 0.1 (not significantly different for the different farm categories, $P>0.05$). Milk price of 400 Ushs litre^{-1} was used. Equations 29-31 were used to obtain the monetary value of elephant grass.

Equation 29: $$Np = \frac{Nf}{Nm_d}$$

Equation 30: $$Nm_p = \frac{((1.5/100)Eq \times 0.1) \times 100}{4.1}$$

Equation 31: $$Me = Nm_p \times 100/12$$

Where: Np = proportion of N in elephant grass converted to milk; Nf = quantity of feed N offered to cattle in the season; Nm_d = N in milk in the season; Nm_p = N in milk expected to be produced from the expected quantity of elephant grass; Eq = quantity of elephant grass expected using the yield response equation and Me = quantity of milk expected to be produced using the predicted elephant grass quantities.

6.3 RESULTS

6.3.1 Manure Requirement to Offset N Imbalances

The largest proportion of manure required on each Patch to attain a zero net N balance was found in the Zero grazing (ZG) Category (Table 25, Appendix 9). This amounted to 52% of the total Farm manure yield in this case. On the other hand, the Tethering (TE) Category had the lowest manure proportion required and this was 9% of the total Farm manure yield.

The proportion of manure required to offset N imbalances for the farm Land (all the farm Patches) was highest in the SI category (Table 25). In this case, the proportion of manure required was 20% above the available quantity. Similarly, HD and ZG categories showed Land manure requirements which were each 4% above the available quantities. Actual quantities (kg (DM)) of manure required beyond that available on the Farms was highest for SI (417), followed by HD (147) and lowest in ZG (17).

6.3.2 Yield Response to Manure in Banana and Elephant Grass

Factors influencing banana yield amounted to seven (Equation 32), while those influencing yield of elephant grass were six (Equation 33). Factors influencing the yields of the two crops were quantities of manure (MN) and crop residues (CR) applied and number of household members above 5 years of age (HH). All the factors influencing yields of both crops had positive effects. Factors influencing banana yield only were season of the year (S3); first or second season, district (MA); either Masaka or not Masaka, proportion (%) of silt in the soil (SI) and proportion (fraction) of the Patch in the Plot. On the other hand, factors influencing elephant grass yield only were soil K in meq per 100 g (K), proportion (fraction) of the Patch in the Farm (PA) and proportion (fraction) of grain legumes in the Patch (GL).

In terms of the factor coefficients, the magnitude of effects was greater among those influencing elephant grass than those for bananas by approximately 5 fold. Generally, coefficients for the positive factors for elephant grass were greater than those for bananas by 84%.

From the yield predictions, manure application caused increase in yields of both banana (Figure 4) and elephant grass (Figure 5). However, increases observed in elephant grass were more than those in bananas, for instance, application of 500 kg (DM) ha^{-1} $season^{-1}$ of manure caused seven times higher increase in elephant grass yield than in that of bananas.

Expected income increment resulting from manure application was higher for elephant grass than banana, despite overall income from harvests being higher for bananas. For instance, yield increase resulting from application of the 500 kg (DM) ha^{-1} $season^{-1}$ of manure is expected to fetch Ushs 717,214 from elephant grass and Ushs 331,853 from banana.

Table 25. Seasonal manure requirements to attain zero Patch Net N balance in the dairy farm categories

Farm categories	Total Farm manure yield in a season	Patch manure requirement (%)	No. of Patches per farm per season	Manure proportion required for whole farm in a season (%)	Manure quantity required for total Land on each Farm (kg (DM))	Manure application rate (kg (DM) ha^{-1} $season^{-1}$)
HD	3678	13	8	104	3825	298.5
TE	1509	9	11	99	1494	1180.7
FE	6587	12	8	96	6323	583.4
SI	2087	15	8	120	2504	1238.6
ZG	416	52	2	104	433	1665.1

Equation 32: Banana yield response equation:

$$\sqrt{BY} = 51.64 + 0.224(\sqrt{MN}) + 0.546(\sqrt{CR}) + 12.32(S3) - 23.58(MA) - 1.059(SI) - 27.87(PP) + 4.73(\sqrt{HH})$$

$\sqrt{BY}$ =	Square root of banana yield (kg ha^{-1} of land covered by bananas)
$\sqrt{MN}$ =	Square root of manure applied (kg ha^{-1} of the Patch land where the bananas are located)
$\sqrt{CR}$ =	Square root of quantity of crop residues applied to the patch (kg ha^{-1} of the Patch land where the bananas are located)
S3 =	Logical variable referring to the season within which the crop is being harvested (1 = the first growing season in the year; long rains, 0 = the second growing season in the year; short rains)
MA =	Logical variable referring to the district (1 = Masaka, 0 = any other district in this case Jinja and Mbarara)
SI =	Percentage of silt in the soil where the crop is grown
PP =	Proportion of the Patch where the bananas are located in relation to the whole Plot
$\sqrt{HH}$ =	Square root of no. of household members above 5 years per ha of crop Land on the Farm

Equation 33: Elephant grass yield response equation:

$$\sqrt{EY} = 69.3 - 177.8(K) + 1.07(\sqrt{MN}) + 0.42(\sqrt{CR}) + 45[\ln(HH)] - 45.11[\ln(PA)] + 65.5(GL)$$

$\sqrt{EY}$ =	Square root of elephant grass yield (Kg ha^{-1} of land covered by elephant grass)
K =	Soil K cmoles kg^{-1}
$\sqrt{MN}$ =	Square root of manure applied (kg ha^{-1} of the patch)
$\sqrt{CR}$ =	Square root of quantity of crop residues applied to the patch (kg ha^{-1} of the Patch)
ln(HH) =	Natural log of the number of household members above 5 years per ha of crop land
ln(PA) =	Natural log of the Patch area as a proportion of the whole farm
GL =	Proportion of grain legumes in the Patch

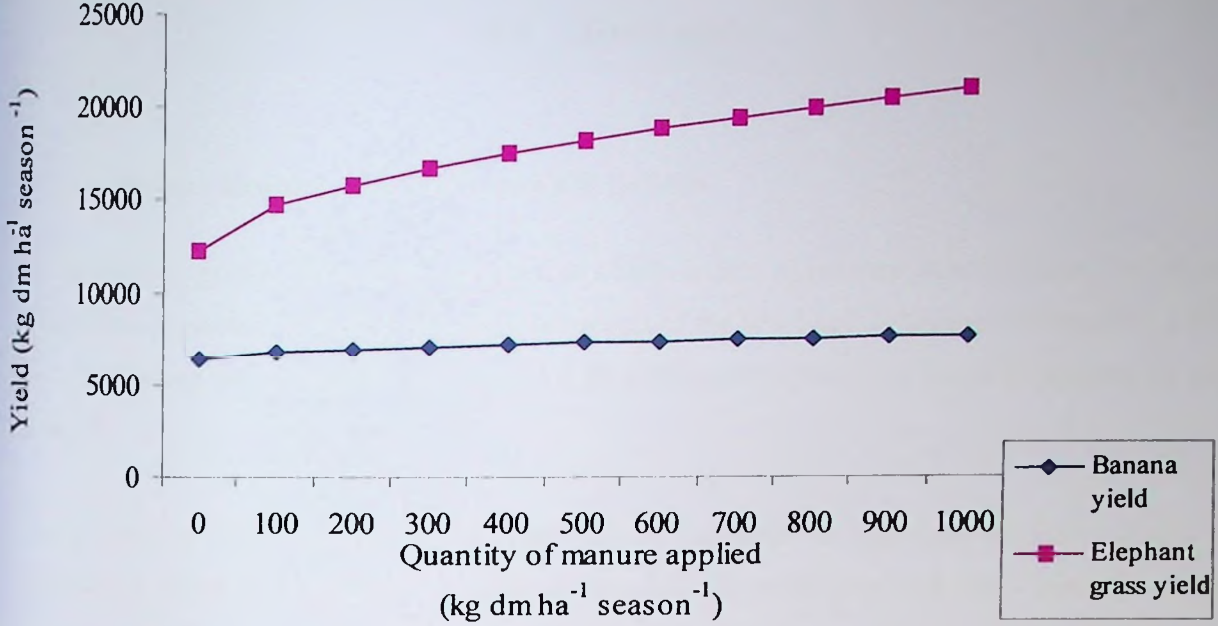


Figure 4. Bananas and elephant grass yield response to manure application.

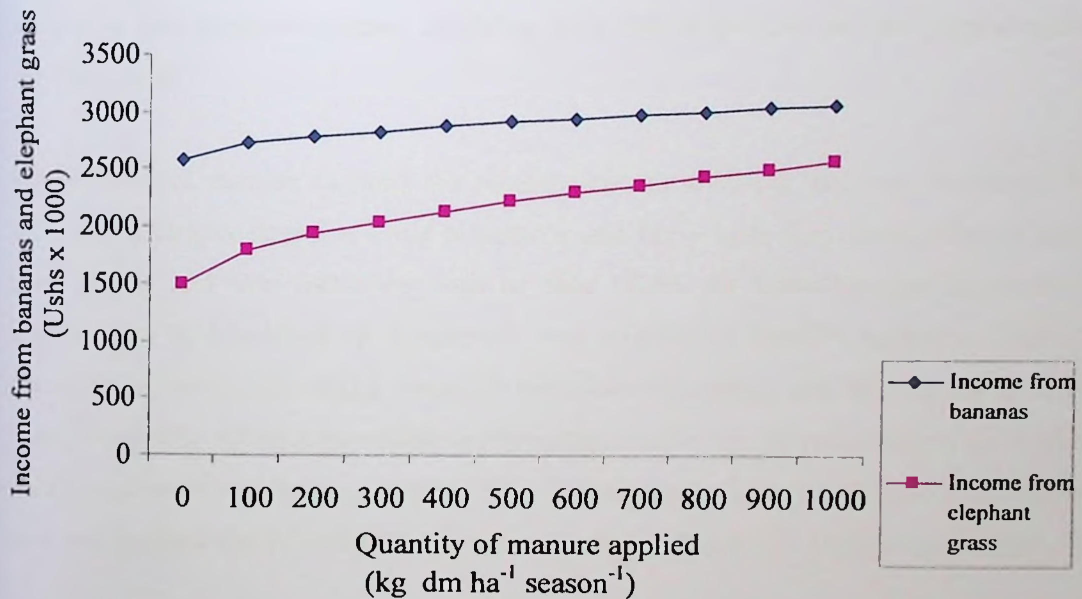


Figure 5. Income from the predicted yields of bananas and elephant grass with different levels of manure application.

6.4 Discussion

6.4.1 Manure Requirements to Remove N Deficits

In terms of proportion of manure required to obtain a zero N balance in each Patch, the largest proportion presented in the ZG category is a result of the low Land N balance observed in Table 16. The lowest proportion observed in TE is attributed to the high Land N balance in this category.

Sufficiency of on-farm manure to meet the N required to eliminate negative Patch N imbalances in the TE category is a result of the relatively small pieces of farm Land, the rather high Land N balance and larger number of cattle per unit of land (Table 6). Manure quantity in FE is adequate to meet the N requirement to offset N imbalances because Land N balances are not largely negative and numbers of livestock kept tend to be large hence providing large quantities of manure. Moreover, the pasture grazing system used is a low feed resource utilisation management system, allowing feed utilisation and nutrient replacement to occur simultaneously.

Insufficiency of manure to meet the requirement for attaining zero net N balance in the SI is owed to the largely negative Land N balance and fairly large farm sizes. The rather large farm sizes in HD and low cattle per unit of land (Table 6), contribute to the state of manure insufficiency in this category, despite the near to positive Land N balances (Table 15). Large quantities of manure resulting from off-farm feeds imported into the Farms in ZG and small farm sizes (Table 6) are responsible for bridging much of the N requirement for offsetting the N imbalance. However, large quantities of crop and fodder harvests (Table 12) which elevate N outflows increase the N replacement requirements leading to the small manure deficit observed.

6.4.2 Yield Response to Manure Application for Banana and Elephant grass

Manure application to crop fields is expected to increase yield because of the numerous production enhancing qualities that it imparts to the soil. These have been outlined in section 2.2.6 of this thesis. Use of crop residues for mulch is also one of the practices known to enhance production through soil nutrient and texture improvement as well as reduction of soil moisture loss and smothering of weeds. Advantages of mulch are described in Section 2.2.6. Members of household per unit of crop land has an indication towards labour availability for management of the fields which is an advantage to production and could be the reason for the positive effect on yields.

The season of planting is likely to affect a crop depending on its characteristics. While some crops grow well in the season with the long rains others may prefer an extended period of water stress and therefore grow better in the short rains. In the case of bananas they are favoured by the long rains. With respect to silt, increasing proportion of silt in the soil will reduce its water holding capacity and as a result reduce the amount of moisture available for crop growth and eventually have a negative effect on banana yield.

The negative effect of Masaka district on banana yields seems to arise out of a number of speculative social, agro-ecological and biological factors. Masaka was largely affected by HIV/AIDS largely reducing its labour force, it has been experiencing short but abnormal periods of drought and changes in the rainfall pattern in the past 4 years. Rainfall in mm was 1,023 mm in 1998 - 2000 compared to 1,144 mm in 1993 - 1997 (Meterological Department data). In addition, banana plantations in the district were greatly devastated by banana weevils in the 1980s. These factors combined are likely to put the district in a disadvantaged position in comparison to Jinja and Mbarara in banana production.

The negative effect of the proportion of the Patch in the Plot/Parcel on banana yield and proportion of Patch in the Farm on elephant grass yield is related to management of the fields. A smaller field tends to be easier to manage appropriately than a large one. Negative effect of soil K on elephant grass yield is not clear but could, perhaps, result from over supply of the nutrient in the soil. Positive effect of the presence of grain legumes in the Patch is a result of BNF.

From the predictions made, yield increases occur for both bananas and elephant grass as a result of manure application. Such yield increase was also observed for Bananas by Karugaba and Kimaru (1999) of up to 41.3% increase in bunch mass resulting from application of manure. Also elephant grass fields grown on land manured by approximately 600 kg (DM) ha^{-1} in Masaka gave yields of 18,236 kg (DM) ha^{-1} $season^{-1}$ (Mubiru *et al.*, 2003) which compares well with the value of 18,188 kg (DM) ha^{-1} $season^{-1}$ in this study. Larger increases resulting from manure application in elephant grass in comparison to bananas is a result of the differences in the 2 plant types in their uses and agronomy. While bananas are harvested only from those trees where the fruit is ready during a season, fields or large portions of fields of elephant grass are harvested in a season. Furthermore, plant response, particularly, to N stimulates vegetative growth more than fruit development. As a result the leaves of elephant grass which is the harvested portion will largely benefit from the added manure both in terms of quantity and resultant income.

6.5 CONCLUSION

Basing on the predictive ability of the nutrient balance indicators developed in Chapter Five and their coefficients, it is evident that manure use can offset Patch N imbalances. The largest quantity of manure required to do this in terms of kg (DM) ha^{-1} $season^{-1}$ is in the ZG category followed by the SI, TE, FE and HD categories. Clearly, the categories at the top of the intensification continuum require larger quantities of manure to eliminate N imbalances than those at the lower end.

Manure quantity required to offset N imbalances is available on farms in the TE and FE categories. In the SI, HD and ZG categories additional manure, or any other nutrient input, from off-farm sources would be required for this purpose.

Assessment of the effect of manure application on yields of bananas and elephant grass necessitated use of yield response functions whose development and use have been demonstrated. In this respect, banana yield is a function of quantity of manure applied (MN), quantity of crop residues put on the Land (CR) and the number of household members above 5 years per unit of cropped land (HH). These have positive effects on yields. Factors with negative effect on banana yield are the plantation location (within or outside Masaka district) (MA), proportion of Patch in the Plot (PP) and proportion of silt in the soil (SI).

Elephant grass yield is a function of MN, CR, HH and proportion of grain legumes in the Patch (GL). These have positive effects on yield. Factors with negative effects on elephant grass yield are soil K (K) and proportion of the Patch out of the total Farm area (PA).

The use of these functions shows that manure application causes increase in yields of both bananas and elephant grass. However, expected increases in quantity of elephant grass and resultant income is higher than that for bananas.

It is recommended, therefore, that farmers put emphasis on manure use as a major and regularly practiced nutrient management method. The benefits in terms of sustainability of the production system and crop and fodder yields have been well demonstrated.

In addition, there is need to identify numerous other alternatives for improvement of nutrient management. This would provide options from which favourable choices can be made depending on each farmer's resources. This can be done by identifying more indicators of nutrient balances. The development of banana and elephant grass yield models derived from this study data and used in testing manure use effects is a novel approach. In this respect, detailed yield response functions should be developed for all major crops and fodder to provide information on expected effects of nutrient management improvement alternatives on yields. This approach will enhance adoption of these methods by farmers.

CHAPTER SEVEN

GENERAL CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

This study has identified five categories of dairy intensification in Uganda, namely Herding (HD), Tethering (TE), Fenced (FE), Semi-intensive (SI) and Zero grazing (ZG). The path of dairy intensification enriches the Farm in terms of N, P and K balances; however, these gains are not evident at arable Land (Land) level. The high Farm nutrient balance values are mainly caused by importation of feeds into the Farms, particularly, those at the intensive end of the continuum. The causes of low and mostly negative nutrient balances values at Land level are (i) minimum in-situ nutrient recycling, (ii) massive nutrient removal through crop and fodder harvests and (iii) minimum and non-utilisation of external nutrient resources. The Beans-Maize crop pattern within the farm categories has a positive effect on N balance, while Banana-Beans has a similar effect on P balance. The Fodder crop pattern has a negative effect on N, P and K balances.

Indicators of Patch balances common to N, P and K identified in the study are proportion of manure used (Mn), quantities of materials harvested and grazed from the patch as a proportion of that from the whole farm (HvGz) and the Coffee-Fodder (CF) crop pattern. In addition to these, other indicators for N balances are proportion of the Patch in the Plot (PP), and specific crop patterns namely Sweet potatoes (SP) and Legume based intercrops (LI). Additional indicators for Patch P balances are PP and specific crop patterns namely LI and Banana-Beans (BB) while those for Patch K balances are Fodder crops (FC), SP and Pasture (Pa). Manure application, PP, LI, Pa and BB have positive effects on Patch balances, while HvGz, CF and FC have negative effects. Sweet potatoes (SP) crop pattern has a positive effect on Patch N and a negative one on Patch K balances.

One major option for improving N, P and K balances is manure application. Manure required to offset N imbalances is higher in the farm categories at the higher levels of intensification and less at the lower end of the intensification continuum. Seasonal DM manure requirement to offset N imbalances amounts to 298, 1181, 583, 1239 and 1665 kg ha^{-1} for HD, TE, FE, SI and ZG categories, respectively. While the TE and FE categories have adequate quantities of manure on their farms to meet this requirement, additional manure (kg (DM)) amounting to 367 for HD, 410 for SI and 17 for ZG is required from off-farm sources. Manure application has the potential to increase yields of bananas and elephant grass (Napier grass). Application of 500 kg (DM) ha^{-1} $season^{-1}$ of manure is predicted to increase yields by 13% in bananas and 48% in elephant grass.

7.2 RECOMMENDATIONS

From this study, a few recommendations can be advanced for improvement of nutrient management and productivity on farms. First and foremost, (i) development efforts need to target promotion of utilisation of farm nutrient resources locked up in certain farm spots particularly manure, particularly in the SI and ZG farm categories, (ii) farmers should be equipped with adequate knowledge on BNF to maximise benefits obtained from legumes, and (iii) field advisors should be equipped with decision support tool such as the indicators of nutrient balances as well as the yield response functions to assist in decision making at farm level. Policy makers should also use these tools for guidance in policy development.

As for future research, the following merit attention:

i. There is a need for on-farm testing of the manure utilisation options developed in this study, for the different farm categories. This is necessary to verify the extent of their applicability within the specified categories. It is also critical to assess the effect of their implementation on crop and fodder yields and subsequently livestock productivity particularly milk yields and eventually their translation into monetary terms. Costs incurred in application of manure should be put into consideration when calculating potential increments from expected yield increases to provide more convincing figures.

ii. There is need to do in depth studies on nutrient use efficiencies to be able to understand ways and means to obtaining maximum benefit from available nutrients. This study had concentrated on manure use as one of the options for improving nutrient management, however, there are a number of other methods that need to be developed with concrete procedures of implementation.

iii. The indicators for N, P and K balances developed, should be tested on an independent data set to check their precision and identify areas that require adjustments to enable development of dependable inferences. Such adjustments would include addition of other factors with substantial effects on nutrient balances but were not included as indicators here because they were not practiced on the study farms. The most prominent among omitted factors among the indictors is application of inorganic fertilisers. Improvement of these indicators will provide a useful tool for assessment of nutrient management on farms and testing proposed nutrient management improvement options with applicability on a wider variety of farms.

iv. Furthermore, yield response equations for all the major crops and fodder plants should be developed to enable assessment of various nutrient management practices on plant yields. The response functions should take into account as many factors as possible for high precision of output. It will also be important to identify appropriate yield ceilings for the crops and fodder for different circumstances and include them in the yield response equations to avoid making unrealistically high predictions.

v. In addition, it is also critical to understand the links between nutrient management and the economies and livelihoods of farmers and subsequently the national economy. This will create the possibilities for development of holistic and viable nutrient management improvement options that will be more readily adopted by, particularly, poor smallholder farmers with tangible impacts.

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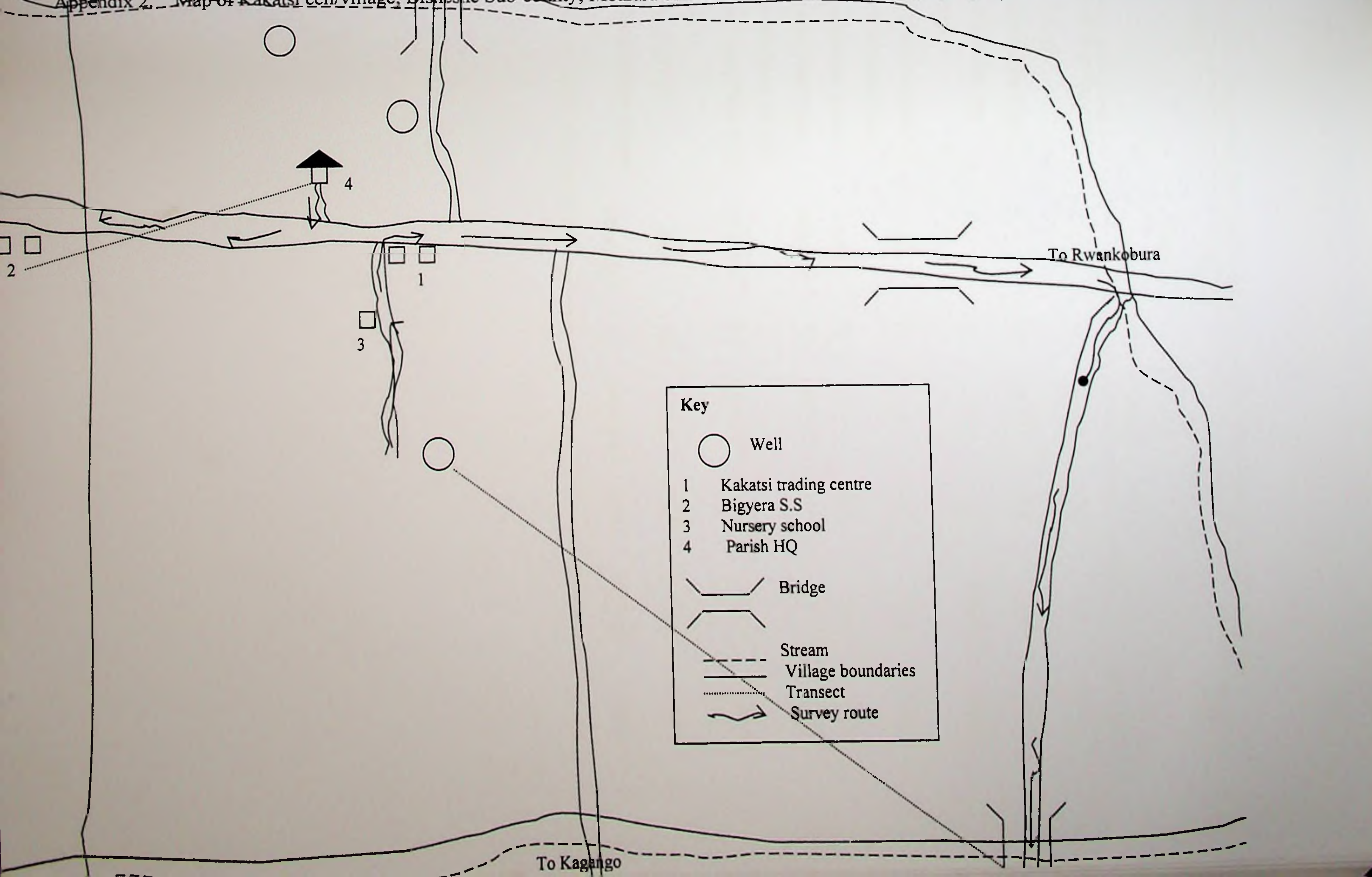
Appendix 1. Selected sites for data collection for the characterization survey in Mbarara, Masaka and Jinja, populations used in sampling, and sample sizes

District	Sub-county	Village	Number of households	Human Population	Sample size selected for data collection
Masaka	Kalungu	Mirembe	49		17
		Byaana	73		17
	Kisekka	Kyanangaazi	130	650	17
		Bunyere	120	700	17
	Kyanamukaka	Bukunda	180		17
		Katikamu & Nabitaka	200		16
Mbarara	Buremba	Kakoni	100		17
		Mushambya	96		17
	Bisheshe	Kakatsi	250		26
		Rwebikoona	80		9
	Rwanyamahembe	Nyakayojo A & B, Kakyerere &Rweishaka		1288	17
		Rutooma I & V, Owengoma, Bugatsi		1156	14
Jinja	Budondo	Buwairama	154	774	10
		Ibungu –West	210	1903	24
	Mafubira	Musima	150	2800	18
		Kayunga	624	2532	16
	Butagaya	Kiwagama North & South	177	1153	20
		Mpumwire Nawaguma B	91	859	14
Totals	9	18			303

Appendix 2. Map of Kakatsi cell/village; Bisheshe Sub-county; Mbarara district with key sites *(not drawn to scale)*



Appendix 3. Analysis of variance (ANOVA) information for the cluster variables

Variables	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
Proximity to the main road (Km)	3.944	15	6.549	198	.602	.871
Long term hired labour	3.749	15	1.409	198	2.660	.001
Household income (Score)	18.198	15	1.812	198	10.042	.000
Proportion of improved breeds in cattle herd	.533	15	.165	198	3.237	.000
Intensification score	18.864	15	7.531	198	2.505	.002
Total farm land (ha)	558.490	15	406.139	198	1.375	.162
Expenditure on AI and vet services (Ushs TLU^{-1} $year^{-1}$)	7.8×10^{10}	15	2.9×10^{8}	198	273.335	.000
Cattle TLU ha^{-1}	.664	15	.904	198	.735	.747
Off-farm income (Ushs $month^{-1}$)	3.6×10^{11}	15	3.4×10^{8}	198	1074.264	.000

Appendix 4. Farms selected for longitudinal survey data collection

Names	village	Sub-county	District	Farm category
Majere	Rutooma	Rwanyamahembe	Mbarara	FE
Matimbano Sedrasi	Kakyerere	Rwanyamahembe	Mbarara	FE
Kamugabirwe	Rutooma	Rwanyamahembe	Mbarara	FE
Muhangi Twairo	Kakatsi	Bisheshe	Mbarara	FE
Tusubira Godfrey	Kakatsi	Bisheshe	Mbarara	HD
Sserinda Joseph	Byaana	Kalungu	Masaka	TE
Mubiru Ssalongo Mohammed	Kyananganzi	Kisekka	Masaka	HD
Mukuuma Hajat	Byaana	Kalungu	Masaka	ZG
Nakalyowa Immaculate	Kyananganzi	Kisekka	Masaka	HD
Lukera Emmanuel	Byaana	Kalungu	Masaka	TE
Kibirige Dirisa	Kyananganzi	Kisekka	Masaka	TE
Byekwaso Abdul	Musima	Mafubira	Jinja	TE
Musabi Charles	Mpumwire	Butagaya	Jinja	SI
Ikoona	Mpumwire	Butagaya	Jinja	SI
Zaake Magid	Kayunga	Mafubira	Jinja	ZG
Luyuuyo Sam	Kayunga	Mafubira	Jinja	ZG
Kaganjwa Valentin	Buwairama	Budondo	Jinja	ZG
Gabula Steven	Mpumwire	Butagaya	Jinja	SI
Baligeya George William	Musima	Mafubira	Jinja	SI

Appendix 5a: Data collection schemes for the longitudinal survey

Appendix 5a (contd.)

PRODUCTION DATA

RESEARCH TO EXAMINE THE EFFICIENCY OF PRODUCTION UNDER INTENSIFICATION OF DAIRY PRODUCTION IN UGANDA

WHOLE FARM MONITORING LONGITUDINAL SURVEY

International Livestock Research Institute (ILRI)

National Agricultural Research Organisation (NARO)

Danish Institute of Agricultural Sciences (DIAS)

Makerere University (MU)

2003-2004

To be filled every 2 weeks

DATE OF CURRENT VISIT ____________________

DATE OF LAST VISIT ____________________

DISTRICT ____________ SUB-COUNTY ____________ VILLAGE ____________

RESPONDENTS NAME ____________ NAME HOUSEHOLD HEAD ____________ FARM ID NUMBER ____________

VISIT NUMBER (*eg Number for 1st visit is 1*) ____________________

MAJOR CROP ACTIVITIES ____

MAJOR LIVESTOCK ACTIVITIES ____

DATE OF PREVIOUS WEEKLY/LIVESTOCK MARKET ____________________

ENUMERATOR'S NAME ____________________

Appendix 5a (contd.)

FORM 1: ENTRIES AND DEPARTURES OF ANIMALS

Table 1.1: Livestock entries (Since last visit = in the past 2 weeks)

Type of entry	**Livestock type**	**Number**	**Breed** ***(for cattle only)***	**Breeding method** ***(if entry is by birth-for cattle only)***	**Age (years or months)**	**Source of cash for purchase**	**Cost (Ushs)**	**Cost of transport** ***(only if paid by farmer)***	**Use of animal if not born on the farm**

Table 1.2: Livestock departures (Since last visit = in the past 2 weeks)

Type of departure	**Livestock type**	**Number**	**Breed** ***(for cattle only)***	**Age (yr/months)**	**Reasons for sale if sold**	**Location of buyer if sold**	**Sale Price (U shs) if sold**	**Cost of transport** ***(only if paid by farmer)***	**Reasons/causes for death** ***(if departure was by death)***

Appendix 5a (contd.) FORM 2- LIVESTOCK SERVICES

Table 2.1: Animal treatment and services (Since the last visit = in the past 2 weeks)

Service/ treatment	Livestock type	No. of Livestock	Service provider	Cost of service or treatment excluding drugs	Drug/ medication	Unit of drugs used	No.of units	Price/unit (USh)	Total cost for drugs used	Mode of payment

Appendix 5a (contd.) FORM 3: PRODUCT CONSUMPTION AND SALES

Table 3.1: Milk production Consumption and sales (yesterdays record)
NB: (Record milking for each milking period separately ie morning, midday, evening))

Period of day *(morning, midday, evening)*	**Breed of cattle**	**Number of animals milked**	**No. of suckling calves**	**Milk unit**	**No. of units produced that day**	**No. of units consumed by the household**	**No. of units consumed by the calf/calves through bucket or bottle feeding**	**No. of units sold**	**No. of units given away**
	Exotic								
	Cross								
	Local								
	Exotic								
	Cross								
	Local								
	Exotic								
	Cross								
	Local								

NB: Number of milk units consumed by the household, consumed by calves through bucket/bottle feeding, sold and given away should total to number of milk units produced

Appendix 5a (contd.) *Table 3.2: Milk sales by buyer type (yesterdays record)*

Period of day	Buyer types	Milk unit	No. of milk units bought by each buyer type	Price per unit (Ushs) paid by the different buyer type	Transport costs or means (Ushs) by farmer to each buyer type (where relevant)	Terms of payment for each buyer type
AM						
Midday						
PM						

Table 3.3: Production/Consumption/Use and Sale of (non-meat) other livestock products (since the last visit = in the past 2 weeks))

Product *(from other livestock product list)*	Unit	No. of units produced	No. of units consumed/used by the household	No. of units given away	No. of units sold	Price (Ushs) per unit	Amount (Ushs) obtained	Transport costs (Ushs)

Appendix 5a (contd.) FORM 4: FEEDS OFFERED TO LIVESTOCK

Table 4.1: Livestock feeding per day (Complete table below for stall fed feeds and fodder. Entries into the table should be feeds offered yesterday. The feed types are in the Input-Output codes. Each line should have an entry for only one feed type.)

Livestock type	Numbers of type	Livestock type	Numbers of type	Livestock type	Numbers of type	Time of day when feed is offered	Input-Output Type (feed type)	If planted fodder, time since last cut	Plot of origin	Patch of origin	Source if not from the farm	Unit of feed	Weight of unit (kg)	Number of units offered

Appendix 5a (contd.)

Table 4.2: Time Spent Grazing, Pasture Type and Quality (Complete Table below for the Grazing animals, take yesterdays record)

Livestock type	Numbers of type	Livestock type	Numbers of type	Livestock type	Numbers of type	Pasture Type (from input-output list)	% in pasture	Source	Plot	Patch	Time taken (Hrs or Mins)	% of grazing at high ambient temperature	Quality of pasture 1 = Very good 2 = Good 3 = Moderate 4 = Poor 5 = Very poor	Leaf:Stem ratio 1 Very stemmy 2 Stemmy 3 Stem=Leaf 4 Leafy 5 Very Leafy	Foliage colour 1 Yellow 2 Greenish yellow 3 Yellowish green 4 Green 5 Deep Green	Height score of pasture 1 = Very good 2 = Good 3 = Moderate 4 = Poor 5 = Very poor	Number of days grazing during the last 2 weeks

Appendix 5a (contd.) FORM 5: HOUSEHOLD LABOUR ALLOCATION

Table 5.1: Labour allocation for crops (Since the last visit = in the past 2 weeks. Fill a separate row for each person or groups of persons if for instance are contract workers who contributed towards labour)

Name or identification of person who carried out the task	Labour type *(1=family member>12 years, 2=longterm hired labourer, 3=casual labourer, 4=neighbour>12 years)*	Activity	No. of days worked in the past 2 weeks	Total time spent on the task in the past 2 weeks

Appendix 5a (contd.) *Table 5.2: Labour allocation for livestock (Yesterdays record only. Fill a separate row for each person or groups of persons if for instance are contract workers who contributed towards labour)*

Name or identification of person who carried out the task	Labour type (*1=family member>12 years, 2=longterm hired labourer, 3=casual labourer, 4=neighbour>12 years)*	Activity	Livestock type	Period of time (minutes or hours) spent on the task yesterday

on each plot and patch. *Fill in a separate row for each different activity on each different patch (Total no. of hours in this form should match the total in form 5.1)*

Plot	Patch	Major crops in patch *(from input-output list)*	Actvitity	Time taken to complete activity	No. of individuals required to complete activity
		[ ][ ][ ][ ]			
		[ ][ ][ ][ ]			
		[ ][ ][ ][ ]			
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Table 6.1: Expenditure on hired labour for crop, livestock and non-farm income generating activities (Since last visit = in the past 2 weeks)

NAME OR IDENTIFICATION OF PAID LABOURER	**Number of persons in the labour group** ***(if entry is not an individual)***	Labour type *(1= family member>12 years, 2=longterm hired labourer, 3=casual labourer, 4=neighbour>12 years)*	**Major activity**	**Amount (Ushs) paid in past 2 weeks**

Appendix 5a (contd.) FORM 7: INPUTS ACQUISITION

Table 7.1: Inputs purchased or obtained (Since last visit = in the past 2 weeks)

Input-Output type	unit	Number of units purchased	Cost (Ushs) per unit	Total amount (Ushs) paid for input	Cost (Ushs) of transport	Source of input

Appendix 5a (contd.) Table 7.2: *Inputs per patch (Since last visit = in the past 2 weeks)*

Plot No.	Patch No.	Major crop *(obtain codes from Input-Output type*	Input-Output type	Unit	Total quantity of units applied	Source of input	*Source plot if* from own farm	*Source patch* if from own farm
		[ ][ ][ ][ ]						
		[ ][ ][ ][ ]						
		[ ][ ][ ][ ]						
		[ ][ ][ ][ ]						
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		[ ][ ][ ][ ]						

Appendix 5a (contd.) FORM 8: HARVESTS AND USE OF INPUTS-OUTPUTS

Table 8.1: Harvests, consumption and sale (Since the last visit = in the past 2 weeks) Each Input-Output type must be entered in a separate row even if they are from the same patch – crop residues and grasses should be considered as outputs.

Plot No.	Patch No.	Major crop *(from input-output list)*	Input-Output type	Harvest unit	No. of units harvested	No. of units consumed at home	No. of units offered to livestock	No. of units stored	No. of units sold	No. of units given to neighbours	Transfers to other plots			Price (Ushs) per unit	Total (Ushs) amount obtained from sale	Cost (Ushs) of transport
											No. of units transferred	Plot transferred to	Patch transferred to			

Appendix 5a (contd.) *Table 8.2: Sales and consumption from stored products (Since last visit = in the past 2 weeks)*

Input-Output type	Unit	No. of units sold	Price (Ushs) per unit	Total amount (Ushs) obtained	Cost (Ushs) of transport	No. of units consumed	No. of units given away

Appendix 5a (contd.) FORM 9: HOUSEHOLD NON-FARM INCOME

Table 9.1: Income from non-farm products sales (Since last visit = in the past 2 weeks)

Non-farm product	Unit	No. of units sold	Price (Ushs) per unit	Total amount (Ushs) obtained	Cost (Ushs) of transport

Appendix 5a (contd.) *Table 9.2: Household off-farm/non-farm income, services and remittances (Since last visit = in the past 2 weeks)*

Off-farm income type	Household member earning *(Name)*	Amount (Ushs)

NB: The name written here should be as it is in the inventory household information in section A3.

FORM 10: HOUSEHOLD EXPENDITURE

Table 10.1: Household expenditure on food stuffs (Since last visit = in the past 2 weeks)

Food items	Purchase unit	Price (Ushs) per unit	No. of units purchased	Source	Total cost (Ushs)

Appendix 5a (contd.)

Table 10.2: Household expenditure on fuels (Since last visit = in the past 2 weeks)

Fuel items	Purchase unit	Price (Ushs) per unit	No. of units purchased	Source	Total Amount (Ushs)

Table 10.3: Household expenditure on tools and equipment (Since last visit = in the past 2 weeks)

Tools and equipment	Purchase unit	Price (Ushs) per unit	No. of units purchased	Source	Total Amount (Ushs)

Appendix 5a (contd.) Table 10.4: ...

the past 2 weeks)

Code	Item	Expenditure (Ushs)
1	Medical care (Ushs)	
2	Education (Ushs)	
3	Taxes (Ushs)	
4	Fees (Ushs)	
5	Kitchen utilities and domestic ware	
6	Assets	
7	Public water	
8	Telephone	
9	Electricity	
10	Donations (Ushs)	
11	Clothing (including shoes)	
12	Entertainment	
13	Other (specify) ______	
14	Other (specify) ______	
15	Other (specify) ______	
16	Other (specify) ______	

FORM 11: WATER ACQUISITION AND OTHER UTILITIES

Table 11.1: Water collection per day (Record water use for yesterday)

Water use(domestic, cattle, other Livestock) ***(Fill in actual use)***	**Water source**	**Water units**	**Water quantity per day**	**Total cost (Ushs)**
Cattle & other livestock				
Domestic				
Other (specify) ______				
Other (specify) ______				
Other (specify) ______				
Other (specify) ______				
Other (specify) ______				

 FORM 1: ENTRIES AND DEPARTURES OF ANIMALS

Code Set 1: *Entries and Departures of Animals*

Livestock type

Local cattle breeds
1=Cows
2=Lactating (milking) cows
3=Heifers
4=In-calf heifers
5=Female calves
6=Male calves
7=All calves
8=Immature males/steers
9=Castrates
10=Bulls
11=All cattle
12=All cattle except lactating cows
13=All cattle except calves

Crossbreeds
21=Cows
22=Lactating (milking) cows
23=Heifers
24=In-calf heifers
25=Female calves
26=Male calves
27=All calves
28=Immature males/steers
29=Castrates
30=Bulls
31=All cattle
32=All cattle except lactating cows
33=All cattle except calves

Exotic breeds
41=Cows
42=Lactating (milking) cows
43=Heifers
44=In-calf heifers
45=Female calves
46=Male calves
47=All calves
49=Castrates
50=Bulls
51=All cattle
52=All cattle except lactating cows
53=All cattle except calves

Other Livestock types
61=Sheep
62=Goats
63=Pigs
64=Donkeys
65=Chickens
66=Turkeys
67=Rabbits
68=All animals
69=Other (specify) ________

Breed *(for cattle only)*

1=Friesian pure
2=Friesian cross
3=Ayrshire pure
4=Ayrshire cross
5=Jersey pure
6=Jersey cross
7=Guernsey pure
8=Guernsey cross
9=Boran
10=Zebu
11=Ankole
12=Red poll
13=Other (specify)
____

Source of cash for Purchase

1=Own savings
2=Credit – group
3=Formal credit
4=Donations
5=Dowry
6=Other (specify)
____

Location of buyer/seller

1=Within district
2=Outside district
3=Other (specify)
____

Reasons for sale

1=Culling old/sick
2=Feed/fodder shortage
3=Farm labour shortage
4=School fees
5=Buy food
6=Obtain revenue
7=Other (specify)
____

Use of animals sold/bought

1=Slaughter in butchery
2=Slaughter for home consu
3=For breeding
4=For dairy production
5=Draught
6=Other (specify)
____

Causes of death

1=Disease
2=Injury / accidents
3=Poisoning (acaricide, snal
4=Bloat
5=Slaughter due to disease
6=Unknown
7=Other (specify)
____

Types of entry & departure

1=Purchase
2=Sale
3=Dowry
4=Donation/Gift
5=Caretaking
6=Birth
7=Consumed by household
8=Exchange
9=Slaughter for sale
10=Death
11=Other (specify)
____

Breeding method *(for cattle)*

1=Artificial insemination (AI)
2=Own bull
3=Neighbours bull
4=Village bull scheme
5=Other (specify)
____

Appendix 5b (contd.) **FORM 2- LIVESTOCK SERVICES**

Code Set 2: Livestock Services

Livestock type

Local cattle breeds

1=Cows
2=Lactating (milking) cows
3=Heifers
4=In-calf heifers
5=Female calves
6=Male calves
7=All calves
8=Immature males/steers
9=Castrates
10=Bulls
11=All cattle
12=All cattle except lactating cows
13=All cattle except calves

Crossbreeds

21=Cows
22=Lactating (milking) cows
23=Heifers
24=In-calf heifers
25=Female calves
26=Male calves
27=All calves
28=Immature males/steers
29=Castrates
30=Bulls
31=All cattle
32=All cattle except lactating cows
33=All cattle except calves

Exotic breeds

41=Cows
42=Lactating (milking) cows
43=Heifers
44=In-calf heifers
45=Female calves
46=Male calves
47=All calves
49=Castrates
50=Bulls
51=All cattle
52=All cattle except lactating cows
53=All cattle except calves

Other Livestock types

61=Sheep
62=Goats
63=Pigs
64=Donkeys
65=Chickens
66=Turkeys
67=Rabbits
68=All animals
69=Other (specify) ___________

Drug/medication

1=Antihelminthic (Dewormer)
2=Acaricide
3=Vaccine
4=Milking salve
5=Teat dip
6=Antibiotic
7=Antifungal
8=ECF drugs
9=Trypanocidal
10=Mineral/vitamin
11=Disinfectant
12=Herbs
13=Other (specify)

____

Service/treatment

1=AI
2=Bull service
3=Antihelminthic (Deworming)
4=Acaricide application (Spraying)
5=Vaccination
6=Castration
7=Foot trimming
8=Dehorning
9=Disease treatment
10=Pregnancy diagnosis
11=Assistance when calving down
12=Other (specify) _____________

Mode of payment

1=Single cash sale
2=Informal contract – cash
3=Credit sale
4=Formal contract – credit
5=Other (specify)

____

Service provider

1=Veterinarian
2=Animal health assistant
3=Local traditional herbalists
4=Neighbour
5=Self
6=Family member
7=Herdsman
8=Other (specify)

____

Appendix 5b (contd.) **FORM 3: PRODUCTION, CONSUMPTION AND SALES OF LIVESTOCK PRODUCTS**

Code Set 3: Daily Milk Consumption and Sales

Units

1=No.
2=Kgs
3=Cubic centimeters (Mls)
4=Litre
5=Half litre/Large cup/500mls
6=Small cup/350 mls
7=Kawujo (50mls)
8=5 litre bucket
9=20 litres/Jerrican
10=120 litre drum
11=Half Kg
12=Quarter Kg
13=Bunch
14=Tray
15=Pair
16=Kimbo tins
17=Debe tin
18= Packet
19=Sachet
20=Heap
21=Bundle
22=Standard sacks
23=Donkey cart
24=Pick-up
25=Wheel barrow
26=Cylinder
27=Basin
28=10 Litre bucket
29=Bar
30=Bicycle load
31=Other (specify) ______________

Buyer type

1=Dairy corp. centre
2=Private processor
3=Private cooler
4=Society centre
5=Trader/vendor
6=Restaurant
7=Local household
8=Ordinary shop
9=Other (specify) ______________

Other livestock products

1=Eggs
2=Hides and skins
3=Goat milk
4= Cattle manure
5=Smallruminant (goats and/or sheep) manure
6=Ghee
7=Chicken manure
8=Other (specify) ________

Terms of payment

1=Immediate cash
2=Payment weekly
3=Payment Fortnightly
4=Payment monthly
5=Other (specify)____________

Appendix 5b (contd.) **FORM 4: FEEDS OFFERED TO LIVESTOCK**

Code set 4: Feeds Offered to Livestock

Livestock type

Local cattle breeds

1=Cows
2=Lactating (milking) cows
3=Heifers
4=In-calf heifers
5=Female calves
6=Male calves
7=All calves
8=Immature males/steers
9=Castrates
10=Bulls
11=All cattle
12=All cattle except lactating cows
13=All cattle except calves

Crossbreeds

21=Cows
22=Lactating (milking) cows
23=Heifers
24=In-calf heifers
25=Female calves
26=Male calves
27=All calves
28=Immature males/steers
29=Castrates
30=Bulls
31=All cattle
32=All cattle except lactating cows
33=All cattle except calves

Exotic breeds

41=Cows
42=Lactating (milking) cows
43=Heifers
44=In-calf heifers
45=Female calves
46=Male calves
47=All calves
48=Immature males/steers
49=Castrates
50=Bulls
51=All cattle
52=All cattle except lactating cows
53=All cattle except calves

Other Livestock types

61=Sheep
62=Goats
63=Pigs
64=Donkeys
65=Chickens
66=Turkeys
67=Rabbits
68=All animals
69=Other (specify)
____

Source

1=Own farm
2=Roadside
3=Forest/rangeland
4=Neighbour
5=Institution
6=Market
7=Restaurant
8=Private dealer
Cooperative
Public area
Ordinary shop
9=Other (specify)
____

Input-Output type

Manures

1=Wet cattle manure
2=Wet sheep manure
3=Wet goat manure
4=Wet pig manure
5=Wet chicken manure
6=Wet turkey manure
7=Wet rabbit manure
8=Dry cattle manure
10=Dry Sheep manure
11=Dry goat manure
12=Dry pig manure
13=Dry chicken manure
14=Dry turkey manure
15=Dry rabbit manure
16=Compost manure
17=Slurry
18=Cattle slurry (manure & urine)
19=Sheep slurry (manure & urine)
20=Goat slurry (manure & urine)
21=Pig slurry (manure & urine)
22=Rabbit slurry (manure & urine)
23=Cattle urine
24=Sheep urine
25=Goat urine
26=Pig urine
27=Rabbit urine

Food crops & their products

40=Bananas
41=Beans
43=Cabbage
44=Cassava
45=Cow peas
46=Dry maize
47=Finger millet
48=Green maize
49=Ground nuts
50=Irish potatoes
51=Onions
52=Tomatoes
53=Other vegetables…
54=Sorghum
55=Soy beans
56=Sugar canes
57=Sweet potatoes
58=Dessert bananas (eg bogoya ndiizi, gonja)
59=Pineapples

Cash crops

70=Coffee
71=Tea
72=Cut flowers
73=Tobacco
74=Fruit tree crops
75=Eucalyptus trees/forest

Pasture/fodder types

90=Elephant grass
91=Lablab
92=Calliandra
93=Natural pasture
94=Improved pasture
95=Bush fallow
96=Tanzania grass (Setaria)
97=Brachiaria
98=Panicum
99=Desmodium
100=Lablab
101=Sesbania
102=Leucaena
103=Centrosema
104=Siratro
105=*Chloris gayana*
106=Stylo
107=Muluco
108=Moringa
109=Guatemala

Crop residues

120=Banana psuedostems (stems)
121=Banana peels
122=Banana leaves
123=Banana flowers
124=Bean haulms
125=Bean pods
126=Cassava tops
127=Cowpea haulms
128=Cowpea pods
129=Maize stover
130=Millet straw
131=Ground nut haulms
132=Ground nut pods
133=rish potato residue
134=Onion residue
135=Tomato residue
136=Other vegetable residue
137=Sorghum straw
138=Soybean haulms
139=Soybean pods
140=Sugarcane tops
141=Sweet potato vines
142=Sweet potato peels
143=Horticultural by-products
144=Maize stover

Agro-industrial products

160=Maize bran
161=Cotton seed cake
162=Brewers waste
163=Bone meal
164=Fish meal
165=Commercial concentrate
166=Homemade concentrate
167=Calf pellets

Chemical

180=NPK fertilizers
181=Phosphate fertilizers
182=Urea
183=Herbicide
184=Insecticide
185=Fungicide
186=Seed
187=Acaricide
189=Antihelminthic (dewormer)
190=Vet. Drugs
191=Disinfectant
192=Rock salt
193=Mineral salt
194=Milking salve

210=Water

211=Weeds

212=Other (specify)
____

Quality Of Feed

Age

1 = Very mature
2 = Very immature
3 = Mature

Leaf colour

1 = Yellow
2 = Greenish yellow
3 = Yellowish green
4 = Green
5 = Deep Green

Leaf:stem ratio

1 = Very stemmy
2 = Stemmy
3 = Stem=Leaf
4 = Leafy
5 = Very Leafy

Units

1=No.
2=Kgs
3=Cubic centimeters (M
4=Litre
5=Half litre/Large cup/5
6=Small cup/350 mls
7=Kawujo (50mls)
8=5 litre bucket
9=20 litres/Jerrican
10=120 litre drum
11=Half Kg
12=Quarter Kg
13=Bunch
14=Tray
15=Pair
16=Kimbo tins
17=Debe tin
18= Packet
19=Sachet
20=Heap
21=Bundle
22=Standard sacks
23=Donkey cart
24=Pick-up
25=Wheel barrow
26=Cylinder
27=Basin
28=10 Litre Bucket
29=Bar
30=Bicycle load
31=Other (specify)
____

Appendix 5b (contd.) **FORM 5 AND 6: HOUSEHOLD LABOUR ALLOCATION AND HOUSEHOLD LABOUR EXPENDITURE AND NON-FARM/OFF-FARM AND FARM INCOME**

Code Set 5 and 6: Household labour Allocation, Expenditure and Non-farm/Off-farm and farm Income

Input-Output type

Manures
1=Wet cattle manure
2=Wet sheep manure
3=Wet goat manure
4=Wet pig manure
5=Wet chicken manure
6=Wet turkey manure
7=Wet rabbit manure
8=Dry cattle manure
10=Dry Sheep manure
11=Dry goat manure
12=Dry pig manure
13=Dry chicken manure
14=Dry turkey manure
15=Dry rabbit manure
16=Compost manure
17=Slurry
18=Cattle slurry (manure & urine)
19=Sheep slurry (manure & urine)
20=Goat slurry (manure & urine)
21=Pig slurry (manure & urine)
22=Rabbit slurry (manure & urine)
23=Cattle urine
24=Sheep urine
25=Goat urine
26=Pig urine
27=Rabbit urine

Food crops & their products
40=Bananas
41=Beans
43=Cabbage
44=Cassava
45=Cow peas
46=Dry maize
47=Finger millet
48=Green maize
49=Ground nuts
50=Irish potatoes
51=Onions
52=Tomatoes
53=Other vegetables...
54=Sorghum
55=Soy beans
56=Sugar canes
57=Sweet potatoes
58=Dessert bananas (eg bogoya ndiizi, gonja)
59=Pineapples
60=Yams
61=Maize flour

Cash crops
70=Coffee
71=Tea
72=Cut flowers
73=Tobacco
74=Fruit tree crops
75=Eucalyptus trees/forest

Pasture/fodder types
90=Elephant grass
91=Lablab
92=Calliandra
93=Natural pasture
94=Improved pasture
95=Bush fallow
96=Tanzania grass (Setaria)
97=Brachiaria
98=Panicum
99=Desmodium
100=Lablab
101=Sesbania
102=Leucaena
103=Centrosema
104=Siratro
105=*Chloris gayana*
106=Stylo
107=Muluco
108=Moringa
109=Guatemala

Crop residues
120=Banana psuedostems (stems)
121=Banana peels
122=Banana leaves
123=Banana flowers
124=Bean haulms
125=Bean pods
126=Cassava tops
127=Cowpea haulms
128=Cowpea pods
129=Maize stover
130=Millet straw
131=Ground nut haulms
132=Ground nut pods
133=rish potato residue
134=Onion residue
135=Tomato residue
136=Other vegetable residue
137=Sorghum straw
138=Soybean haulms
139=Soybean pods
140=Sugarcane tops
141=Sweet potato vines
142=Sweet potato peels
143=Horticultural by-products
144=Maize stover
145=Cassava peels
146=Yam peels

Agro-industrial products
160=Maize bran
161=Cotton seed cake
162=Brewers waste
163=Bone meal
164=Fish meal
165=Commercial concentrate
166=Homemade concentrate
167=Calf pellets

Chemical
180=NPK fertilizers
181=Phosphate fertilizers
182=Urea
183=Herbicide
184=Insecticide
185=Fungicide
186=Seed
187=Acaricide
189=Antihelminthic (dewormer)
190=Vet. Drugs
191=Disinfectant
192=Rock salt
193=Mineral salt
194=Milking salve

210=Water

211=Weeds

Activities

Crop activities
1=Preparing fields
2=Planting
3=Weeding
4=Manure application
5=Fertiliser (inorganic) application
6=Harvesting + transporting/heaping
7=Processing (Drying, shelling, winnowing etc)
8=Pesticide application
9=Herbicide application
10=Prunning
11=Other (specify) ______________

Livestock activities
20=Herding/grazing
21=Tethering
22=Deworming
23=Spraying/dipping
24=Purchase of animals
25=Selling/transporting/milk /dairy products
26=Sale of manure
27=Purchase of feeds
28=Drawing/collecting water
29=Milking
30=Processing milk
31=Collecting & chopping fodder
32=Feeding grains or concentrates
33=Calf feeding (bucket feeding, offering calf pellets)
34=Barn/Kraal cleaning
35=Cleaning of water and feed troughs
37=Offering feeds
38=Others (specify)
____

Activities with other livestock
40=Pig management
41=Poultry management
42=Rabbit management
43=Small ruminant management
44=Other (specify) ______

48=Repairing of farm structures & fencing

Non-farm income generating activities
50=Handcraft work
51=Charcoal burning
52=Brick making
53=Carpentry
54=Brewing
55=Other (specify) ______________

Livestock type

Local cattle breeds
1=Cows
2=Lactating (milking) cows
3=Heifers
4=In-calf heifers
5=Female calves
6=Male calves
7=All calves
8=Immature males/steers
9=Castrates
10=Bulls
11=All cattle
12=All cattle except lactating cows
13=All cattle except calves

Crossbreeds
21=Cows
22=Lactating (milking) cows
23=Heifers
24=In-calf heifers
25=Female calves
26=Male calves
27=All calves
28=Immature males/steers
29=Castrates
30=Bulls
31=All cattl...
32=All cattle except lactating cows

33=All cattle e: calves

Exotic breeds
41=Cows
42=Lactating (milkin
43=Heifers
44=In-calf heifers
45=Female calves
46=Male calves
47=All calves
48=Immature males/s
49=Castrates
50=Bulls
51=All cattle
52=All cattle except lactating cows
53=All cattle except c

Other Livestoc types
61=Sheep
62=Goats
63=Pigs
64=Donkeys
65=Chickens
66=Turkeys
67=Rabbits
68=All animals
69=Other (specify)
____

Type of payment

1=Cash
2=Crop produce
3=Milk
4=Other livestock prc
5=Actual livestock
6=Other (specify) ___

Code Set 7 and 8: Farm Inputs-Outputs

Input-Output type

Manures
1=Wet cattle manure
2=Wet sheep manure
3=Wet goat manure
4=Wet pig manure
5=Wet chicken manure
6=Wet turkey manure
7=Wet rabbit manure
8=Dry cattle manure
10=Dry Sheep manure
11=Dry goat manure
12=Dry pig manure
13=Dry chicken manure
14=Dry turkey manure
15=Dry rabbit manure
16=Compost manure
17=Slurry
18=Cattle slurry (manure & urine)
19=Sheep slurry (manure & urine)
20=Goat slurry (manure & urine)
21=Pig slurry (manure & urine)
22=Rabbit slurry (manure & urine)
23=Cattle urine
24=Sheep urine
25=Goat urine
26=Pig urine
27=Rabbit urine

Food crops & their products
40=Bananas
41=Beans
43=Cabbage
44=Cassava
45=Cow peas
46=Dry maize
47=Finger millet
48=Green maize
49=Ground nuts
50=Irish potatoes
51=Onions
52=Tomatoes
53=Other vegetables…
54=Sorghum
55=Soy beans
56=Sugar canes
57=Sweet potatoes
58=Dessert bananas (eg bogoya ndiizi, gonja)
59=Pineapples
60=Yams
61=Maize flour

Cash crops
70=Coffee
71=Tea
72=Cut flowers
73=Tobacco
74=Fruit tree crops
75=Eucalyptus trees/forest

Pasture/fodder types
90=Elephant grass
91=Lablab
92=Calliandra
93=Natural pasture
94=Improved pasture
95=Bush fallow
96=Tanzania grass (Setaria)
97=Brachiaria
98=Panicum
99=Desmodium
100=Lablab
101=Sesbania
102=Leucaena
103=Centrosema
104=Siratro
105=*Chloris gayana*
106=Stylo
107=Muluco
108=Moringa
109=Guatemala

Crop residues
120=Banana psuedostems (stems)
121=Banana peels
122=Banana leaves
123=Banana flowers
124=Bean haulms
125=Bean pods
126=Cassava tops
127=Cowpea haulms
128=Cowpea pods
129=Maize stover
130=Millet straw
131=Ground nut haulms
132=Ground nut pods
133=rish potato residue
134=Onion residue
135=Tomato residue
136=Other vegetable residue
137=Sorghum straw
138=Soybean haulms
139=Soybean pods
140=Sugarcane tops
141=Sweet potato vines
142=Sweet potato peels
143=Horticultural by-products
144=Maize stover
145=Cassava peels
146=Yam peels

Agro-industrial products
160=Maize bran
161=Cotton seed cake
162=Brewers waste
163=Bone meal
164=Fish meal
165=Commercial concentrate
166=Homemade concentrate
167=Calf pellets

Chemical
180=NPK fertilizers
181=Phosphate fertilizers
182=Urea
183=Herbicide
184=Insecticide
185=Fungicide
186=Seed
187=Acaricide
189=Antihelminthic (dewormer)
190=Vet. Drugs
191=Disinfectant
192=Rock salt
193=Mineral salt
194=Milking salve

210=Water

211=Weeds

212=Other (specify) ____________

Source

1=Own farm
2=Roadside
3=Forest/rangeland
4=Neighbour
5=Institution
6=Market
7=Restaurant
8=Private dealer
Cooperative
Public area
Ordinary shop
9=Other (specify) ________

Units
1=No.
2=Kgs
3=Cubic centimet (Mls)
4=Litre
5=Half litre/Large cup/500mls
6=Small cup/350 ı
7=Kawujo (50mls
8=5 litre bucket
9=20 litres/Jerrica
10=120 litre drum
11=Half Kg
12=Quarter Kg
13=Bunch
14=Tray
15=Pair
16=Kimbo tins
17=Debe tin
18= Packet
19=Sachet
20=Heap
21=Bundle
22=Standard sack
23=Donkey cart
24=Pick-up
25=Wheel barrow
26=Cylinder
27=Basin
28=10Litre bucke
29=Bar
30=Bicycle load
31=Other (specify

Appendix 5b (contd.) **Code Set 9: Household Off-Farm Income**

Off –farm income type

1=Casual labour
2=Professional services
3=Livestock services
4=Retail trade
5=Remittances
6=Loan
7=Tailoring
8=Other (specify)
____

Non-farm products

1=Crafts
2=Charcoal
3=Bricks
4=Furniture
5=Local brew
6=Other (specify)
____

Units

1=No.
2=Kgs
3=Cubic centimeters (Mls)
4=Litre
5=Half litre/Large cup/500mls
6=Small cup/350 mls
7=Kawujo (50mls)
8=5 litre bucket
9=20 litres/Jerrican
10=120 litre drum
11=Half Kg
12=Quarter Kg
13=Bunch
14=Tray
15=Pair
16=Kimbo tins
17=Debe tin
18= Packet
19=Sachet
20=Heap
21=Bundle
22=Standard sacks
23=Donkey cart
24=Pick-up
25=Wheel barrow
26=Cylinder
27=Basin
28=10 Litre bucket
29=Bar
30=Bicycle load
31=Other (specify) ____________

Appendix 5b (contd.) **FORM 10: HOUSEHOLD EXPENDITURE**

Code Set 10: *Food Purchases and Household Expenditure*

Food and other Household Items

1=Bananas
2=Beans
3=Cabbage
4=Cassava
5=Cow peas
6=Dry maize
7=Finger millet
8=Green maize
9=Ground nuts
10=Irish potatoes
11=Onions
12=Other vegetables…
13=Soy beans
14=Sugar canes
15=Sweet potatoes
16=Tomatoes
17=Yams
18=Milk
19=Beef
20=Eggs
21=Poultry meat
22=Goat meat
23=Mutton
24=Fish
25=Pork
26=Butter/ghee/ cooking oil
27=Sugar
28=Salt
29=Ingredients (curry powder & other spices)
30=Tea leaves
31=Wheat flour
32=Maize flour
33=Alcohol
34=Cigarettes
35=Soap
36=Bread
37=Rice
38=Millet flour
39=Other (specify)

Fuels

1=Charcoal
2=Firewood
3=Kerosene
4=Gas
5=Dry cells
6=Battery charging
7=Match boxes
8=Petrol
9=Diesel
10=Other (specify)

Tools/equipment

1=Farm hand implements
2=Ox implements
3=Milk cans
4=Other dairy equipment
5=Construction materials
6=Other (specify)

Source

1=Individual/neighbour
2=Local trader
3=Shop
4=Local market
5=Butchery
6=Other (specify)

Units
1=No.
2=Kgs
3=Cubic centimeters
4=Litre
5=Half litre/Large cup/500mls
6=Small cup/350 mls
7=Kawujo (50mls)
8=5 litre bucket
9=20 litres/Jerrican
10=120 litre drum
11=Half Kg
12=Quarter Kg
13=Bunch
14=Tray
15=Pair
16=Kimbo tins
17=Debe tin
18= Packet
19=Sachet
20=Heap
21=Bundle
22=Standard sacks
23=Donkey cart
24=Pick-up
25=Wheel barrow
26=Cylinder
27=Basin
28=10 Litre bucket
29=Bar
30=Bicycle load
31=Other (specify)

Appendix 5b (contd.) **FORM 11: WATER ACQUISITION AND OTHER UTILITIES**

Code Set 11: Water Acquisition and Other Utilities

Source

1=Own well
2=Own piped water
3=Off farm piped
4=Off farm borehole
5=Off farm well/dam
6=Own borehole
7=River
8=On farm roof catchment
9=Other (specify)

____

Units

1=No.
2=Kgs
3=Cubic centimeters (Mls)
4=Litre
5=Half litre/Large cup/500mls
6=Small cup/350 mls
7=Kawujo (50mls)
8=5 litre bucket
9=20 litres/Jerrican
10=120 litre drum
11=Half Kg
12=Quarter Kg
13=Bunch
14=Tray
15=Pair
16=Kimbo tins
17=Debe tin
18= Packet
19=Sachet
20=Heap
21=Bundle
22=Standard sacks
23=Donkey cart
24=Pick-up
25=Wheel barrow
26=Cylinder
27=Basin
28=10 Litre bucket
29=Bar
30=Bicycle load
31=Other (specify)

____

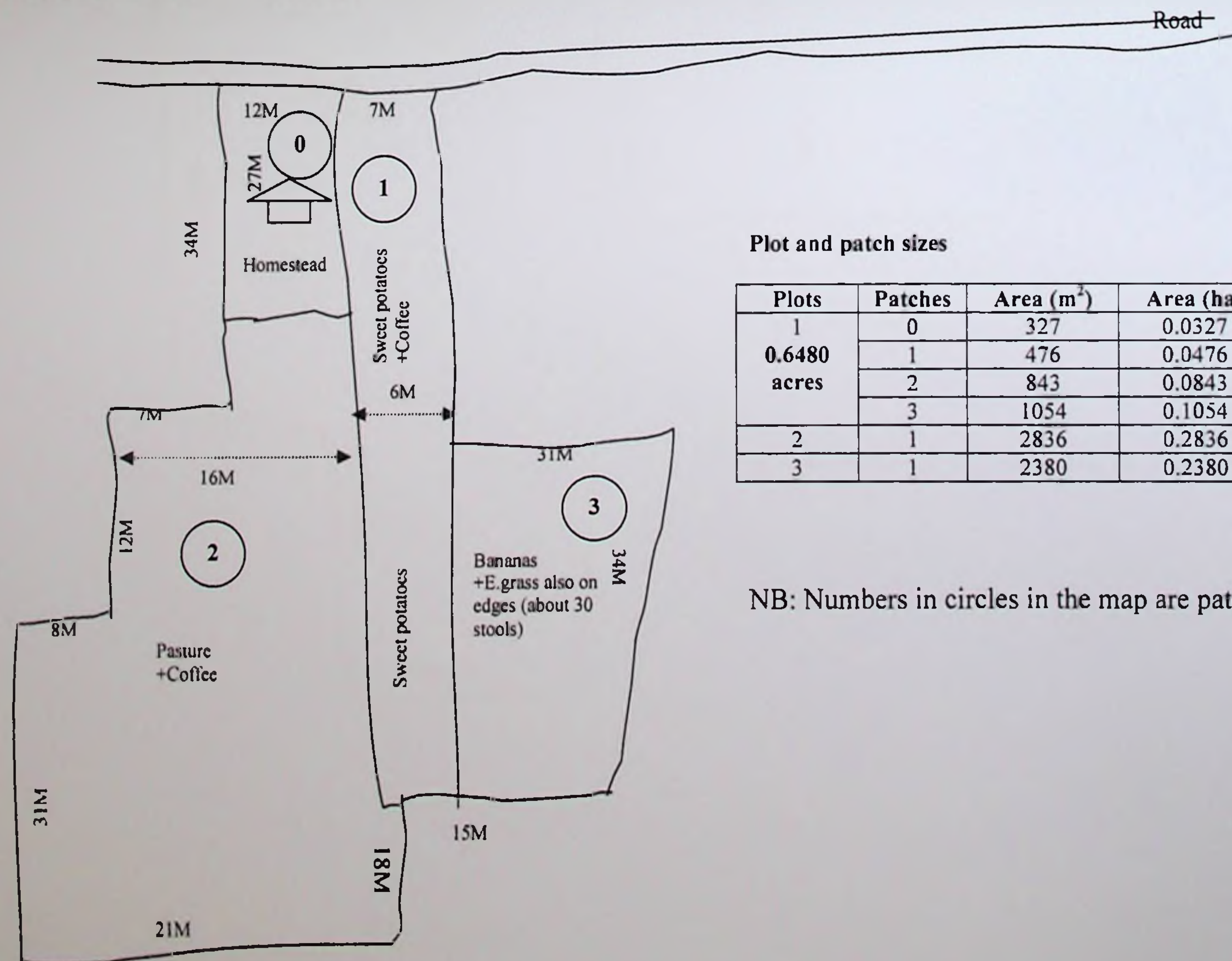
Utility

1=Water
2=Electricity
3=Telephone
4=Other (specify)

____

Appendix 6. Illustration of a farm map: Sketch map for the farm of Baligeya George William, (JN 48), Musima, Mafubira Sub-county, Jinja district, in season 1, 2003 (not drawn to scale)

Plot I: (Plot with the homestead)

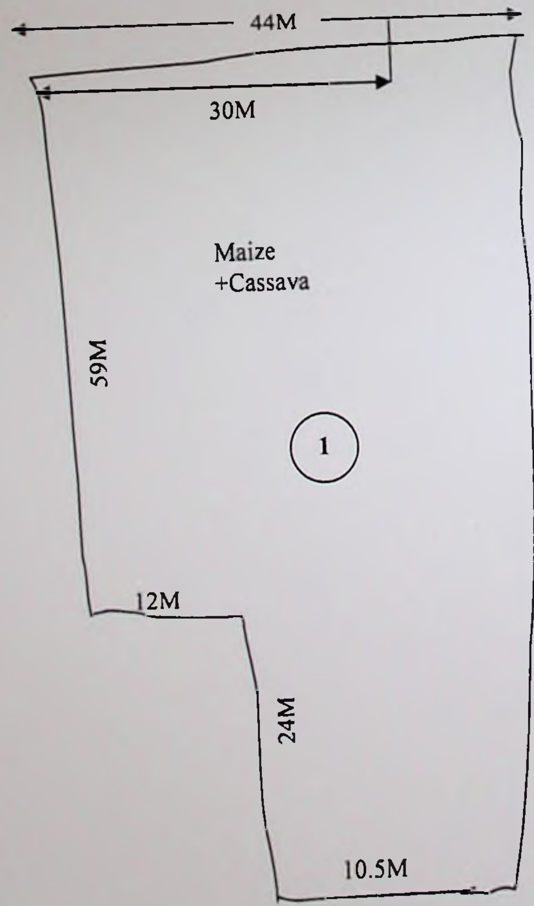


Plot and patch sizes

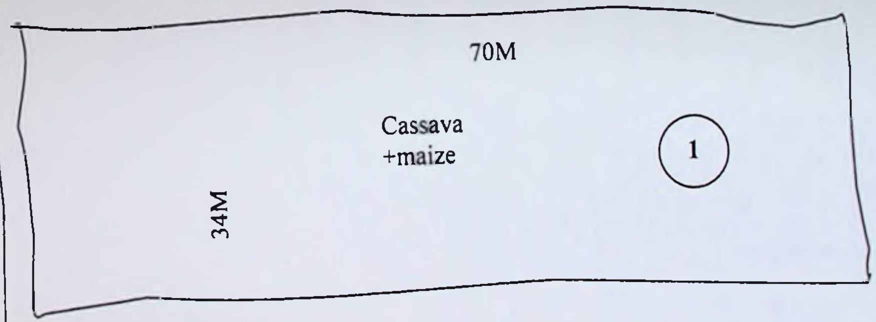
Plots	Patches	Area (m^2)	Area (ha)	Area (acres)
1	0	327	0.0327	0.0785
0.6480	1	476	0.0476	0.1142
acres	2	843	0.0843	0.2023
	3	1054	0.1054	0.2530
2	1	2836	0.2836	0.6806
3	1	2380	0.2380	0.5712

NB: Numbers in circles in the map are patch numbers

(About 60M up on slope above the homestead, hired land)



Plot III (20M up on slope above plot II, is managed mainly by the wife



Appendix 7a. Chemical composition for manures

Patch input item	DM%	N%	P%	K%
Dry cattle manure	50.00	1.40	0.60	1.24
Dry chicken manure	70.00	5.00	1.80	1.20
Dry goat manure	80.00	2.20	1.50	3.00
Dry sheep manure	80.00	2.20	1.50	3.00
Sheep slurry (manure & urine)	31.00	1.70	1.50	2.40
Wet cattle manure	25.00	1.50	0.54	0.80
Wet chicken manure	22.00	1.80	1.27	0.67
Wet goat manure	55.00	1.50	0.40	1.37
Wet sheep manure	55.00	1.50	0.40	1.37

Appendix 7b. Chemical composition for harvest items and crop residues

Harvest item	DM%	N%	P%	K%
Avocado	19.70	0.22	0.05	0.70
Banana	20.90	0.60	0.10	1.44
Banana flowers	6.75	3.60	1.00	2.80
Banana leaves	19.50	1.82	0.42	2.60
Banana peels	13.50	1.04	0.12	5.00
Banana psuedostems(stems)	9.47	0.60	0.22	2.50
Bananas	20.90	0.60	0.10	1.44
Bean haulms	17.00	1.60	0.20	0.12
Bean pods	94.60	2.18	0.20	1.50
Beans	85.00	3.67	0.33	2.04
Cabbage	28.30	3.86	0.43	0.87
Cassava	38.86	0.52	0.07	0.70
Cassava peels	27.94	0.69	0.10	0.70
Cassava stems	93.80	1.71	0.10	0.90
Cassava tops	21.10	3.96	0.22	0.90
Coffee	25.00	0.32	0.30	2.00
Cowpea haulms	17.00	0.40	0.04	0.33
Dessert bananas (eg bogoya ndiizi, gonja)	20.90	0.83	0.11	1.71
Dry maize	87.00	1.55	0.29	0.35
Elephant grass	22.40	1.50	0.22	2.39
Finger millet	97.50	1.70	0.27	1.15
Fruit tree crops	36.60	2.24	0.15	0.41
Ginger	30.00	0.32	0.07	0.54
Ginger leaves	28.00	0.50	0.10	0.80
Green maize	24.04	2.30	0.22	1.87
Ground nut haulms	17.60	1.60	0.15	1.76
Ground nuts	90.00	4.07	0.40	0.69
Irish potatoes	22.30	1.35	0.20	2.44

Appendix 7b (contd.)

Harvest item	DM%	N%	P%	K%
Lablab	15.30	3.14	0.30	0.12
Maize bran	85.00	1.95	0.67	0.90
Maize stover	50.00	1.81	0.34	3.36
Millet straw	86.00	0.35	0.33	1.50
Muluco	25.40	4.80	0.18	0.40
Natural pasture	33.70	1.60	0.33	0.22
Onions	10.32	0.22	0.05	0.19
Other vegetables…	15.54	3.40	0.36	2.88
Pawpaw	9.20	0.06	0.02	0.03
Pineapples	14.70	0.00	0.00	0.12
Sorghum	88.00	1.78	0.28	0.54
Sorghum straw	78.10	0.75	0.24	0.86
Sugar canes	32.40	1.44	0.30	1.50
Sugarcane tops	22.50	0.89	0.15	2.31
Sweet potato vines	14.60	3.42	0.61	3.55
Sweet potatoe peels	7.40	0.19	1.44	11.53
Sweet potatoes	30.70	0.82	0.12	0.70
Tobacco	13.20	4.00	0.20	4.90
Tomatoes	16.00	2.26	0.36	3.43
Weeds	15.00	1.32	0.18	1.65
Yam leaves	24.10	1.92	0.30	3.20
Yam peels	27.00	1.00	0.10	2.00
Yams	30.20	1.07	0.14	2.70
Bush fallow	33.70	1.60	0.33	0.22
Other vegetable residue	20.00	2.00	0.30	2.00
Eggs	24.67	1.91	0.20	0.15

Concentrations of N, P and K and %DM were collected from different sources and some obtained from laboratory analysis. Details of these sources have not been provided here but can be made available on request.

Appendix 8. Crop mixtures in the intercrops used in development of the crop patterns

Crop mixture	Crops included and their proportion	Crop Pattern name
Banana-beans	Bananas70Beans50	Banana-beans
Banana-beans	Bananas90Beans80Cassava20Maize20Tomatoes10	Banana-beans
Banana-beans	Beans70Bananas40Cassava40Fruit/tree crops20Other vegetables5Onions2Elephant gras	Banana-beans
Banana-beans	Beans70Bananas40Cassava40Pineapple20Mituba10Other vegetables5Onions2Other trees2	Banana-beans
Banana-beans	Beans60Bananas40Coffee20Yams20Sugar cane15Elephant grass10Moringa10	Banana-beans
Banana-beans	Bananas50Beans30Cassava20Coffee20Elephant grass10	Banana-beans
Banana-beans	Bananas30Beans30Coffee30Cassava20Beer banana10	Banana-beans
Banana-beans	Bananas30Beans30	Banana-beans
Banana-beans	Bananas100Beans75	Banana-beans
Banana-beans	Bananas100Beans30Beer bananas5	Banana-beans
Banana-beans	Bananas50Beans30Cassava20Coffee20Elephant grass10	Banana-beans
Banana-beans	Beans100Bananas40	Banana-beans
Banana-beans	Bananas30Beans30Coffee30Cassava20Beer bananas10	Banana-beans
Banana-beans	Bananas30Beans30	Banana-beans
Banana-beans	Bananas40Beans30Cassava15Muluco15Elephant grass10	Banana-beans
Banana-beans	Bananas30Beans30	Banana-beans
Banana-beans	Bananas70Beans50	Banana-beans
Banana-beans	Bananas70Beans60	Banana-beans
Banana-beans	Bananas50Beans50Coffee30Grass edges10	Banana-beans
Banana-beans	Bananas100Beans30Beer banana5	Banana-beans
Banana-beans	Bananas30Beans30	Banana-beans
Banana-beans	Bananas70Beans50Coffee30	Banana-beans
Banana-beans	Beans60Bananas30Coffee30Yams3Jackfruit2	Banana-beans
Banana-beans	Beans70Bananas60	Banana-beans
Banana-beans	Bananas70Beans60	Banana-beans
Banana-beans	Beans100	Banana-beans
Banana-beans	Beans100Beans70Bananas60Cabbages60Vegetables40Sugar cane5	Banana-beans
Banana-beans	Bananas40Beans30Elephant grass10	Banana-beans
Banana-beans	Beans100Bananas40Maize40	Banana-beans
Banana-beans	Bananas90Beans80Cassava20Maize20Tomatoes10	Banana-beans
Banana-beans	Bananas40Beans30Elephant grass10	Banana-beans

Crop mixture	Crops included and their proportion	Crop Pattern name
Cereals, cassava & general intercrops	Cassava75Elephant grass10Bananas5Coffee5Muluco5	Intercropped cassava
Cereals, cassava & general intercrops	Cassava50Maize50Coffee5	Intercropped cassava
Cereals, cassava & general intercrops	Cassava90Millet90Maize30	Intercropped cassava
Cereals, cassava & general intercrops	Maize60Cassava30Jack fruit5	Intercropped maize
Cereals, cassava & general intercrops	Cassava75Elephant grass10Bananas5Coffee5Fodder trees5	Intercropped cassava
Cereals, cassava & general intercrops	Maize80Cassava15	Intercropped maize
Cereals, cassava & general intercrops	Cassava70Maize40	Intercropped cassava
Cereals, cassava & general intercrops	Cassava50Maize40	Intercropped cassava
Cereals, cassava & general intercrops	Maize40	Mainly maize
Cereals, cassava & general intercrops	Cassava100	Mainly cassava
Cereals, cassava & general intercrops	Maize70Cassava60	Intercropped maize
Cereals, cassava & general intercrops	Maize60Cassava50Yams10	Intercropped maize
Cereals, cassava & general intercrops	Cassava70Bananas40	Intercropped cassava
Cereals, cassava & general intercrops	Cassava100	Mainly cassava
Cereals, cassava & general intercrops	Sorghum90Beans20	Finger millet/sorghum
Cereals, cassava & general intercrops	Vanilla40	Mixed intercrops
Cereals, cassava & general intercrops	Cassava10	Mainly cassava
Cereals, cassava & general intercrops	Cassava70	Mainly cassava
Cereals, cassava & general intercrops	Finger millet100Maize10	Finger millet/sorghum
Cereals, cassava & general	Maize60Coffee40Bananas15	Intercropped maize

Crop mixture	Crops included and their proportion	Crop Pattern name
intercrops		
Cereals, cassava & general intercrops	Sorghum90Beans20	Finger millet/sorghum
Cereals, cassava & general intercrops	Cassava70	Mainly cassava
Cereals, cassava & general intercrops	Vanilla40	Mixed intercrops
Cereals, cassava & general intercrops	Maize100	Mainly maize
Cereals, cassava & general intercrops	Cassava90	Mainly cassava
Cereals, cassava & general intercrops	Maize60Cassava30	Intercropped maize
Cereals, cassava & general intercrops	Maize70Elephant grass30	Intercropped maize
Cereals, cassava & general intercrops	Maize60Cassava40	Intercropped maize
Cereals, cassava & general intercrops	Maize100	Mainly maize
Cereals, cassava & general intercrops	Cassava70Elephant grass20	Intercropped cassava
Cereals, cassava & general intercrops	Cassava60Sorghum40	Intercropped cassava
Cereals, cassava & general intercrops	Maize100	Mainly maize
Fallow	Paddock100	Fallow
Fallow	Fallow100	Fallow
Fallow	Fallow100	Fallow
Fallow	Eucalyptus70Pastures50	Fallow
Fallow	Fallow90	Fallow
Fallow	Fallow100Coffee5	Fallow
Fallow	Bush Fallow100	Fallow
Fallow	Fallow100	Fallow
Coffee intercrops	Coffee90Cassava30Bananas20	Mainly coffee
Coffee intercrops	Coffee30Elephant grass30Muluco10Yams10	Coffee-fodder crop
Coffee intercrops	Coffee90Cassava40Maize40Calliandra10Elephant grass10Local fruit3Passion fruit3Ot	Mainly coffee
Coffee intercrops	Coffee90Cassava40Maize40Calliandra edge rows10Elephant grass10Fruit/tree	Mainly coffee

Crop mixture	Crops included and their proportion	Crop Pattern name
	crops7O	
Coffee intercrops	Coffee10	Mainly coffee
Coffee intercrops	Coffee30Elephant grass30Fodder trees10Yams10	Coffee-fodder crop
Coffee intercrops	Coffee70Elephant grass25	Coffee-fodder crop
Coffee intercrops	Coffee70Elephant grass20	Coffee-fodder crop
Banana intercrops	Bananas40Fruit/tree crops25Coffee20Lablab5Yams5	Intercropped banana
Banana intercrops	Bananas40Fruit/tree crops25Coffee20Lablab5Yams5	Intercropped banana
Banana intercrops	Beans90Cassava75Maize50	Beans-cassava
Banana intercrops	Bananas100Elephant grass30Yams20Juice sugarcane10	Banana-fodder crop
Banana intercrops	Bananas70Vanilla70Elephant grass5	Intercropped banana
Banana intercrops	Coffee70Bananas40Cassava10Fruit/tree crops5Vanilla5	Coffee-banana
Banana intercrops	Bananas100	Mainly banana
Banana intercrops	Bananas90Elephant grass20	Banana-fodder crop
Banana intercrops	Bananas50Coffee30Elephant grass10	Coffee-banana
Banana intercrops	Beer bananas90Elephant grass20	Mainly banana
Banana intercrops	Bananas90Maize30Elephant grass20Cailiandra10	Intercropped banana
Banana intercrops	Beans60Cassava40Maize40	Beans-cassava
Banana intercrops	Bananas100Elephant grass5Juice sugarcane1	Banana-fodder crop
Banana intercrops	Bananas100	Mainly banana
Banana intercrops	Bananas90	Mainly banana
Banana intercrops	Bananas30Coffee20	Coffee-banana
Banana intercrops	Bananas60	Mainly banana
Banana intercrops	Bananas100Elephant grass30Yams20Juice sugarcane10	Banana-fodder crop
Banana intercrops	Bananas100	Mainly banana
Banana intercrops	Beans40Cassava40Maize40	Beans-cassava
Banana intercrops	Bananas60Sweet potatoes60	Intercropped banana
Banana intercrops	Bananas60	Mainly banana
Banana intercrops	Beans100Cassava10	Beans-cassava
Banana intercrops	Coffee60Bananas50Beans30	Coffee-banana
Banana intercrops	Beans90Cassava70Maize40	Beans-cassava
Banana intercrops	Bananas80Cassava10Fruit/tree crops2	Banana-cassava
Banana intercrops	Bananas100Coffee5	Coffee-banana
Banana intercrops	Bananas80Cassava10Musizi2	Banana-cassava
Banana intercrops	Beans85Cassava5Maize2	Beans-cassava
Banana intercrops	Bananas100	Mainly banana

Crop mixture	Crops included and their proportion	Crop Pattern name
Banana intercrops	Beans90Cassava75Maize50	Beans-cassava
Banana intercrops	Beans85Cassava5Maize2	Beans-cassava
Banana intercrops	Bananas90Maize30Elephant grass20Calliandra10	Intercropped banana
Banana intercrops	Bananas80Elephant grass20	Banana-fodder crop
Banana intercrops	Beans100Cassava10	Beans-cassava
Banana intercrops	Bananas40Coffee20Yams20Elephant grass10Maize10	Coffee-banana
Banana intercrops	Bananas80	Mainly banana
Banana intercrops	Bananas100	Mainly banana
Banana intercrops	Beer bananas90	Mainly banana
Legume based intercrops	Groundnuts100	Ground nuts
Legume based intercrops	Beans75Maize25	Beans-maize
Legume based intercrops	Beans80Maize40	Beans-maize
Legume based intercrops	Beans40Maize40Groundnuts30Coffee20Elephant grass5	Beans-maize
Legume based intercrops	Beans70Maize60	Beans-maize
Legume based intercrops	Beans60Maize40Cassava20	Beans-maize
Legume based intercrops	Beans70Maize60	Beans-maize
Legume based intercrops	Beans70Maize40Coffee20	Beans-maize
Legume based intercrops	Coffee40Beans30Bananas15	Coffee-beans
Legume based intercrops	Beans80Maize70Bananas40Coffee10	Beans-maize
Legume based intercrops	Beans90Maize30Cassava10	Beans-maize
Legume based intercrops	Beans90Maize50Elephant grass30	Beans-maize
Legume based intercrops	Groundnut100	Ground nuts
Legume based intercrops	Beans40Coffee30Sweet potatoes20Maize15Guatemala10Avocado5Elephant grass5	Coffee-beans
Legume based intercrops	Beans80Maize50Cassava20	Beans-maize
Legume based intercrops	Beans60Maize50	Beans-maize
Legume based intercrops	Beans70Maize40Coffee20	Beans-maize
Legume based intercrops	Beans90Maize40Bananas10	Beans-maize
Legume based intercrops	Beans70Coffee30Maize10Elephant grass5	Coffee-beans
Legume based intercrops	Beans40Coffee30Sweet potatoes20Maize15Planted pasture10Fruit/tree crops6Elephant	Coffee-beans
Legume based intercrops	Beans90Maize40Bananas10	Beans-maize
Legume based intercrops	Groundnuts100Cassava10	Ground nuts
Legume based intercrops	Beans70Maize60	Beans-maize
Specialised crops	Yams90Muluco5	Yams
Specialised crops	Yams90Fodder trees5	Yams

Crop mixture	Crops included and their proportion	Crop Pattern name
Specialised crops	Sweet potatoes100	Sweetpotatoes
Specialised crops	Pineapples100	Pineapples
Specialised crops	Sweet potatoes70Cassava10Coffee10Elephant grass10Fodder trees10	Sweetpotatoes
Specialised crops	Sweet potatoes80Bananas10Coffee10Lablab5Yams3Fruit/tree crops2	Sweetpotatoes
Specialised crops	Sweet potatoes100	Sweetpotatoes
Specialised crops	Sweet potatoes80Maize20	Sweetpotatoes
Specialised crops	Sweet potatoes60Cassava20Maize20Groundnuts10	Sweetpotatoes
Specialised crops	Sweet potatoes100	Sweetpotatoes
Specialised crops	Sweet potatoes70Cassava10Fodder trees10	Sweetpotatoes
Specialised crops	Juice sugarcane100	Sugarcane
Specialised crops	Sweet potatoes100Coffee30	Sweetpotatoes
Specialised crops	Juice sugarcane100	Sugarcane
Specialised crops	Sweet potatoes70Cassava10Coffee10Elephant grass10Fodder trees10	Sweetpotatoes
Specialised crops	Sweet potatoes100	Sweetpotatoes
Specialised crops	Sweet potatoes60Maize25Cassava20Groundnuts10	Sweetpotatoes
Specialised crops	Sweet potatoes100	Sweetpotatoes
Specialised crops	Pineapples40Cassava10	Pineapples
Specialised crops	Other vegetables100	Vegetables
Specialised crops	Fruit/tree crops100	Fruit trees
Specialised crops	Sweet potatoes100	Sweetpotatoes
Specialised crops	Sweet potatoes100Cassava5	Sweetpotatoes
Specialised crops	Sweet potatoes100	Sweetpotatoes
Specialised crops	Sweet potatoes100	Sweetpotatoes
Specialised crops	Sweet potatoes80Bananas10Coffee10Lablab5Yams3Jackfuit2	Sweetpotatoes
Specialised crops	Sweet potatoes100	Sweetpotatoes
Specialised crops	Sweet potatoes100	Sweetpotatoes
Specialised crops	Sweet potatoes100Coffee30	Sweetpotatoes
Specialised crops	Sweet potatoes100Cassava5	Sweetpotatoes
Specialised crops	Sweet potatoes100	Sweetpotatoes
Specialised crops	Sweet potatoes100	Sweetpotatoes
Specialised crops	Sweet potatoes80Cassava5	Sweetpotatoes
Specialised crops	Sweet potatoes100Coffee5	Sweetpotatoes
Specialised crops	Sweet potatoes70Cassava10Fodder trees10	Sweetpotatoes
Specialised crops	Mango5	Fruit trees
Specialised crops	Sweet potatoes100	Sweetpotatoes

Crop mixture	Crops included and their proportion	Crop Pattern name
Fodder crops	Elephant grass100	Fodder crop
Fodder crops	Elephant grass100	Fodder crop
Fodder crops	Elephant grass90Maize50Beans30	Fodder crop
Fodder crops	Lablab100	Fodder crop
Fodder crops	Lablab70Mucuna40Elephant grass20	Fodder crop
Fodder crops	Lablab100Yams3	Fodder crop
Fodder crops	Lablab100	Fodder crop
Fodder crops	Elephant grass100	Fodder crop
Fodder crops	Elephant grass95Coffee10Fruit/tree crops10Yams1	Fodder crop
Fodder crops	Lablab100	Fodder crop
Fodder crops	Elephant grass90Fruit/tree crops10	Fodder crop
Fodder crops	Lablab90Beans70Pasture60Groundnuts40Maize40Coffee20Cassava10Elephant grass3Misam	Fodder crop
Fodder crops	Elephant grass95Coffee5Misambya5	Fodder crop
Fodder crops	Planted pasture (Chloris)60Planted pasture (Setaria)10	Fodder crop
Fodder crops	Elephant grass95Coffee5Fruit/tree crops5	Fodder crop
Fodder crops	Elephant grass100Cassava5	Fodder crop
Pasture	Natural pasture100	Pasture
Pasture	Fallow100	Pasture
Pasture	Fallow100	Pasture
Pasture	Fallow100	Pasture
Pasture	Natural pasture100	Pasture
Pasture	Paddock100	Pasture
Pasture	Fallow100	Pasture
Pasture	Improved pasture100	Pasture
Pasture	Fallow100	Pasture
Pasture	Fallow100	Pasture
Pasture	Improved pasture100	Pasture
Pasture	Fallow100	Pasture
Pasture	Fallow100	Pasture
Pasture	Planted pasture(Chloris)100	Pasture
Pasture	Planted pasture(Chloris)100	Pasture
Pasture	Improved pasture100	Pasture
Pasture	Fallow100	Pasture
Pasture	Pastures100	Pasture

Crop mixture	Crops included and their proportion	Crop Pattern name
Pasture	Fallow100	Pasture
Pasture	Pasture100	Pasture
Pasture	Natural pastures90Coffee20	Pasture
Pasture	Pastures100	Pasture
Pasture	Fallow100	Pasture
Pasture	Fallow100	Pasture
Pasture	Pastures100	Pasture
Pasture	Pastures100	Pasture
Pasture	Fallow100	Pasture
Pasture	Pasture100	Pasture
Pasture	Paddock100	Pasture
Pasture	Planted pasture(Chloris)60Setaria10	Pasture

Appendix 9. Seasonal manure requirements to attain zero Patch Net N balance in the dairy farm categories

Farm categories	Total Farm manure yield in a season	Patch manure requirement (%)	Manure quantity required for application to each patch (kg dm)	Patch size (ha)	Manure requirement (kg (DM) ha^{-1} $season^{-1}$)	No. of Patches per farm per season	Manure proportion required for whole farm in a season (%)	Extra manure proportion required from off-farm sources in a season (%)	Manure quantity required from off-farm sources (kg (DM))
HD	3678	13	478.2	1.60	298.48	8	104	4	147
TE	1509	9	135.8	0.12	1180.72	11	99	-	-
FE	6587	12	790.4	1.35	583.37	8	96	-	-
SI	2087	15	313.1	0.25	1238.56	8	120	20	417
ZG	416	52	216.5	0.13	1665.11	2	104	4	17