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Research Report 1



Dairy farming in Uganda

Production Efficiency and Soil Nutrients under Different Farming Systems

I. Baltenweck, S. Mubiru, W. Nanyeenya, L. Njoroge, N. Halberg, D. Romney and S. Staal

In collaboration with J. S. Tenywa and J. Mugisha

NARO
National Agricultural Research Organisation

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Supported by

DANIDA Danish International Development Agency and CGIAR Consultative Group on International Agricultural Research

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INTRODUCTION

Prior to the 1980s, milk production in Uganda occurred largely in two contrasting production systems. In the wetter parts of the country, especially in the southwest, there were a few large, mostly government-owned commercial dairy farms on which exotic and cross-bred dairy cattle were kept in paddocks and grazed on improved or natural pastures. In the drier eastern and northeastern parts of the country, pastoralists kept large numbers of local cattle breeds, notably the Small East African Zebu (SEAZ), under traditional extensive management systems. Although the pastoralists marketed some milk, most was consumed by the household. Cattle were also valued as an expression of cultural prestige and a means of accumulating capital and meeting planned and emergency expenses. Smallholders, who tended to keep a few low yielding indigenous cattle as well as growing crops, made little contribution to the nation's marketed milk and were primarily subsistence-oriented.



CHANGING POLICY ENVIRONMENT

This situation changed in 1986 with the introduction of the National Economic Recovery, Rehabilitation and Development Programs. This led to a shift in policy emphasis which sparked off a number of initiatives, including the introduction of zero-grazing, a system under which improved dairy cattle are kept permanently in stalls and their feed – including specially grown fodder crops, crop residues and bought-in feed and water – is 'cut-and carried' to them. Farm size tends to be small, typically around 1.5 hectares, and crops such as bananas, maize, beans, sweet potatoes, sorghum, vegetables and coffee are commonly grown in intercropping systems alongside between one and five zero-grazed dairy cattle.

From the mid 1980s, a number of non-governmental organizations, such as Heifer Project International, promoted zero-grazing through schemes which often involved donation of in-calf dairy heifers to beneficiaries together with training on managing improved dairy breeds, fodder production and other related activities. Beneficiaries repaid their loans in the form of the first heifer born, which was passed on to another beneficiary. Other smallholders, inspired by the experience of project beneficiaries, acquired their own dairy cattle or gradually upgraded their indigenous animals by cross-breeding through use of artificial insemination or bull schemes. Some adopted strict zero-grazing systems, while others combined grazing paddocks with stall feeding – a system that came to be known as 'semi-intensive'. As a result, over the last two decades in Uganda there has been a steady increase in the number of improved dairy cattle, national milk production, proportion of milk produced and marketed by smallholders, contribution of dairying to the national economy and per capita milk consumption.

In 1992, the Government launched its Milk Master Plan, which aimed to improve rural incomes and living standards of small-scale farmers; achieve self sufficiency in milk production; foster diversification of dairy products through improved processing; provide surplus for export through improved dairy production; improve sustainability of milk production systems by increasing productivity of individual animals rather than increasing cattle populations; and ensure existence of competitive and liberal markets that reduce transaction costs and increase producers' share of consumer prices. Liberalization of the sub-sector in 1993 saw the government monopoly on milk processing broken and the emergence of a dozen or more medium-scale and around 60 small-scale private milk processors. Under the Dairy Industry Act of 1998 a statutory body, the Dairy Development Authority, was established with a mandate to realize the objectives of the master plan.

APPROPRIATE INTENSIFICATION LEVELS FOR SMALLHOLDERS

Whilst development agencies in Uganda have tended to promote intensification of dairy production to smallholder farmers – where intensification is associated with improved breeds of dairy cattle, smaller farm sizes and increased usage of labour and purchased inputs per unit of milk produced – farmers themselves have adopted a range of intensification options that form a continuum, ranging from traditional extensive systems to intensive zero-grazing systems. Some farmers, having initially adopted more intensive options, have 'extensified/de-intensified'; based on their experiences with labour, feed and management costs, they have reverted to less intensive systems such as relaxation from zero-grazing to semi-intensive and downgrading of high-grade breed categories in other grazing systems. This has raised questions about whether intensification is always the best option for smallholder farmers but to date there has been a lack of systematic studies of the smallholder dairy sector in Uganda to provide the answers. Therefore, the current study sought to fill this information gap, particularly to understand competitiveness of different dairy production systems under different agro-climatic and market potential scenarios. To inform the design of development projects, it is particularly important to understand farmers' motivation to intensify so that projects are successful and sustainable.

LOW SOIL FERTILITY

Concerns have also been expressed about sustainability of mixed dairy-crop systems. There is a general assumption that soil and general nutrient management in these systems is efficient. It is expected that manure from the cattle is applied to the soil for fertility management. Similarly, the option of feeding crop residues to cattle is an opportune efficient nutrient recycling channel. On the other hand, substantial quantities of nitrogen are expected to be fixed by forage legumes which ideally should be planted for cattle feeding in intensive systems. However, it is not clear to what extent such nutrient management options are harnessed in these mixed dairy-crop systems.

Although commonly perceived to be fertile, many soils in Uganda are in fact naturally poor: they are ancient (more than 500 million years old) and in the final stage of the weathering process (and so most of the naturally occurring nutrients have been leached out); the predominant minerals do not directly supply nutrients to soils; they are acidic and infertile; nitrogen levels are generally low, phosphorus commonly occurs in forms not readily available to crops and there are no primary minerals that can supply potassium; and many minerals are easily leached out of the root-zone of most crops[1].

Previously practised 'slash and burn' and farming systems incorporating periods of fallow have, with growing human populations, given way to permanent cultivation, often with poor soil management practices. The combination of naturally infertile soils and poor soil husbandry represents a serious threat to sustainable farming, not just in Uganda but throughout much of Africa.

[1]Nkedi-Kizza, Peter, Jacob Aniku, and Christina Gladwin. "Gender And Soil Fertility In Uganda: A Comparison Of Soil Fertility Indicators For Women And Men's Agricultural Plots." African Studies Quarterly 6, no.1: [online] URL: http://web.africa.ufl.edu/asq/v6/v6i1a2.htm

STUDY RATIONALE AND FOCUS

To respond to this situation, an in-depth study was carried out between 2001 and 2005 to gain a better understanding of dairy production systems in Uganda. Such knowledge was expected to improve the targeting of evidence-based extension messages to specific production systems and enable development of policies to support the contribution of dairying to sustainable livelihoods of resource-poor farmers. These outcomes would help to realize the vision of the Milk Master Plan. The partners in the study were the Ugandan National Agricultural Research Organization (NARO), Makerere University, the International Livestock Research Institute (ILRI) and the Danish Institute of Agricultural Sciences (DIAS). The study was funded by the Danish International Development Agency (DANIDA).

The study had two main components: one primarily economic and one focused on nutrient cycling, although both components also involved broader characterization of the Ugandan dairy sector. Each of the components was the basis for PhD theses by Ugandan students, supported and supervised by researchers from NARO, Makerere University, ILRI and DIAS. This summary paper is based on these two theses[2].

The economic component examined the economic efficiency of the dairy and whole farm enterprise as well as the factors and incentives influencing farmers' adoption of dairy intensification and crop–livestock interactions, such as feeding crop residues and using manure to improve soil fertility. Although intensive management methods, such as zero-grazing, are often promoted by development agents in Uganda, the study set out to test whether intensification was always the most appropriate option.

The nutrient cycling component evaluated the balance of nitrogen, phosphorus and potassium – key nutrients essential for successful crop production. Throughout Africa there is a tendency to 'mine soils' by returning insufficient nutrients to replace those lost through harvested crops; the result is negative nutrient balances which can lead to land degradation and threaten sustainable farming.

[2]Mubiru, SL. 2006. Development of nutrient management strategies along a continuum of dairy production intensification in Uganda. *PhD thesis,* Makerere University.

Nanyeenya WN. 2006. Incentives to intensification of dairy production in Uganda. *PhD thesis,* Makerere University.

STUDY DISTRICTS

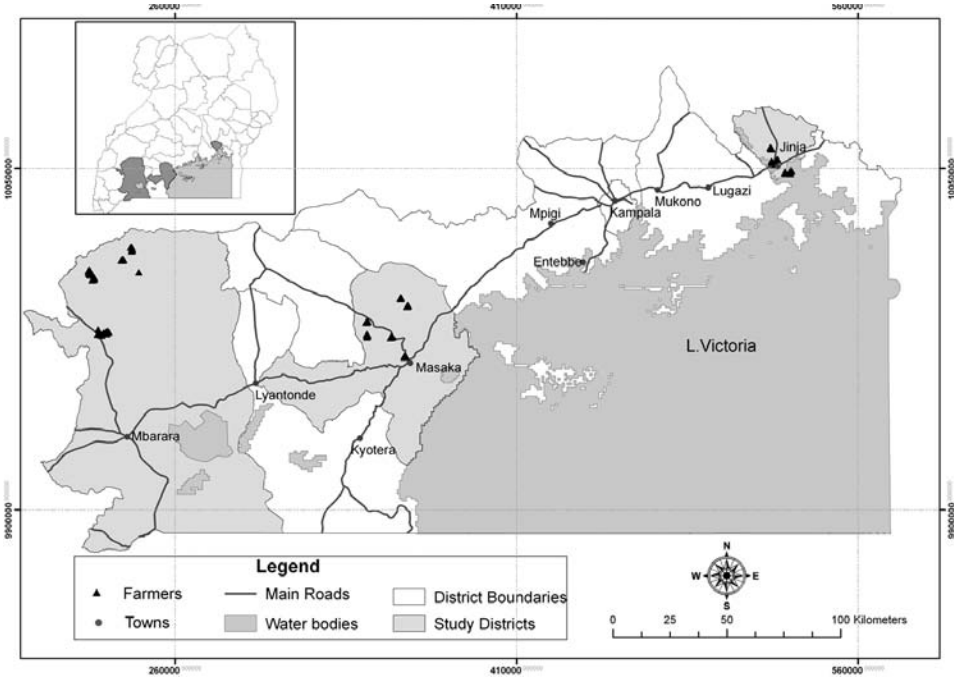


Figure 1: Surveyed districts and location of the farms.

The study was carried out in three districts – Mbarara, Masaka and Jinja – all of which supply milk to the Ugandan capital (Figure 1). The three districts represent different scenarios within the 'Kampala milk shed', including a range of agro-ecological zones, cattle management practices and differing degrees of market access. Previous studies had indicated that nutrient management practices designed to maintain or improve soil fertility rarely occurred in any of the study districts.

Mbarara is in the southwest of Uganda, bordering Tanzania, and is the most distant of the three study districts from Kampala. Cattle production is largely extensive, with agro-pastoralism being common. Most households combine crop and livestock production, with bananas and coffee being the main crops. It is estimated that 12% of cattle are exotic or cross-bred.

Masaka district is in southern Uganda. The banana-coffee-livestock system is most common although agro-pastoralism is also practised. Intensive dairying occurs in peri-urban areas whilst extensive communal grazing is practised in the more remote semi-arid areas. An estimated 11% of cattle are exotic or cross-bred.

Jinja is much smaller than the other two districts, has the highest human population density and is closest to the capital city Kampala. It can be classified as agro-industrial with livestock rearing, fishing and crop production all being practised; the last includes subsistence agriculture as well as large-scale commercial sugar and small-scale maize production. An estimated 18% of cattle in the district are exotic or cross-bred.

STUDY METHODS

Cross-sectional and longitudinal surveys were employed and standard models were used in data analysis. The cross-sectional survey – consisting of a pre-tested, structured questionnaire administered during a single visit per household – was performed in 2001 and covered 303 farmers. The in-depth longitudinal survey comprised repeat visits made between August 2003 and August 2004 and covered 24 farmers (sampled from the farmers covered in the cross-sectional survey). The same data sets were used for the economic and nutrient cycling components of the study.

For the cross-sectional survey, data were collected on household composition; farm activities, labour and facilities; land tenure, size and use; objectives for farming; constraints to production; soil fertility enhancement practices; pest 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 farm and non-farm income and expenditure. Each farm included in the survey was geo-referenced and this information was used to generate data for each household on annual rainfall and population densities based on published information. Within each district, three sub-counties were selected which represented different human population and road densities. For each sub-county, two villages were chosen at random from which households were selected using two transects.

For the longitudinal survey, households were selected that fell in all five dairying categories identified during the study and interviews were carried out every two weeks.

Of the 303 households covered in the cross-sectional survey, 214 owned cattle while 89 did not. Similarly, of the 24 households covered in the longitudinal study, 19 owned cattle and the rest did not.

Data on farm inputs, outputs and transfers were collected during three cropping seasons (May 2003 to August 2004) from the 19 households that kept cattle. Inputs comprised bought-in feed, off-farm grazing, off-farm mulch and nitrogen fixation by legumes. Outputs included all harvested crops, milk, soil erosion and gaseous losses. Transfers comprised farm-generated crop residues and manure applied to fields. In addition, samples of soil, milk and manure were collected and analyzed for nitrogen, phosphorus and potassium.

These data, together with published information, were then used to calculate nutrient balances as nutrient inputs from all sources minus nutrient outputs. Nutrient balances were determined at three levels: farm, land and patch (Figure 2). 'Land' corresponded to the area of the farm that was cultivated (e.g. in Figure 2, Plot 1 + Plot 2). 'Patch' corresponded to an area within the cultivated land on which a single crop or combination of crops, such as bananas or maize and beans, was grown (e.g. in Figure 2, Patch 1 and Patch 2 within Plot 1). Pasture and fallow were included within the designation 'crop'.

A variety of modelling approaches were used for different elements of the economic and nutrient cycling components of the study. Synthesis of the economic data adopted both regression analysis and a linear programming approach while the nutrient cycling component was largely based on the NUTMON[3] method with minor modifications.

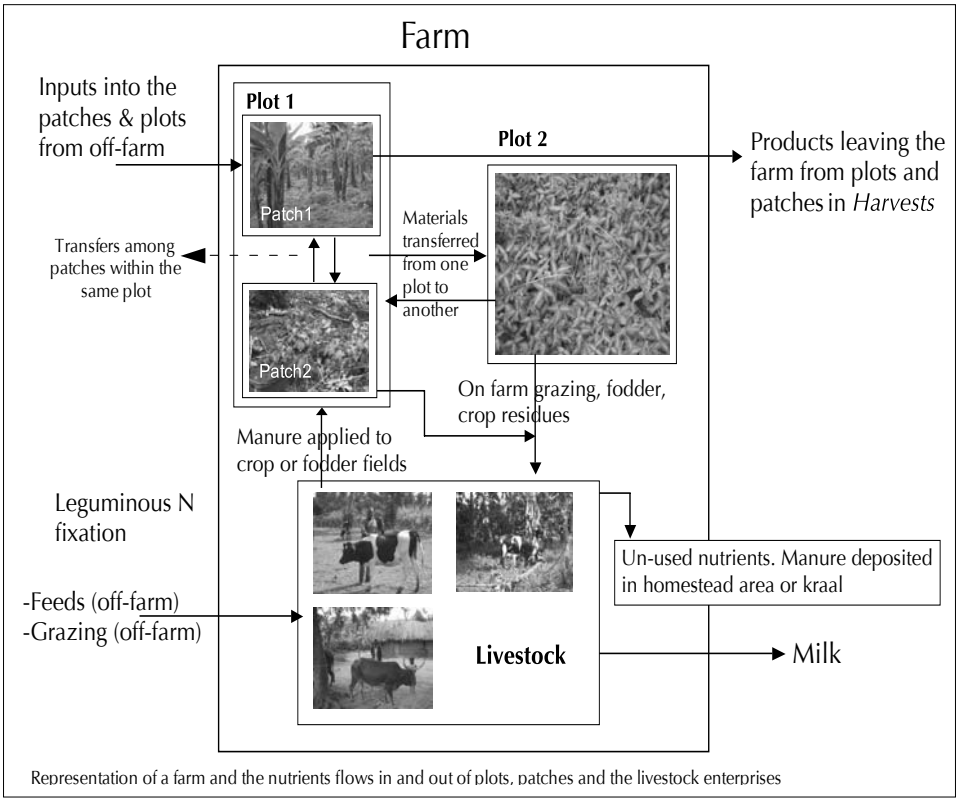


Figure 2: Model for the analysis of nutrient flows and balances.

[3]Vlaming, J., Van den Bosch, H., Van Wijk, M. S., De Jager, A., Bannick, A. and Keulen, H. 2001. Monitoring nutrient flows and economic performance in tropical farming systems (NUTMON) Part 1: Manual for the NUTMON-toolbox. Alterra, Green World research, Wageningen the Netherlands. p.180.

FARM CHARACTERIZATION

Cross-sectional survey data were subjected to a process called cluster analysis, a statistical tool used to group observations with similar tendencies based on a set of variables (Table 1). Using this approach, five different dairy production systems were identified. These are listed below in descending order of intensification:

- zero-grazing
- semi-intensive
- fenced
- tethered
- herded

Zero-grazing is the most intensive of the five production systems. In this system improved dairy cattle are permanently kept in stalls with no free-grazing and there is a high level of external inputs, including bought-in feeds, and significant expenditure on livestock and veterinary services. Farm size is small, productivity high and farms tend to be close to towns. Because cattle are permanently confined, a large proportion of the farm is cultivated for crops although the actual area cropped is small. A wide variety of crops are grown but banana and beans are predominant. The majority of the farms practising zero-grazing were located in Jinja district where about a quarter of farms fall into this category.

Semi-intensive is similar to zero-grazing except cattle spend some time confined to stalls and some time grazing in paddocks. A large proportion of the farm tends to be devoted to growing fodder crops.

In fenced systems, cattle – a large proportion of which are improved dairy breeds – graze in paddocks and therefore, not surprisingly, large pasture fields dominate. There is low input of feeds from off the farm, little or no off-farm grazing and fenced dairy farms tend to be close to road networks. Most farms practising fenced dairy production were located in Mbarara district, where more than 70% of farms fall into this category.

In the tethered system, predominantly local cattle breeds are mostly grazed off-farm, freeing up land for cultivation, with sweet potatoes being the dominant crop. Density of cattle tends to be high. Farms in the tethered category tend to co-exist with zero-grazing, semi-intensive or fenced farms. Tethered farms were most

common in Jinja and Masaka districts where about one third and one fifth of farms, respectively, fell into this category.

Herding is the least intensive of the five production systems and consists of mostly local breeds of cattle being grazed on and off-farm with pasture, fallow, banana and beans as the main forms of cultivation. Sometimes cattle are grazed on fields after harvesting has occurred. Most farms which practised herding were located in Masaka district, where about 70% of farms fell into this category.

Table 1: Descriptive statistics of key farm characteristics from the cross-sectional survey

Variable	Jinja	Masaka	Mbarara
Per cent of surveyed households owning cattle	72.6	71.9	75.8
Per cent of households practising only stall feeding	20.3	10.3	0
Per cent of household practising mainly stall feeding with some grazing	10.8	1.5	5.5
Per cent of households practising grazing with some stall feeding	48.6	50.0	7.6
Per cent of household practising only grazing	20.3	38.2	84.9
Average land size (ha)	1.8 (0.1, 20.2)*	1.7 (0.2, 11.9)*	6.0 (0, 72.8)*
Average number of cattle heads	3	5	17
Per cent of herd that is high grade	14	1.8	6

*Minimum and maximum hectarage

ECONOMIC FINDINGS

Four factors were identified which were statistically associated with adoption of dairy intensification (see Table 2). These included two human capital factors, years of formal education of the household head and proportion of adults working off-farm, and two demand factors, human population density and distance to local markets.

More formal education appears to equip farmers better to acquire and utilize the information and skills needed for more intensive dairy production systems. The finding related to off-farm working suggests that family labour is important for dairy intensification; with less family labour available there is a reduced tendency to intensify. Not surprisingly, higher human population densities and more accessible markets, both of which would be expected to increase demand, encouraged dairy intensification.

Table 2: Factors associated with adoption of dairy intensification

Variable	Impact on dairy intensification
Years of formal education	Positive
Proportion of adults working off farm	Positive
Human population density	Positive
Distance to local markets	Negative

The study considered two examples of crop-livestock interactions: application of manure to fields and feeding of crop residues to dairy cattle. A high degree of interdependence was found; farmers were likely to adopt both practices, although some factors were associated with one practice only (see Table 3).

Households where the head had more years of farming experience were more likely to feed crop residues, although this factor had no impact on manure application. The higher the rainfall (as measured by PPE which is the ratio of precipitation to evapotranspiration), the less likely was the farm to feed crop residues, presumably reflecting the greater abundance of fodder and grazing in wetter areas. It was more likely that crop residues would be fed the further the farm was from a main road, which could be due to the greater difficulty of transporting

bought-in feed but more probably due to the low marketing opportunities. Finally, more crop residues were fed where human population density was highest, which could be explained by higher demand for milk in these areas but also by reduced opportunities for off-farm grazing and increased crop production to meet the demand for food making more crop residues available.

Application of manure to fields was associated with higher cattle densities. On farms with high cattle densities, less land would be available for cropping thereby increasing the need for higher yields which could be achieved through use of manure. Farms where more adults worked off-farm were also more likely to apply manure, perhaps because this increased their exposure to different ideas, knowledge and skills, especially if they worked on other peoples' farms. However, the level of manure utilization was low on all farm types.

Table 3: Determinants of crop residue feeding and manure application

Variable	Impact on residue feeding	Impact on manure application
Household characteristics		
Household head's farming experience	Positive	No significant impact
TLU* per hectare	No significant impact	Positive
Adults working off farm	No significant impact	Positive
Distance to all weather roads	Positive	No significant impact
Distance to district main town	Positive	No significant impact
Neighbourhood factors		
Annual PPE	Positive	No significant impact
Human population density (person/km^2)	Positive	Positive

*TLU: tropical livestock units

The cost of milk production was compared for each of the five dairy production systems using data obtained from the longitudinal study. The cost of production per litre was highest in the tethered and lowest in the herded system. Estimates of fixed costs (cattle housing, dairy equipment and herd depreciation) were not included in the estimates of cost of milk production so a true profit margin could not be calculated. However, the contribution margin – which is the difference between sales price and cost estimates excluding fixed costs – was highest for zero-grazing and lowest for the tethered system. Break-downs of the cost components under the different systems are shown in Figure 3.

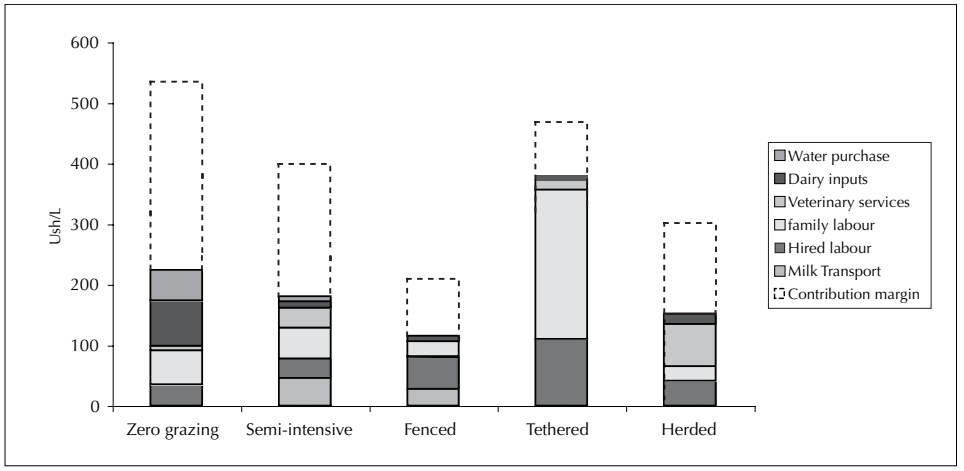


Figure 3: Cost (Ush per litre) of milk production and its components by dairy production system.

Dairy farming was profitable (as measured by a positive contribution margin) under all five production systems (Figure 3). Farms which practised zero-grazing, semi-intensive or fenced production systems sold more milk and operated closer to profit maximization (i.e. were more commercially oriented) than those which practised tethered or herding production systems. Moreover, analysis of milk productivity of the different farming systems revealed that increasing the level of intensification resulted in an increase in the milk productivity and the percentage of milk sold (Figure 4).

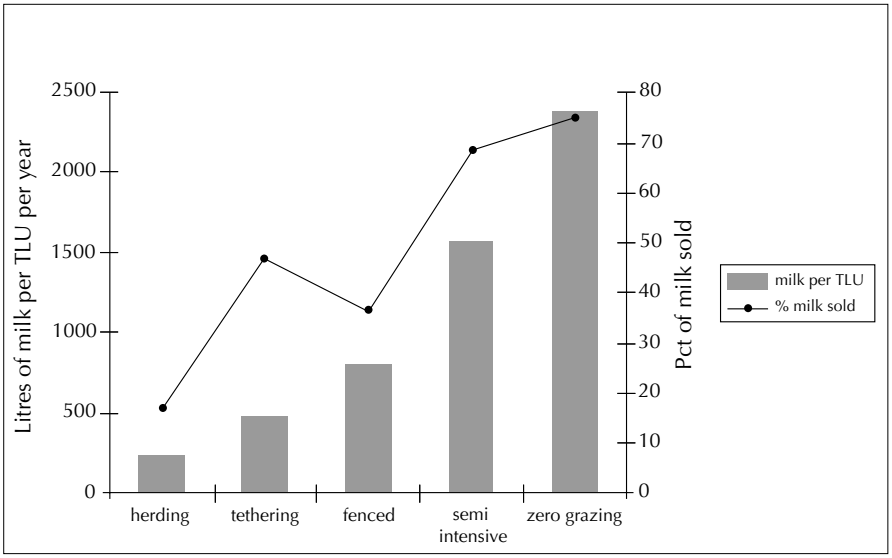


Figure 4: Relationship between milk productivity, market orientation and cattle farming system.

Net benefits achieved from dairying were close to profit maximization in all five systems although overall farm benefits/hour were below the profit maximization in all systems except zero-grazing (Figure 5). Profit maximization refers to the degree to which net benefits match the economic efficiency level of profitability (as determined by the linear programming model). This suggests that different cropping patterns would give better economic returns. Choices of intensification options and of crops grown were evidently not solely driven by desire for profit maximization; other considerations such as the need for diversity of diets and to meet subsistence food requirements, as well as risk aversion, also influenced decision making. Risk-averse individuals' decisions and plans are hatched such that they avoid worst possible future outcomes and hence trade potential income for lower risk. Farmers in all five intensification categories were risk averse to some extent, with farmers in the more intensified systems being least averse to risk and farmers in the more extensive systems being more risk averse.

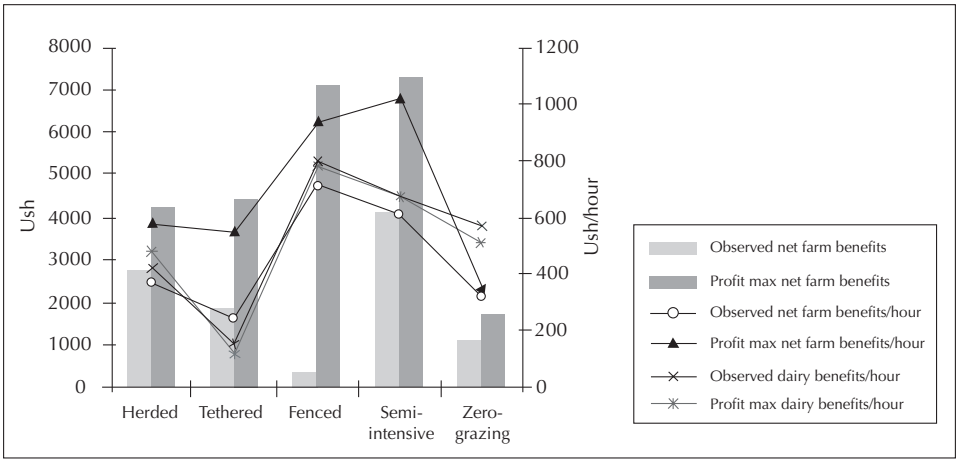


Figure 5: Comparison of observed and profit maximization net farm and dairy benefits.

Besides examining to net farm and net dairy benefits, the study also examined the opportunity cost of farm labour (i.e. the local wage rate) by comparing the net benefits per hour of labour employed on the farm or dairy enterprise and the prevailing hourly wage rates. Despite the variability in milk productivity and the market orientation between farming systems, the net farm and dairy benefits per hour invested remained above the cost of labour for all five systems (Figure 6) and there was no apparent relationship between degree of intensification and the dairy benefits per hour. This indicates that in the current situation, all systems are remunerating the farmers' labour above what they could get if they were to offer their services outside their farms.

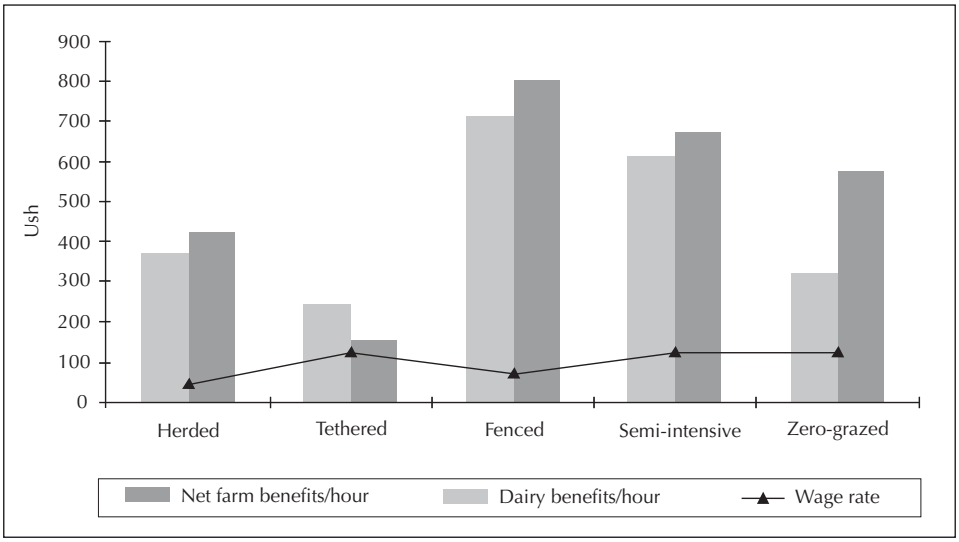


Figure 6: Comparison of the net farm and dairy benefits per hour and the local wage rate for different cattle farming systems.

It would be economically advantageous to increase the amount of crop residues fed in the zero-grazing, semi-intensive and tethered systems, reflecting relative feed scarcity in these systems. In all systems except tethering, it would be beneficial to increase the amount of available land, for example by renting additional land.

Manure use was generally low; in no system was more than 15% of available manure applied to the land. Utilization of manure was highest on zero-grazing farms, where it was mostly applied to banana and coffee plots, and tethered systems, where it was applied to banana and bean plots.

Labour is a major limiting factor in dairy production. Although there is a labour market to bridge labour gaps in farm production, rising wage rates may render hiring labour prohibitive and tremendously erode net benefits. A sensitivity analysis was carried out to investigate the effect of a three-fold increase in current wage rates on the net benefits currently realized in the different dairy production systems. This increase is considered to be likely in the medium term based on previous experience in the country; between 1988 and 2006, the daily wage rate for unskilled labour in Uganda more than doubled. The results of the sensitivity analysis are presented in Table 4.

Table 4: Sensitivity analysis of wage rate changes on net benefits

Dairy system	Market wage rate (shillings/hour) (2002/2003)	Wage rate (shillings/hour) inflated 200%	% reduction in net farm benefits
Zero grazing	126	378	21
Semi-intensive	126	378	6
Fenced	74	222	23
Tethered	126	378	9
Herded	48	144	8

The highest reduction in net farm benefits occur in the fenced system followed closely by the zero-grazing system. These systems are therefore more sensitive to increases in the price of hired labour and their long-term viability would be affected most by raising labour costs. On the other hand, the semi-intensive, herded and tethered systems show minor decreases in net farm benefits, suggesting that these systems would not be adversely affected by rising labour costs.

NUTRIENT CYCLING FINDINGS

The nitrogen levels in all five farm categories were below the critical levels (Figure 7). Phosphorus was above the critical level in all farm categories except zero-grazing where it was below the critical level. Potassium was above the critical level in all farm categories.

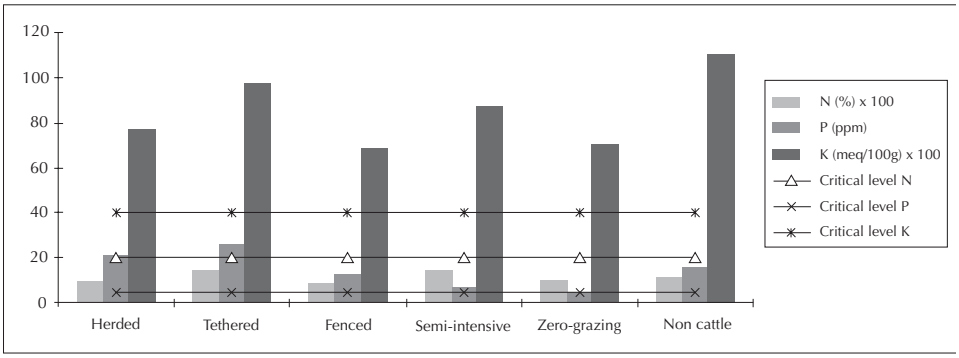


Figure 7: Comparison of soil nitrogen (N), phosphorus (P) and potassium (K) levels with critical minimum levels under different cattle farming systems (land-level based on soil samples).

The comparison of farm and land nutrient balances demonstrates the difference between nutrients available on the farm and those actually utilized on cultivated land. Table 5 summarizes the farm and land nutrient balance results for nitrogen, phosphorus and potassium for each of the five dairy production systems.

Table 5: Farm and land nutrient balances

	Farm level nutrient balance*			Land level nutrient balance*		
	N	P	K	N	P	K
Zero grazing	+ 15.8	+ 12.0	+ 18.9	- 39.6	- 2.4	- 53.5
Semi-intensive	+ 24.8	+ 2.0	+ 13.3	- 49.9	- 2.6	- 32.6
Fenced	- 16.7	+ 0.4	- 3.0	- 22.7	- 0.4	- 5.2
Tethered	- 8.1	+ 4.3	+ 0.9	- 19.6	+ 1.2	- 9.6
Herded	- 15.8	+ 1.6	- 3.4	- 18.1	+ 1.1	- 6.1

Nutrient balances in kilograms of dry matter per hectare per season

*Includes 'farmer controlled' and 'uncontrolled' flow of nutrients: the former includes harvest, patch inputs, livestock feeds, grazing and milk while the latter includes soil erosion, deposition, gaseous losses and non-symbiotic N fixation. Leguminous nitrogen-fixation was considered to be within farmers' control.

N: nitrogen, P: phosphorus, K: potassium

There were large differences between nutrient balances at farm and land level, reflecting failure to apply available nutrients to the land. With the exception of phosphorus in the tethered and herded systems, nutrient balances were negative at the land level for all systems and nutrients.

Combining the results from the soil analyses with the nutrient balance results points to a worrying situation; soils that are already below the critical level for nitrogen are becoming ever more depleted. The same situation prevails for phosphorus in the zero-grazing system. Although phosphorus levels are above the critical level in all systems except zero-grazing, in the semi-intensive and fenced systems the balance is negative, meaning that phosphorus levels are declining. Whilst potassium levels are currently above the critical level in all five systems, the balance in all five is negative. In summary, the situation is one of wholesale soil mining, which has very severe implications for long-term sustainability of these farming systems.

Within the negative nutrient balances at the land level, depicted in Table 5, are smaller pockets of positive balances. These correspond to patches of land on which specific crops are grown. For example, a large amount of manure tends to be applied where pineapples, a high-value cash crop, are grown and as a result the nutrient balance on the patches where pineapples are grown tends to be positive. Leguminous crops such as beans and groundnuts, which can fix atmospheric nitrogen, have a beneficial impact on nitrogen balances. On the other hand, some crops are associated with very large negative nutrient balances; patches where fodder crops and vegetables were grown had large negative balances for nitrogen, phosphorus and potassium.

Nutrient balances can be important indicators of soil productivity and level of nutrient management and could be useful for extension agents, researchers, farmers and policymakers in determining the nutrient status of farms and identifying areas in need of improvement. However, calculation of nutrient balances is a highly complex process – far too complicated to be used routinely. The study therefore set out to identify simple indicators of nutrient balances that could be used to target advice and interventions and guide research and policies for improving nutrient management. This was done by modelling data collected previously for the nutrient balance studies.

The factor that had the largest positive influence on nutrient balance of nitrogen, phosphorus and potassium was the proportion of available manure that was applied to a patch. The factor that had the largest negative influence was the

quantity of materials removed from the patch, including those removed during harvesting and grazing. In addition, several crops were associated with either positive or negative influences on balances of some nutrients. For example, legume crops were associated with positive nitrogen balances due to their nitrogen-fixing properties while the crop combination 'coffee-fodder' has a large negative influence on all three nutrients, likely due to harvesting of large amounts of fodder with minimal or no nutrient replacements. For other crops, the influence on the balance of specific nutrients is likely to be due to the amount of that nutrient in the crop. For example, sweet potatoes tend to have a negative influence on potassium balances due to the high level of potassium extracted from the soil and transferred to their vines and peels.

Although negative nutrient balances are a cause for concern and indicate degradation of soils, they do not relate directly to crop yields, which are perhaps of greatest immediate interest to farmers. Based on the finding that application of manure had the largest positive influence on nutrient balances, the study considered the impact of application of manure on the yields of two key crops, bananas and elephant grass (also known as Napier grass). Bananas are an important food and cash crop and elephant grass is a fodder crop used in zero-grazing and semi-intensive production systems. The study focused on nitrogen balance as the soil analyses found this nutrient to be most lacking.

The equations used earlier to derive the nutrient balances were also used to calculate the quantity of manure that would be needed to attain zero nitrogen balance. Zero nitrogen balance would infer that the amount of nitrogen removed from the land was exactly balanced by the amount returned. For the tethered, fenced and zero-grazing systems, sufficient manure was available on the farm to meet these needs. Assuming 25% dry matter content, application of about 2000 kg of fresh manure per hectare (or 200 g per square metre) per growing season would generate incremental yields of elephant grass worth about USD 400 and bananas worth USD 185 per hectare. Assuming that labour and other costs would be below these figures and that a market existed for the extra production, this appears to be a financially worthwhile intervention although one rarely utilized at present.

FARMER FEEDBACK

At the end of the study, the results were conveyed to farmers in the three districts. Farmers were asked what constraints they faced which prevented more widespread use of manure to improve soil fertility. Answers provided included lack of awareness and failure to prioritize this activity (it was regarded as work for women and children); lack of knowledge of the benefits; lack of the necessary equipment, such as wheelbarrows; and fear of introducing pests and diseases to their fields.

Related resources from the farmer feedback workshop and from another paper associated with this study are available online from the following websites: http://www.ugandadairy.dk/UgandaDairy.asp and http://www.cipav.org.co/lrrd/lrrd19/7/mubi19100.htm

CONCLUSIONS

While dairy farming is profitable under all five farming systems, profitability (as measured by the contribution margin) was highest under the two most intensive systems, zero-grazing and semi-intensive. However, intensification was not necessarily the best option in all situations; for instance, profitability was higher under the herded system, considered to be the least intensive system, than under the fenced or tethered systems. The study did not include estimates of fixed costs; opportunity cost of land is likely to be higher under the zero-grazing, semi-intensive and tethered systems and the cost of purchasing improved breeds of dairy cattle will be high in the more intensive systems that use these breeds.

The study identified factors associated with adoption of dairy intensification. These included years of formal education of the household head and proportion of adults working off-farm as well as factors associated with increased demand for milk. This suggests that extension messages and policies regarding intensification in the smallholder dairy sector need to be carefully targeted to ensure they are relevant and appropriate. It also highlights the value of personally witnessing benefits for oneself, such as by working on neighbours' farms, and of farmer-to-farmer training approaches.

A worrying situation is revealed with regards to nutrient management on mixed dairy-crop farms in Uganda. Irrespective of degree of intensification, levels of some key plant nutrients in the soil, especially nitrogen, are already below the level considered critical for successful crop production and the levels are continuing to drop; nutrients removed in crops and milk are not being replaced. This has serious implications for the long-term sustainability of these farming systems; if nothing is done, the food insecurity and poverty situation is likely to get worse.

In all systems except fenced and semi-intensive, adequate amounts of manure are available on the farm to reverse this situation but currently the vast majority of this potentially valuable manure is not utilized. In addition to improving the soil nutrient balance, application of manure results in other beneficial effects, such as increased soil organic matter and capacity for holding water and nutrients, and the benefits persist for more than one season. The situation on the farms was exacerbated by the fact that there was no recorded use of artificial fertilizers and very little use of any other off-farm sources of nutrients, such as mulch; inputs of nutrients to the land from off-farm sources were close to nil for all five categories of farming systems except zero-grazing.

Shortage of labour may be one reason that manure is underused; in cases where manure is applied, this tends to be done during the school holidays when family labour is most plentiful. Also, in some cases the cultivated plots may be distant from the zero-grazing units, exacerbating transport problems. But in feedback provided by the farmers at the end of the study, other factors were also mentioned such as lack of awareness of the benefits of using manure, lack of basic equipment for transporting manure and fear of introducing pests and diseases to their plots. More work needs to be done to investigate the economics and practicalities of manure application and how best to integrate this activity with other activities that compete for available labour.

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