Effects of input subsidies on intensive versus extensive margin supply growth in Tanzania’s dairy sector: implications for GHG emissions savings from land use change

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November 2017

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1. **Introduction**

The dairy sector plays an essential role in livelihoods of the rural population in East Africa, providing both cash income and nutrition for smallholders owning cattle (Thornton et al., 2009; Tubiello et al., 2007). Omamo et al. (2006) shows that milk is the most important commodity for supporting GDP growth and poverty reduction in East and Central Africa. In Tanzania, large ruminants dominate total milk production in the country, producing ~98% of all fluid milk (Mgeni and Salim Nandonde, 2012). The cattle population is comprised mostly of indigenous Zebu animals, representing >95% of total cattle (NBS, 2015). However, the population of improved cattle (*Bos taurus* x *Bos indicus*) produces a disproportionate quantity of milk: \_\_ relative to \_\_ from the traditional herd (NBS, 2015). Milk offtakes of Zebu cattle are on average 517 litres per lactation, whereas crossbred cattle produce on average 1,990 litres per lactation (Mruttu et al, 2016). Given that milk production and sale offers a higher return to investment compared to other livestock (Udo et al, 2015), the dairy sector is a crucial component of rural poverty alleviation efforts in the country. Through the Tanzanian Livestock Development Strategy, the government of Tanzania aims to improve productivity and efficiency of the livestock sector, including dairy, from primary production, through to transportation, processing, and distribution (LSDP, 2011). The dairy sector also represents a major contributor to Tanzania’s national greenhouse gas (GHG) emissions budget, both directly, from emissions from enteric fermentation, manure, and feed production, as well as indirectly, from land degradation and conversion of natural ecosystems to crop and pasture land. Due to the important role of the dairy sector in rural poverty alleviation, as well as climate initiatives by the Tanzanian government, there is a need to identify low emission development pathways, allowing the dairy sector to develop concurrently with declining greenhouse gas (GHG) emissions.

The literature has provided strong evidence that there exist synergies between efficiency improvement in the dairy sector, declines in emissions intensities, and improvements in income and nutrition based welfare indicators for dairy households. Bryan et al. (2011) finds that improved feeding practices and soil fertility management lead to both lower emissions intensities and higher profitability for milk producing households across the central Kenyan highlands. Shikuku et al. (2017) consider feeding practices and adoption of crossbred cattle in Lushoto, Tanzania, and find that these practices reduce emissions intensities across household types. Paul et al. (2017) considers crossbred cow adoption, mineral fertilizer application, and improved feeding in relation to farm GHG emissions and household food availability in Rwanda, and propose that feeding is most essential to reaching the CSA triple win[[1]](#footnote-1). Using the GLEAM model for mixed dairy systems in East Africa, Mottet et al. (2015) estimate that improved feeding and herd management can reduce emissions by up to 13% with growth in output up to 18%, and up to 31% with constant output. Furthermore, given that deforestation emissions represent 70% of total land based GHG emissions in Tanzania (Carter et al., 2015), there exists potential emissions savings from reductions in deforestation and achieving net reforestation/afforestation. Bosire et al. (2016) estimate that intensification of the feed crop sector can reduce total land requirements (sum of feed crop and grazing land) by up to 40% for the livestock sector in Kenya. In studies that specifically quantify the impact of reductions in land use and sparing of land with naturally high carbon (C) content in sub Saharan Africa, the implications of spared and/or set aside land is highlighted as a critical factor in the climate impact reductions of different livestock development scenarios (Havlik et al., 2014; Valin et al., 2013). Because of these findings, reducing land occupation to reduce net forest loss and increase net forest growth should feature prominently in policy efforts for climate change mitigation in the dairy sector in Tanzania.

This study assesses the role of input subsidies in improving the climate smartness of dairy production in the Tanzanian southern highlands. The study follows the lead of other recent studies assessing the potential for reducing land occupation in the livestock sector in East Africa (e.g. Bosire et al., 2016), and aims to quantify the potential for improved efficiency in the dairy sector to reduce demand of additional land and offset emissions through reduced forest disturbance. This approach is needed as deforestation and forest degradation represent the largest emissions source in Tanzania (Carter et al., 2015), and is primarily driven by subsistence agriculture (Hosonuma et al., 2012). A mathematical programming model is used to assess *ex ante* the influence of changes in feed prices, prices of improved replacement animals, and the interest rate on loans taken out for investments in dairy production, herd sizes, and land occupation for smallholder dairy producers. The study focusses on these types of input support interventions as previous literature in Tanzania has highlighted feeding, adoption of improved breeds, and financial access as three important factors for increasing the climate smartness of livestock production (Shikuku et al., 2017). Further, input support represents the centrepiece of national development strategies in the livestock sector, which has the main purpose of increasing food security, stakeholder’s incomes, and contribution to the national economy (LSDP, 2011, vi). The research questions to be addressed are

1. Can reductions in absolute GHG emissions, concurrent with growth in milk production be achieved?
2. What are the household welfare implications of growth in milk production and emissions reductions?
3. What is the potential to intensify land use to prevent expansion of agricultural land driven by demand of dairy feeds?

The modelling framework therefore provides insight into the trade-offs associated with reconciling dairy sector development initiatives with competing goals of climate change mitigation.

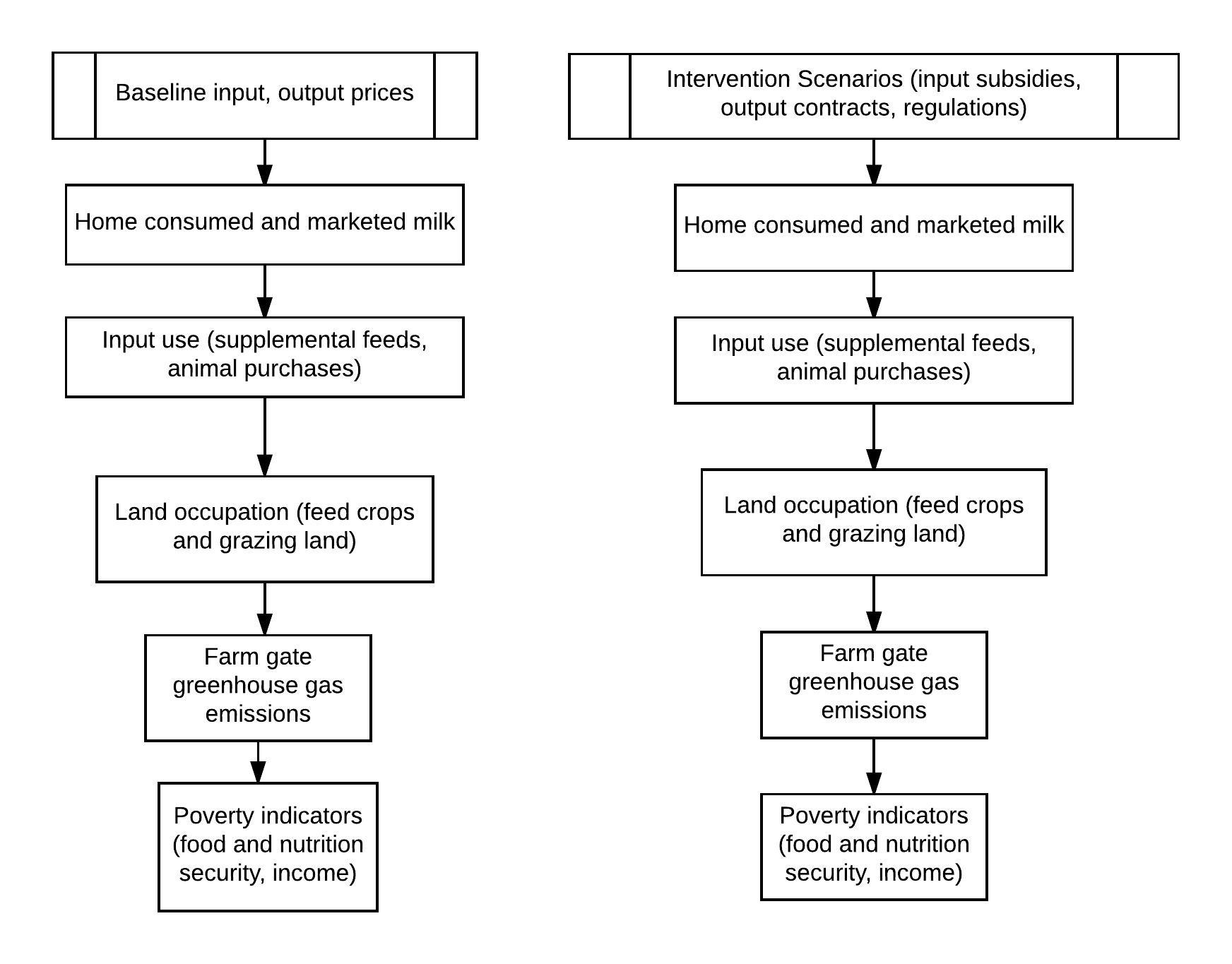
1. **Methods**

**2.0 Overview**

Mathematical programming (MP) is a powerful tool for conducting positive analysis[[2]](#footnote-2) of farm level decision making under hypothetical policy interventions or changing market conditions (i.e. prices of inputs or outputs). Such models combine decision making theory with biophysical simulation models representing dynamic feedbacks within and between different farm components (i.e. crops, grazing land, and livestock) and can therefore be used to assess the effect of existing or proposed policy interventions on environmental indicators including greenhouse gas emissions) and household welfare (Van Wijk et al., 2014). MP models have been used previously for assessing the impacts of fertilizer subsidies on smallholder household food security (Komarek et al., 2017), as well as the effect of household resource endowments on natural resource management and pathways out of poverty (Stephens et al., 2012). The MP modelling framework developed for this study aims to consider the decisions relating to management of the dairy enterprise, especially with respect to total milk production, type and quantity of cattle owned and structure of the herd, and land use, and to assess the implications of these decisions on outcomes for both absolute and intensity of emissions from milk producing households in Tanzania. The influence of changes in relative returns between dairy production and other farm activities (i.e. cash crops), and between allocation of land, capital, and labour to food production *versus* income producing activities is considered. Such an approach therefore allows assessing to what extent changes in input prices can incentivize the household to increase milk production, and the extent to which this growth results from increasing productivity, as opposed to increasing herd size and land requirements. The feedbacks between dairy cattle numbers and land requirements is needed in order to assess the potential emissions savings from reductions in forest disturbance driven by feed requirements for dairy cattle.

Figure 2 illustrates the farm household framework, including livestock, household cash availability, and nutrient supply and biomass production. A livestock module is coupled to a cropping and grazing module, to assess the feedbacks between land allocation to food, cash, and fodder crops, and biomass availability for cattle, and the requirements for grazing land. The model simulates the household’s purchasing decisions with respect to feeds, local and improved cattle, as well as the allocation of available land to food, fodder, and cash crops, for both a baseline scenario representing current prices of inputs, and policy intervention scenarios representing various types of input subsidies (Figure 1). The livestock module simulates the changes in herd size, structure, and offtake, based on the effects of the feeding regimes on physiological characteristics of the herd, including growth rate and lactation milk yields. The cropping and grazing module specifies the supply of food crops for home consumption, fodder crops for feed, and cash crops for sale based on the assumed yields and model determined acreage under each scenario. The simulations are run for households representing different wealth classes and resource endowments, in order to identify how the household’s characteristics influence the household’s capacity for supply growth under given input subsidies (e.g. Hammond et al., 2017).

Figure 1: Analytical framework for farm-household level ex ante analysis



The household model is developed in the General Algebraic Modelling System (GAMS); a software package useful for developing optimization and simulation models for (Brooke et al, 2008). The model parameters are from household survey data gathered in the Tanzanian southern highlands milkshed region during the years 2017-2018 [list the names and affiliations of the surveys]. The administrative regions covered by the survey include Mbeya, Iringa, Morogoro, and Dodoma (Table 1). [Discuss basic agro-ecological and geographic conditions of region, including major markets for inputs and outputs, population, incomes].

Table 1: Site statistics

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Region | Agro-ecologies | Number of households | Population density | Average altitude | Average precipitation |
| Mbeya |  |  |  |  |  |
| Iringa |  |  |  |  |  |
| Morogoro |  |  |  |  |  |
| Dodoma |  |  |  |  |  |

Sources: NBS (2015)

Table 2: Income, resource endowments, household dependents, degree of market orientation, and input use by household

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Household types | | | |
|  |  |  |  |
| Food Crop only – Local Cows | Cash and food crop – local cows | Food crop only – improved cows | Food and cash crop – improved cows |
| Land holdings (ha) |  |  |  |  |
| Cattle holdings (hd) |  |  |  |  |
| Household members  (people) |  |  |  |  |
| Annual marketed milk surplus  (kg yr-1) |  |  |  |  |
| Off farm income  (Tsh yr-1) |  |  |  |  |
| Input Use | | | | |
| Breeding  Method | Natural breeding | Natural  breeding | Artificial Insemination | Artificial Insemination |
| Expenses on breeding and health services  (TSh TLU-1 yr-1) |  |  |  |  |

Sources: Surveys

Notes: All values are means of sample stratification.

*Assessment of Policy Effectiveness*

The cost effectiveness of the input support policies considered with respect to the dual policy objectives of rural poverty alleviation and GHG abatement, respectively, are calculated as follows:

1. The cost-benefit ratio (CBR) of a given input subsidy is defined as the public cost of the policy with respect to the change in value of milk production caused after the policy is implemented. The public cost of the policy is defined as the change in mean input (i?) price for a given input in a given region multiplied by the change in aggregate consumption of inputs for a given household in region r. This is meant to assess the effectiveness of the policy with respect to rural poverty alleviation:
2. The cost effectiveness of the policy with respect to greenhouse gas mitigation is defined as the change in GHG emissions after the input subsidy is implemented relative to the public cost of the input subsidy:

CEi,r

Where CEi,r is the cost effectiveness of the input support policy with respect to greenhouse gas mitigation (TSh Mg CO2eq yr-1), and is the change in absolute emissions attributable to dairy production for a given household in region r (Mg CO2eq yr-1).

* 1. **Ex Ante Analysis of Input Support Policies at Household Level**

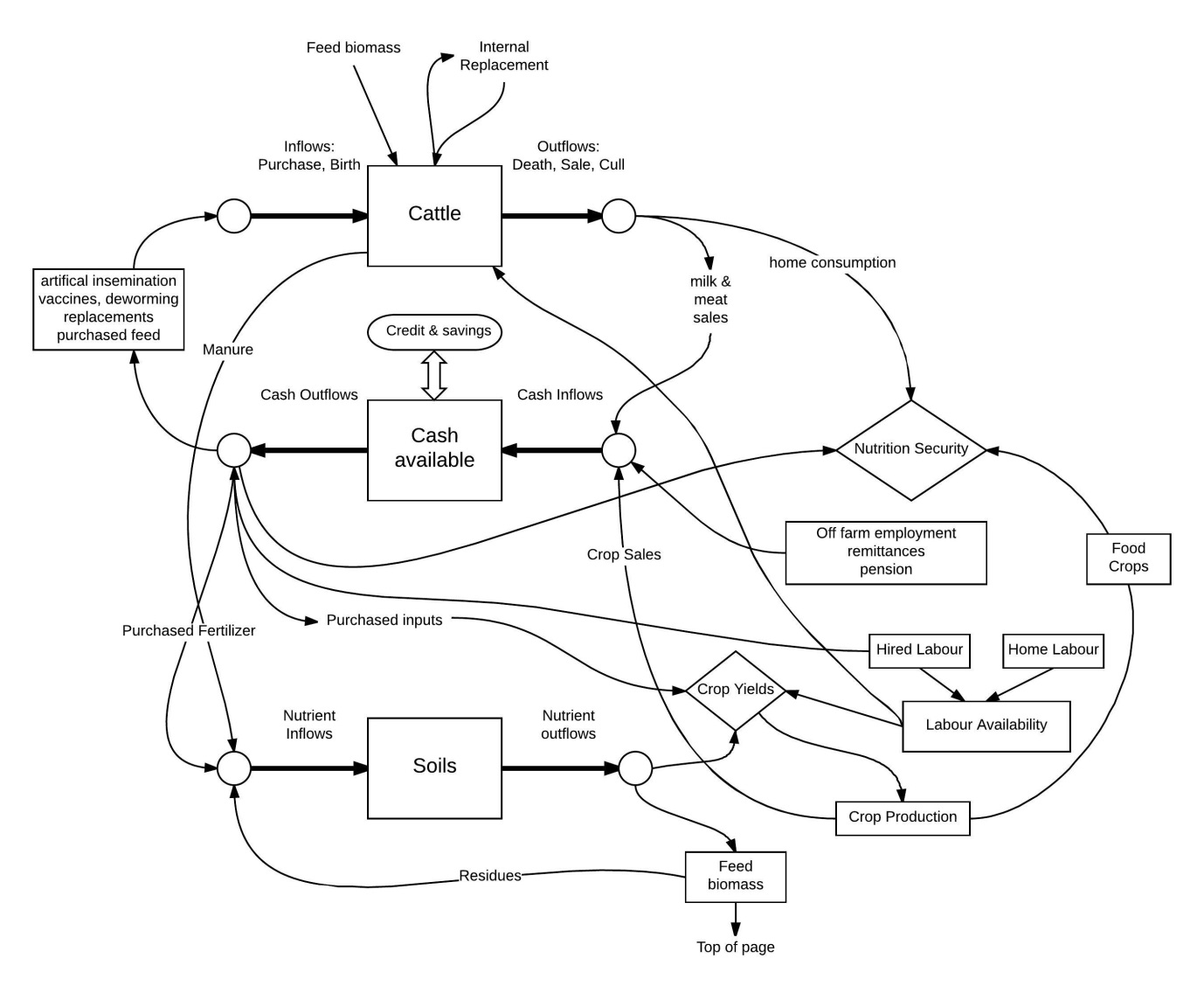
**2.1.1 Household simulation model**

The following section presents the framework for the household mathematical programming model. For a more complete listing of model equations, see Appendix B. A flow diagram of the conceptual framework for the household systems analysis is presented in Figure 1. The household model maximizes a risk adjusted utility function based on the discounted value of future cash income from the farm enterprise, the value of cattle assets, and home food consumption (Appendix B.1). Home food production and food expenditures are non-separable; expenditure on food consumption is determined using a linear expenditure system (Louhichi and Gomez y Paloma, 2014), with own price and income elasticities of food demand based on Chongela et al (2014). Off farm sources of income, including employment income, remittances, and pensions, are assumed exogenous and fixed. The model operates on a recursive inter-temporal optimization framework; the objective function is executed sequentially on a one year time step, over a multi-year time period. This dynamic, recursive inter-temporal framework allows for the lagged impacts of interventions on the household to be considered. Milk offtake of the dairy enterprise is an endogenous function of the underlying dynamics with respect to herd composition and lactation milk yield for adult females. The choice variables are the allocation of available cropland to different types of food, cash, and fodder crops, as well as the choice of input intensity for the dairy enterprise. Two inputs are considered, namely the purchases of local and improved replacement cattle, and supplemental feeds purchased at market prices. The choice of home fodder production for feed is also endogenous and subject to the resource constraints of the household (land, labour, and capital). The land holdings are based on the household’s specification of owned and rented land in the household survey. Labour constraints are equal to the total labour availability from household members plus hired in labour paid at market wage rates. A cash constraint specifies that the total expenditure on farm inputs in a given period is equal to total cash income for the household minus farm and non farm expenditures. Non farm expenditure is divided into two categories: food and non-food, with the amount spent on each based on the linear expenditure system (Appendix B.4).

Availability of labour has been cited as a major constraint to home production of fodder crops, as well as gathering, storing, and supplying feed to animals in confinement, in smallholder systems in East Africa (Ogle, 1991). In the survey, we chose a subset of households to develop comprehensive labour schedules for cattle rearing and crop production, disaggregated by activity, month, and source of labour (home versus hired). For livestock, labour requirements were differentiated between households grazing livestock and households which keep animals in confinement. A labour balance equation (Appendix B.3 – Labour Balance) specifies that all labour requirements for cropping and livestock activities is met by home and hired labour in each month. The availability of land for cultivation is based on the survey specified land holdings of the household, which is defined as the land for which the household has ownership, plus the amount rented in. Since households often source forage and pastureland for grazing off farm (including neighbour’s land, communal land, and government land), the total grazing land required to meet the animal’s needs are estimated based on the number of cattle owned and their grazed forage intake, as well as the yield of different types of pasture land (Appendix B.5). Land acquisition/rental are included by specifying the purchase price and rental rate of land as an exogenous variable. Land prices and rental rates were determined by consulting village level authorities (GLBS, 2018). Availability of cash and credit for has been cited as a potential factor contributing to lack of investment in productivity improvement for smallholder dairy systems (Udo et al, 2015), especially the purchase of crossbred dairy cattle (Gerber, 2007). Therefore, we consider the stocks and balances of cash using a household cash balance equation. The role of credit availability is included in this equation by specifying that in a given period, cash can be obtained subject to a fixed repayment schedule in subsequent time periods (Appendix B.2). Calorie availability and nutrition diversity is calculated by […]

[additional model features get described here;]

Figure 2: Systems diagram of farm household



**2.2.2 Dairy cattle**

A livestock simulation sub-model (module) accounts for quantity of cattle by cohort, and the milk offtake per adult female. Cattle are disaggregated by breed (local and improved), sex, and age. The cohorts include male and female calves, heifers, steers, cows, bulls, and castrated adult males. The module runs on a monthly time-step and considers the influence of feed quality and quantity on live weight gain for growing animals and milk yield of adult females for local and improved cattle. This approach is adopted in order to consider the full extent of herd level productivity improvement from feeding and adoption of improved breeds. Feeding higher quality diets in early life can reduce time to sexual maturity, and hence reduce the age of first calving, and increase the total number of calvings and lactations per adult female ((Bagley, 1993; Osuji et al., 2005). Animal numbers for each cohort in each period are determined using stage structured equations which consider the amount of animals moving into and out of a given cohort in each period, and is dependent on the calving interval, mortality rate per cohort, culling due to old age, growth rate, purchases, and sales[[3]](#footnote-3). The growth rate of young animals (calves, heifers, and steers) is dependent on the dietary energy supply for growth provided in each period (Appendix C). Purchases and sales are endogenously determined. All other parameters are specified based on survey data. A more complete description is provided in Appendix C.

The above factors, as well as reproductive management and preventative health interventions, have been proposed as measures that influence emissions intensity of smallholder dairy systems in East Africa (Mottet et al, 2015). Due to lack of epidemiological data on animal mortality and cost data on breeding, the impact of preventative health measures on animal health/mortality, or of interventions on the efficiency of breeding (i.e. from artificial insemination in place of natural breeding, and reducing the need for breeder males), are not considered.

**2.2.3 Cropping and Grazing**

Dairy households in the Tanzanian southern highlands produce food and fodder crops for food and feed, as well as cash crops for sale (Table 4). The acreage of land dedicated to food, fodder, and cash crops, as well as the yields, labour inputs, and purchased inputs was determined based on the household questionnaire (GLBS, 2018). The simulations treat land allocation between food, fodder, and cash crops as endogenous variables.

[additional aspects of cropping practices; rotations, yields]

The majority of households in the region practice semi-zero grazing, and therefore the supply of biomass for cattle is dependent on the quantity supplied during stall feeding, and the quantity grazed. The quantity of purchased feed, and the household’s land allocation between fodder crops, pasture, food and cash crops, and rangeland determines the availability of biomass. Food and cash crops are a source of crop residues for livestock feed. [specify the proportion of residues used as feed versus soil fertility management]. Pasture is distinguished from rangeland in that pasture land involves cultivation, including sowing, fertilizing, and harvesting, whereas rangeland is exclusively grazed. Many households specified having a degree of seasonal scarcity in forage availability, leading households to herd cattle long distances from the homestead in search of grazing resources. The area of land required for grazing is calculated based on the level of pasture intake needed in addition to the feed provided during stall feeding in order to meet the energy requirements of the herd (Appendix D.4).

Table 3: Baseline production parameters for local and improved cattle

|  |  |  |
| --- | --- | --- |
| Parameter | Local | Improved |
| Daily live weight gain 1,c(kg hd-1 d-1) | 0.25-0.9 | 0.25-0.9 |
| Calving rate 1,c (calves born per adult female per year) | 0.2-0.9 | 0.2-0.9 |
| Maximumlifetimed (years) | 13 | 13 |
| Calf mortalityc (%) | 0.25 | 0.25 |
| Heifer mortalityc (%) | 0.13 | 0.13 |
| Cow mortalityc (%) | 0.07 | 0.07 |
| Age to maturity1,c (first calving)(months) | 18-24 | 18-24 |
| Milk yield per adult female1,c (kg hd-1 d-1) | 4-12 | 7-16 |
| Mature weight1,a (kg hd-1) |  |  |
| Feed intake1,2 (kg DM TLU-1 d-1 ) |  |  |
| Selling price – steers and bullsb (Tsh TLU-1) |  |  |
| Purchase price – adult femaleb(Tsh hd-1) |  |  |
| Purchase price – heiferb(Tsh hd-1) |  |  |

Notes:

1Values shown are ranges to account for the variation between management and household types.

2 Feed intake per animal is a combination of supplemental feeds provided during stall feeding and *ad libitum* feed intake during grazing

Sources:

a Mruttu et al (2016)

b GLBS (2018)

c Calculated

d Bebe et al (2003b)

Table 4: Baseline production parameters of cropping enterprisea

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Crop | Purpose | Yield  (Mg ha-1)  (SD) | Area  (ha) | Labour Inputsb  (peson-days month-1) | Non-labour input cost (Sh ha-1) c | Selling price  (Sh Mg-1)  (SD) |
| Maize | Food and sale | -- |  |  |  |  |
| Beans | Food and sale |  |  |  |  |  |
| Tea | Sale |  |  |  |  |  |
| Banana | Sale |  |  |  |  |  |
| Other cash crops | Sale |  |  |  |  |  |
| Napier | Fodder |  |  |  |  |  |
| Other fodder crops | Fodder |  |  |  |  |  |

Notes:

a Values are means for entire sample population

b Values listed are average for entire growing season. For month specific labour inputs, see supplementary material.

c Non-labour inputs include seeds, fertilizer, pesticides, herbicides, machinery.

**2.2.5 Farm level greenhouse gas emissions**

Given that the objective of the study is to consider the influence of dairy management practices on indirect emissions from land use change, including from reductions in forest disturbance, a consequential life cycle approach was used. Consequential life cycle analysis differs from attributional life cycle analysis in the definition of the system boundary, where the former considers system expansion, and the latter does not (Thomassen et al., 2008). This approach differs from IPCC in that GHG emissions from land use change driven by the dairy sector is considered as attributable to the dairy sector, as opposed to other sectors, such as forestry. This allows for the potential land sparing and emissions offsets from reductions in land occupation to be considered in the estimate of emissions intensity (and absolute emissions) from dairy production.

The farm gate emissions intensity of milk production is expressed as kilograms of carbon dioxide equivalent emissions per kilogram of fat and protein corrected milk (kg CO2eq kg-1 FPCM). [discuss how FPCM is calculated]. This is estimated by summing all sources and sinks of emissions up to the farm gate and dividing by annual milk production (farm gate to retail emissions, including from transport and processing, are not considered). The direct emissions categories are therefore: methanefrom enteric fermentation, methane and nitrous oxide from manure management, manure applied on pasture, soils, and in storage, and nitrous oxide from feed crop production.[refs for processing and transportation of supplement feeds]. Increasing purchase of feed crops on farm has implications for land use change upstream from the farm and is therefore considered by estimating the emissions from land conversion to cropland. This, as well as land use change on farm from changes in cropland, and total grazing land requirements, are estimated using the stock change method, which involves subtracting the C content of the initial land use from the new land use (IPCC, 2006). C storage values for grassland, cropland, and forest in Tanzania are obtained from Willcock et al. (2012), and take values of 162.1, 127.9, and 416.9 Mg C ha-1 for crop, grassland, and forest, respectively. To consider the variation in initial land uses which undergo conversion, sensitivity analysis is conducted (Section 3.3). As discussed above, the grazing land requirements are calculated based on cattle forage requirements for each simulation. Reductions in forage requirements from grazing both reduces grazing intensity and grazing land requirements.[discuss how this leads to reductions in forest degradation and how emissions savings are calculated. Uncertainty exists in the initial land use undergoing conversion, as well as the types of land cattle graze on. Therefore these two sources of uncertainty are considered in the sensitivity analysis (section 3.3 below). ]

**2.2 Interventions**

[specify baseline prices of improved cattle, feeds, and interest rates, and the values under the intervention scenarios]

1. **Results**
   1. Model Validation

Validation of the model involves comparing observed herd sizes and composition, milk offtake, and land allocation in the study region to the endogenously determined values from the base model simulation. This ensures that the model reproduces the production characteristics of dairy producers given the same exogenous factors.

* 1. Intervention scenarios

The intervention scenarios are changes in market prices of improved replacement cattle, market prices of supplemental feeds, and the interest rate of loans taken out for investment in the dairy enterprise. Further, these three intervention scenarios are assessed under changes in the farm gate milk price.

The total farm milk production, land use (total feed crop land and grazing area for dairy), farm gate greenhouse gas emissions intensity of milk, household income, and household nutrition security are presented for each scenario.

* 1. Sensitivity analysis

Key sources of uncertainty in the modelling analysis are with respect to biomass yields and labour demands for biomass production. Due to high data requirements for acquiring labour data, and the high data and modelling requirements for estimating crop and pasture yields endogenously, we conduct sensitivity analysis by varying the values for these parameters.

Further, uncertainty exists in the initial land use undergoing conversion to cropland (in the case the household expands total crop production), as well as the types of land cattle graze on. Therefore these two sources of uncertainty are considered in the sensitivity analysis by considering the full range of initial C storage values for the land which undergoes conversion.

1. **Discussion**

Tanzania’s livestock policy has since 1984 focussed on improving input support for small scale as opposed to large scale farmers (Kurwijila, L.R and K.J. Boki. 2003). Is this the most efficient way of improving the productivity of the sector? Are there tradeoffs between efficiency and equity, and can they be quantified? What are the tradeoffs between strategies to reduce greenhouse gas emissions and increase incomes and nutrition security for rural households?

**5.0 Conclusion**

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**Appendix A – Summary Statistics of Household Survey Data**

[monthly labour data and other summary statistics goes here]

**Appendix B – Summary of household mathematical programming model**

**B.1 Objective function**

The household mathematical programming model is summarized as follows. The model maximizes an objective function subject to a series of constraints and identities which define household resource endowments, and the relationships between the endogenous decision variables and production. The mathematical specification of the model is as follows:

Maximize U = NPV -

By choosing area allocated to food, cash, and fodder crops, and replacement and feed purchases for the dairy enterprise, and,

Subject to:

Household cash constraint,

Household labour constraint,

Household arable land for crop production,

and model identities defining relationships between the decision variables and farm production.

The above objective function is further defined as follows: U is the household’s utility function, NPV is the net present value of the household, including farm income, farm assets, and food consumption, is the standard deviation of net present value, and is the risk aversion coefficient. Off farm income is assumed exogenous.

Net present value is further defined as follows:

NPV =

Where FI is farm income (TSh yr-1), the sum of CI, crop income (TSh yr-1) , LI, livestock income (TSh yr-1) , and Livestock Assets (TSh). VFC is the value of food consumption (TSh yr-1). A 10 year horizon is set (Y = 10). The discount rate used is 4 %.

Crop income is revenues from crop sales minus cash expenses on crop inputs. The selling prices of crops and prices of inputs are specified in Table 4 and section 2.1.1 of the text, respectively. Cash expenses on crop inputs include fertilizer, seeds, and labour. Cash expenses on the dairy enterprise include replacements, feeds, breeding services, health services, and hired labour.

The types of risk considered are biomass yields (crops and pasture), and output prices (crops and milk). Variation in the biomass yields are specified based on the historical standard deviation of the individual types of biomass, in relation to a trend line (representing annualized average change in yields) (see text Table 4). The standard deviation of net present value, is then calculated based on the standard deviation of the underlying yields and prices.

**B.2 Cash constraint**

The cash constraint considers the inflows and outflows of cash for the household in each time period. It is defined as follows:

Farm Incomey + Off Farm Incomey = Farm Expensesy + Household Expenditurey + Net Savingsy

Where Off Farm Income (TSh yr-1) is equal to off farm employment income, pensions, and remittances. Farm expenses are the sum of expenses for crop and livestock production (as described above). Household expenditure is the sum of cash expenses for household food and non food expenses. Food expenses by the household are defined below. Non food expenses are set at \_\_ % of annual household income. Net savings is equal to savings in year y (TSh yr-1) minus loans in year y (TSh yr-1). Annual expenses on credit/loans are equal to the size of the loan multiplied by the interest rate (TSh yr-1).

**B.3 Labour Constraint**

A household level labour balance equation ensures that total labour requirements for farm activities is supplied by either home or hired labour. The farm activities include labour allocation per crop and livestock.

Labour\_Requirement,m = +

Where

Labour\_Requirement m is the total household labour requirement for farm activities in month m

is the area dedicated to crop c (ha)

is the required labour input for crop c in month m (person days per month)

is the quantity of cattle (hd) in cohort a

a is the quantity of labour input per head of cattle in cohort a (person-days per month)

The index a includes all cohorts of cattle in the herd, including male and female calves, heifers, steers, cows, castrated adult males, and bulls

The following equation specifies the source of labour for farm activities:

Labour\_Requirementm = Home\_Labourm + Hired\_Labourm

Where

Home\_Labourm is the total availability of labour from household members (person-days per month)

Hired\_Labourm is the quantity of hired labour (person-days per month)

**B.4 Arable land constraint**

Arable land area

Where

Arable land area is the total land holdings of the household (owned plus rented) which are arable) and suitable for growing crops (ha).

**B.5 Household expenditure**

A Linear Expenditure System, as used in Louhichi and Gomez y Paloma (2014), calculates the quantity of food consumed by the household each year:

piqi = γi +βi (I − ∑ γj pj )

Where

0 < βi < 1

= 1

qi – γi >0

where pi is the price of good i, qi is the quantity of good i consumed by the household; I is household income from farm and non-farm activities. βi and Υi are the parameters in the Linear Expenditure System. This system considers ∑γjpj as subsistence expenditure and I− ∑γjpj as supernumerary income (Sadoulet and de Janvry, 1995). To compute βi and Υi we adapted the income elasticities of food demand for Tanzania from Chongela et al (2014) and the Frisch parameter for Africa south of the Sahara from Aguiar et al. (2016).

**Appendix C – Livestock**

**C.1 Stage structured mathematical accounting of herd cohorts**

The quantity of cattle of a given breed and cohort in each time period are defined in the following equation:

Qm,a,b = Qm-1,a,b - Net transitsm-1,a,b− Deathsm-1,a,b- Offtakem-1,a,b + Birthsm-1,a,b + Purchasesm-1,a,b

Where Qm,a,b is the quantity of cattle of a given breed, b, a given cohort, a, in month m, Transits represents the fraction of animals that transition from one cohort to the next, Deaths represents the fraction of animals that exit due to mortality, Offtake represents the animals that are culled for meat consumption (at home or sold), Net Purchases is equal to purchase of replacement animals minus those sold, and Births represent new born calves that are born from adult females maintained by the household. The cohorts include male and female calves, heifers, steers, adult females, and bulls. The breeds include local (Bos Indicus) and improved (Bos Taurus, potentially mixed with Bos Indicus).

The specification of the above parameters for stage structured demographics are based jointly on model parameters, and endogenous variables dependent on household decision making. The transits are calculated based on the growth rate and the amount of time from which calves transfer to heifers/steers, and heifers/steers transfer to adults. The offtake regime is also dependent on household management. For households relying on sexed semen, males are kept within the herd in a ratio sufficient to reproduce. The ratio of adult males to females for self reproducing households is based on sex ratios obtained from GLBS (2018). For households relying on AI, males are sold after reaching maturity. Adult females are maintained until the end of life and sold for meat. Deaths are equal to the cohort specific mortality rate multiplied by animals per cohort. Births per adult female are dependent on the calving interval.

Replacement heifers and cows are purchased in order to sustain the herd (internal replacement rate is not sufficient to meet household requirements for cows). Purchases on replacement females are needed as smallholder dairy herds are generally not self sustaining (Bebe et al, 2003a). Therefore, the purchases of replacement heifers and cows is sufficient to maintain the desired cow population on farm.

**C.2 Productivity at individual animal level**

Table C.2: Feed dependent animal productivity

[the productivity parameters for different diet regimes gets described here]

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Bos Indicus | | Bos Taurus | |
|  | Calves | | | |
|  | Growth rate (kg/hd/d) |  |  |  |
| Extensive |  |  |  |  |
| Medium |  |  |  |  |
| Intensive |  |  |  |  |
|  | Heifers | | | |
|  |  |  |  |  |
| Extensive |  |  |  |  |
| Medium |  |  |  |  |
| Intensive |  |  |  |  |
|  | Cows | | | |
|  | Milk Yield (kg/hd/d) |  |  |  |
| Extensive |  |  |  |  |
| Medium |  |  |  |  |
| Intensive |  |  |  |  |

**Appendix D – Cropping and grazing**

**D.1 Arable land constraint**

≤ Arable land area

Where

crop\_areac,y is area dedicated to crop c in year y (ha)

land\_holdings are total land holdings of the household (sum of owned and rented land) (ha)

[rotation constraints]

[pasture land]

**D.4 Grazing land requirements**

Land required for cattle grazing per household is estimated based on the quantity of cattle owned by the household, the quantity of pasture consumed *ad libitum*, and the average pasture yield of grazing land:

Grazing Land y =

Where

Grazing Land is the quantity of grazing land in year y required to provide forage intake for the herd (ha)

DM Intake is the *ad libitum* dry matter intake of grazed pasture for animals in cohort a (Mg TLU-1 yr-1)[[4]](#footnote-4)

Pasture yield is the average dry matter yield of pasture land (Mg yr-1)

**Appendix E – Estimation of farm level greenhouse gas balance**

1. Climate smart agriculture has three pillars: food security, low emissions, and adaptation to climate change. [↑](#footnote-ref-1)
2. Positive, as opposed to normative analysis, is a concept in the social sciences used to distinguish between the description and explanation of economic phenomena, including behaviour, as opposed to the expression of value or normative judgements. [↑](#footnote-ref-2)
3. This approach has previously been described in Hary (2004). Missing in reference list [↑](#footnote-ref-3)
4. Note this value is calculated as the required feed intake in addition to the feed provided during stall feeding. [↑](#footnote-ref-4)