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Assessing the environmental impacts of smallholder dairy intensification through improved feeding strategies in the Southern Highlands of Tanzania

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Emmanuel Mwema
Jessica Mukiri
Beatus Nzogela
Birthe Paul
An Notenbaert

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Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT) Africa Hub
c/o icipe (International Centre of Insect Physiology and Ecology)
Duduville Campus O Kasarani Road
P.O. Box 823-00621
Nairobi, Kenya
Telephone: (+254) 0709134000
Website: https://alliancebioversityciat.org/

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About the authors

Emmanuel Mwema is a research consultant with CIAT Kenya.

Jessica Mukiri is a research associate with the Tropical Forages Program at CIAT Kenya.

Beatus Nzogela is a research assistant with the Tropical Forages Program at CIAT Tanzania.

Birthe Paul, farming systems scientist, Alliance of Bioversity International and CIAT, Nairobi, Kenya.

An Notenbaert is a senior scientist with the Tropical Forages Program at CIAT Kenya.

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Abstract

Tanzania's livestock sector contributes 7.4% of the county's gross domestic product and provides employment to twenty-two-and-a-half million people. However, the sector is Tanzania's second-highest emitter of greenhouse gases (GHG) and negatively affects other ecosystem services. This study aims to assess the environmental impacts of different livestock intensification pathways in smallholder farms in the Southern Highlands of Tanzania. Data was collected through a literature review, household surveys, key informant interviews, and focus group discussions. The Comprehensive Livestock Environmental Assessment for improved Nutrition, a secured Environment and sustainable Development along livestock value chains (CLEANED) tool was applied to estimate the potential environmental footprints associated with current farming practices and interventions to foster improved feeding and heightened productivity in terms of land, soil health, water, and GHG emissions. The study's baseline results show higher absolute land, soil, and GHG emission footprints, but lower environmental impacts per unit of output across the case study farms. An improved wet season has an insignificant impact on feed basket quality, but on improving dry season, average feed basket quality is enhanced by an average of 67%. An increase of 20 % in productivity is the level of investment at which most environmental efficiency goals are met. At 20%, several environmental footprints can be lessened by 14% across dairy-intensifying farms: land required (ha/MT FPCM), erosion (Kg soil/Kg FPCM), water use (m^3/kg milk), and GHG emission intensity (Kg C02eq/ kg milk). However, each farm requires an average of 3% more land to enable this productivity boost. Generally, all this study's scenarios result in neutral or positive environmental change, except for the absolute increases in land requirements. This study's recommendations can inform dairy policy development in Tanzania and help development partners to promote climate-smart dairy.

Keywords: Environmental assessment, greenhouse gases, livestock enterprise

Acknowledgements

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Acronyms and abbreviations

CIAT	International Center for Tropical Agriculture
CLEANED	Comprehensive Livestock Environmental Assessment for improved Nutrition, a secured Environment and sustainable Development along livestock value chains
CP	Crude protein
CSFs	Case Study Farms
DM	Dry matter
FPCM	Fat- and protein-corrected milk
GHG	Greenhouse gas
ha	Hectare
IFAD	International Food and Agriculture Development
ILRI	International Livestock Research Institute
ME	Metabolizable energy
MT	Metric ton
N	Nitrogen
N_20	Nitrous oxide
CO2eq	Carbon dioxide equivalent

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Farmers in Lushoto are working with researchers to test different forage varieties like Brachiaria for yield and drought resilience.
GeorginaSmith/CIAT

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An Notenbaert/ Alliance of Bioversity International and CIAT

1. Introduction

Sixty to seventy percent of farmers across rural Africa depend on livestock for their livelihoods (FAO 2013, AU-IBAR 2016, Cornelis 2016, WEF 2019). Trends indicate that between 2030 and 2050, the demand for livestock and livestock products will increase two to eight-fold (LiDeSA 2015). Similar growth is expected in Sub-Saharan Africa, where demand for animal source foods (ASFs) will surge alongside a growing population and rising middle class (Thornton 2010, Robinson & Pozzi 2011, Henchion et al. 2017). Tanzania's livestock industry has multifaceted benefits. For example, it uses manure to produce crops via draught power and nutrient cycling, it produces meat and milk for human consumption, it produces capital and insurance, and it carries cultural importance and status (Ministry of Livestock and Fisheries Department 2015). It also contributes 7.4% of the county's gross domestic product (Michael et al. 2018).

In Tanzania, dairy farming is practiced predominantly under mixed crop and livestock farming systems (Alonso et al. 2014). Most of the improved dairy cattle are concentrated in the high potential, cooler highland regions with subtropical climates. These regions are found around Kilimanjaro, Arusha, Tanga, and Mbeya (Lusato et al. 2012). Dairy cattle farming in Tanzania's southern highlands is practiced under intensive, semi-intensive, and extensive production systems. In intensive farming systems, cattle are kept and fed in enclosures throughout the day and require intensive labor. In extensive production systems, animals are grazed out on the fields on a day-to-day basis. A semi-intensive production system is a mix of the previous two: In a semi-intensive production system, animals are grazed outside for some time before taken back to an enclosure (Farmers' trend 2019).

Mixed crop and smallholder dairy farming systems are acknowledged as sustainable due to their complementarity and synergy, contribution to welfare, food security, income, and poverty alleviation (Amejo et al. 2019). The disparity between supply and demand for ASFs indicates enormous potential to increase dairy production and improve the welfare of producers and their market agents (Omore et al. 2019). Moreover, smallholder dairy farming is quick to recover its initial investment in profit (Michael et al. 2018). Although the sector has burgeoning opportunities, achieving optimal and efficient production is a point at issue. Low quality feeds, insufficient feeds, poor animal health, and a myriad of other issues that are exacerbated by climate change have hindered milk and meat productivity (Swai & Karimuribo 2011, Marc & Martucci 2019, Maleko et al. 2018). Strategies to modernize the dairy livestock sector are underway with additional investments such as animal feeding, animal health, research, and value addition considered as vital initiatives that can reach a target production of 3, 816 million liters of milk countrywide by 2022 (Michael et al. 2018). However, the inception and anticipation of these initiatives, for example, improved animal feeding may pose a threat to the environment. Therefore, it is often necessary to assess their upshot in existing ecosystem services.

The environmental impacts of dairy livestock production present a significant challenge and source of concern for stakeholders (Vries & De Boer 2010, Grossi et al. 2019). Livestock activities significantly impact air and climate change, land and soil, water, and biodiversity (Bosire et al. 2016). The traditional intensification practices of livestock production in developing countries have resulted in continued expansion of land to accommodate forage needs (Steinfeld et al. 2006). Besides its extensive land footprint and significant use of biomass, livestock rearing also accounts for almost one third of agricultural water use globally (Mekonnen & Hoekstra 2012). Water used in producing feeds has stifled competition in producing forages for animal use and food crops for human consumption escalating the water stress index in Sub-Saharan Africa (Peden et al.

2009). Moreover, livestock rearing accounts for 15% of anthropogenic GHG emissions (FAO 2013). For example, in 2016, the agricultural sector contributed 65.2% of Tanzania's GHG emissions (WRI 2016). GHG emissions in Tanzania increased by 3% between 1990 and 2016 representing 0.59% of the world's total emissions (WRI 2016). Agricultural emissions increased by 65% between 1990 and 2016, mostly due to enteric fermentation and manure left on pasture (WRI 2016). Overgrazing has also caused severe land degradation and soil erosion (Steinfeld et al. 2006).

Perpetuating and protecting the environment, while intensifying dairy production systems to harness their potential, remains a challenge in the region. Data and research on the environmental impacts of dairy farming in the Southern Highlands is limited (Tungaraza 2013). This missing data is vital for decision-makers such as farmers, policymakers, and scientists. This study looks at how to design eco-efficient systems and better understand their environmental tradeoffs. In this case, a minimum data ex-ante model, CLEANED, assessed the potential environmental impacts of improved feeding and increased productivity in smallholder dairy farming systems to reach a solution that satisfies consumer-driven demand while maintaining ecological integrity.

This study assesses the environmental impacts of increasing productivity through improved feeding as livestock intensification pathway in smallholder dairy farming in the Southern Highlands of Tanzania. Specifically, the study explores the following research questions:

1. What are the land, soil, water and GHG footprints of the current feeding practices in dairy intensified farming systems in Rungwe, Mufindi, and Njombe?
2. What are the changes in baseline feed basket quality when you introduce improved forages?
3. What tradeoffs and synergies result when you increase dairy productivity by 10%, 15%, 20%, 25% and 30% through improved feeding strategies?

2. Materials and methods

2.1 Description of the study area

The study was undertaken within a CIAT-led, IFAD-funded research project called 'Climate-smart dairy systems in East Africa through improved forages and feeding strategies: enhancing productivity and adaptive capacity while mitigating GHG emissions.' This study focuses on the Rungwe, Mufindi, and Njombe Districts of the Southern Highlands of Tanzania (Figure 1).

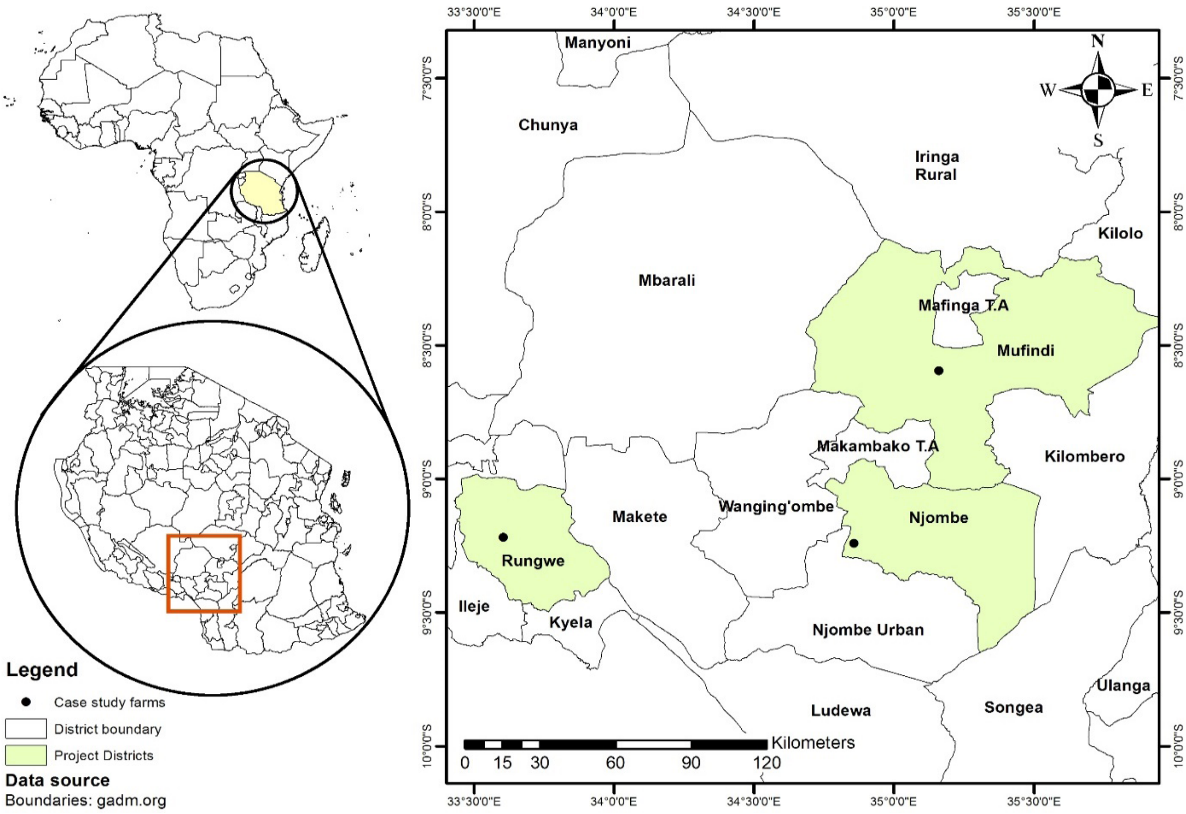

Figure 1: Map of the study district

Physical and socio-economic attributes of the study area

Rungwe is an administrative district located in the Mbeya region. It is bordered by the rural Mbeya District in the north, the Njombe Region in the east, the Kyela District in the southeast, the Ilege District in the southwest, and the Mbeya Urban District in the west. Rungwe District lies between latitude 9°15'00.0"S and longitude 33°40'00.0"E (Google Earth 2019). It covers a total area of 2,221 square kilometers and is one of the most densely populated districts in Tanzania, with a total population of 339,157 people and a population density of forty-five people per square kilometer (Paul et al. 2017, Tanzania National Bureau of Statistics 2013). The study site is located in Lufingo ward, 1,303 meters above sea level. It receives an average annual precipitation of 1100 mm, with an average temperature of twenty degrees centigrade (Climate Data Organization 2019). Lufingo ward has deep and well-drained fertile soil that is composed of sandy clay loam and sandy loam soils. These soils are classified as Acrisols by the Food and Agriculture Organization. Agriculture is the main economic activity of Rungwe District. According to the 2019 Rungwe Dairy Livestock Report, Rungwe District produced 44,758,989 L of milk in 2018 and 2019, which is equivalent to nearly 146,751 L per day. Production decreased by 29%, or from 62,971,875 L to 18,212,886 L between 2017 and 2018. Rungwe is also one of the leading food baskets of Tanzania. The predominant crop is maize. Other crops include cooking bananas, beans, round potatoes, sweet potatoes, and cassava. The major cash crops grown in the area are tea, coffee, and pyrethrum.

Mufindi is an administrative district located in the Iringa region of Tanzania. It lies between latitude 8°30›00.0»S and longitude 35°15›00.0»E (Google Earth 2019). Its total land size of 6,170,000 ha, of which 4,504,000 ha is suitable for cultivation (Paul et al. 2017). Mufindi District has a total population of 265,829, with a population density of twenty-seven people per square kilometer (NBS & OCGS 2012). The study site is located in Igowole Ward, 1,934 meters above sea level. This zone usually receives an average annual precipitation of 1400 mm, with temperatures between thirteen and eighteen degrees centigrade (Paul et al. 2017). Igowole Ward is also well endowed with reddish loam and clay soils, which favor various crops. Farmers in this area practice mixed crop-livestock and tree farming systems. The main economic activity in Mufindi District is cropping wheat, potato, common bean, and vegetables, and selling livestock products such as beef and milk. Timber harvesting is also common in some areas.

Njombe is an administrative district located in the Njombe region. It was under the Iringa region's administration until 2012, when it was declared an independent region with four district zones. It falls between latitude 9°15'00.0"S and longitude 35°00'00.0"E (Google Earth 2019). Njombe District Council borders Njombe Town Council in the south and the southwest. Wanging'ombe District borders Njombe District in the west. Njombe District is bordered by the Morogoro region in the east and Mufindi District in the north. Its total land surface area is 3134 square km (Paul et al. 2017). According to the 2012 National Population and Housing Census General Report, Njombe had a total population of 85,747 people, with a population density of thirty-three people per square km. The study site is in Kichiwa Ward, 1,826 meters above sea level. This area usually receives an average annual precipitation of 1160 mm, with an average temperature of sixteen degrees centigrade (Climate Data Organization 2019). The soils are composed of reddish loams and clay with medium fertility. Agriculture is the main economic activity in Njombe. Food crops include maize, wheat, beans, and Irish potatoes. Cash crops grown in the area include tea, pyrethrum, and flowers. Other economic activities include livestock keeping and forestry. The photo below shows maize, a predominant crop in the study area.

Beatus Nzogela/CIAT, 2018.

2.2 Farm types and case study farms

To understand the farming systems in the Southern Highlands, this study adopted the typology formulated by the International Livestock Research Institute (ILRI) through the IFAD-funded Greening Livestock project. The ILRI team collected data from 1,200 households in four regions. This study only focuses on the three study sites of the Climate-Smart Dairy Project (Table 1). To develop the typology, the team used seven indicators: asset index following, progress out of poverty index, household dietary diversity score, Tropical Livestock Units, income indicator, diversity indicator, and dependency ratio (Filmer & Pritchett 2001, Innovations for Poverty Action 2015, Schreiner 2016, FAO 2011, Njuki et al. 2011). From this assessment, we created a typology that consists of five farm types:

1. Poor
2. Dairy intensifying
3. Diversifying households
4. Livestock dependent and off-farm income
5. Non-livestock revenue, mainly crop

Table 1: Farm types and number of households surveyed in the Greening livestock project per region

Farm types	*Total number of households (without Mvomero Region)*	%	Mufindi	%	Rungwe	%	Njombe	%
Poor	123	*13%*	10	*4%*	68	*19%*	45	*13%*
Dairy intensifying	308	*33%*	76	*31%*	78	*22%*	154	*45%*
Diversifying households	230	*25%*	62	*26%*	77	*22%*	91	*26%*
Livestock dependent and off-farm income	108	*12%*	51	*21%*	34	*10%*	23	*7%*
Non-livestock revenue, mainly crop	169	*18%*	44	*18%*	93	*27%*	32	*9%*
	938	**1**	**243**	**1**	**350**	**1**	**345**	**1**

33% of all farmers in the Southern Highlands were categorized as dairy intensifying (Kihoro et al. 2021). This was the highest in numbers, showing the importance of assessing the dairy intensified type. Characteristics of a dairy intensifying farm include around 5.3ha of land, 7.5 Tropical Livestock Units, or (at least two improved dairy cows under a zero-grazing system, 9 L of milk yield during the dry season, and 10 L during the wet season. In addition to the ILRI criteria, this study required participation in the Feed Gap Assessment (Paul et al. 2020) and assessed the 36 households that were part of the Climate Smart Dairy Project. Farms were scored based on ILRI's characteristics of a dairy intensifying farm, and the highest-scoring farm from each district was chosen to be modeled. From now on, these farms will be referred to as Rungwe, Mufindi, and Njombe. These farms are case studies, and not representative of their district (Table 2).

Table 2: An overview of the case study farms

Case study farms	District	Population density (pp/km2)	Precipitation (mm/yr)	Altitude (meter above sea level)	Topography	Number of animals (Tropical Livestock Units/ha)	Productive animals	Milk/lactating cow (kg/yr)	Fertilizer (Kg N/yr)
Rungwe	Rungwe	45	1100	1303	Hilly	4.87	1	2135	64
Mufindi	Mufindi	27	1400	1934	Steep	6.53	1	1525	5
Njombe	Njombe	33	1160	1826	Flat	4.63	1	2440	40

Source :Paul et al. 2018 & Nyangaga 2019.

2.3 Data analysis and modeling

CLEANED approach

This study used the CLEANED tool to assess the potential environmental footprints of the Southern Highlands' smallholder dairy farming systems. CLEANED is a rapid ex-ante environmental impact assessment tool that allows the users to explore multiple impacts of developing livestock value chains in, straightforward ways. The CLEANED tool is a minimum data entry tool that consists of inputs, results, parameters, and calculations (Mukiri et al. 2019). The tool was used to model the potential consequences of intensifying livestock by examining four indicators, which include land requirements, impacts on soil, impacts on water, and GHG emissions (Table 3).

Table 3: A summary of CLEANED indicators used

Indicator	Explanation
Land requirements	Estimates the total land required to grow the feed items prerequisite for the animals present on the livestock enterprise.
Soil impacts	Calculated by nitrogen (N) flows, entering and leaving the livestock enterprise.
Water impacts	Estimates the amount of water used for feed production. It is presented by the actual crop evapotranspiration.
GHG impacts	It is calculated from different sources of emission using the Intercontinental Panel on Climate Change tier one and two methodologies.

CLEANED inputs and parameterization

For each of the three farms, this study constructed a typical feed basket (Figure 2). In order to analyze the feeding practices of farmers, the team used two data collection tools. The Feed Assessment Tool is a general tool that gives an overview of feeding trends throughout the year (ILRI 2014). This tool extracted essential data on livestock production systems, feed management, agro-climatic conditions, and season lengths. The second tool, the Feed Gap Assessment, gives detailed information about cattle management on a daily basis. To understand feeding practices at different times of the year, this study conducted two data collections per farm in wet and dry seasons. The team then extracted input:

i. Current feed baskets and their quantities

ii. Livestock numbers

iii. Daily milk yields

iv. Heart girth, circumference, (later converted to weight)

Other input data included crop residue uses and management and farm inputs. This data was obtained from the IFAD socio-economic household survey (Nyangaga 2019).

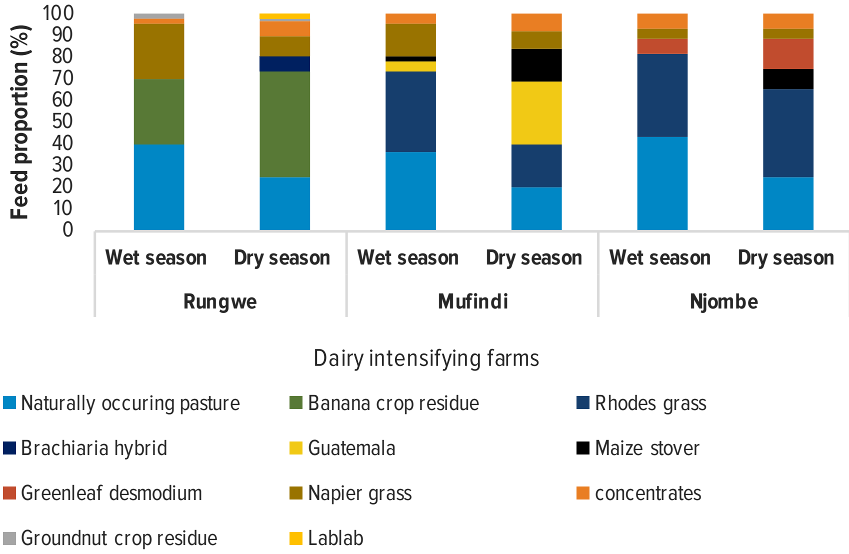

Figure 2: Current annual feed baskets in CSFs

The tool was parameterized for each site. The parameterization criteria included agroecological attributes, livestock characteristics, crop performance, and nutritional value of feed items. The data for parameterization was sourced from experimental data, literature sources, and experts' opinions. The literature sources used for this study included but are not limited to Feedipedia, Bairnsley Highlands, the United States Department of Agriculture's nutritional database, the New South Wales Department of Primary Industries, Access to Global Online Research on Agriculture, Food and Agriculture Organization repositories, the International Soil Reference and Information Center, tropical forages facts sheets, and CGIAR publications. Appendices 1-4 give a breakdown of the data that was used for parameterization and its sources.

Improved feeding scenarios

Once the processes of parametrization and inputting were complete, it was possible to run baselines and different feed intervention scenarios (Table 4).

Table 4: Improved feeding scenarios

Scenario	Explanation
Improved wet season feeding (scenario one)	This scenario involved replacing food crop residues such as groundnut and maize stover with Brachiaria, so that Brachiaria was taking up 15% of the feed basket.
Improved dry season feeding (scenario two)	Low-quality feed such as maize crop residue was replaced with Rhodes and Brachiaria hay, with the hay taking up 40% of the feed basket.
Improved wet and dry season feeding (scenario three)	A combination of the first two scenarios, comprising of a high-quality feed intake in the wet season and high-quality hay in the dry season to maintain a constant supply of quality forage.

It is imperative to note that, during both seasons, the percentage of natural pasture intake was reduced to improve the quality of the animals' diet. Brachiaria and Rhodes grass were chosen because of their high CP levels (Appendix 4). These grasses are extensively piloted by farmers in the region, with promising performance. Brachiaria and Rhodes grass varieties have a higher DM content than food crop residues. An additional advantage of Brachiaria is its high tolerance to drought; thus, it performs better during the beginning of the drier months (Osele et al. 2018).

Productivity scenarios

This study assessed each of the three aforementioned feed intervention scenarios within the context of a 10%, 15%, 20%, 25%, and 30% increases in milk yield. This resulted in fifteen separate analyses. A feasibility test, meant to assess whether daily DM requirements were less than or equal to three or four percent of the animals' body weight, concluded that these increases were realistic (Table 5).

Table 5: Productivity increases in relation to daily DM requirements

Farms	Feeding scenarios	10%	15%	20%	25%	30%	2.2% of body weight	3.5 % of body weight	4% of body weight
Rungwe - Daily DM requirements	scenario 1	11.97	12.17	12.37	12.57	12.77			
	scenario 2	12.64	12.85	13.06	13.27	13.48	12.41	19.74	22.56
	scenario 3	12.35	12.60	12.85	13.09	13.34			
Mufindi - Daily DM requirements	scenario 1	9.30	9.48	9.66	9.83	10.01			
	scenario 2	8.66	8.80	8.94	9.08	9.22	8.38	13.34	15.24
	scenario 3	8.72	8.86	9.00	9.14	9.28			
Njombe - Daily DM requirements	scenario 1	12.14	12.46	12.78	13.10	13.42			
	scenario 2	11.92	12.20	12.48	12.76	13.04	10.03	15.96	18.24
	scenario 3	11.68	11.95	12.22	12.50	12.77			

The CLEANED model then quantified smallholder dairy farming's environmental footprints for each scenario. These footprints were analyzed in terms of land requirements, impacts on soil, impacts on water, and GHG emissions (Table 3). The differences between the aforementioned baseline and these scenarios were presented using a legend (Figure 3).

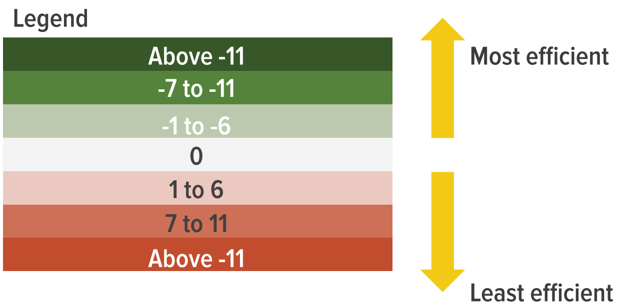

Figure 3: Different color shades and intervals used to visualize feed and productivity scenarios

Scenarios that result in a positive environmental change are referred to as best scenarios and are represented in this study's tables by + signs. They represent an eco-efficient path and increased milk yields. Any scenario that results in a negative change is referred to as a worst-case scenario and considered undesirable because it negatively affects the environment. Worst-case scenarios are represented in this study's tables by - signs.

An Notenbaert /CIAT, 2018.

3. Results and discussion

The baseline results were computed using the current livestock enterprise's inputs. These inputs include feed basket and milk production data. The projected environmental responses to changes in feed and productivity are results of the scenarios formulated by this study. To understand the differences between the baseline results and the scenarios, see the overview of the case study farms (Table 2).

3.1 Environmental footprints of current feeding practices across case study farms

The case study farms' total on and off-farm land requirements varied between 0.86 and 1.4 ha. Under the current feeding and milk production system, Mufindi requires more land than Rungwe and Njombe (Figure 4). This is because Mufindi has more livestock per ha than Rungwe and Njombe (Table 2). Results show that Njombe is likely to be more intensive in terms of production, as it needs less land to produce more milk. This is because the region has some of the highest percentages of improved or purebred cattle, thanks to a Sokoine University research program. Crop residues account for 48% of the farms' total land requirements. For example, maize, a staple food in the region, occupies a large portion of land in Mufindi and Njombe showing the importance of Mixed crop-livestock farming systems in these regions. Grasses and food crops compete for land on these farms (Maleko et al. 2018). Smallholders face a formidable challenge in choosing whether to grow food crops or forages on their limited land (Thornton 2010). This issue calls for sustainable intensification efforts.

The area on each farm that is dedicated exclusively to planted grass varies from 0.1 to 0.4 ha. These areas account for only 20% of the farms' total land requirements. This percentage can be attributed to competition with other, more profitable, land uses and decreasing land sizes (Bosire et al. 2019).

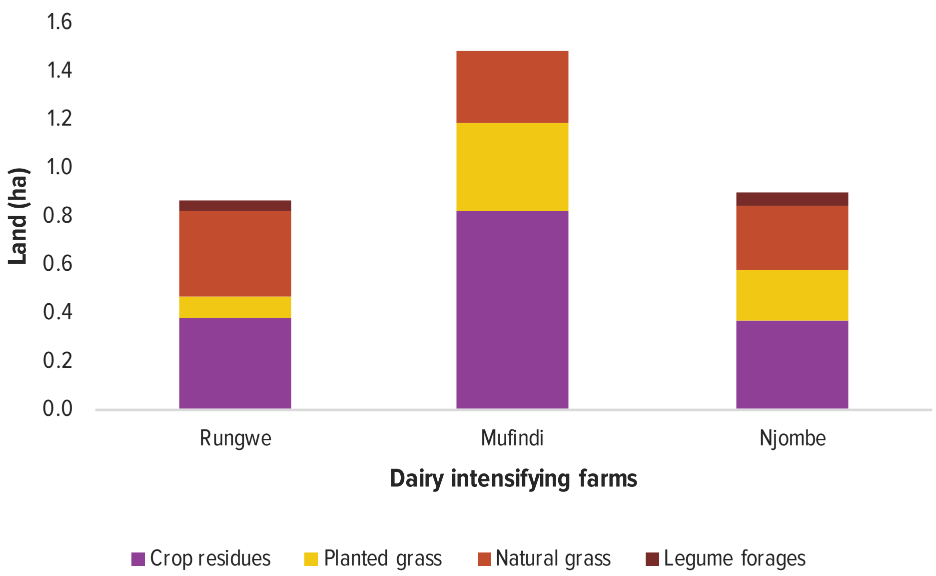

Figure 4: Total land area required for feed production

This study also analyzed nutrient mining within smallholder dairy systems (Figure 5). It is imperative to note that soil loss and nutrient loss can decrease efficiency. Rungwe displays more nutrient mining than Mufindi and Njombe. Despite having an inorganic fertilizer application rate of 64 Kg nitrogen (N) per year, with additional organic animal manure, Rungwe was unable to meet nutrient requirements. During the dry season, when there was little natural pasture and planted forage, Mufindi and Njombe use more than 95% of their food crop residues as feed, leaving little biomass on the ground. This is a common farming practice (Maleko et al. 2018). Despite Rungwe and Njombe farmers' efforts to balance nutrients by using organic and inorganic sources of N and planting N-fixing crops such as legumes, they were unable to replenish the soil's N. Mufindi's minimal mineral fertilizer application amounted to 5 Kg nitrogen (N) per year. Most soils in Tanzania are severely weathered and have limited but variable capacities to hold and release nutrients in plant-available forms and to sustain low-input subsistence agriculture (Funakawa et al. 2012). It is therefore important for Tanzanian farms to leave substantial amounts of biomass on their fields to help in regaining N in the soil. However, these intensifying dairy farms play a critical role in soil fertility, as their manure is recycled rather than wasted (Nyangaga 2019). Even though these organic and inorganic fertilizer inputs do not have a broad visible effect on the soil's N balance, they count as efforts towards maintaining a nutrient balanced cycle.

Njombe recorded the least soil erosion because the farm lies on flat topography. Rungwe and Mufindi are situated on hills with different slope angles. Mufindi experiences more erosion due to steep topography and planting crops with minimal cover. Increased cultivation on terraneous land can compromise soil stability and compactness (Fu et al. 2016). This is evident in Mufindi. Forages are soil stabilizers that assist in revegetation (Singer et al. 2009). Stabilization and revegetation are crucial for agricultural lands that are situated on hills, such as Mufindi and Rungwe. The important food crops in Rungwe and Njombe, such as banana and maize, have minimal cover factor. This study advises planting more forage at these farms to curb erosion.

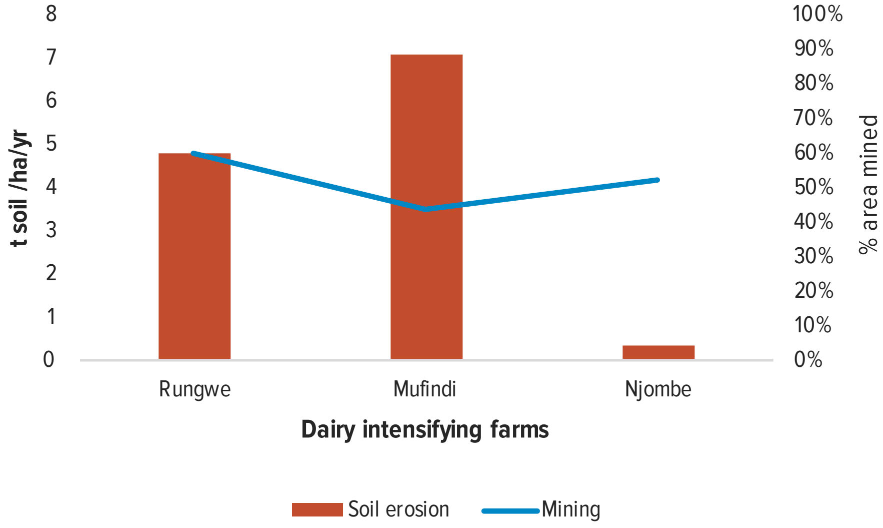

Figure 5: Nutrient mining and soil loss in the case study farms

Testing different forage varieties like Brachiaria for yield and drought resilience. Local livestock feed does not have the same nutritional value as improved varieties. Livestock farmers in Tanzania, are finding ways of boosting their production and lowering their environmental impact by planting improved forages. Georgina Smith/CIAT

While the farms used similar amounts of water, water use varied considerably depending on feed area. The dairy intensifying farms were entirely dependent on rain-fed crop and feed production. In fact, more than 80% of Tanzania's population depends on climate-sensitive, rain-fed agriculture (Natai 2016). Tanzania is therefore likely to be vulnerable to the effects of climate change. However, the farms' predominant feeding systems used an average of 45m^3 per ton of water. This is below the global average of 200 m^3 per ton (Gerbens-Leenes et al. 2013). In producing a liter of milk, these farms display great efficiency when compared to the global average (Ritchie & Roser 2020). In general, these dairy intensified farms seem to be water efficient. Appendix 5 shows the farms' water use.

GHG emission intensity varied greatly across the farms (Figure 6). Enteric fermentation was the farms' main source of GHG emission and is in accordance with existing estimates (WRI 2016). This type of fermentation is a result of low-quality feeding practices, such as using natural pastures and crop residues with high fiber content. This slows the animals' digestive process and creates more room for methane emissions. The farms report similar off-farm emissions. Nitrous oxide (N_20) emissions result from mineral N fertilizers, animal manures, crop residues, N-fixing crops, and sewage sludge (Bockman & Olfs 1998). It is therefore important to ensure that fertilizers are used correctly to avoid excessive N_20 emissions.

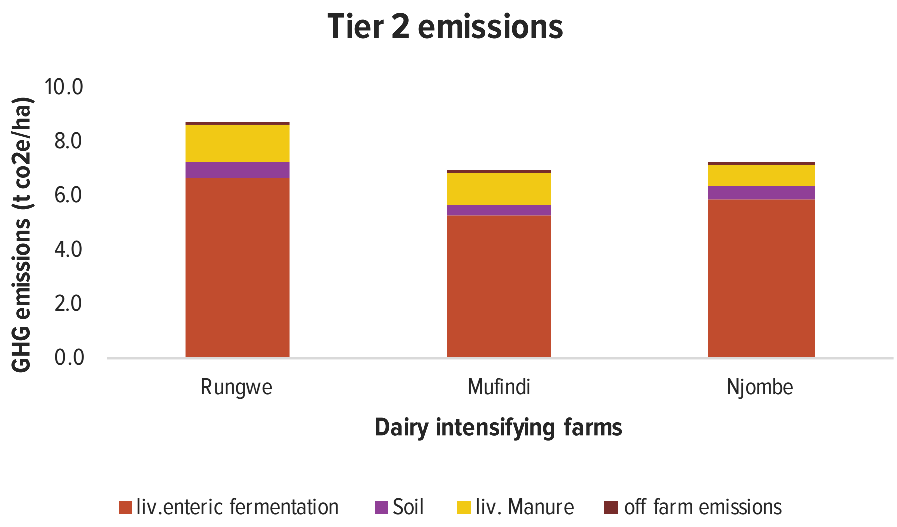

Figure 6: GHG emission intensity per ha in the case study farms

Absolute GHG emission intensities are similar across the farms (Figure 7). In relative terms, Mufindi requires more emission intensity to produce a kilogram of protein than Rungwe and Njombe. The average global emission intensity required to produce a liter of milk is 2.8 kg of CO2eq per kg of FPCM (FAO 2013). Only Njombe falls below this number, which indicates a possible reduction in farm's GHG footprints at the lowest production unit. Mufindi's emission intensity is twice the global average, while Rungwe is slightly above the average. Farming practices in Rungwe and Mufindi are further increasing the concentration of GHG in the atmosphere.

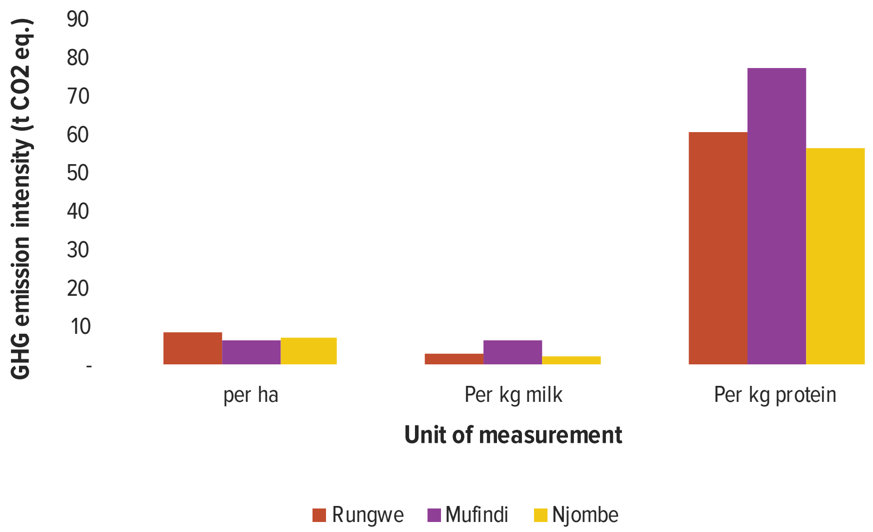

Figure 7: GHG emission intensity per unit ha and per livestock products

Responses to changes in baseline feed basket

Reducing natural pasture intake and improving wet season feed with 15% Brachiaria hybrid increased CP content by 5%, 1%, and 4% in Rungwe, Mufindi, and Njombe respectively. However, after adding Brachiaria hay and reducing the intake of banana crop residue during the dry season in Rungwe, DM, CP, and ME contents doubled. During the dry season, replacing maize stover with Brachiaria and Rhodes hay in Mufindi and Njombe increased the overall feed basket quality by 41% and 44% respectively. Improving feeding during both the wet and dry seasons reduced the overall quality of the feed basket in Rungwe by 8% but had no effect in Mufindi and Njombe. However, during the dry season, feed basket quality improved by an average of 67% in dairy intensifying farms. It is patently clear that these smallholder farms' priority should be improving feeding during the dry season. In addition, data shows that Rhodes grass and Brachiaria hybrid grass yield more per ha than food crops. These grasses also boast high CP levels, which is necessary for improving feed digestibility. Increased ME in these farms supports the cattle's growth and other metabolic processes. Increased DM content can help smallholders resist drought, especially when forage is scanty. Appendix 6 shows the data that supports these conclusions.

Trade-offs in environmental impacts following increased productivity through improved forages

Feed production and increased milk productivity requires more land (Bosire et al. 2019, Notenbaert et al. 2020). Increased milk production in Njombe can augment the livestock industry's land footprint by 8% as introducing planted forages requires land. This can result in converting new areas, such as forests, into farms and negatively affecting other ecosystems. A reduced demand for land indicates that intensification may help reduce land requirement and promote environmental conservation (Steinfeld et al. 2006, Bosire et al. 2016). However, very few studies have analyzed the consequences of reduced demand for land due to increased productivity in livestock production (Wirsenius et al. 2010, Tilman et al. 2011). This presents an opportunity for scientists and breeders to increase production on small portions of land.

The proposed interventions did not have a visible effect on the farms' percentage of mined and leached land. Moreover, increased productivity did not affect absolute erosion but rather reducing erosion per kg milk. It is possible to minimize soil loss in hilly areas such as those of Rungwe and Mufindi by planting forages while increasing productivity. It is important to note that soil quality and health are vital to productivity in sustainable agro-ecosystems.

The farms' absolute water requirements remained unchanged in all the scenarios. However, within the context of producing kgs of milk and protein, water requirements decreased. This implies increased production efficiency per unit product. When productivity increased by 15%, the protein water requirements for Mufindi reduced, indicating a possible maximum efficiency threshold. This reduced water requirement can be attributed to improved feed baskets that consist of climate-smart forage such as Brachiaria, which is well known for its efficiency, quick maturation rate, and fast absorption (Njarui et al. 2016).

The results did not show changes in the farms' absolute GHG emissions. However, as productivity increases, GHG emissions in relation to milk and protein production decrease. Mufindi, for example, shows a 12% reduction in GHG emissions related to milk if productivity increases by 15% during the dry season or both seasons. The farms' gross energy efficiency improved with the introduction of improved forages, reducing their relative emission intensities. Studies have found that more energy-efficient animals produce less waste in the forms of methane and N excretion (Chagunda et al. 2009). Enteric methane can also be mitigated because it is a short-lived climate pollutant (FAO 2017). Farms with low emission intensities are the most environmentally sustainable (Osele et al. 2018). In general, the farms' production tends towards increased efficiency and productivity. This bodes well for both a reduced carbon footprint and food security (FAO & GDP 2018). A variety of factors also changed in relation to improved productivity (Table 6-9).

Table 6: Land required in relation to increased productivity through improved forages

Case study farms and improved feeding scenarios		Land requirements									
		10%		15%		20%		25%		30%	
		ha/yr	ha/MT FPCM	ha/yr	ha/MT FPCM	ha/yr	ha/MT FPCM	ha/yr	ha/MT FPCM	ha/yr	ha/MT FPCM
Rungwe	Improved wet season feeding	-	++	-	++	-	+++	-	+++	-	+++
	Improved dry season feeding	-	++	-	++	-	+++	-	+++	-	+++
	Improved wet and dry season feeding	-	++	-	++	-	+++	-	+++	-	+++
Mufindi	Improved wet season feeding	-	++	-	++	-	+++	-	+++	-	+++
	Improved dry season feeding	-	++	-	+++	-	+++	-	+++	-	+++
	Improved wet and dry season feeding	-	++	-	+++	-	+++	-	+++	-	+++
Njombe	Improved wet season feeding	-	++	-	++	-	+++	--	+++	--	+++
	Improved dry season feeding	-	++	-	++	-	+++	-	+++	--	+++
	Improved wet and dry season feeding	-	++	-	++	-	+++	-	+++	--	+++

Table 7: Increased productivity through improved forages and impacts on soil

Case study farms and improved feeding scenarios		***Soil impacts***																			
		10%				15%				20%				25%				30%			
		% soil mining (ha/yr)	% soil leaching (ha/yr)	Erosion (t soil/ha/yr)	Erosion (kg soil/kg FPCM)	% soil mining (ha/yr)	% soil leaching (ha/yr)	Erosion (t soil/ha/yr)	Erosion (kg soil/kg FPCM)	% soil mining (ha/yr)	% soil leaching (ha/yr)	Erosion (t soil/ha/yr)	Erosion (kg soil/kg FPCM)	% soil mining (ha/yr)	% soil leaching (ha/yr)	Erosion (t soil/ha/yr)	Erosion (kg soil/kg FPCM)	% soil mining (ha/yr)	% soil leaching (ha/yr)	Erosion (t soil/ha/yr)	Erosion (kg soil/kg FPCM)
Rungwe	Improved wet season feeding				++				++				+++				+++				+++
	Improved dry season feeding				++				++				+++				+++				+++
	Improved wet and dry season feeding				++				++				+++				+++				+++
Mufindi	Improved wet season feeding				++				++				+++				+++				+++
	Improved dry season feeding				++				+++				+++				+++				+++
	Improved wet and dry season feeding				++				+++				+++				+++				+++
Njombe	Improved wet season feeding				++				++				+++				+++				+++
	Improved dry season feeding				++				++				+++				+++				+++
	Improved wet and dry season feeding				++				++				+++				+++				+++

Table 8: Increased productivity through improved forages and impacts on water

Case study farms and improved feeding scenarios		***Water impacts***														
		10%			15%			20%			25%			30%		
		Water/ha (m3/ha)	water/milk (m3/kg milk)	water/protein (m3/kg protein)	Water/ha (m3/ha)	water/milk (m3/kg milk)	water/protein (m3/kg protein)	Water/ha (m3/ha)	water/milk (m3/kg milk)	water/protein (m3/kg protein)	Water/ha (m3/ha)	water/milk (m3/kg milk)	water/protein (m3/kg protein)	Water/ha (m3/ha)	water/milk (m3/kg milk)	water/protein (m3/kg protein)
Rungwe	Improved wet season feeding		++	+		++	++		+++	++		+++	++		+++	+++
	Improved dry season feeding		++	+		++	++		+++	++		+++	++		+++	+++
	Improved wet and dry season feeding		++	+		++	++		+++	++		+++	++		+++	+++
Mufindi	Improved wet season feeding		++	+		++	+		+++	++		+++	++		+++	++
	Improved dry season feeding		++	+		+++	+		+++	++		+++	++		+++	++
	Improved wet and dry season feeding		++	+		+++	+		+++	++		+++	++		+++	++
Njombe	Improved wet season feeding		++	+		++	++		+++	++		+++	++		+++	+++
	Improved dry season feeding		++	+		++	++		+++	++		+++	+++		+++	+++
	Improved wet and dry season feeding		++	+		++	++		+++	++		+++	+++		+++	+++

Table 9: Increased productivity through improved forages and impacts on GHG emissions

Case study farms and improved feeding scenarios		*GHG emissions*														
		10%			15%			20%			25%			30%		
		GHG/ha (t CO2eq/ha)	GHG/milk (kg CO2eq/kg milk)	GHG/protein (kg CO2eq/kg protein)	GHG/ha (t CO2eq/ha)	GHG/milk (kg CO2eq/kg milk)	GHG/protein (kg CO2eq/kg protein)	GHG/ha (t CO2eq/ha)	GHG/milk (kg CO2eq/kg milk)	GHG/protein (kg CO2eq/kg protein)	GHG/ha (t CO2eq/ha)	GHG/milk (kg CO2eq/kg milk)	GHG/protein (kg CO2eq/kg protein)	GHG/ha (t CO2eq/ha)	GHG/milk (kg CO2eq/kg milk)	GHG/protein (kg CO2eq/kg protein)
Rungwe	Improved wet season feeding		++	+		++	++		+++	++		+++	++		+++	+++
	Improved dry season feeding		++	+		++	++		+++	++		+++	++		+++	+++
	Improved wet and dry season feeding		++	+		++	++		+++	++		+++	++		+++	+++
Mufindi	Improved wet season feeding		++	+		++	+		+++	++		+++	++		+++	++
	Improved dry season feeding		++	+		+++	+		+++	++		+++	++		+++	++
	Improved wet and dry season feeding		++	+		+++	+		+++	++		+++	++		+++	++
Njombe	Improved wet season feeding		++	+		++	++		+++	++		+++	++		+++	+++
	Improved dry season feeding		++	+		++	++		+++	++		+++	+++		+++	+++
	Improved wet and dry season feeding		++	+		++	++		+++	++		+++	+++		+++	+++

Testing different forage varieties like Brachiaria for yield and drought resilience. Local livestock feed does not have the same nutritional value as improved varieties. Livestock farmers in Tanzania, are finding ways of boosting their production and lowering their environmental impact by planting improved forages. Georgina Smith/CIAT

4. Conclusions and recommendations

This study shows that current smallholder dairy farming practices in the Southern Highlands have large land, soil, and GHG emission footprints but little environmental impact per unit of output. Njombe farm is more intensified than other farms as it produces more milk with less land. Rungwe and Mufindi experience more erosion because of their topography. Enteric fermentation is a major source of GHG emissions, mainly due to increased crop residue feeding and readily available natural pasture. Also, the feed baskets of the Southern Highlands are similar to those of the Tanga region.

This analysis shows that the dairy industry's feeding and productivity strategies result in neutral and positive environmental impacts, apart from the absolute increases in land requirements. Improving the baseline feed basket with Brachiaria and Rhodes grass during both the wet and dry seasons reduced the quality of the feed basket in Rungwe by 8% but had no effect on Mufindi and Njombe. Improving feeding during the dry season yields an average of 67% improvement in the DM, CP, and ME contents of the feed basket, and is therefore an optimal strategy.

From an environmental point of view, a 20% increase in production is ideal, as most environmental efficiencies are improved. At this level, land requirements (ha/MT FPCM), erosion (kg soil/ kg FPCM), water use (m^3/kg milk), and GHG emission intensity (kg CO2eq/kg milk) became 14 % more efficient in the case study farms. Each farm requires an average of 3% more land at this level. The results of this study show that smallholder dairy farmers can fill gaps in the milk market because of surplus milk production. With a 20% increase in productivity, these farms can produce an average of 12L of milk per day per crossbred cow. Although this is not the recommended average, it could begin to shift Tanzania's milk industry from sustenance farming towards commercial farming.

This study also shows that scenarios that analyze both feed and productivity better inform decision-making. Finally, this study presents a tool that can help stakeholders make plans and update policies geared towards intensifying livestock systems within environmental limits.

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Appendix 1: Area parameters

		Rungwe	Mufindi	Njombe	Source
Annual precipitation	**mm/yr.**	**1100**	**1400**	**1160**	**1**
Rainy season	No. of months/year	7	7	7	1
Soil type	FAO	Acrisols	Lixisols	Lixisols	2
SoilN	g/kg	0.5	0.3	0.8	2
SoilC	g/kg	2	1.3	1.7	3
Soil clay	%	32	34	39	2
Bulk density	g/c m3	1.3	1.5	1.5	2
Soil depth	M	1.25	2	2	4
ET0	mm/year	1460	1460	1460	5

Notes: 1. Paul et al. 2017. 2. ISRIC 2020. 3. Experimental data from soil tests. 4. ISRIC – World Soil Information. Lixisols (LX). 5. FAO. 1998a.

Appendix 2: Livestock parameters

	Category	Average Body weight (kg)	Grazing displacement (km/day)	calving interval (years)	Sources	Notes
Rungwe	Cows – improved	564	0	1.2	1, 2	The average body weight given represent a disaggregated number of cows, i.e., 1 cow
	Steers/heifers improved	327	0		1, 2	"
Mufindi	Cows – improved	381	0	1.2	1, 2	"
	Steers/heifers improved	290	0		1, 2	"
Njombe	Cows – improved	456	0	1.2	1, 2	"
	Steers/heifers improved	246	0		1, 2	"

Notes: 1. Bairnsley Highlands 2009. 2. Paul et al. 2017.

Appendix 3: Crop parameters

Crop product	Main product fresh yield (t FW/ha)	Main product DM content fraction	Average harvest index	Main product N content (kg N/kg DM)	Crop residue N content (kg N/kg DM)	C (crop cover) factor	Energy (kcal per FW 100g)	Water content (g per 100 g)	Energy (kcal per 100 g DM)	Kc: Initial	Kc: Midseason	Kc: Late
Banana	73.06[3]	0.22[2]	0.44[13]	0.015[11]	0.014[11]	0.600[4]	89.00[11]	74.91[11]	346.00[11]	0.500[12]	1.100[12]	1.000[12]
Brachiaria hybrid	57.00[1]	0.26[1]	0.90[1]	0.022[1]	0.000	0.010[4]	-	-	-	0.600[12]	1.100[12]	1.050[12]
Brachiaria hay	57.00[1]	0.84[1]	0.90[1]	0.008[1]	0.000	0.010[4]	-	-	-	0.600[12]	1.100[12]	1.050[12]
Rhodes hay	54.00[2]	0.86[2]	0.90[1]	0.016[2]	0.000	0.010[4]	-	-	-	0.600[12]	1.100[12]	1.050[12]
Groundnut	2.32[3]	0.24[2]	0.45[8]	0.010[13]	0.013[13]	0.150[4]	567.00[11]	6.50[12]	606.42[11]	0.000[12]	1.050[12]	0.600[12]
Lablab	8.00[1]	0.22[2]	0.90[9]	0.037[2]	0.000	0.150[4]	-	-	-	0.400[12]	1.150[12]	0.550[12]
Napier	105.00[6]	0.21[6]	0.90[6]	0.013[5]	0.000	0.010[4]	-	-	-	0.600[12]	1.100[12]	1.050[12]
Natural pasture	45.00[2]	0.28[2]	0.90[1]	0.008[2]	0.000	0.010[4]	-	-	-	0.300[12]	0.750[12]	0.750[12]
Desmodium	51.00[2]	0.24[2]	0.90[1]	0.025[2]	0.000	0.150[4]	-	-	-	0.400[12]	1.150[12]	0.550[12]
Bothriochloa	36.00[5]	0.37[2]	0.90[1]	0.013[2]	0.000	0.050[4]	-	-	-	0.300[1]	0.750[1]	0.750[1]
Rhodes	54.00[2]	0.25[2]	0.90[1]	0.014[2]	0.000	0.010[4]	-	-	-	0.550[1]	1.000[1]	0.850[1]
Hyparrhenia rufa	42.00[2]	0.26[2]	0.90[1]	0.011[2]	0.000	0.050[4]	-	-	-	0.300[12]	0.750[12]	0.750[12]
Guatemala	90.00[2]	0.22[2]	0.90[1]	0.014[2]	0.000	0.010[4]	-	-	-	0.600[12]	1.100[12]	1.050[12]
Buffel	45.00[2]	0.30[2]	0.90[1]	0.011[2]	0.000	0.010[4]	-	-	-	0.600[12]	1.100[12]	1.050[12]
Maize	4.33[3]	0.30[2]	0.52[10]	0.013[12]	0.006[14]	0.100[4]	365[11]	10.37[1]	407.23[11]	0.150[12]	1.200[12]	0.600[12]
Natural pasture-Njombe (average of natural pasture, Bothriocloa & *Hyparrhenia rufa*)	41[1]	0.30[1]	0.90[1]	0.011[1]	0.011[1]	0.050[1]	-	-	-	0.300[12]	0.750[12]	0.750[12]
Natural pasture-Mufindi (average of natural pasture and *Cenchrus ciliaris*)	45[1]	0.29[1]	0.90[1]	0.010[1]	0.000[1]	0.050[1]	-	-	-	0.300[12]	0.750[12]	0.750[12]

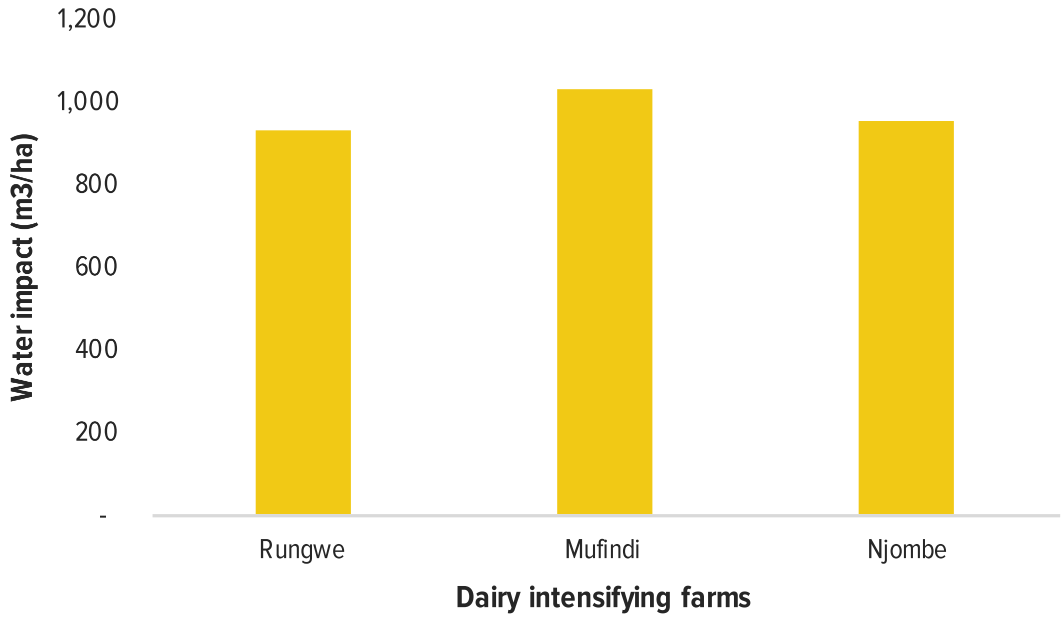
Notes: 1. Expert data from Dr. Solomon Mwendia – forage agronomist, Alliance of Bioversity and CIAT; Jessica Mukiri – research associate, Tropical Forages Program, Alliance of Bioversity and CIAT; and Emmanuel Mwema – research consultant, Alliance of Bioversity and CIAT. 2. Feedipedia 2019. 3. Paul 2017. 4. Ahmed et al. 2014. 5. The Alliance of Bioversity International and CIAT & Australian Government 2019. 6. Osele et al. 2018. 7. Trevor Wilson 2015. 8. Maheswarappa et al. 2011. 9. Grotelüschen et al. 2014. 10. Australian Society of Plant Scientists et al. 2018. 11. USDA 2019. 12. FAO 1998b. 13. New South Wales Government Nutritional Database. 14. National Research Council 1978.

Appendix 4: Feed parameters

Feed	DM content (%)	ME content (megaJoules/kg DM)	CP content (% DM)
Banana (*Musa acuminata*) - crop residue	9.00[4]	8.66[4]	9.50[4]
Groundnut (*Arachis hypogaea*) - crop residue	89.83[4]	8.4[2]	14.5[2]
Lablab (*Lablab purpureus*) - forage	18.30[4]	11.43[4]	22.94[2]
Napier grass (*Pennisetum purpureum*) - forage	15.00[3]	9.88[3]	11.00[3]
Rhodes grass (*Chloris gayana*) - hay	86.40[2]	8.10[2]	10.10[2]
Brachiaria hybrid – hay	84.00[1]	7.00[3]	9.00[3]
Greenleaf desmodium (*Desmodium intortum*) -forage	24.20[2]	7.40[2,3]	15.50[2]
Creeping bluegrass (*Bothriochloa insculpta*) - forage	36.60[2]	8.10[2]	4.30[2]
Hyparrhenia rufa (forage)	31.10[2]	7.80[2]	4.20[2]
Rhodes grass (*Chloris gayana*) - forage	24.90[2]	8.10[2]	10.10[2]
Naturally occuring pasture - grazing	28.00[1]	5.00[1]	6.00[1]
Guatemala grass (*Tripsacum andersonii*) - forage	22.00[2]	8.20[1]	5.50[1]
Buffel grass (*Cenchrus ciliaris*) - forage	30.10[2]	8.10[2]	9.00[2]
Brachiaria hybrid (forage)	26.00[3]	7.00[3]	9.00[3]
Maize (*Zea mays*) – stover	87.00[5]	6.9[2]	3.90[2]
Natural pasture – Njombe (average of natural pasture, Bothriocloa & *Hyparrhenia rufa*)	31.90[1]	6.97[1]	4.83[1]
Natural pasture - Mufindi (average of natural pasture & *Cenchrus ciliaris*)	29.05[1]	6.55[1]	7.50[1]

Notes. 1: Expert data from Dr. Solomon Mwendia – forage agronomist, Alliance of Bioversity and CIAT; Jessica Mukiri – research associate, Tropical Forages Program, Alliance of Bioversity and CIAT; and Emmanuel Mwema – research consultant, Alliance of Bioversity and CIAT. 2. Feedipedia 2019. 3. Osele et al. 2018. 4. New South Wales Government Nutritional Database. 5. National Research Council 1978.

Appendix 5: Water requirements



Appendix 6: Response to changes in baseline feed baskets

Rungwe

Improved Wet season only	Wet season improved					Dry season				
	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)
Concentrate (commercial)	0.03	90.00	14.40	0.80	10.89	0.07	90.00	14.40	0.80	10.89
Banana (Musa acuminata)-crop residue	0.30	9.00	0.86	0.57	0.78	0.48	9.00	0.86	0.57	0.78
Brachiaria hybrid (forage)	0.15	26.00	2.34	0.46	1.82	0.07	26.00	2.34	0.46	1.82
Groundnut (Arachis hypogaea) - crop residue	0.02	89.83	13.03	0.55	7.55	0.01	89.83	13.03	0.55	7.55
Lablab (Lablab purpureus) - forage	0.00	18.30	4.20	0.75	2.09	0.02	18.30	4.20	0.75	2.09
Naturally occuring pasture - green fodder	0.25	28.00	1.68	0.33	1.40	0.25	28.00	1.68	0.33	1.40
Pennisetum purpureum - forage	0.25	15.00	1.65	0.65	1.48	0.10	15.00	1.65	0.65	1.48
Average		**21.85**	**2.13**	**0.52**	**1.70**		**22.20**	**2.38**	**0.53**	**1.88**

Improved Dry season only	Wet season					Dry season improved				
	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)
Concentrate (commercial)	0.03	90.00	14.40	0.80	10.89	0.07	90.00	14.40	0.80	10.89
Banana (Musa acuminata)-crop residue	0.30	9.00	0.86	0.57	0.78	0.28	9.00	0.86	0.57	0.78
Rhodes grass (Chloris gayana) - hay	0.00	86.40	8.73	0.53	7.00	0.20	86.40	8.73	0.53	7.00
Groundnut (Arachis hypogaea) - crop residue	0.02	89.83	13.03	0.55	7.55	0.00	89.83	13.03	0.55	7.55
Brachiaria hybrid (hay)	0.00	84.00	7.56	0.46	5.88	0.20	84.00	7.56	0.46	5.88
Naturally occuring pasture - green fodder	0.40	28.00	1.68	0.33	1.40	0.18	28.00	1.68	0.33	1.40
Pennisetum purpureum - forage	0.25	15.00	1.65	0.65	1.48	0.07	15.00	1.65	0.65	1.48
Average		**22.15**	**2.03**	**0.50**	**1.64**		**48.99**	**4.92**	**0.52**	**3.91**

Improved Wet & Dry seasons	Wet season improved					Dry season improved				
	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)
Concentrate (commercial)	0.03	90.00	14.40	0.80	10.89	0.07	90.00	14.40	0.80	10.89
Banana (Musa acuminata)-crop residue	0.32	9.00	0.86	0.57	0.78	0.28	9.00	0.86	0.57	0.78
Rhodes grass (Chloris gayana) - hay	0.00	86.40	8.73	0.53	7.00	0.20	86.40	8.73	0.53	7.00
Brachiaria hybrid (forage)	0.15	26.00	2.34	0.46	1.82	0.00	26.00	2.34	0.46	1.82
Brachiaria hybrid (hay)	0.00	84.00	7.56	0.46	5.88	0.20	84.00	7.56	0.46	5.88
Naturally occuring pasture - green fodder	0.25	28.00	1.68	0.33	1.40	0.18	28.00	1.68	0.33	1.40
Pennisetum purpureum - forage	0.25	15.00	1.65	0.65	1.48	0.07	28.00	1.65	0.65	1.48
Average		**20.23**	**1.89**	**0.52**	**1.57**		**48.99**	**4.92**	**0.52**	**3.91**

Mufindi

Improved Wet season only	Wet season improved					Dry season				
	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)
Concentrate (commercial)	0.05	90.00	14.40	0.80	10.89	0.08	90.00	14.40	0.80	10.89
Naturally occuring pasture - green fodder	0.21	29.05	2.18	0.43	1.90	0.20	29.05	2.18	0.43	1.90
Maize (Zea mays) - stover	0.02	87.00	3.39	0.46	6.00	0.15	87.00	3.39	0.46	6.00
Guatemala (Tripsacum andersonii) - forage	0.05	22.00	1.21	0.54	1.80	0.30	22.00	1.21	0.54	1.80
Rhodes grass (Chloris gayana) - forage	0.37	24.90	2.51	0.53	2.02	0.19	24.90	2.51	0.53	2.02
Pennisetum purpureum - forage	0.15	15.00	1.65	0.65	1.48	0.08	15.00	1.65	0.65	1.48
Brachiaria hybrid (forage)	0.15	26.00	2.34	0.46	1.82	0.00	26.00	2.34	0.46	1.82
Average		**28.80**	**2.83**	**0.53**	**2.40**		**38.59**	**3.07**	**0.53**	**3.20**

Improved Dry season only	Wet season					Dry season improved				
	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)
Concentrate (commercial)	0.05	90.00	14.40	0.80	10.89	0.08	90.00	14.40	0.80	10.89
Naturally occuring pasture - green fodder	0.36	29.05	2.18	0.43	1.90	0.10	29.05	2.18	0.43	1.90
Brachiaria hybrid (hay)	0.00	84.00	7.56	0.46	5.88	0.20	84.00	7.56	0.46	5.88
Guatemala (Tripsacum andersonii) - forage	0.07	22.00	1.21	0.54	1.80	0.15	22.00	1.21	0.54	1.80
Rhodes grass (Chloris gayana) - forage	0.37	24.90	2.51	0.53	2.02	0.19	24.90	2.51	0.53	2.02
Pennisetum purpureum - forage	0.15	15.00	1.65	0.65	1.48	0.08	15.00	1.65	0.65	1.48
Rhodes grass (Chloris gayana) - hay	0.00	86.40	8.73	0.53	7.00	0.20	86.40	8.73	0.53	7.00
Average		**27.96**	**2.77**	**0.53**	**2.32**		**53.42**	**5.42**	**0.54**	**4.41**

Improved Wet & Dry seasons	Wet season improved					Dry season improved				
	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)
Concentrate (commercial)	0.05	90.00	14.40	0.80	10.89	0.08	90.00	14.40	0.80	10.89
Naturally occuring pasture - green fodder	0.28	29.05	2.18	0.43	1.90	0.20	29.05	2.18	0.43	1.90
Brachiaria hybrid (hay)	0.00	84.00	7.56	0.46	5.88	0.20	84.00	7.56	0.46	5.88
Brachiaria hybrid (forage)	0.15	26.00	2.34	0.46	1.82	0.00	26.00	2.34	0.46	1.82
Rhodes grass (Chloris gayana) - forage	0.37	24.90	2.51	0.53	2.02	0.24	24.90	2.51	0.53	2.02
Pennisetum purpureum - forage	0.15	15.00	1.65	0.65	1.48	0.08	15.00	1.65	0.65	1.48
Rhodes grass (Chloris gayana) - hay	0.00	86.40	8.73	0.53	7.00	0.20	86.40	8.73	0.53	7.00
Average		**28.00**	**2.86**	**0.53**	**2.32**		**54.27**	**5.58**	**0.53**	**4.43**

Njombe

Improved Wet season	Wet season improved					Dry season				
	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)
Concentrate (commercial)	0.07	90.00	14.40	0.80	10.89	0.07	90.00	14.40	0.80	10.89
Naturally occuring pasture - green fodder	0.28	31.90	1.54	0.46	2.22	0.25	31.90	1.54	0.46	2.22
Rhodes grass (Chloris gayana) - forage	0.38	24.90	2.51	0.53	2.02	0.40	24.90	2.51	0.53	2.02
Pennisetum purpureum - forage	0.05	15.00	1.65	0.65	1.48	0.05	15.00	1.65	0.65	1.48
Greenleaf desmodium (Desmodium intortum) - forage	0.07	24.20	3.75	0.50	1.85	0.12	24.20	3.75	0.50	1.85
Maize (Zea mays) - stover	0.00	87.00	3.39	0.46	6.00	0.11	87.00	3.39	0.46	6.00
Brachiaria hybrid (forage)	0.15	26.00	2.34	0.46	1.82	0.00	26.00	2.34	0.46	1.82
Average		**31.04**	**3.09**	**0.53**	**2.63**		**37.46**	**3.31**	**0.53**	**3.08**

Improved Dry season	Wet season					Dry season improved				
	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)
Concentrate (commercial)	0.07	90.00	14.40	0.80	10.89	0.07	90.00	14.40	0.80	10.89
Naturally occuring pasture - green fodder	0.43	31.90	1.54	0.46	2.22	0.07	31.90	1.54	0.46	2.22
Rhodes grass (Chloris gayana) - forage	0.38	24.90	2.51	0.53	2.02	0.29	24.90	2.51	0.53	2.02
Pennisetum purpureum - forage	0.05	15.00	1.65	0.65	1.48	0.05	15.00	1.65	0.65	1.48
Greenleaf desmodium (Desmodium intortum) - forage	0.07	24.20	3.75	0.50	1.85	0.12	24.20	3.75	0.50	1.85
Brachiaria hybrid (hay)	0.00	84.00	7.56	0.46	5.88	0.20	84.00	7.56	0.46	5.88
Rhodes grass (Chloris gayana) - hay	0.00	86.40	8.73	0.53	7.00	0.20	86.40	8.73	0.53	7.00
Average		**31.92**	**2.97**	**0.52**	**2.69**		**53.49**	**5.64**	**0.54**	**4.37**

Improved Wet & Dry seasons	Wet season improved					Dry season improved				
	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)	"as fed" (/)	DM (/)	CP (%)	DE (/)	ME (MJ/Kg fresh)
Concentrate (commercial)	0.07	90.00	14.40	0.80	10.89	0.07	90.00	14.40	0.80	10.89
Naturally occuring pasture - green fodder	0.33	31.90	1.54	0.46	2.22	0.10	31.90	1.54	0.46	2.22
Rhodes grass (Chloris gayana) - forage	0.38	24.90	2.51	0.53	2.02	0.31	24.90	2.51	0.53	2.02
Brachiaria hybrid (forage)	0.15	26.00	2.34	0.46	1.82	0.00	26.00	2.34	0.46	1.82
Greenleaf desmodium (Desmodium intortum) - forage	0.07	24.20	3.75	0.50	1.85	0.12	24.20	3.75	0.50	1.85
Brachiaria hybrid (hay)	0.00	84.00	7.56	0.46	5.88	0.20	84.00	7.56	0.46	5.88
Rhodes grass (Chloris gayana) - hay	0.00	86.40	8.73	0.53	7.00	0.20	86.40	8.73	0.53	7.00
Average		**31.88**	**3.09**	**0.52**	**2.66**		**54.19**	**5.65**	**0.53**	**4.41**

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Duduville Campus Off Kasarani Road
P.O. Box 823-00621
Nairobi, Kenya

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