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Feeding a productive dairy cow in western Kenya: environmental and socio-economic impacts

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Vivien Osele
Birthe Paul
Jessica Mukiri
Sheila Halder
Titus Sagala
Alfred Juma
An Notenbaert

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Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture
Regional Office for Africa
PO Box 823-00621
Nairobi, Kenya
Website: www.ciat.cgiar.org

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About the authors

Vivien Osele, MSc student intern, ETH Zurich, and Tropical Forages Program, CIAT-Kenya

Birthe Paul, scientist, Tropical Forages Program, CIAT-Kenya

Jessica Mukiri, research associate, Tropical Forages Program, CIAT-Kenya

Sheila Halder, Farms Systems Coordinator, Send a Cow, United Kingdom

Titus Sagala, Country Director, Send a Cow, Kenya

Alfred Juma, Project Manager, Send a Cow, Kenya

An Notenbaert, senior scientist, Tropical Forages Program, CIAT-Kenya

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Acronyms and abbreviations

AEZ	agro-ecological zone
AME	adult male equivalent
BW	body weight
CIAT	International Center for Tropical Agriculture
CO_2	carbon dioxide
CP	crude protein
CSF	case study farm
DM	dry matter
DMI	dry matter intake
FGA	feed gap assessment
FGD	focus group discussion
FW	fresh weight
GHGe	greenhouse gas emissions
LU	livestock unit
ME	metabolizable energy
MJ	megajoule
MW	metabolic weight
NGO	nongovernmental organization
NPV	net present value
ROI	return on investments
SAC	Send a Cow
VOP	value of production
WCP	Wealth Creation Project


Photo: Vivien Osele/CIAT

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Introduction

Send a Cow (SAC) is a nongovernmental organization (NGO) that has been working in Kenya since 1996. It focuses on groups of smallholder farmers, providing them with training in sustainable agriculture and improved animal management. SAC is mostly active in western Kenya, one of the country's most populated and poorest region. The population density for this region ranges from 337 to 1,300 inhabitants per km² with an average density of 590 people per km² (Kenya Ministry of Agriculture and Rural Development, 2001; KNBS, 2010). Over 50% of the people in this area are dependent on agriculture and live below the poverty line of US$1/day (Iruria et al., 2009; Makokha et al., 2007). In 2013, SAC started the "Wealth Creation Project" (WCP) in Busia, Kakamega, Siaya, and Bungoma Counties in the Western Province of Kenya. The project aims to increase the agri-production systems of 9,500 smallholder farming families by diversifying their diets and giving them an additional source of income. Farmers are provided with training in animal management and sustainable agricultural practices throughout the project. After comprehensive trainings and farm asset evaluation, farmers were given livestock.

The gift of one improved livestock head to each rural, poor family created wealth and security for them, contributing to wealth creation by improving the quality of life and offering a potential pathway out of poverty (Nicholson et al., 2003). The WCP adds to the increasing number of smallholder farmers who keep improved dairy cows as a source of income and financial security. In 2007, it was estimated that 99,000 smallholder dairy farmers in the Western Province were keeping about 192,300 improved dairy cattle (Muriuki, 2011).

Land has become the main limiting factor in this already densely populated region, due to continuous population growth and land fragmentation. The small land size per farm (1 acre on average), which is further subdivided in each generation, is a major obstacle to providing adequate energy and protein intake for a dairy cow and a household. Due to limited land size, farmers put most of the available land under food crops and dedicate little area to planted fodder. Researching on the land area that is necessary to adequately feed a productive dairy cow and a family is essential for effective decision making and for training the farmers in sustainable feed production and farm planning.

Therefore, SAC collaborated with CIAT in assessing the land requirement for a dairy cow under different feeding regimes and explored the trade-offs of these feeding strategies in terms of food vs. feed land requirements, environmental impacts, and profitability. This research field is a focus area in farming systems research and trade-off analysis, both areas where CIAT has expertise.

The main research questions of this joint study of SAC and CIAT are:

- How much land is needed to feed a cow and a family with various feeding strategies across farming systems?
- What are the synergies/trade-offs of these feeding strategies in terms of environmental impacts, profitability, and labor requirements?

Photo: Nathan Russell/CIAT

2. Material and methods

2.1 Study area and case study farms

The study area and selected farming systems were based on SAC's target population for the WCP where SAC supported and gifted livestock to 46 farmer groups in western Kenya. The farmer groups were in four counties: Kakamega, Bungoma, Busia, and Siaya (Figure 1).

For this study, a subsample of eight representative case study farms (CSFs) was selected. The SAC field staff carried out the selection process for farms which had to meet the following criteria:

- Administrative units: Two farms per county were identified.
- Market accessibility: In each county, one farm was in a "market accessible = Near" area and the other farm was in a "market non-accessible = Remote" location.
- Agro-ecological gradient: Farms in different agro-ecological zones with varying altitude, precipitation, and soil types were selected.
- Land size and performance: The total land size of the farm should be the same as the group's average land size.
- Performance: The farmer should be representative of the other group members in terms of performance.
- Milk yield: The farmer must have one dairy cow that is currently being milked and has a milk yield close to the group's average milk yield.

A list of the selected farms can be found in Table 1. The farms located near the market are less than 1 km away, whereas the remote farms are located 2.5 to 14 km away from the main trading centers. The analyzed farms are located along an agro-ecological gradient, the main agro-ecological zones (AEZ) are upper midland (UM) and lower midland (LM) with a moisture gradient between semi-humid and humid. The differences in precipitation range from 1,460 mm/yr to 1,924 mm/yr and the differences in elevation vary between 1,204 m and 1,394 m in Siaya and Kakamega, respectively. The two rainy seasons, March to June and September to November, with a short dry season between January and February, allow two planting seasons per year; planting takes place in March and August and harvesting is carried out in August and December, respectively.

The target population of the WCP are subsistence farmers with limited access to land and resources. These resource-poor farms are managed almost exclusively by household members who do most of the on-farm labor. Because of a low level of mechanization, all activities are performed by the labor force. All farmers rely on a minimum amount of external inputs such as inorganic fertilizer, and are trained by SAC staff to make the best use of on-farm resources such as manure that is collected and used as organic fertilizer. Manure is collected from a zero-grazing unit where the improved dairy cow is permanently kept. Additional livestock are local chickens and sometimes local goats or cows. Common crops are maize, beans, cassava, sweet potatoes, fruit trees and local vegetables. Most of these are grown for family consumption. The household sizes range from six to fourteen members.

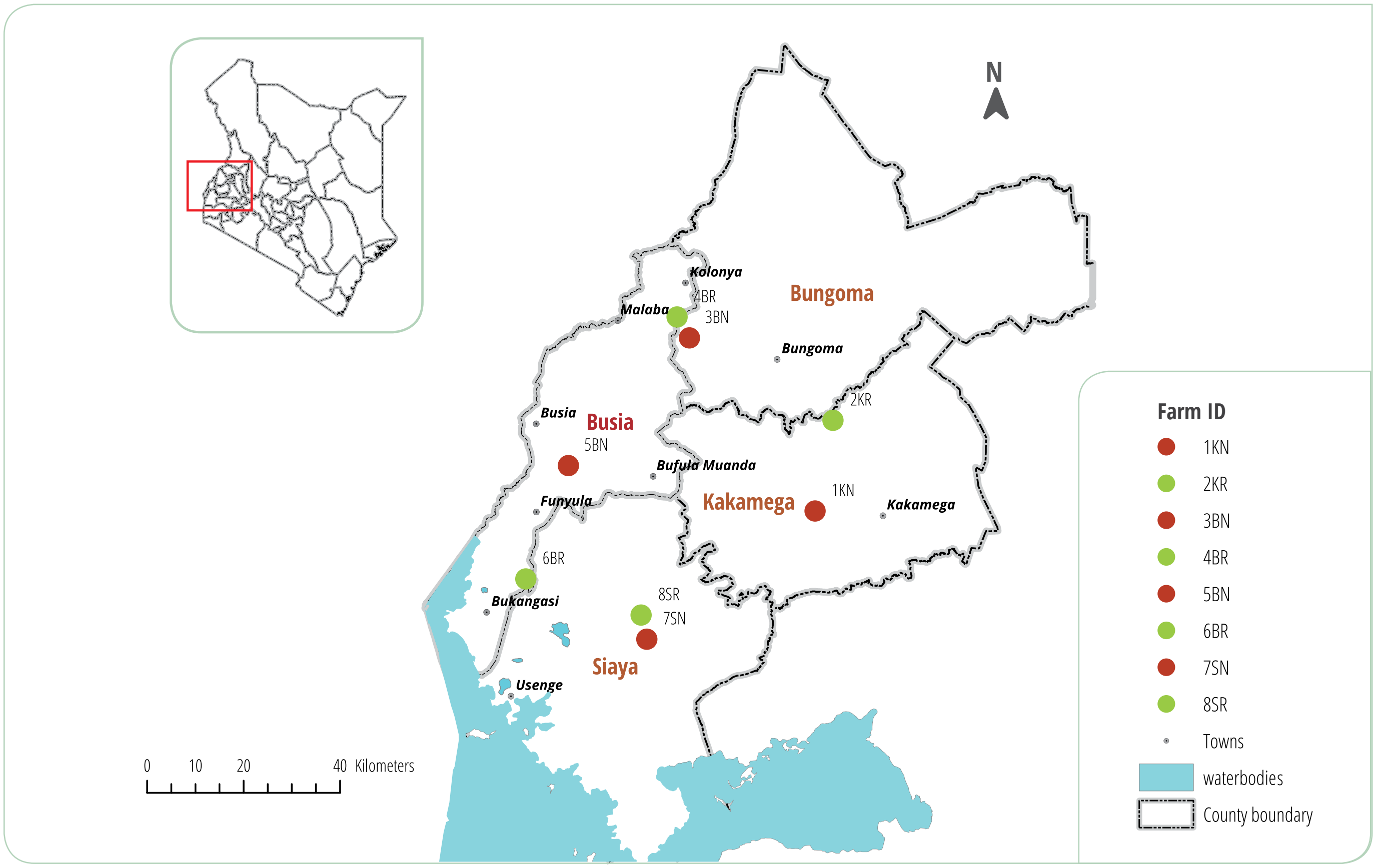


Figure 1 Study area in western Kenya with the location of eight CSFs in Bungoma, Busia, Kakamega and Siaya Counties.

Table 1 Overview of case study farms (CSFs) characteristics

The farm IDs are composed of: ascending Arabic numbers, the first letter of the County in ascending Arabic numerals (K=Kakamega, B=Bungoma/ Busia, S=Siaya) and market distance (N=Near, R=Remote). The population density is expressed in people per square km (pp/ km^2); this data was from a national census in 2009. Distance to market is expressed in km. Values for agro-ecological zones (AEZ), precipitation (mm/yr) and altitude (m.a.s.l.) were extracted from a preexisting database (ArcGIS). The household members are composed of adults plus children living on the farm for at least three consecutive months in each year.

FARM ID	COUNTY	POPULATION DENSITY (pp/ km^2)	MARKET DISTANCE (km)	AEZ	PRECIPITATION (mm/yr)	ALTITUDE (m.a.s.l.)	HOUSEHOLD MEMBERS
1KN	Kakamega	547	< 1	LM1	1924	1389	7+7
2KR	Kakamega	547	14	LM2	1895	1395	2+5
3BN	Bungoma	623	< 1	UM3	1725	1296	2+5
4BR	Bungoma	623	7.5	UM3	1726	1243	4+6
5BN	Busia	457	< 1	LM1	1717	1206	5+5
6BR	Busia	457	4.5	LM3	1430	1205	2+4
7SN	Siaya	337	< 1	LM1	1460	1327	3+4
8SR	Siaya	337	2.5	LM1	1350	1281	4+2

2.2 On-farm data collection

The eight selected farms were visited between 3 and 19 October 2017 for intensive data collection. Directly measured data and farmer-reported survey data was collected during a ‘12-hour farm visit’ (6 a.m. to 6 p.m.) on each farm. Prior to the visit, farmers were asked not to alter their daily routine. The exact locations of the farms household, dairy cowshed, water supply source, milk selling point as well as total farm area and main field areas were recorded with a Garmin GPS device. The recorded geodata was mapped out on a satellite image using the desktop-app ArcMAP (v.10.4.1). For the main fields, planted crop variety and yields were recorded. Main soil types, precipitation, elevation and agro-ecological zones (AEZ) of the sampling sites were extracted from secondary GIS data.

Other measured on-farm data focused on activities and feed management for supporting a dairy cow. The quantity of feeds given during the day, milk production, water supply, and labor invested in dairy cow upkeep (i.e. feed collection, chopping, milking, cleaning of shed, fetching water and selling the milk). The amounts of feed given to the dairy cow during the day were weighed separately with a hanging scale, after fetching and before chopping and mixing it. After the last milking in the evening, any leftover fodder in the trunk was weighed. The quantity of milk was measured after each milking with a measuring cylinder. The time spent on different activities was measured with a stopwatch, and the name of the household member performing the task was recorded.

The survey data included the number of household members, the number and type of livestock, field calendar and management of the dairy cow throughout the year. Additionally, seasonal feed baskets were recorded, and overview maps of the farms were drawn.

2.3 Data analysis and modelling

Collected data was used as input for the rapid assessment tool “CLEANED” (Notenbaert et al., 2018) and for the “Feed Gap Assessment” calculations (Paul et al., 2017).

2.3.1 Feed gap assessment (FGA)

The tool used for the feed gap assessment (FGA) was an Excel calculation balance sheet of feed intake and requirements for maintenance and milk production for 1 day. The feed intake was reported in fresh weight (FW) by adding all feeds, minus the leftovers in the trunk and minus the leftovers on the ground – estimated at 7% (total losses up to 20%). Total daily intake of each feed item was converted into dry matter (DM), metabolizable energy (ME) and crude protein (CP) equivalent.

Feed properties were taken from literature reviews and feed databases and were the same as the one used in the CLEANED tool calculations. Total feeds were calculated for one dairy cow and were presented per adjusted body weight (BW) of one livestock unit (LU) (1 LU = 350 kg BW). Total feed supply was then compared with cattle requirements. For DM requirements, a daily DM intake of 2.4% per kg BW (8.4 kg DMI/LU) was used. For CP requirements, we assumed 6.27 g/kg per metabolic weight (MW) for maintenance (507 g/LU) and 92.6 g CP per liter of milk produced. For ME, we used 0.598 MJ/kg MW (48.4 MJ/LU) for maintenance and 5.65 MJ per liter of milk (Paul et al., 2004).

2.3.2 CLEANED model

The CLEANED model is a rapid assessment tool in the form of an Excel-spread sheet for *ex-ante* modelling. The model focused on livestock enterprises and was used to identify the possible impacts of implementing specific technologies related to livestock feeding.

The CLEANED tool is based on an annual calculation. Input information for the model can be categorized in environmental conditions (soil characteristics, rainfall, and seasons), herd composition (type and number of livestock), manure management system, and feed baskets for dry and wet seasons. For each feed crop, information on management was collected (residue management and fertilizer regimes). Additionally, some economic parameters were collected. For this study, the livestock enterprise focused exclusively on the one improved lactating dairy cow gifted by SAC. The reference year was always a “lactating year” and included a complete 10-month lactation period. On the day of data collection, the milk quantity, the date of calving down, and the peak milk production were recorded. By combining this data, annual milk production for a 10-month lactation period was estimated. The seven main feed items for the dry and the wet season were listed. For the wet season, the fraction of each feed item in the feed baskets was estimated by transforming the measured feed items into percentages, while for the dry season, the reported data from the farmers' interviews was used.

The CLEANED tool had the following output indicators:

- Land requirement: Based on the relative importance of the items in the feed basket, and the dairy cows’ live weights and milk production, the tool generated the amount of land required to produce each feed crop.
- Productivity: The contribution of dairy cow to food security was calculated based on the energy (calories) produced through this livestock enterprise – directly

from the dairy cow and from the dual-purpose crops fed to the cow – and compared to the energy requirement of an adult male equivalent, i.e. 2,500 kcal per day (AME). To compare livestock's contribution to food security across the farm, the energy data were expressed per land unit (calories/acre).

- Soil nitrogen balance: The balance between nitrogen inputs (i.e. mineral fertilizers, manure, symbiotic fixation by legumes crops, nonsymbiotic fixation, and atmospheric deposition) and outputs (i.e. crops and residues exported off the field, leaching of nitrate, gaseous loss of nitrogen (e.g. NH_3 and N_2O), soil erosion) are expressed in kg liters per milk and kg N per land area unit.
- GHG emissions: GHG emissions are calculated following the guidelines of the International Panel on Climate Change (IPCC, 2006). Emissions from livestock (methane from enteric fermentation), manure (methane and nitrous oxide), and field emissions (nitrous oxide) were considered. Most of the calculations followed IPCC Tier 1 methods, while Tier 2 calculations were performed for enteric fermentation and manure production. GHG emissions were expressed in CO_2 equivalents per liter of milk and land area unit.
- Economics: The total value of livestock production was calculated combining the economic value of milk, meat and manure and expressed in US$. For scenarios of improved livestock finding differences from the baseline were represented with the economic parameters net present value (NPV), payback period, and return on investments (ROI).

Before utilization, the CLEANED tool was calibrated and adapted to western Kenyan characteristics. Most parameters were derived from the literature and expert opinion. Because of a big uncertainty of on-farm Napier yields, a direct calibration was performed on two farms. For the farms 1KR and 7SN, the CLEANED output for the required Napier land was adjusted to the measured Napier plots. The parameter 'Napier fresh weight (FW) yield' was set at 35 t/ha/yr (Table 2).

Table 2 Napier yield calibration

FARM ID	MEASURED NAPIER PLOTS (acre)	NAPIER LAND REQUIREMENT CLEANED OUTPUT (acre)	FRESH WEIGHT (FW) SET AT (t/ ha/yr)
1KR	0.1	0.11	35
2 SN	0.104	0.1	35

For the baseline calculations, the CLEANED worksheets were filled out with input data of the current bio-economical state of each farm. In a second-step scenarios were run, i.e. milk yields and/or feed baskets were modified. The first scenario was called "Milk high". For this scenario, the annual milk yield was increased to 3,000 liters. We assumed that this milk yield was a realistic goal for smallholder farmers in western Kenya and could be reached. Currently, one of the eight farmers produces approximately 3,000 liters of milk per lactation period and in every farmer group, at least one member reached this milk level.

The following feeding scenarios were implemented in the CLEANED model. In each scenario the "Milk high"-goal was kept constant and only the feed baskets were adjusted by adding new feed items or changing their fractions (see Appendix I).

i. "Baseline"
This was set at the current feed basket and current milk production level.

ii. "Milk high"
This was when the current feed basket and annual milk production was set at 3,000 liters.

iii. "*Brachiaria*"
For this scenario, 50% of the Napier was converted into an improved *Brachiaria variety*. *Brachiaria* has a higher quality compared to Napier in terms of both protein content and digestibility. Additionally, this variety is more drought tolerant and not affected by typical Napier diseases occurring in this region that can drastically reduce yield (e.g. Napier smut and stunt disease).

iv. "2:1 Ratio"
The "2 to 1 Ratio" was part of the training farmers received on dairy cow feeding from the SAC staff. This recommendation is based on a feed ratio with two parts of grasses (e.g. Napier or locally collected grasses) and one part of protein-rich plants (e.g. *Desmodium*, beans, sweet potatoes and fodder trees). For the CLEANED feed basket, this ratio was expressed in 35% protein-rich feeds and 65% grasses. The changes in feed baskets

were implemented on each farm according to available feed item. In both seasons, *Desmodium* and common beans covered at least 25% of the feed basket and the remaining 10% of protein-rich plants were sweet potatoes vines, *Calliandra* or *Leucaena*. To increase the proportion of protein-rich feeds, the fraction of feeds with lower quality (maize stover) or the surplus (above 65%) grasses were decreased.

v. "Dairy meal"
For this scenario, dairy meal was introduced in all diets. The dairy meal fraction in the feed basket was increased to 5% throughout the year. This amount is equivalent to 2.5 to 3 kg dairy meal per day if a total of 50 to 60 kg (FW) was fed. To compensate for the 5% increase in dairy, 5% meal was subtracted from the qualitatively poorest feed item (i.e. maize stovers or local mixed grasses).

vi. "*Calliandra*"
SAC promotes and trains farmers on feeding cows fodder trees with the goal of reaching 300 trees per farm. *Calliandra* is a common, protein-rich fodder tree in western Kenya. In this scenario, the fraction of *Calliandra* was increased to 15% of the feed basket throughout the year. Fractions of available maize stover or grasses (i.e. local mixed grasses or Napier) were decreased to compensate for the increase in *Calliandra* in the feed baskets. In a 50 to 60 kg FW diet, this results in 7.5 to 9 kg FW *Calliandra* per day.

2.4 Focus group discussions (FGDs)

From 13 to 17 November 2017, FGDs with group members of the visited farmers were held at the analyzed farms. A total of 129 farmers (102 women and 27 men) participated in the eight FGDs.

The results of the on-farm data collection and modelling were presented and discussed. Information about the total farm size and peak milk production was collected from the participants. These answers were used to confirm the assumed representativeness of the selected CSFs within the group. A "feed scenario and farm planning" exercise was performed in each FGD. Farmers were randomly divided into four discussion groups.

Each group was given a printed map of the CSF and a "feeding scenario". The exercise task was to draw on the printed farm map fields for food and fodder production and to answer questions about different feeding scenarios.

In addition, the groups were asked to reflect about the proposed feeding scenario and add own ideas for increasing the milk production to 15 liters through new feeding regimes.

The farmers were given the following scenarios to focus on:

1. Convert all Napier (*Pennisetum purpureum*) into *Brachiaria* (*Brachiaria* hybrid cv. Mulato II).
2. Integrate Napier/*Desmodium* (*Desmodium intortum*) intercropping.
3. Integrate fodder trees such as *Calliandra* (*Calliandra calothyrsus*), use of niches and dry season feeding strategies.

After some planning time, the groups would answer the following questions and present their ideas:

a. What is the cost of establishment, in terms of material inputs and labor?

b. What are positive and negative aspects and challenges of this scenario?

c. Is it realistic, would you do it and why?

d. How much crop land for family consumption would you convert into fodder land?

The goal of the FGD exercise was to gain more insights into farmers' existing knowledge and their perception and acceptability of different feeding scenarios. The farmers were asked to share their own ideas and reflect about related positive effects as well as barriers to different feeding strategies.

Photo: Vivien Osele/CIAT

Photo: Vivien Osele/CIAT

3. Results and discussion

3.1 Reported and measured outputs

3.1.1 Farm areas

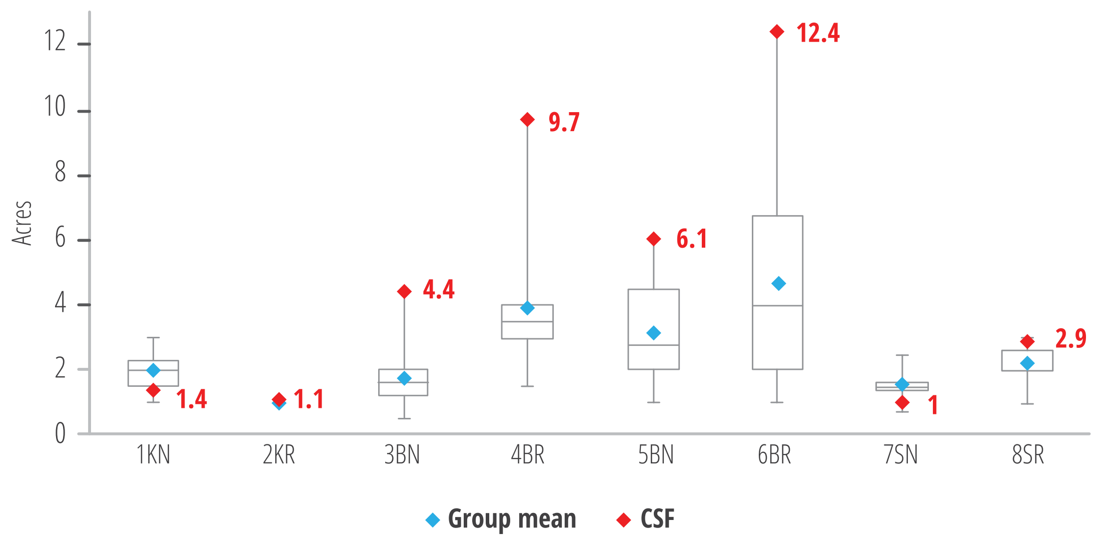


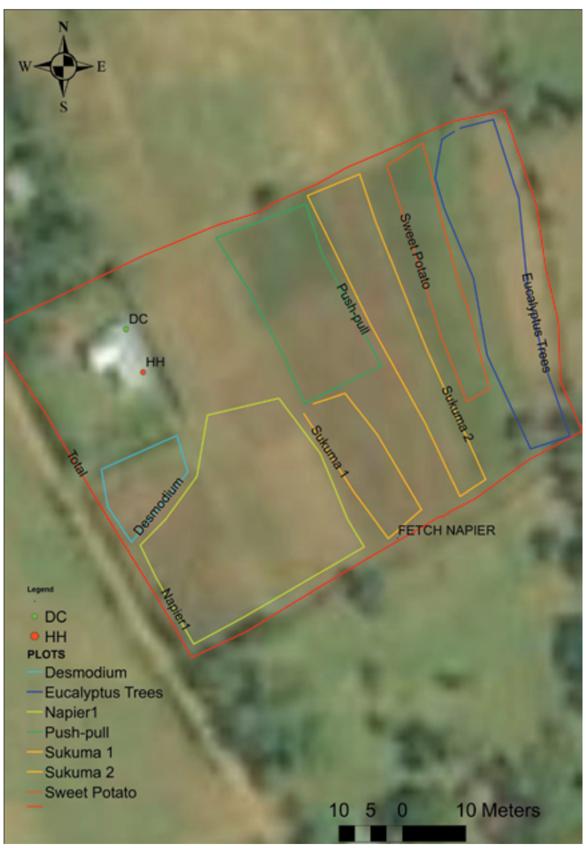
Figure 2 FGD group members' total area.

Figure 2 is the reported total land area of the farmers who participated at the FGD. The blue dots show the group members land size mean, while the red dots represent the measured total area of the CSF.

When comparing the total land areas reported by the farmer group members, the group means varied between 1 and 4.2 acres. Except for the farms in Kakamega County, the CSF areas and the average group areas in the remote locations were larger than those in market accessible locations. This difference was expected and could be explained by the higher population density and the consequently higher land pressure in the proximity of urban centers compared to remote areas. The calculated total farm area of the most visited farms was visibly higher than the reported group mean (except for 1KN and 7SN), possibly because of the farmers' perception about the total area they owned compared to the area they cultivated. An example of this discrepancy was seen in the CSF 4BR and 6BR. In these CSFs, the total area was three to four times larger than the cultivated area (Figures 3 and 4). In contrast, farmers with a small area (e.g. 2KR and 1KN) had used the limited space intensively (Figures 5 and 6). Some farmers reported the land close to their homestead, without adding on the area of more distant plots they might have cultivated as well. Examples of such farms with fields in different locations were 3BN and 7SN (Figures 7 and 8). For this study, we calculated the areas of all owned and leased fields, close and more distant from the homestead. Therefore, when considering this difference, it was concluded that, in general, the CSFs were representative of their region in terms of the area that was cultivated. See maps for farms 5BN and 8SR in Appendice 5.

Figure 3 Map 4BR farm.

Figure 4 Map 6BR farm.



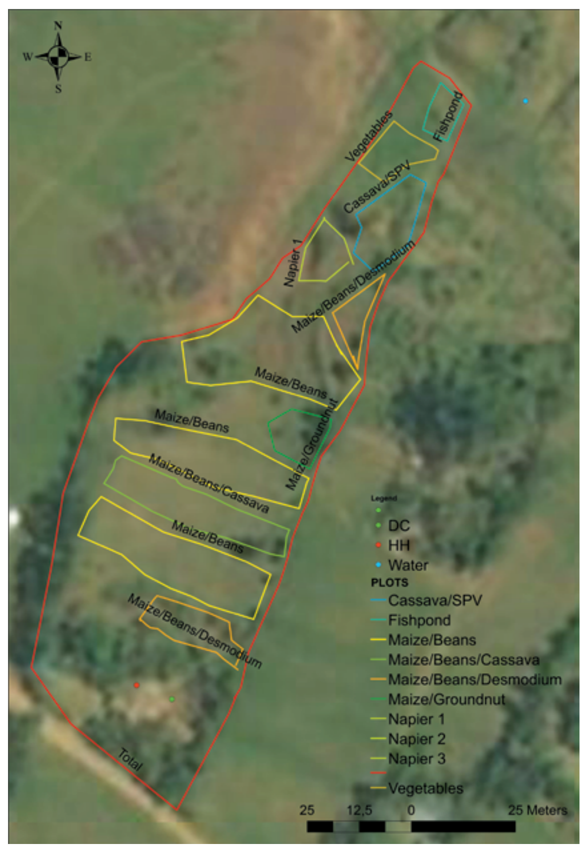


Figure 5 Map 2KR farm.

Figure 6 Map 1KN farm.

Figure 7 Map 3BN farm.

Figure 8 Map 7SN farm.

Figure 9 represents the measured farm areas and main field areas corresponding to the farm maps. All measured plots were grouped into six main categories. The category 'Dual-purpose crops' represented all fields where the crops were used for human consumption and the crop residues were fed to the cows (e.g. maize, beans and sweet potato). In contrast, the area known as 'Food' represented the land were crops for human consumption were exclusively grown (e.g. kitchen gardens and vegetables) and for the category 'Feed' only animal fodder (e.g. Napier, *Brachiaria*) was grown. The category 'other' was calculated as the difference between the total land area and the sum of all other measured plots. This land could be the compounds, niches, and unused space or roads. The measured total land area was highly variable between the farms (1 acre to 12.4 acres). The fraction of land dedicated to different categories was highly variable (Figure 10). The smallholder survey in western Kenya by Waithaka et al. (2002) reported that, on average, more than 50% of the farm land was dedicated to growing food crops, fallow and natural pasture occupied 20%, while planted fodder crops, including Napier grass, was found on only 6% of the farmland. The land allocation of the CSFs presented in percentages shows a range of findings. The fraction of land used for food production ('Food crops' plus 'Dual-purpose crops') was variable, ranging from below 15% to over 70% of total area. The proportion of planted fodder (including fodder trees) was below 5% on two farms and above 10% on the rest. The relatively high area for planted fodder in most CSFs may be due to SAC training sessions and SAC gifting planting material to the farmers. Except for the farms in Kakamega County, the planted fodder (mainly Napier) proportion was higher in the market accessible areas compared to the farms in the remote areas. This spatial influence could be explained by higher land pressure and need to use high-yielding fodder varieties because the farms were smaller and competition for off-farm collected grasses was higher.

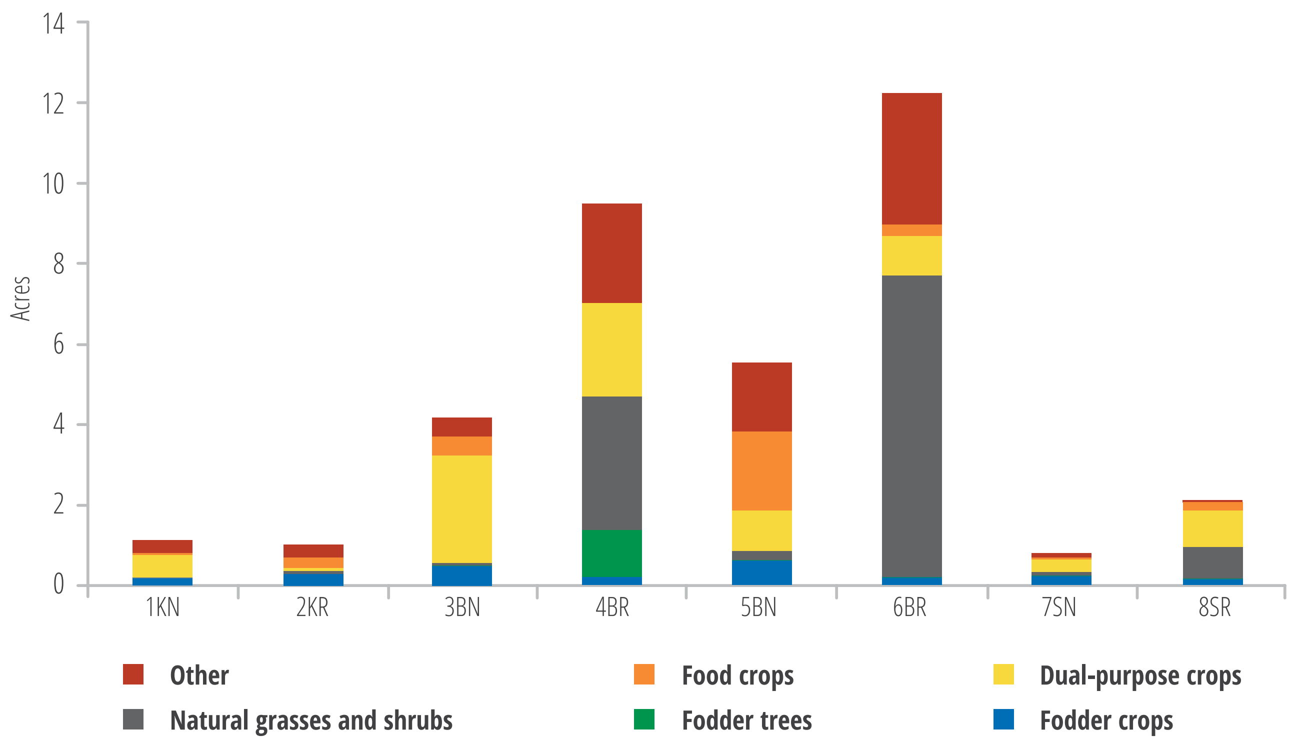


Figure 9 Total land measured and subdivided in plots.

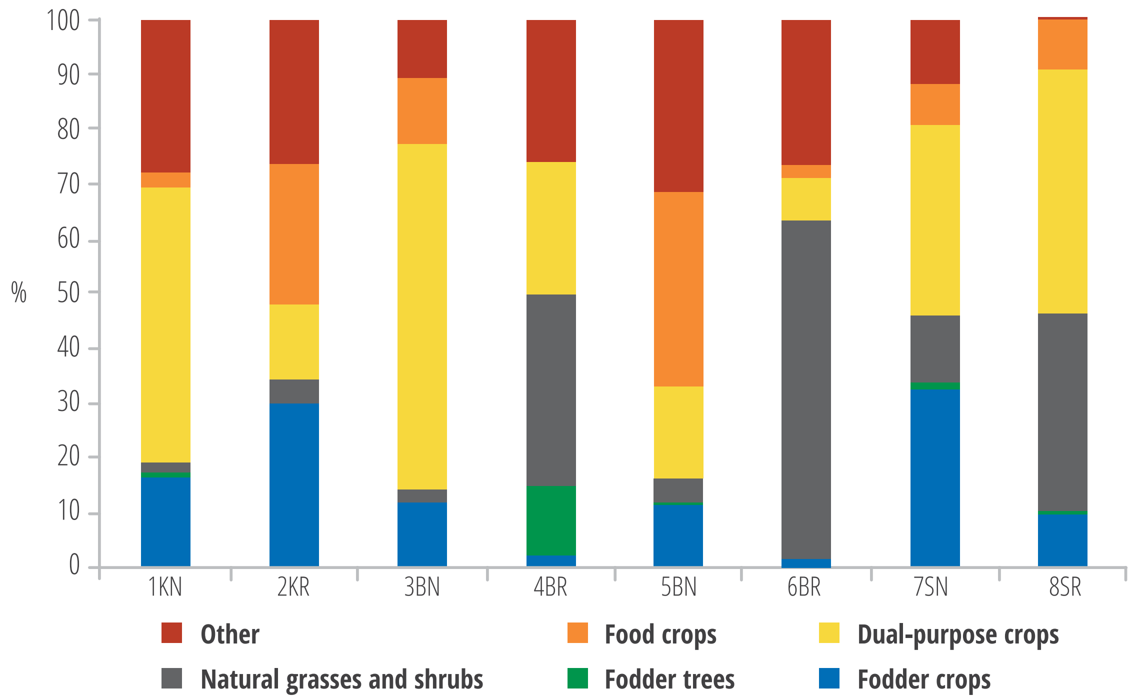


Figure 10 Total land allocation.

3.1.2 Milk yields

The reported milk yields in the various groups showed consistent group means, which were all between 8 and 10 liters (Figure 11). There were no visible trends between the four counties and between the remote compared to near locations. Compared to the other group members in the respective farmer group, the reported milk peak of most CSFs was close to the group average, except for 8SR, which had a visibly higher milk yield than the group average. These results indicated that most of the selected farms were a good representation of their area in terms of milk performance.

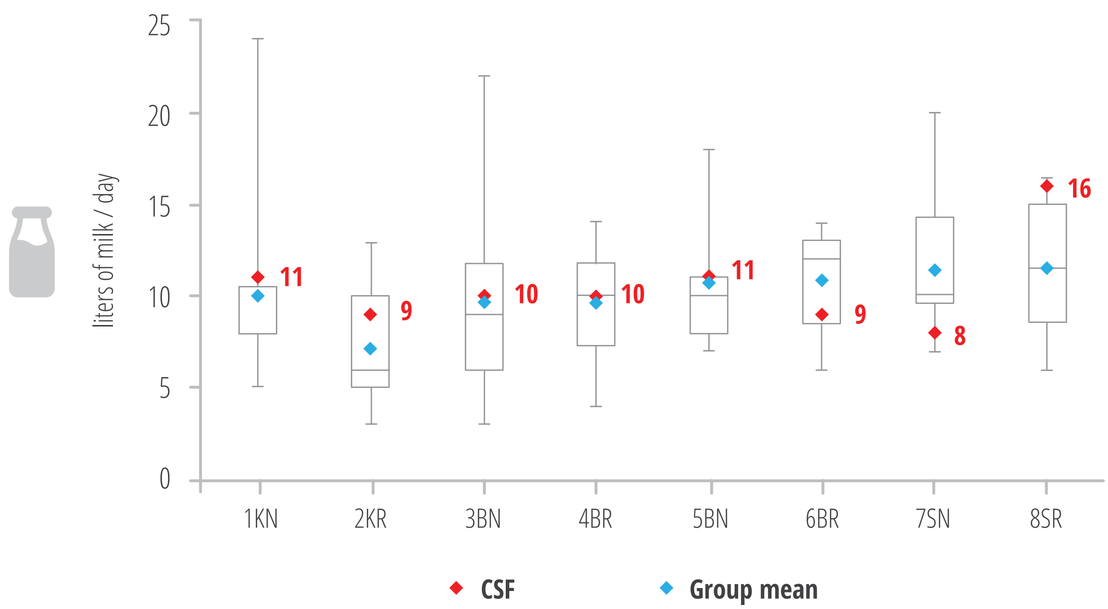


Figure 11 FGD group members' milk yield.

When comparing the milk yields on the CSF with the results of previous studies, it was observed that the cows were producing above the regional average. A study in the Western Province revealed a daily mean milk yield per cow of 6.47 liters with 53.6% of the farms producing less than 5 liters of milk/day, while 35.7% and 6.7% produced 6–10 and 11–15 liters of milk/day, respectively. Only 3.8% of the farms produced more than 15 liters/day. The same study estimated an average annual milk production of 1,168 liters per dairy animal in this region, which is below the estimated country average of 1,600 liters/cow.

The average estimated annual milk production for the CSFs was 1,882 liters, which was even higher than the country average of 1,600 liters (Figure 11). One reason for this high milk production could be an overestimation of the length of the lactating period. We estimated a lactation time of 300 days for this study but most other studies calculated a shorter lactation of 230 days on average and a mean calving interval of 14.77 months (Wanjala & Njehia, 2014). Another reason for our higher annual yield estimates is that we assumed that the full 10-month lactation period would fall within a calendar year and every year. While in reality, we would expect the average annual milk yield to be lower due to the dry period. Other reasons for higher yields on the analyzed farms might be linked to the training in dairy management by SAC staff. In fact, we observed that the farmers were aware of hazards linked to cow health and milk production and did understand and put into practice the information they had previously received during training. During the FGDs, the farmers expressed the importance of good fodder quantity and quality and the influence these factors had on milk yields and taste. The high average milk yields could therefore be attributed to adequately fed lactating cows. Throughout the visited farms, all dairy cows were managed and fed in the same way. Most of the visited animals had a similar milk production level regardless of the agroecological conditions or market accessibility. We expected market accessible farms to have higher milk production by assuming that the purchase of external inputs such as dairy meal was facilitated and the incentive to sell more milk was high since the market access was better. This expected trend did not appear in this study, suggesting that in this case distance to market was not directly correlated to milk production levels.

During the FGDs, market accessibility and the presence of a reliable market was repeatedly pointed out as major issues. Also, in a study by Musalia et al. (2010), 35% of farmers reported problems in selling their milk, and an accompanying high spoilage rate. During the FGDs, the farmers emphasized the need to organize milk cooperatives for marketing of milk from both remote and market accessible areas to reach urban areas where demand was high.

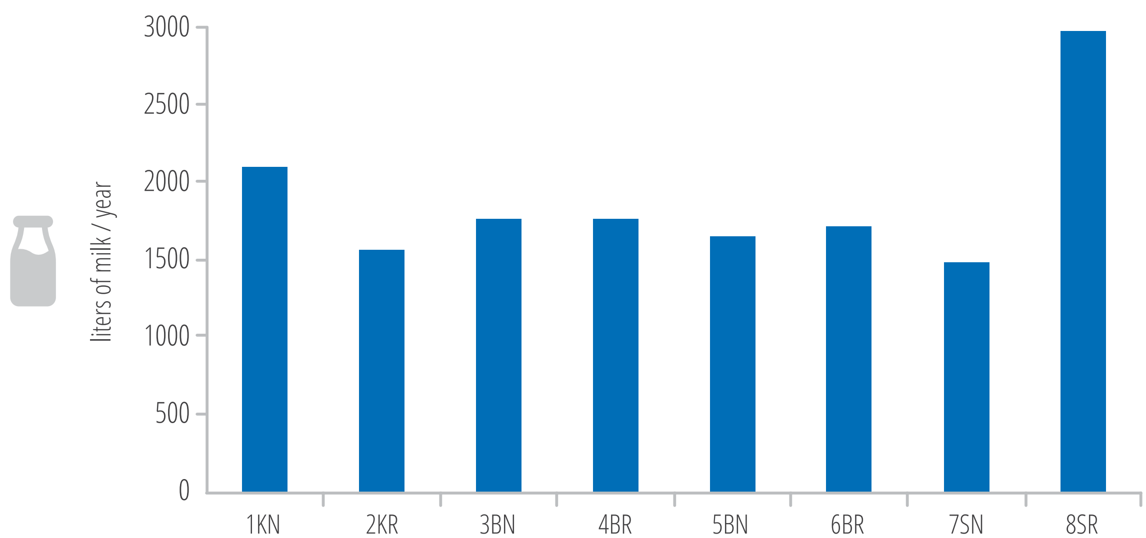


Figure 12 Estimated annual milk production.

3.1.3 Labor and gender implications

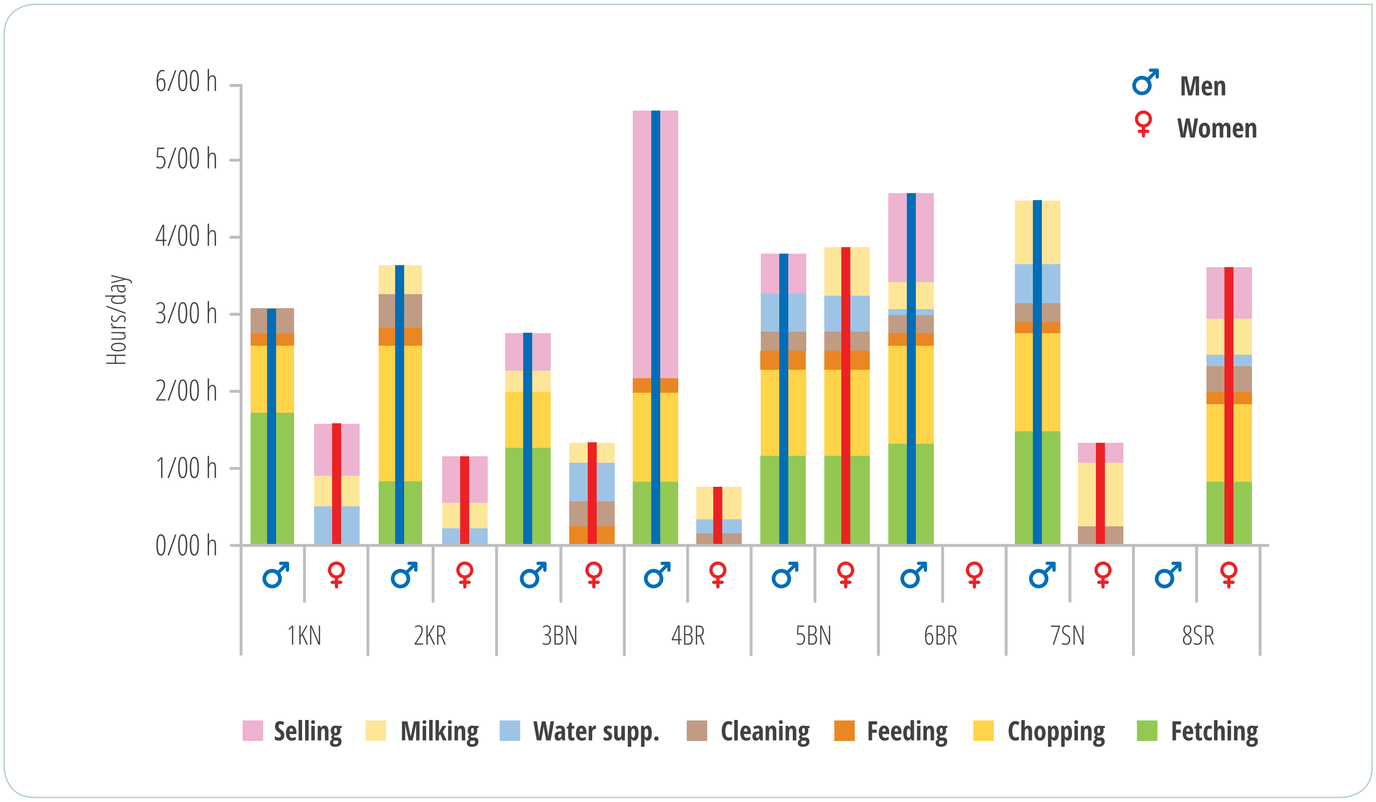


Figure 13 Time spent on activities, related to dairy cow up keeping, expressed in hours per day. Gender of the family member performing the task is represented with blue (men) and red (women) columns.

In the previous section, we stated that "all dairy cows were managed and fed similarly". Here we will explore the labor implications of keeping a lactating dairy cow. Like most dairy farmers in the region (67.1%) (Wanjala & Njehia, 2014), the farmers kept their dairy cows in zero-grazing units and had received a lot of training from SAC staff in animal management; therefore, the daily activities and fodder preparation methods were similar for all farms (Figure 13). The time each day spent carrying out different activities, which ranged from fetching water and feeds to the selling of the product, was recorded as 4 h 30 min, with 3 h 37 min as the shortest and 7 h 40 min as the longest time recorded. No visible trends were observed between the near and the most remote regions across the counties. Although a difference in milk selling time was expected between market accessible and remote farms, this was not the case, because most farmers in the remote areas sold the milk to their neighbors. Fetching and chopping (green and yellow colors) were the most time-consuming tasks and were performed manually.

During the FGDs, a similar labor graph was presented, the farmers were not surprised by the hours per day spent on dairy farming and, in general, they agreed that the time spent and the commitment shown were key for success. Most of the farmers reported "labor restriction" to be an important limiting factor. The lack of a "labor force" will be a problem especially in the future, as most of the farmers were middle-aged or elderly, and the younger generation preferred to seek employment in the urban areas.

The bulk of labor for most farm operations in this region was provided by family members. For this reason, lack of adequate family labor accompanied by financial constraints for hiring external laborers could be a serious problem (Marenya and Barrett, 2007). In general, the household head performed most activities regardless of their gender and decided what needed to be done, while children and casual laborers played a secondary role. Casual laborers were sporadically employed for field activities, while activities directly related to the dairy cow were performed by family members. These results were like previous studies in the region which reported that 59% of the households employed casual laborers mainly for crop- related activities, such as preparing fields for food crops, or for planting and weeding (Waithaka et al., 2002).

Additionally, to the stacked activities, the graph shows the gender of the household member performing the task (i.e. red column for women and blue column for men). For some activities, more people performed the task together and the time was double counted (e.g. 5BN). We observed that when a man was present, he would carry out the labor-intensive tasks of fetching and chopping the feeds. In most farms, milking was performed by the woman or by two people. In this case, one person fed or restrained the animal while the other did the milking. In general, we observed that when both genders were present, the workload was equally divided. SAC trained their farmers in gender equality and the importance of overcoming strict gender-linked activity barriers. These training sessions encouraged different family members to learn how to perform all the required tasks, so that if one family member was not available, the others could step in.

By comparison, in the survey by Waithaka et al. (2002), 35% of the households had adult females taking a bigger role in feeding cattle than all other household members. In 30% of the households, this activity was the responsibility of the household head, regardless of their gender.

Similarly, milking was the responsibility of adult females in most of the households surveyed. The family member selling the milk was usually the same person who controlled the earned money. Milk marketing was mostly carried out by the household head and equally distributed between genders. Our results were different from the 2002 survey, where mostly adult females did the marketing of milk. In general, the strictly gender related tasks that were traditionally performed only by men or women were not observed. In our CSFs, managing a dairy cow involved both men and women.


Photo: Vivien Osele/CIAT

3.1.4 Feed gap

Fodder is the highest ranked most important variable influencing milk yield in western Kenya. Previous research repeatedly reported that dairy animals on smallholder farms in Kenya were underfed and 87% of farmers experienced feed shortages (Staal et al., 1997; Waithaka et al., 2002; Wanjala et al., 2015).

The feed gap assessment was performed to investigate the current feed regimes and the related limitation for achieving higher milk yield in the CSFs.

The weighted daily feeds were categorized in four groups: the local mixed grasses and planted fodder such as *Desmodium*, Napier and *Brachiaria* (in green); all crop residues (in yellow and brown); the fodder trees (in blue) and the purchased dairy meal (in gray). The amounts per category also followed this order; green was the most prominent color followed by the crop residue and the fodder trees in yellowish and bluish colors, respectively. Napier was the dominant feed item in all farms and, according to a study by Wanjala & Njehia (2014), was the main roughage for most farmers in this region (98%). The total FW intake per LU showed a high degree of variation and ranged between 40 kg and almost 85 kg (Figure 14). The three farms with the highest FW intake (above 60 kg) had also the highest Napier intake (above 30 kg). Timing (and climatic conditions) of Napier cutting played an important role in FW regimes. Some of the Napier had been cut the day before and the rest was fresh, depending on the fraction of these two the total Napier FW varied. Except for CSF in Busia County, all market accessible farms had a higher feed intake compared to the remote farm in the same county. Between the three largest farms and the smallest farms there were no differences in quantity or diet. These results suggest a stronger relation between market accessibility rather than size of farmland owned. The only purchased feed item (1–2 kg/day dairy meal) was fed in five of the farms and didn't seem to be correlated to distance to market.

Total dry matter intake (DMI) varied between 8 and 14 kg/DM per day (Figure 15). After converting all feeds into DM, the weight of fodder plants with higher water content (e.g. Napier 15% DM) reduced more drastically compared to crop residues such as maize stovers (ca. 90% DM). Hence the proportion of stored crop residue in the feed basket expressed in DM had increased compared to freshly cut plant material. When applying the rule of thumb that DMI should be 2.4% of BW in an average diet, the DMI per LU (=350 kg BW) should be 8.4 kg. This requirement estimate does not include movement and growth. In this study, the additional requirements for movement could be neglected as all the animals were managed in a confined place in zero-grazing units.

Three farmers were feeding below the current DM requirement. The gaps between the DM requirement, and the total feed was less than 2 kg. The other five cows were sufficiently fed and would, therefore, have the potential to produce more milk, if they were given an adequate energy and crude protein supply.

Metabolizable energy (ME) requirements for maintenance and milk production were expressed in MJ per day and LU (Figure 16). The energy requirements ranged from 71 to 119 MJ/day/LU, while the energy from feeds ranged between 68 and 130 MJ/day/LU. The crude protein (CP) intake and requirements were expressed in g CP/day/LU (Figure 17). In general, all graphs followed a similar pattern for total ME and CP intake. For all feed items, the differences between the ME and CP fractions were given by the specific properties of each feed. For example, maize is characterized by overall small nitrogen (N) content with a high proportion of cellulose, while Napier, for example, could provide higher crude protein content (91 g CP kg/DM versus 50 g CP kg/DM in maize residues), as well as metabolizable energy, favoring live-weight gains and milk production in lactating animals (Tittonell et al., 2009).

Compared to the high number of underfed animals reported in previous studies, the visited farmers were performing better. This result could be influenced by many factors. First, farmers have received extensive trainings by SAC on feed quantity and quality requirements. Second, the farmers were asked not to alter the normal feeding practice during the visit day, a certain "performance pressure" might have played a role and, therefore, more feeds than usual were utilized. A hint for comparatively higher feed regimes on the day of visit was apparent because a "too high" proportion of legumes was harvested in relation to what was growing in the farmers' fields. Third, an important factor in feed availability is seasonality. In fact, most of the interviewed farmers reported a feed scarcity in the dry season, with feed reductions of -30 to -50%. During the dry season, the Napier bulk mostly replaced by collected local grasses and crop residues. The seasonality might also have played an indirect role because of the "compensatory overfeeding" some farmers practice, hereby farmers do overfeed their animal during the wet season so that the animal accumulates some extra weight before the drought period starts. In addition to the ME and CP requirements for present milk production (red marks), the requirements for 15 liters of milk production (blue marks) were calculated. With the new increased milk production, seven out of eight farms would have to increase the feed intake to meet the new ME and CP requirements.

For a productive cow, both ME and CP must be provided in sufficient and equilibrated amounts. A consequence of energy deficiency is poor body condition due to excessive weight loss. Additionally, if the energy demand is not met, lactating cows are unable to reach peak milk production in early lactation, resulting in low lactation yields. Similarly, if CP is the limiting factor, a lactating cow can experience a drop in milk production and weight loss (Lukuyu et al., 2012).

To assess the limiting component in the diets of the eight animals, the fed amounts of both were separately compared to their requirements and expressed in percentages (Table 3). When comparing fed ME and fed CP fractions of requirement, the lowest number indicated which was the most limiting factor. For the current situation, the limiting factor alternated for each farm – on half of the CSFs it was ME, where the other four CSFs had CP as limiting factor. With a higher milk production level (15 liters), CP was the limiting component in most farms. Therefore, feeds with high protein content played an important role in increasing milk production.

Table 3 Assessment of limiting factor in the dairy cow diet

FARM ID	CURRENT		INCREASED MILK PRODUCTION (15L)	
	ME % OF REQ.	CP % OF REQ.	ME % OF REQ.	CP % OF REQ
1KN	75	**67**	**37**	55
2KR	**132**	152	70	70
3BN	133	**99**	95	**66**
4BR	139	**137**	97	**90**
5BN	**153**	160	103	**100**
6BR	**111**	117	73	**71**
7SN	**73**	77	51	51
8SR	72	**66**	75	**69**

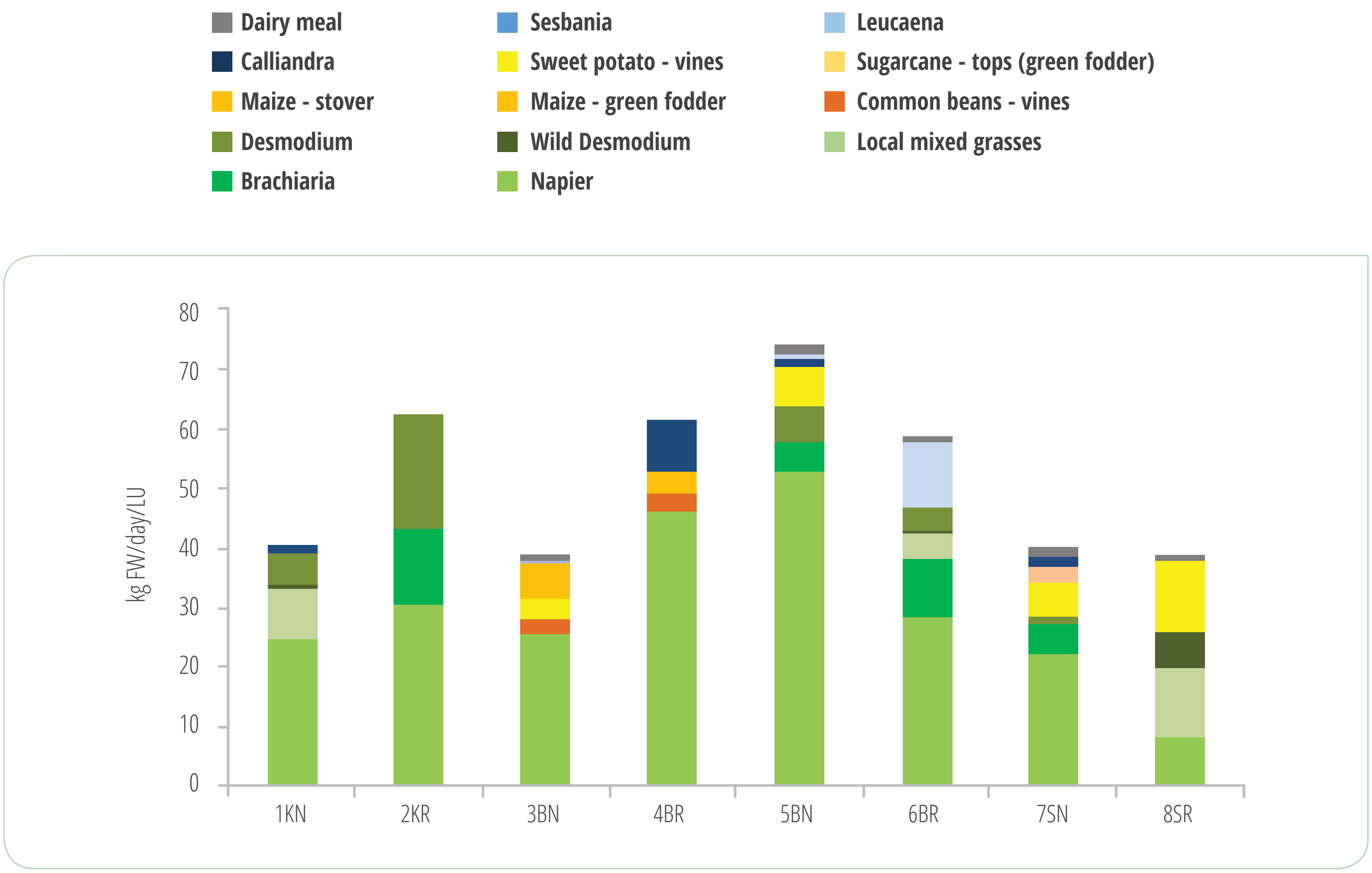


Figure 14 Fresh weight intake per dairy cow.

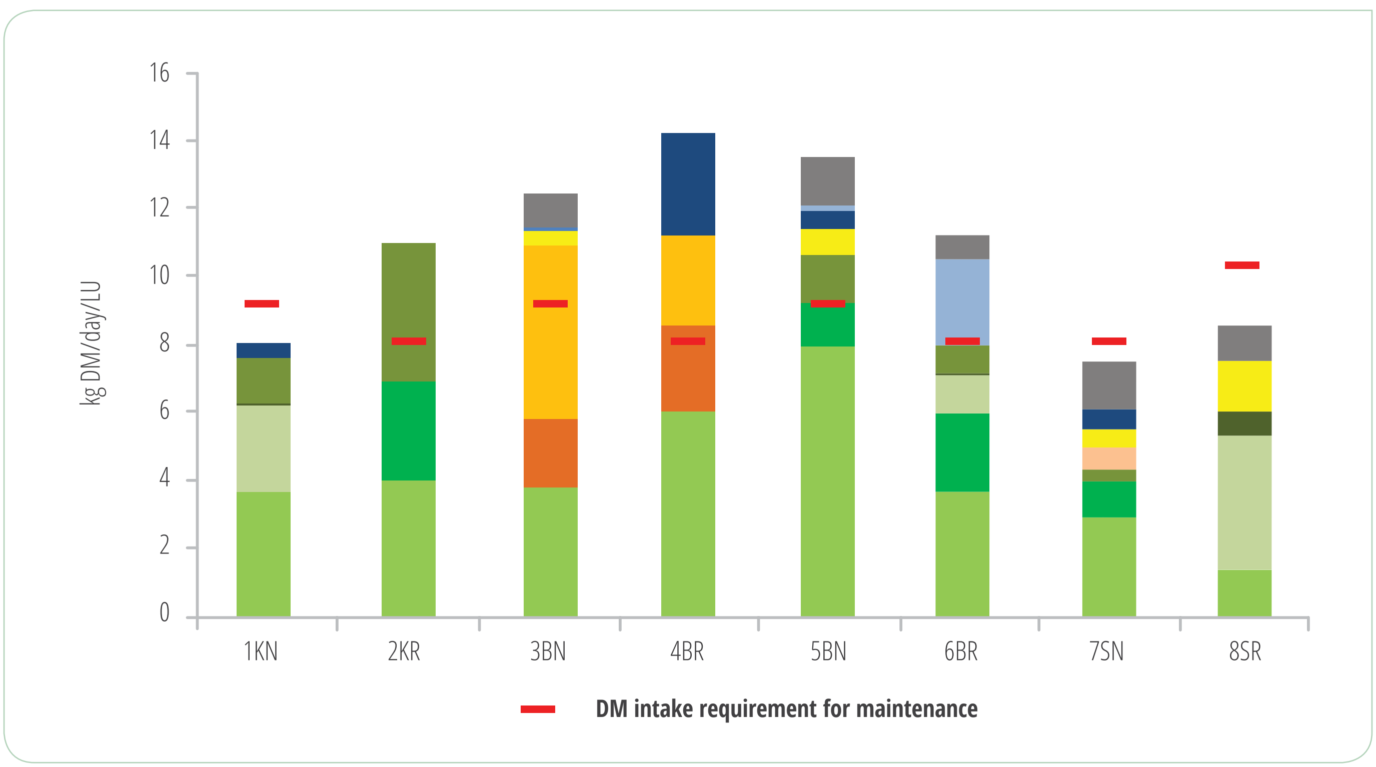


Figure 15 DM intake and requirement for maintenance.

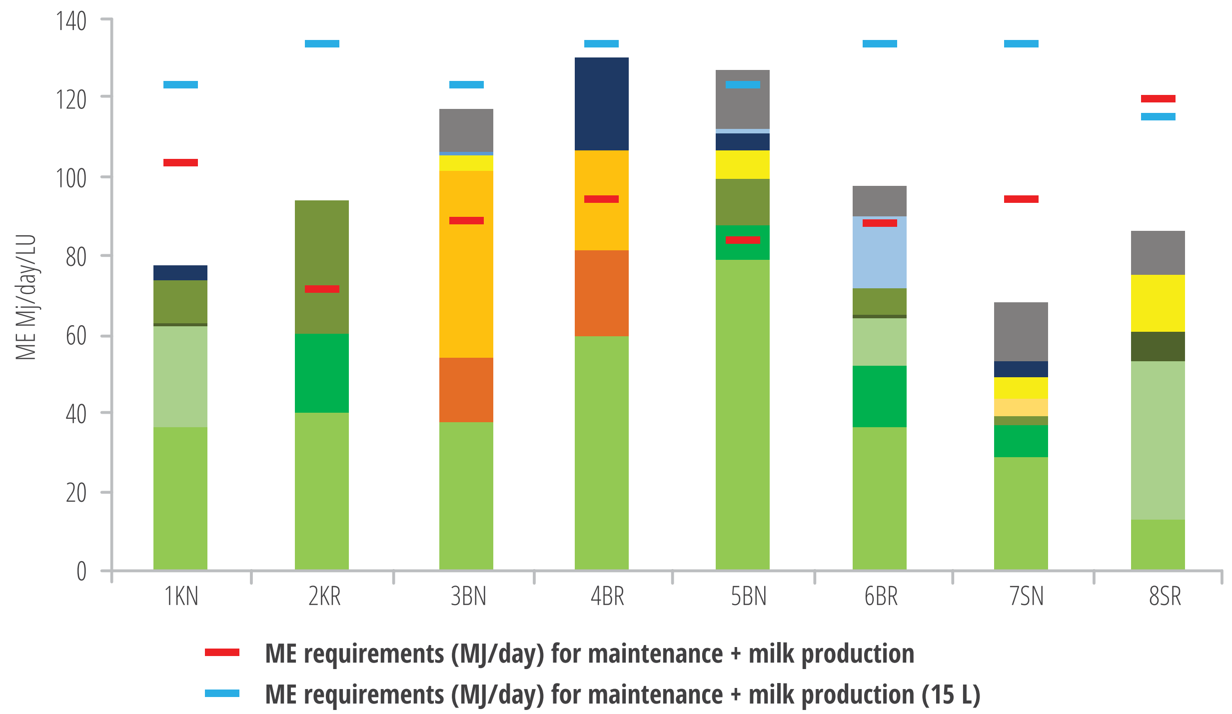


Figure 16 Energy intake and energy requirement for maintenance and milk production now and with 15 liters.

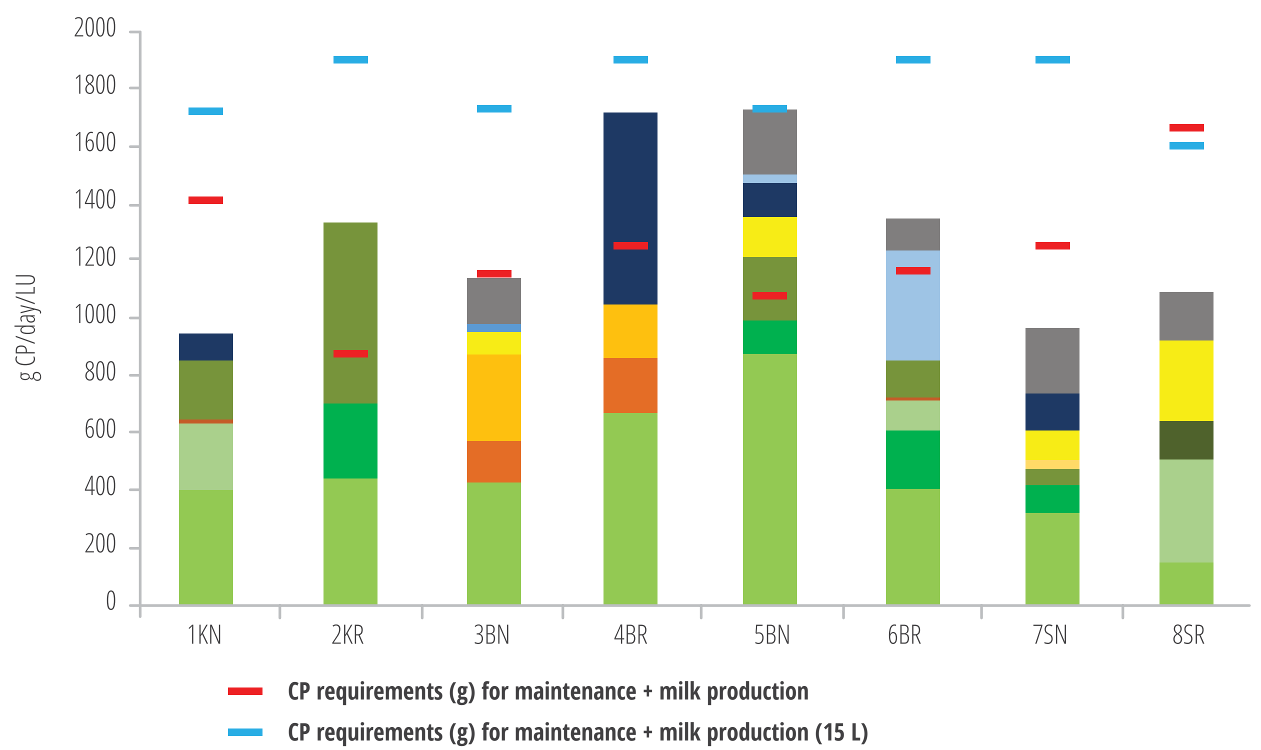


Figure 17 Crude protein intake and crude protein requirement for maintenance and milk production now and with 15 liters.

3.2 CLEANED baseline performance

The following sections are dedicated to the five CLEANED outputs: land requirement, soil N balance, GHGe, profitability, and economics.

All these CLEANED outputs were calculated by using the inputs of the current situation in terms of milk production and feed basket in the CSF.

3.2.1 Land requirements

Figure 18 shows the land requirement to feed one dairy cow under the current feeding regime and milk production. The total on- and off-farm required land to feed a dairy cow varied between 1.34 and 3.24 acres, in 2KR and 8SR, respectively. The off-farm area was estimated based on the fraction of the local mixed grasses fed in high quantity during the dry season.

The required on-farm area varied between 0.92 and 2.77 acre. The area that was dedicated exclusively to fodder production (i.e. Napier, *Brachiaria*, *Desmodium*, local mixed grasses and fodder trees) varied between 0.4 and 1.4 acres, for 3BN and 8SR, respectively. The land where residues of dual-purpose crops, such as maize, beans, and sweet potato were used as livestock feeds, was highly variable (between 0.11 to 1.37 acres).

The CLEANED calculator considered both the energy and protein requirements. In most farms, protein was the limiting factor, especially in the dry season when the fraction of protein-rich fodder was very low. Over one year, the average fraction of leguminous plants (i.e. *Desmodium*, beans residue and fodder trees) was below 30%, and the amount of grasses was above 50%.

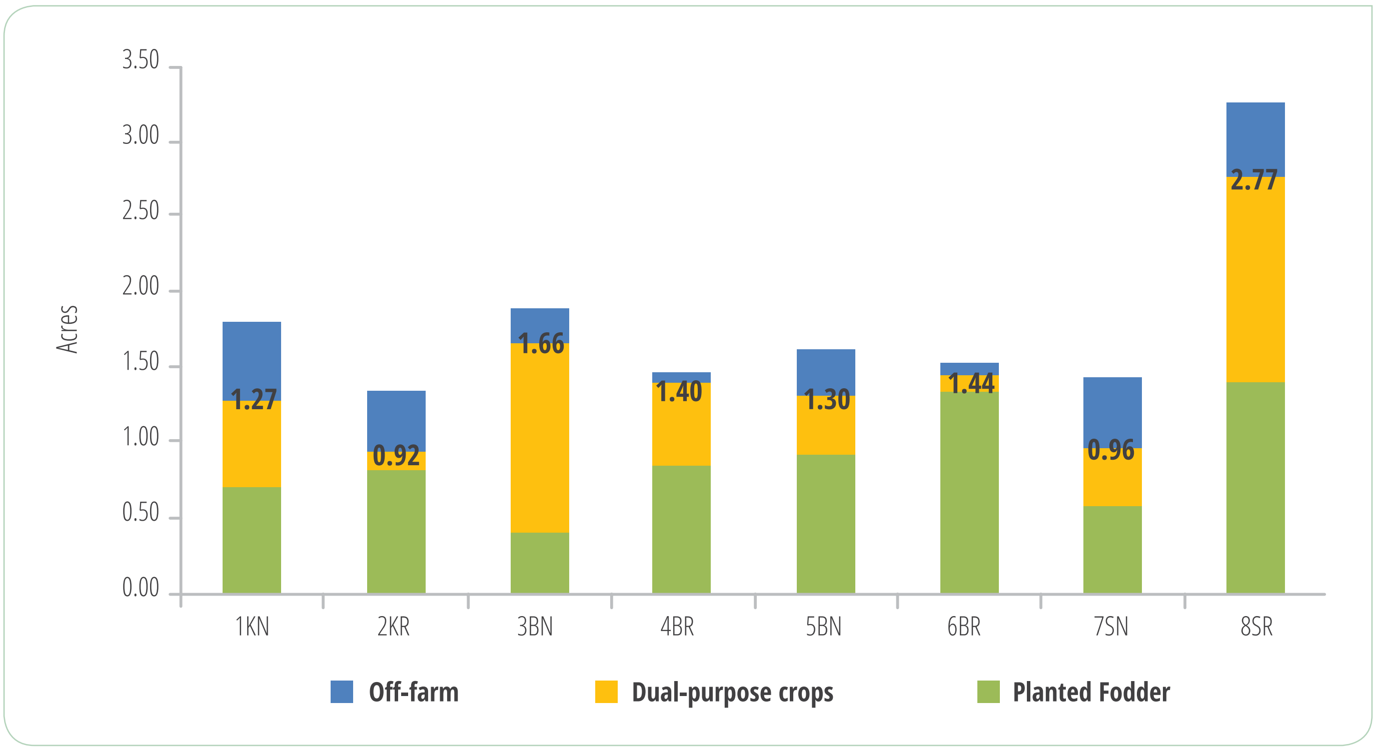


Figure 18 Area to feed a dairy cow. Composed of 'off-farm' area, crop residue (dual-purpose plants) and planted fodder.

A comparison of the 'CLEANED on-farm land requirement' output (Figure 18) with the measured total farm areas (Figure 10) was performed to investigate the accuracy of the CLEANED tool. The 'CLEANED on-farm land requirement' outputs were smaller than total farm areas, and this was the case in all CSFs (Table 4). The differences between total measured area and the on-farm area to feed a dairy cow were very high in the larger farms (4BR and 6BR). Here, only a small portion of total land was dedicated to dairy cow feeding, 11.6% and 14.5%, respectively. Farms with very limited land used most of it to feed their dairy cow by feeding planted fodder and crop residues. The high percentages of required land areas to feed a cow becomes more plausible when considering the fraction of crop residues from dual-purpose crops.

A proper land management plan was essential, especially in farms with limited total area. During the FDGs, the farmers were introduced to this issue through the "farm planning exercise". This exercise was described as an "eye opener" by different groups because it helped the farmers to discuss and find best-bet solutions for allocation of land for the animal and the family. During the FGDs, the farmers reported they would dedicate between 0.15 and 1.5 acres (average of 0.8 acres) to feed their dairy cow. This result showed that the farmers were willing to dedicate a substantial part of their farmland to dairy cow feeding.

Table 4 Modelled area to feed a dairy cow compared to total measured area. Expressed in percentage

FARM ID	MEASURED TOTAL FARM AREA	CLEANED OUTPUT LAND REQUIREMENT (on-farm)	FRACTION (%) OF TOTAL FARM AREA TO FEED A COW
1KN	1.4	1.3	92
2KR	1.1	0.9	83.6
3BN	4.4	1.7	38
4BR	9.7	1.4	14.5
5BN	6.1	1.3	21.4
6BR	12.4	1.4	11.6
7SN	1	1	95.5
8SR	2.9	2.8	96.7

3.2.2 Soil N balance

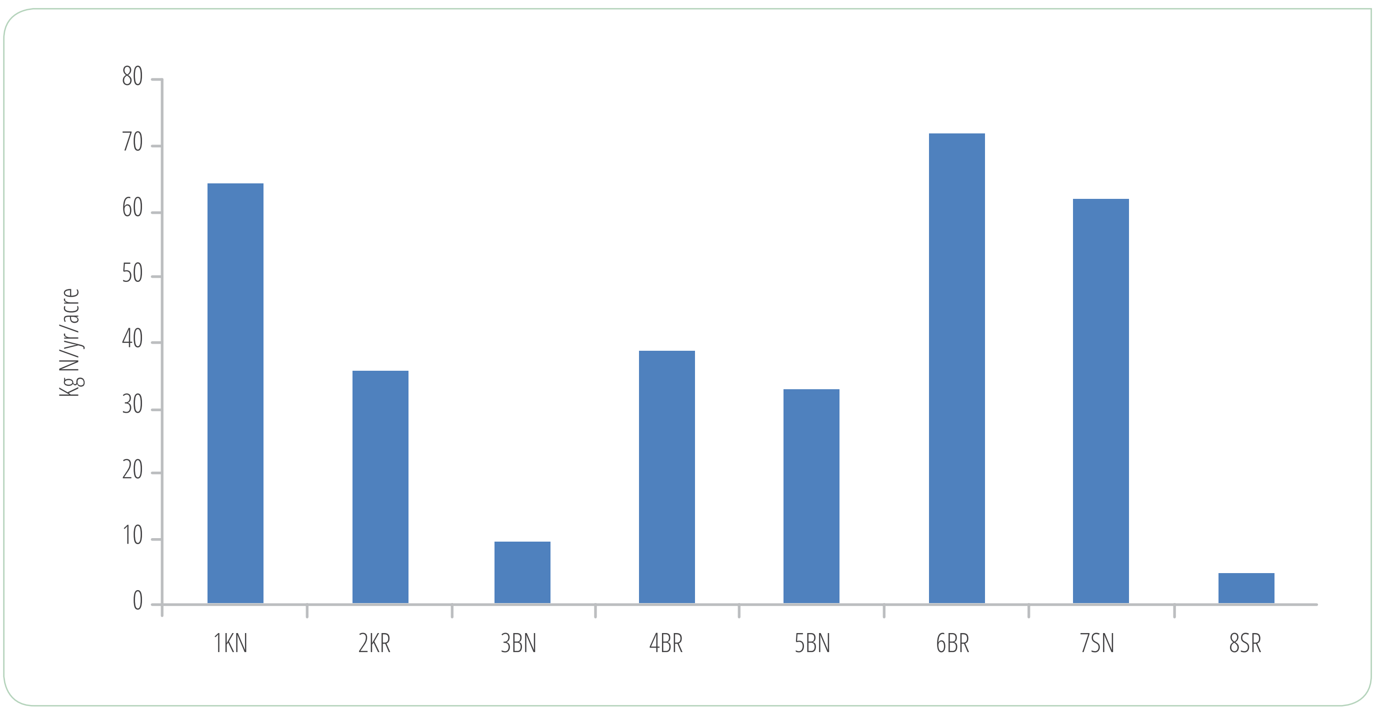


Figure 19 Annual N balance per acre.

In all the visited farms, a positive nitrogen (N) balance was calculated in kg N per year and acres (Figure 19). The considered soil N inputs were: mineral fertilizers, manure, symbiotic fixation by legumes, nonsymbiotic fixation, and atmospheric deposition. The N-outputs were: crops and residues exported off the field, leaching of nitrate, gaseous loss of nitrogen (NH_3 and N_2O), and soil erosion. All N balances were positive, ranging from high N surplus of 72 kg N/acre in 6BR to 5 kg/acre in 7SN.

Drivers for differences in N balances between the farms were manure management and the amount of N-fixing plants (e.g. *Calliandra*). Three farmers (3BN, 5BN and 8SR) reported the use of small quantities of inorganic fertilizer (12 kg/acre CAN and DAP) in the maize fields. These inorganic fertilizer inputs did not have a visible effect on N balance, thus the N balances were not, or only minimally related to, N import through fertilizers from outside the farms and were more related to an intensive nutrient return from high application of manure. Place et al. (2002) reported that 70% of western Kenyan dairy farmers used livestock manure.


Photo: Vivien Osele/CIAT

In all CSFs, the cowsheds were cleaned daily, and the manure was collected and stored. The farmers were trained by SAC staff to use manure in equal proportion for their 'kitchen garden', crop fields (e.g. maize) and Napier plots. As the CLEANED tool considered only the fertilizer applied to fields where a feed item was grown, the fertilizer used in the 'kitchen garden' or non-dual-purpose crop fields was not considered. The main nitrogen input was the manure applied in the Napier plots. Farmers reported application rates of up to 50% of the total manure in intensely managed Napier plots. This high manure input was due to the promoted 'Tumbikiza' technology that implies a high-manure input for first establishment (Orodho, 2007). Nitrogen exported from the fields in harvested plant material, especially in the high-yielding Napier plots, represented the biggest loss of N but this extraction could not compensate for the high inputs. Contrary to Napier, all other crops were managed in an extensive manner (i.e. low input, low output). Because of the heavy labor load linked to carrying manure from the cowsheds to the Napier fields, planting Napier close to the cowsheds was advised. We observed that for different reasons this was rarely the case, for example in 7SN, the carrying distance for manure and daily harvested Napier was over 400 m on a slope.

The mulching of crop residues was a good alternative to manure fertilizer. This was a cheap and nonlabor-intensive alternative to nitrogen cycling. Crop residues are a scarce resource for smallholder farmers, leading to trade-offs between crop residues used as feed and mulch. Most crop residues were not left as mulching material on the field but were used as livestock fodder. Previous studies reported that farmers fed 73% of maize residues to cattle (Castellanos-Navarrete et al., 2015). Crop residues were more valuable when used as livestock feed than when used for improving soil fertility. All visited farmers harvested the main crop products and feed parts of the crop residues in the weeks after harvesting.

The techniques for storing and managing crop residues and manure were similar on all farms. All CSFs had an open-air storage facility for manure, and thus exposure to rainfall and solar radiation favored the loss of gaseous NH_3 for several weeks before the manure was spread on the fields. Castellanos-Navarrete et al. (2015) reported losses of stored N of up to 42%. Additional N losses occur during the time that elapsed between excretion and storage of manure.

These substantial N losses were found to be higher and, therefore, were probably underestimated in the CLEANED model calculations.

3.2.3 GHG emissions

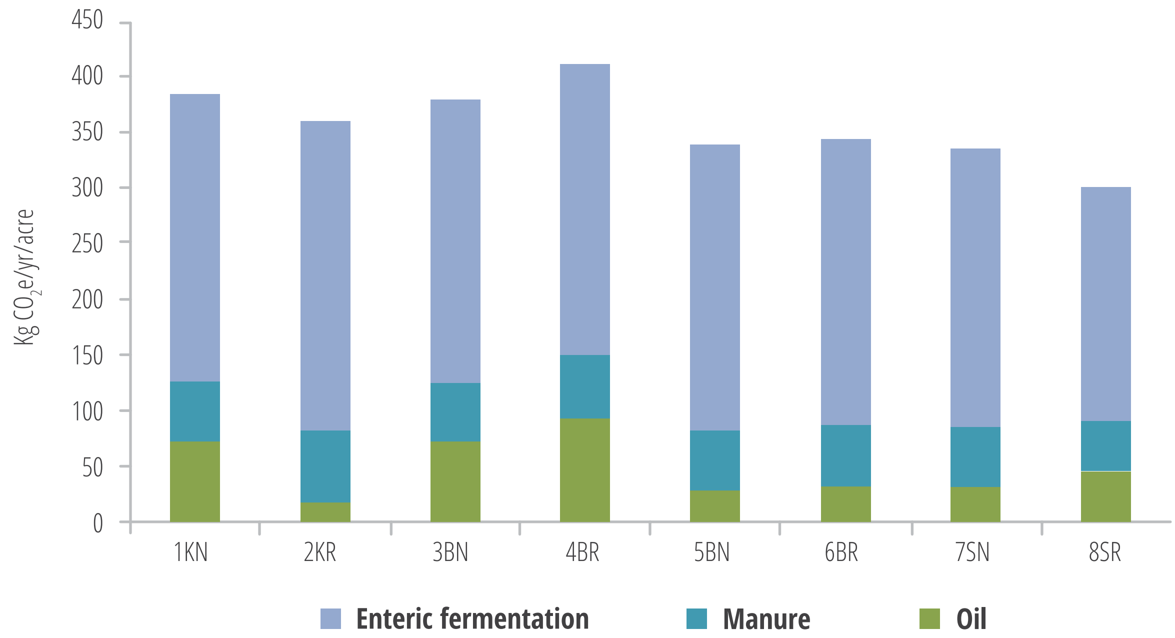


Figure 20 Emission intensity expressed in kg CO_2e/yr/acre.

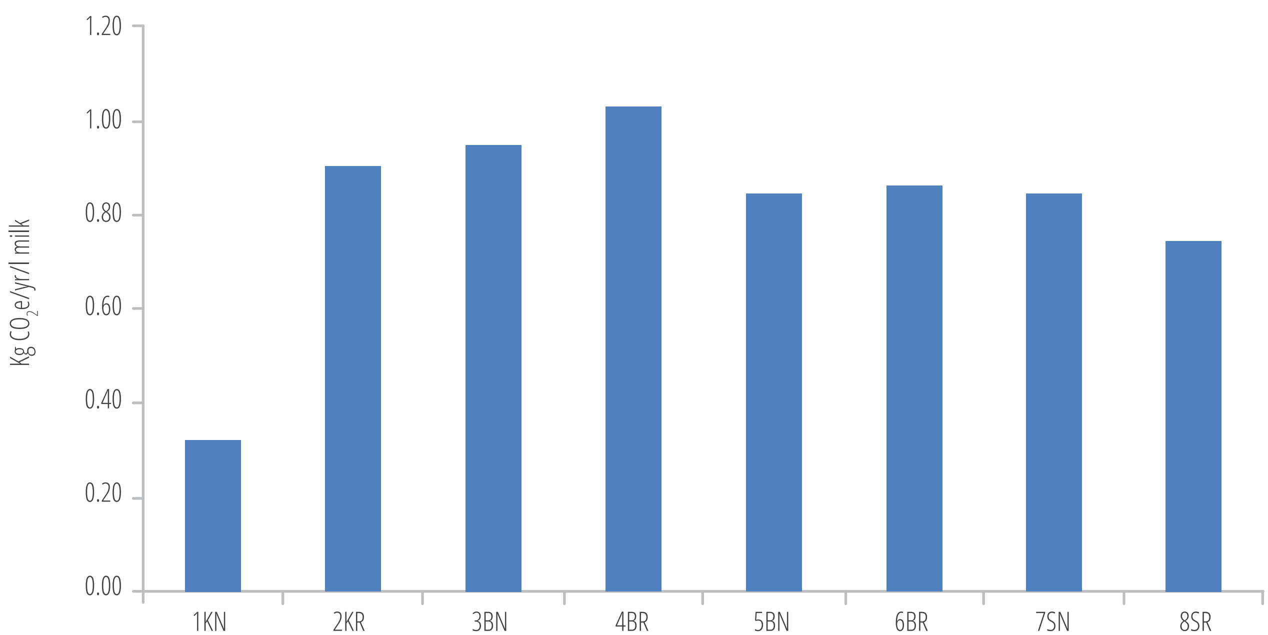


Figure 21 Emission intensity expressed in kg CO_2e/yr/l milk.

The GHG emissions resulting from keeping one dairy cow are represented as annual kg CO_2 equivalent per acre and per liter of milk (Figures 20 and 21). The GHG emissions are a combination of emissions through enteric fermentation (methane), manure management (methane and nitrous oxide) and soil emissions (nitrous oxide). The differences in GHG emission intensity varied between 320 and 420 kg CO_2 equivalent per year per acre.

Enteric fermentation was the major source of GHG emissions, at over 50% in all farms. Emissions from manure were constant throughout the farms as the model uses IPCC tier 1 calculations for this GHG emission source, and only one dairy animal was considered on all farms.

Most increases in N_2O emissions at the soil level was related to increased inputs of N, for example, through N-fixing plants such as *Calliandra* (4BR). Thus, any input would increase emissions. In general, all farms had similarly low GHG emissions because of low input levels. Overall, more milk was linked to higher emissions and to lower emission intensity. Farmers should aim for higher milk production to reduce emissions per unit of product.

Photo: Vivien Osele/CIAT

3.2.4 Food security

The dairy cow contribution to food security is expressed as productivity and number of days that 1 adult male equivalent (AME) can be fed from livestock-related products per acre of land (Figure 22). AME days are composed of two categories: direct animal products and coproducts of the dual-purpose crops, the residues of which are fed to the animal. Dual-purpose crops were part of the livestock enterprise and to generate both food and feed. Total AME days per acre ranged from 542 to 1,452, in 6BR and 8SR, respectively. The AME days per acre from the cow products only showed no differences between the farms (371 to 499 AME days). Milk was the bulk of dairy cow products. Energy from the dual-purpose plants was highly variable and was composed of maize, beans, and sweet potatoes (83 to 1078 AME days).

The AME days represented only what was produced from the livestock enterprise and not the quantity that was consumed by the household members. While most of crop products was consumed by the family members and not sold, most of the milk was marketed. In most farms, only 2 liters per day were kept for family consumption. If a calf was present, 2 to 4 liters were given to the calf, and the rest was sold. By comparison, in another study, interviewed smallholder farmers retained approximately 40% of milk produced mainly for household consumption (70%) and calf feeding (30%), while the rest was marketed (Muthui et al., 2014).

A scenario where a dairy cow was not present was examined to compare the current AME day (dairy products plus dual-purpose crops) with the AME days that could be produced from dual-purpose plants only. We assumed that if there was no dairy cow, all the main dual-purpose crops would still be grown and the residues would probably be left on the fields as mulching material.

For the 'No animal' scenario, all 'Fodder areas' were converted into fields of dual-purpose crops. Because maize and beans were the most common dual-purpose crops, half of the 'fodder' area was converted into maize fields and the other half was converted into bean areas. The red mark represents the energy supplied from dual-purpose plants only. If the red mark was higher than the AME days of the current scenario, this would show that not having a cow and planting maize and beans on the plots previously dedicated to fodder would produce more calories on farm. In contrast, if the red mark was below the current total AME days, keeping a dairy cow would produce more calories. The position of the red marks varied between the farms and did not show a trend. In three farms (5BB, 6BR and 8SR), the AME days per acre were higher without the dairy cow, while in other three farms, the opposite was the case.

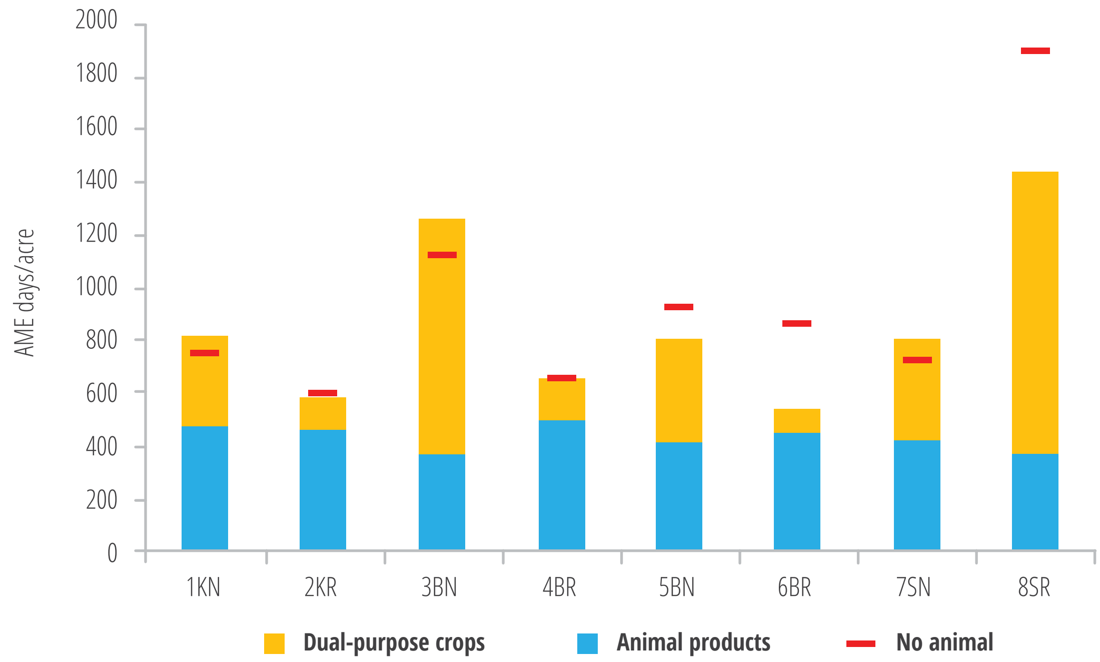


Figure 22 Energy supply from livestock enterprise.

3.2.5 Economics

An important economic indicator is the total value of production (VOP), which is expressed in US dollars (US$) per year. The total value of production is composed of the value of animal products (i.e. milk, meat, manure) and the main products from dual-purpose crops (Figure 23). The value of production (VOP) from animal products (blue) was the bulk of the total value of production and was composed of the potential income from selling milk. Farm gate prices offered by different milk buyers per liter of milk was US$0.30 in 2002 (Waithaka et al., 2002). This price has doubled since then (currently US$0.6 per liter). The VOP from animal products were similar between the first seven farms and due to higher milk production visibly higher in 8SR (US$1,089 to 2,010 per year). Value of production from dual-purpose crops was visibly lower and more variable compared to the VOP from animal products (US$16 to US$437/yr). Compared to the AME/days graph (Figure 22), the blue color (US$ from milk marketing) was more prominent. Milk is a lucrative product for the farmers and has an important role in improving and stabilizing income. In fact, for most farmers, especially during the dry season, milk was the only constant income and gave the farmers the possibility to have some savings. This money was mainly used for school fees and health-related expenses. A part of this money was reinvested in the animal by buying drugs, veterinary services and additional feeds.

The red marks represent a scenario without a dairy cow. The total VOP from current dual-purpose crops and the products from maize and beans that can be produced from converted planted fodder plots is represented. Compared to the current scenario, the 'No animal' scenario would yield a visibly lower VOP for all farms. Therefore, economically keeping a dairy cow was visibly more profitable than cultivating the land for maize and beans instead.

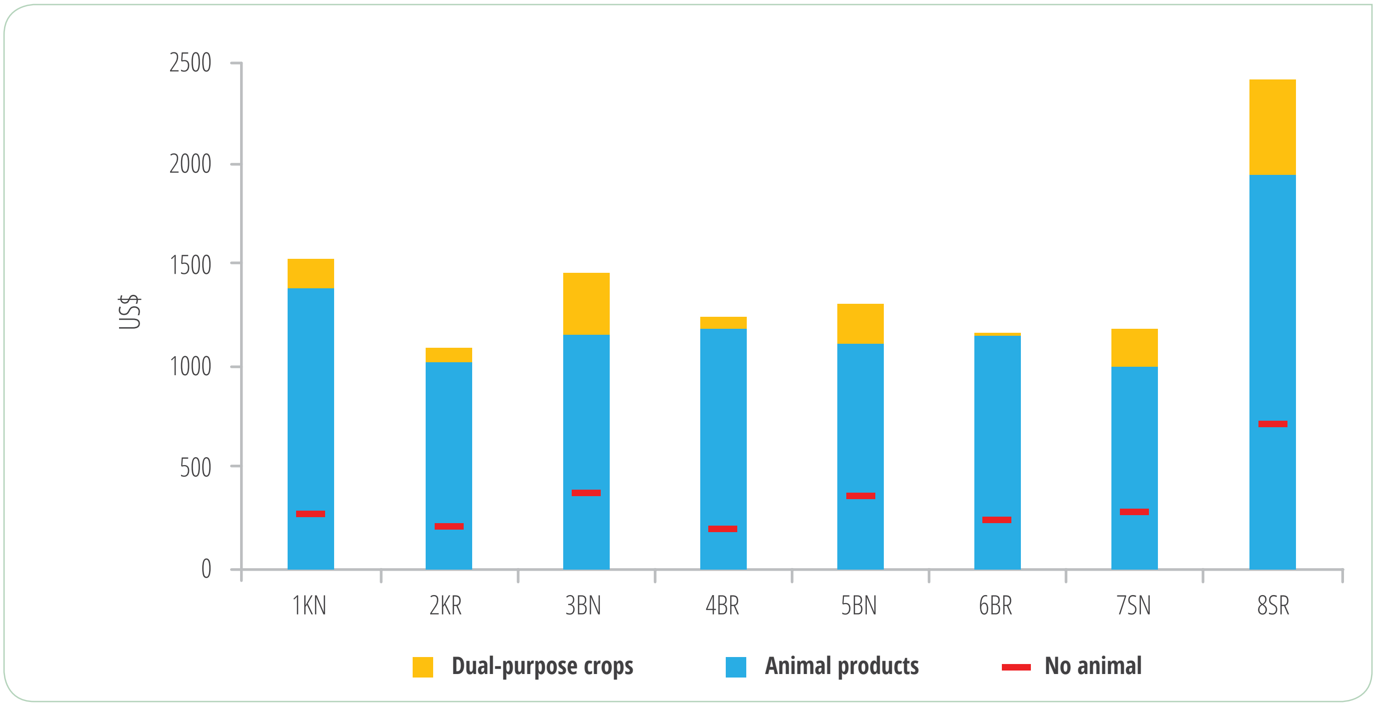


Figure 23 Total value of production per year.

3.3 CLEANED feeding scenarios

The proposed feeding scenarios aimed to address different challenges concerning the cow diet.

1. *Find alternatives for roughages*. For instance, by reducing local mixed grasses, especially the uncertain ones collected off-farm. Also, introduce alternatives to Napier as this species requires high amounts of water and nutrients. Additionally, the Napier stunt disease, caused by phytoplasma, has in the past years caused high forage yield reduction and is still a persistent threat to forage in the region (Lusweti et al., 2004). To address this problem, 50% of the Napier in the 'Baseline' feed basket was substituted with *Brachiaria*. Compared to Napier, the *Brachiaria* variety has a lower yield but higher DM content. An additional advantage of *Brachiaria* is its high tolerance to drought, thus it performs better than Napier during the beginning of the drier months.

2. *Increase the protein content through higher fractions of protein-rich feeds in the feed baskets*. In most farms, the CP was the limiting factor, especially in the dry season where protein-rich plants were hard to find. To address this issue, scenarios with increased fractions of leguminous plants and purchased dairy meal were run. In previous studies, very few households (1.4%) reported the use of herbaceous legumes as feed for animals, and 4% of households with cattle had *Calliandra*. Only 16% of all the households supplemented pasture and forage with concentrates, and two out of three of these households used dairy meal as concentrate (Waithaka et al., 2002).

The goal was to increase diversity in the feed baskets and to introduce robust varieties. We aimed to achieve a balanced animal diet and an improved resilience of the system in times of drought or economic instability.

3.3.1 Land requirements

The land requirements for each scenario in all CSFs are represented in this section. Figure 24 shows the number of acres required to feed a dairy cow under current conditions ('Baseline') and the increase in land requirements for milk production of 3,000 liters ('Milk high') without changing the feed basket composition. In Table 5, the milk changes and the required land to reach the new production level are compared and are represented as percentages of increases from the 'Baseline'. The relative increase in milk volume is always higher than the additional land required. The highest increases were seen in 7SN, with land increases of 45%, milk increased by 51%. The farms where the milk increase was higher compared to the land increase (5BN and 6BR) had the highest intensity levels, whereas CSFs with smaller differences (3BN) showed a low intensity level. In general, feed baskets that required the highest land for the same amount of milk produced had the lowest intensity. The feed baskets were composed of feed items with low yields, ME, or CP contents. This was the case in 8SR. On this farm, local mixed grasses, which were relatively low in quality, represented the feed basket bulk throughout the year.

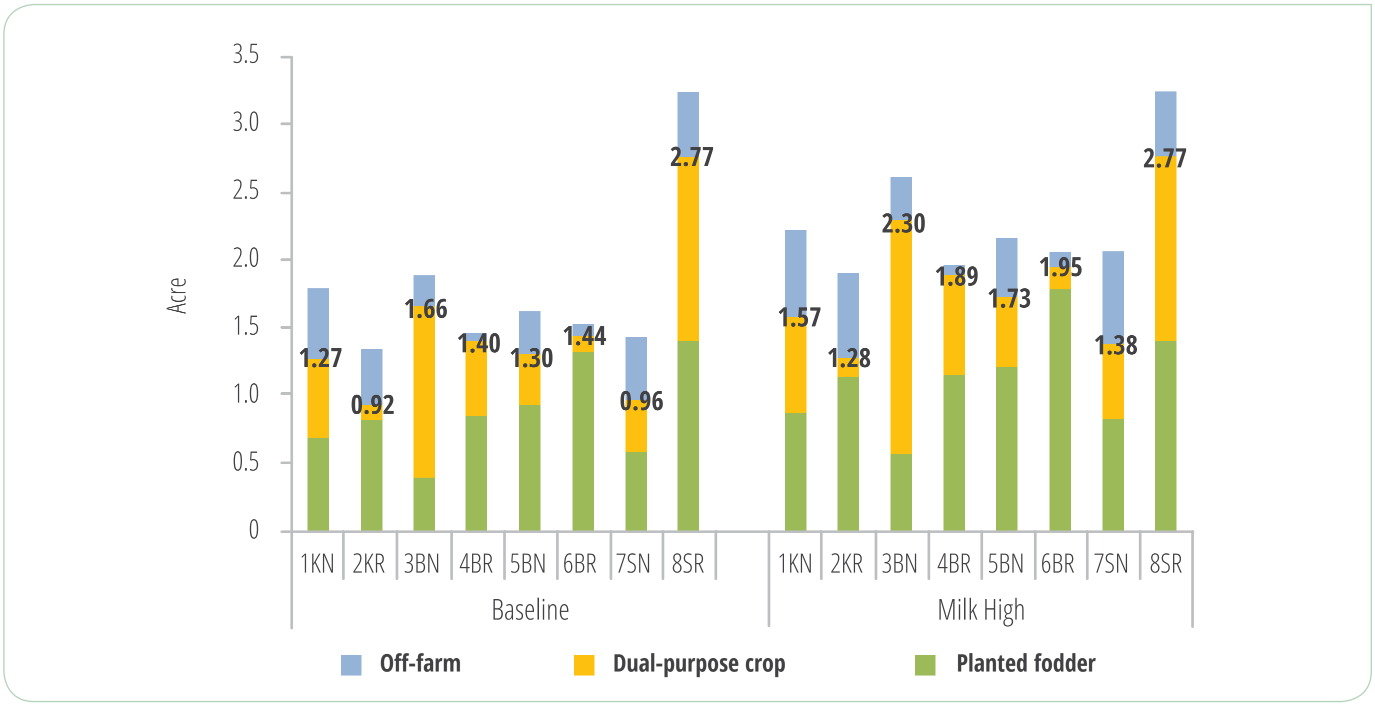


Figure 24 Land requirements for baseline situation and land requirements for increased milk production (3000 liters/year).

Table 5 Milk increase and related land requirements expressed in percentages

Increases of milk and land compared to the relative 'Baseline' are represented in percentages for each CSF. The differences between the two increase levels represent the intensity levels, thus the higher the number, the more milk is increased at a relatively lower land requirement increase.

FARM ID	MILK INCR. %	LAND INCR. %	DIFFERENCE %
1KN	30	24	6
2KR	48	42	6
3BN	41	39	2
4BR	41	35	6
5BN	45	34	11
6BR	43	35	8
7SN	51	45	6
8SR	0	0	0

An overview of the differences in land requirements of each scenario compared with the "Milk high" scenario is presented in Figure 25. In general, the scenario '*Brachiaria'* showed the highest relative increase, whereas 'Dairy meal' was relatively similar, and in some farms the land requirements decreased compared to the 'Baseline'. The *'Brachiaria'* scenario didn't perform as well as the other scenarios in terms of land requirements, but *Brachiaria* is an important feed substitute. In fact, CIAT has been breeding improved *Brachiaria* varieties since 1988 (Pizarro et al., 2013). The developed *Brachiaria* varieties show a high tolerance to drought and common diseases in western Kenya. Another advantage of *Brachiaria* is its potential in making hay, and thus can be stored and fed to animals during the dry season. For improved resilience, we therefore recommend planting *Brachiaria* even on small plots.

The difference in land requirements for *'Brachiaria'* was due to the lower yield of *Brachiaria* (1.7 t DM/acre) compared to Napier (2.25 t DM/acre), at 33% decrease. Therefore, a larger area under *Brachiaria* was required. The relative "lowest land consumer" was the 'Dairy meal' scenario. This was the only scenario that used a purchased concentrate feed item and, therefore, the land that was used to grow this imported energy and protein was not accounted for.

Figure 26 represents the relative differences of area requirements per liter of milk. The pattern of this graph is like that in Figure 25. All scenarios show a negative percentage change. In all farms, the intensity levels have decreased, and less land is needed to produce 1 liter of milk. In this graph, *'Brachiaria'* was the only scenario that showed a slight increase in higher intensity levels. It could be concluded that the scenario *'Brachiaria'*, with the highest intensities, was the least favorable. The scenario *'Calliandra'* has the lowest intensity levels with the best bet choice.

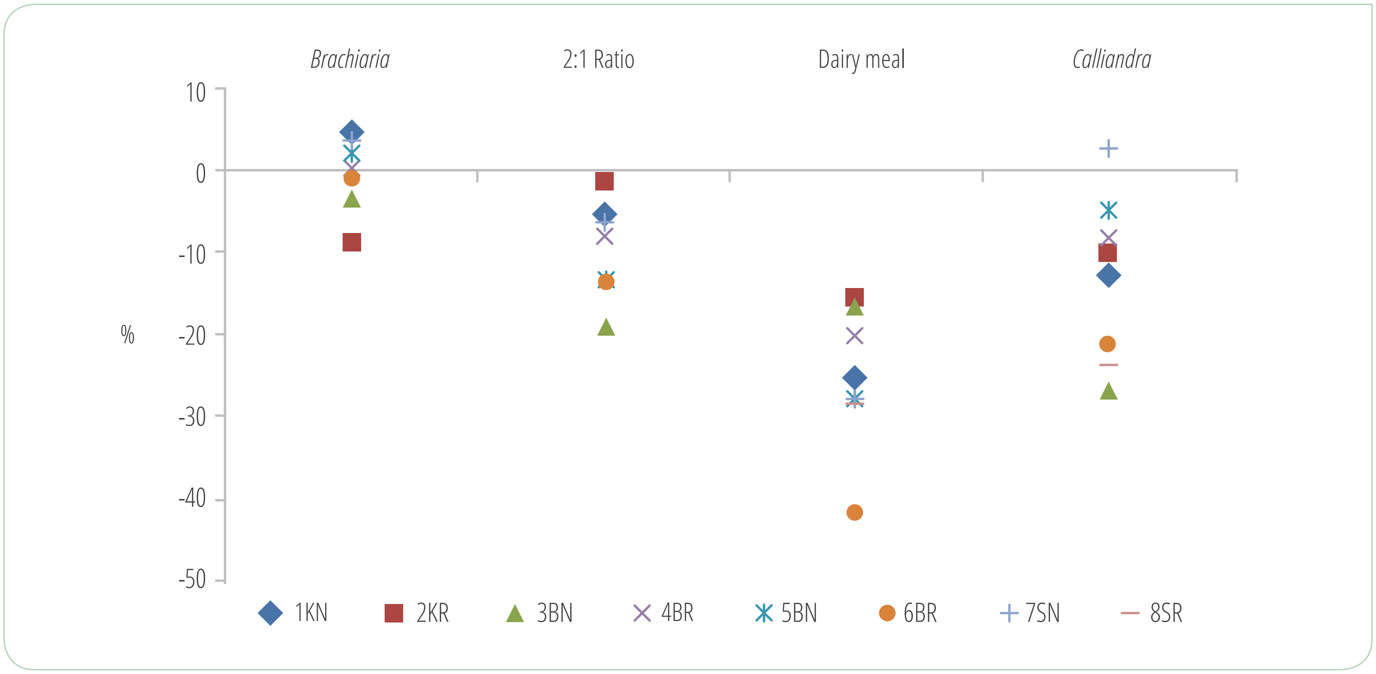


Figure 25 Changes from the "Milk high" in total required area.

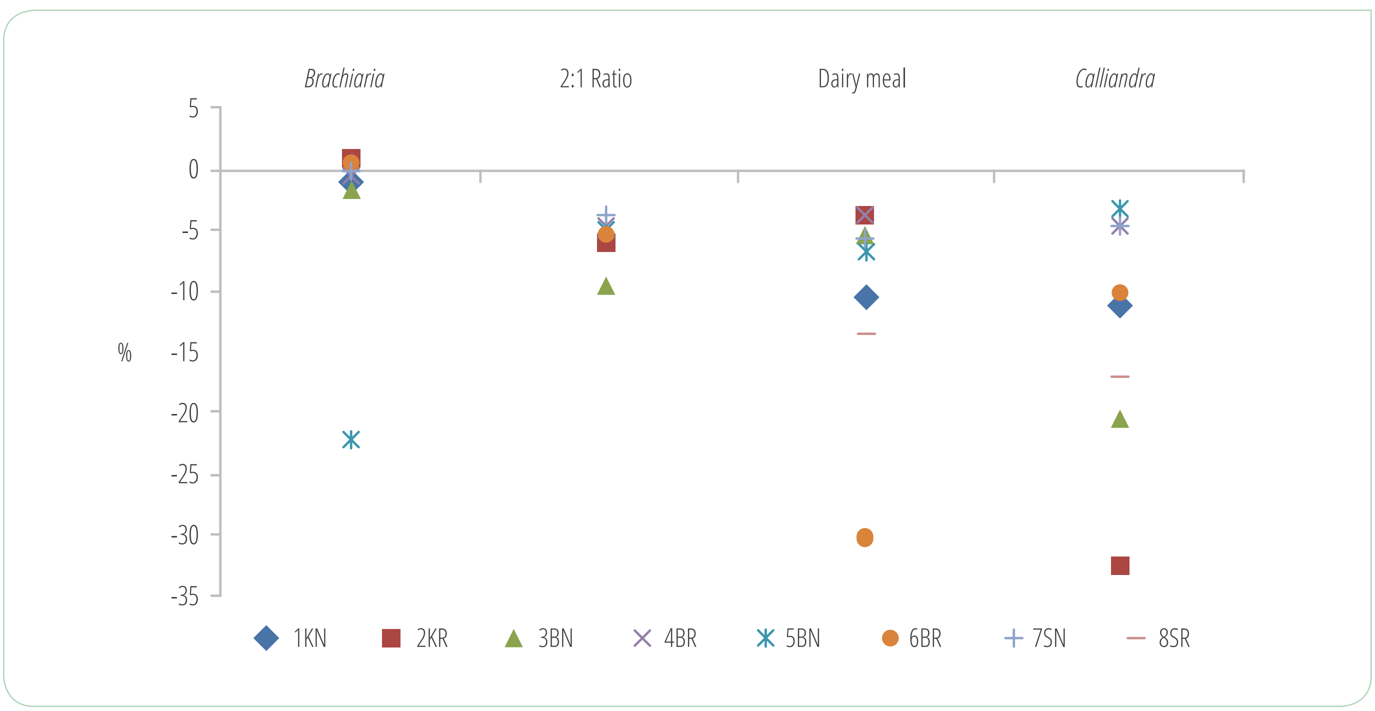


Figure 26 Changes from the "Milk high" in area requirements per liter of milk.

3.3.2 Greenhouse gas (GHG) emissions

Environmental sustainability of the different feeding options is expressed by relative difference of CO_2 equivalents per acre and per produced milk compared to the 'Milk high' (Figures 27 and 28). In Figure 27, most scenarios showed an increase in GHG emissions per acre. In contrast to other scenarios, only '*Brachiaria*' showed a relative decrease in GHG emissions compared to the 'Milk high'. This difference is mainly driven by the higher land requirements of this scenario.

The three scenarios where N was added, either through purchased concentrate ('Dairy meal') or N-fixing plants ('2:1 Ratio' and '*Calliandra*') resulted in increased soil N_2O emissions and higher GHG emissions per acre. When considering the GHG intensity per acre, the three scenarios with increased N inputs were the weakest, while '*Brachiaria*' was the strongest scenario.

Figure 28 represents the GHG emission intensities of each scenario per unit of milk. In this graph, all scenarios showed a percentage decrease in GHG emissions compared to 'Milk high' scenario, thus the intensity levels were lower (less GHG emissions per liter of milk). The differences between the scenarios were small. Here '*Brachiaria*' was slightly less preferable than the other scenarios as the relative difference with the 'Milk high' was closer to zero. When choosing a scenario based on its environmental sustainability, in general a scenario with lower intensity (and therefore less emissions per unit of product) is the best choice. Looking at GHG intensities for milk, the best-bet scenario choice is '*Calliandra*', which had the highest decrease emission rate per unit of produced milk, and thus the lowest intensity.

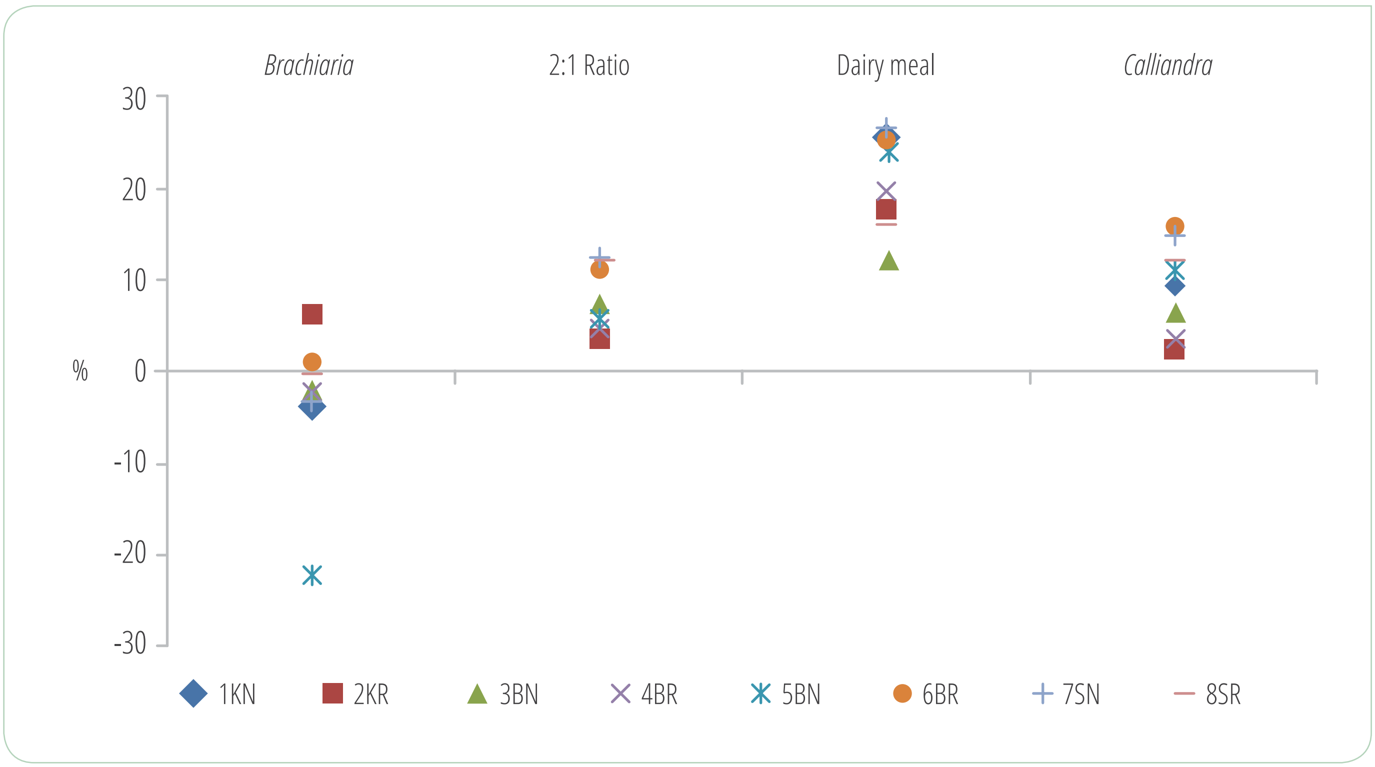


Figure 27 Changes from the "Milk high" in CO_2e/yr/acre.

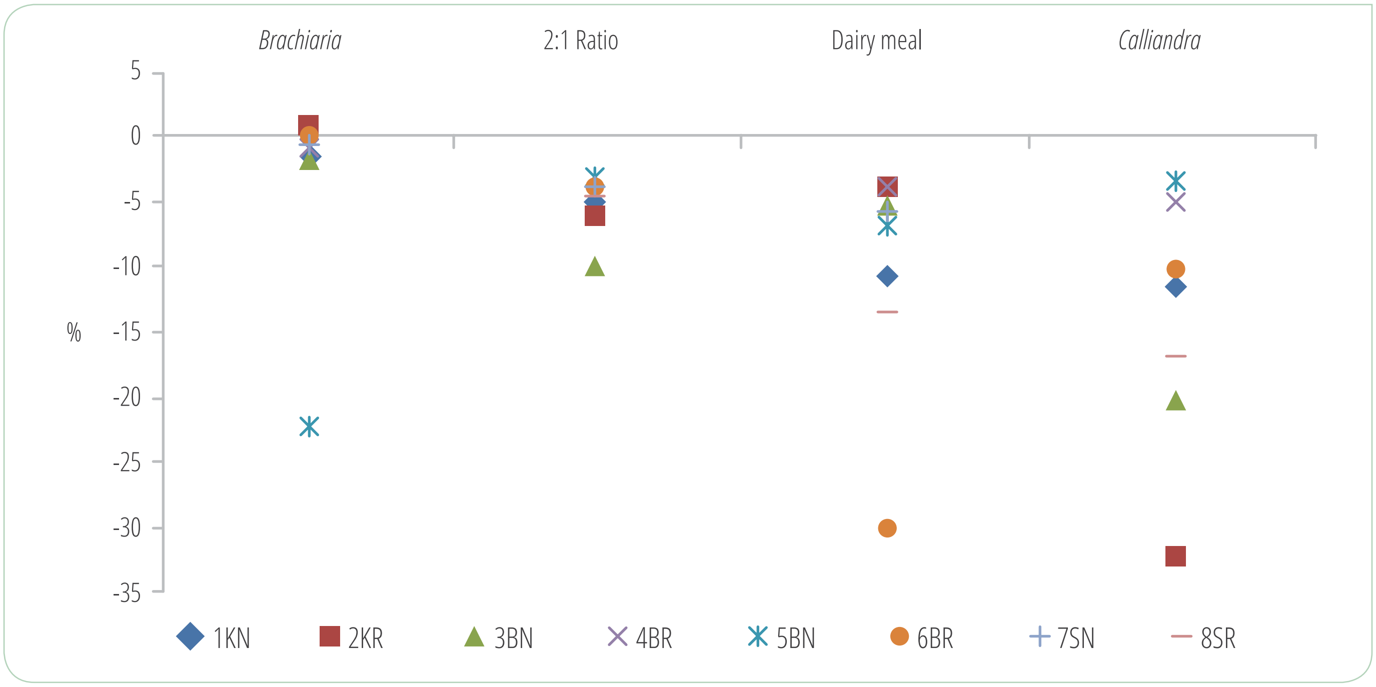


Figure 28 Changes from the “Milk high” in CO_2e/yr/liter of milk.

3.3.3 Livestock’s contribution to food security

Figure 29 represents the difference compared to ‘Milk high’ in AME days per acre for all scenarios. Except for 8SR, all relative changes were positive because of an increase in milk production, which was the bulk of livestock enterprise energy supply. ‘*Calliandra*’ had the lowest relative increase compared to the other scenarios.

In general, it seemed that slightly higher increases in differences from the ‘Milk high’ could be seen for ‘Dairy meal’ followed by ‘2:1 Ratio’. In terms of dairy cows’ contribution to food security, the scenario ‘*Calliandra*’ was the weakest, while scenarios ‘Dairy meal’ and ‘2:1 Ratio’ was the best-bet choices.

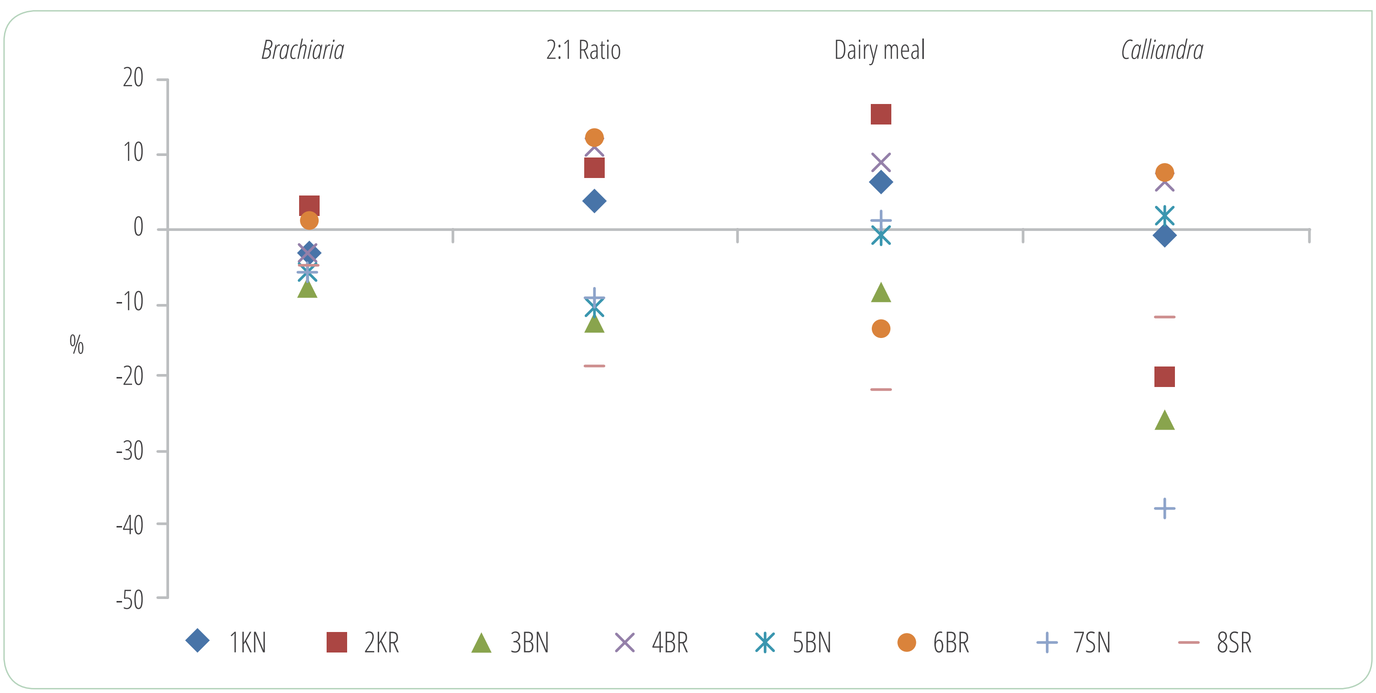


Figure 29 Changes from the “Milk high” in AME days per acre.

3.3.4 Economics

In all scenarios, the total VOP was similarly high because the same milk level was produced. The percentage increases in total VOP per acre is presented in Figure 30. Here visible differences between the scenarios were attributed to the differences in area requirements for each scenario. Hence, the graph in Figure 30 follows a similar pattern as that in Figures 27 and 29. This strong influence of land requirements leads us to conclude that *'Brachiaria'* is the least favorable and 'Dairy meal' the most favorable scenario for this parameter.

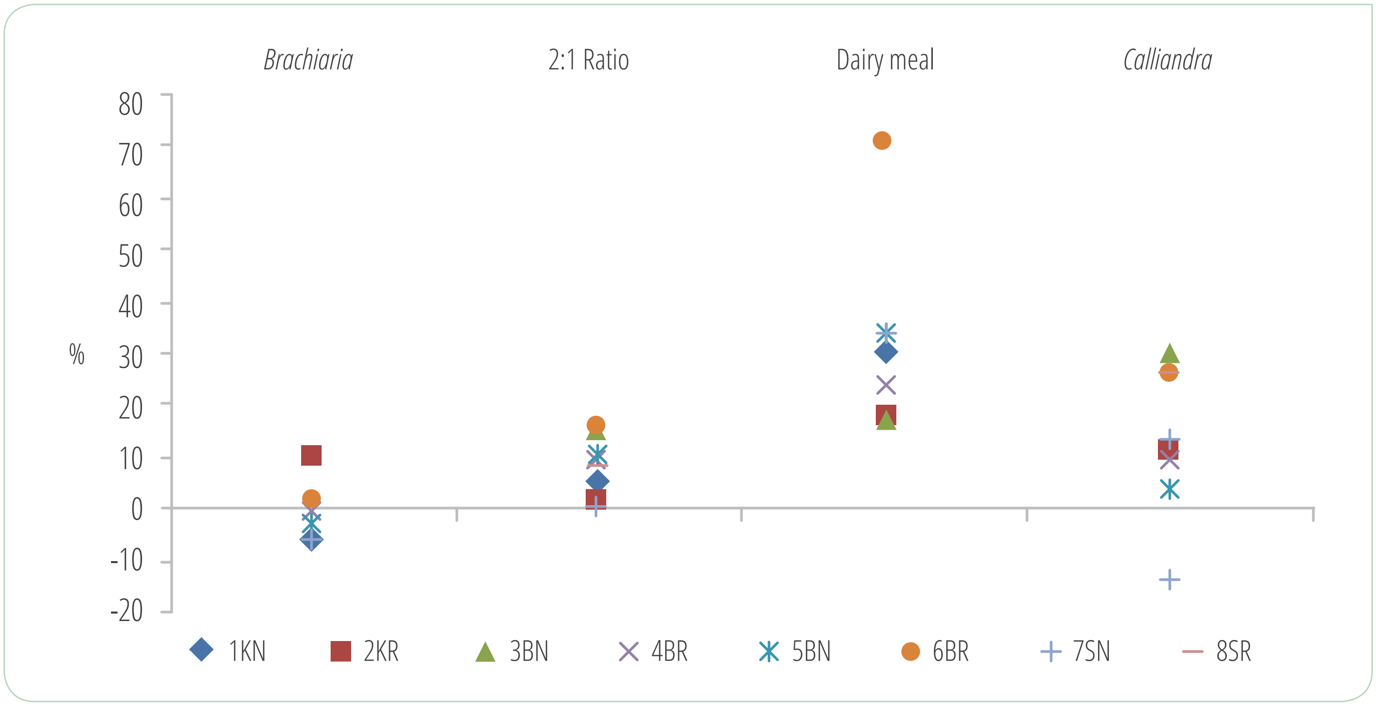


Figure 30 Changes from "Milk high" in total value of production acre.

Further economic calculations were added to the CLEANED model to better describe the economic profitability of an intervention and to examine the investments and costs to establish and operate the feeding scenario (Notenbaert et al., 2018).

Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period. An NPV indicates that the earnings from the changes generated by a scenario or investment (in present dollars) exceed the anticipated costs (also in present dollars). Generally, an investment with a positive NPV will be profitable, and one with a negative NPV will result in a net loss. Therefore, only the investments that result in a positive NPV value should be made. In general, the higher the NPV, the higher is the probability of the investments success (Investopedia, 2018a).

The following economic calculations represent differences from the 'Baseline' after a period of 5 years.

The NPVs shown in Figure 31 are almost all positive and very high. The only negative values were found for 8SR, where no milk increase had taken place and, therefore, every investment would not bring any added value but would be a loss. The example of 8SR illustrates what would happen in each scenario if the milk production stagnated. Thus, positive NPVs in the other CSFs were mainly driven by a high increase in milk production levels, which compensated for the initial establishment cost in the first year and the operational cost in the following years. In other words, an increase in milk production (up to 3,000 liters) paid off in every scenario. This was not only the case after 5 years, as in Figure 31. In the first year of establishment, the initial investment could already be paid off completely by the milk sales. For every scenario, the payback period (i.e. the number of years necessary to pay back the initial investment) was within the year of establishment. The costs of establishment were mainly the purchase of new seeds and the related labor of establishing and maintenance of the new areas. Although all scenarios had a positive NPV, the least profitable compared to the others would have been 'Dairy meal'. This imported feed concentrate was relatively expensive and needed to be bought and transported every year.

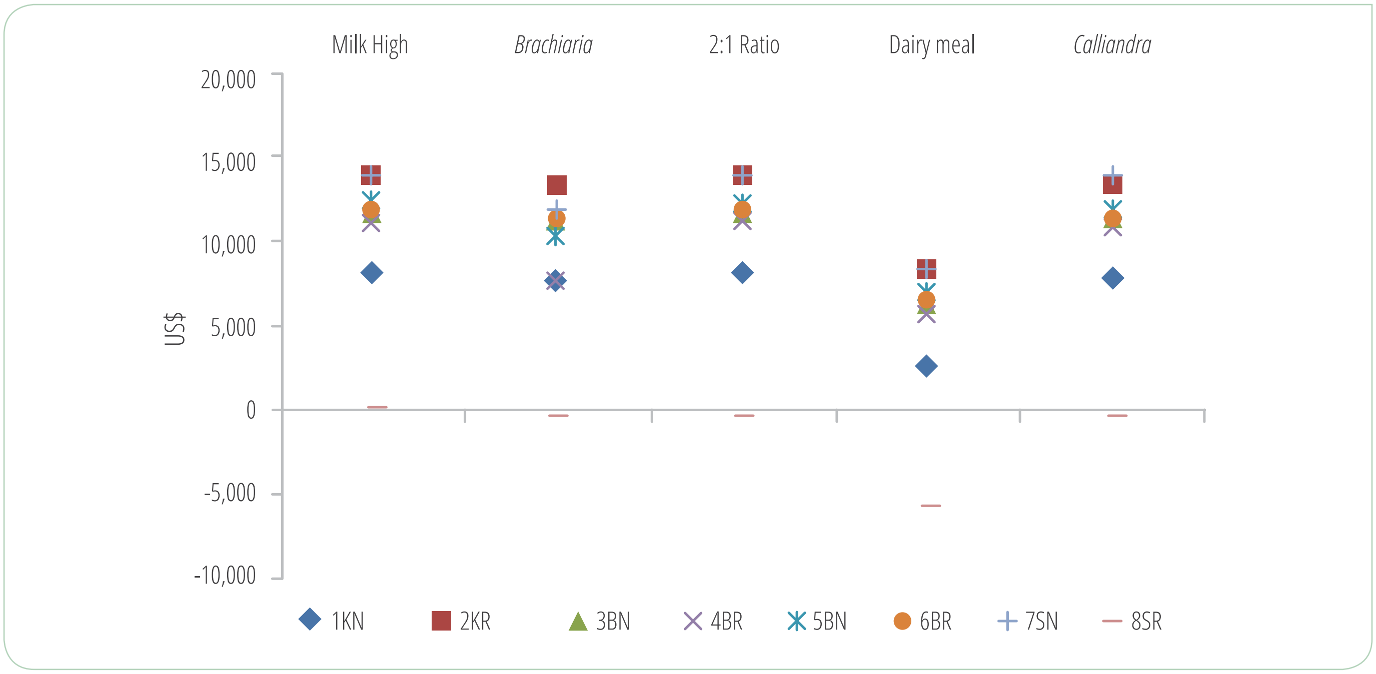


Figure 31 Changes in net present value (NPV) from "baseline" to all other scenarios in farms in US$.

A second economic indicator was the return on investment (ROI). This is a performance measure used to evaluate the efficiency of an investment or to compare the efficiency of many different investments. ROI measures the amount of return on an investment relative to the investment cost. To calculate ROI, the benefit (or return) of an investment was divided by the cost of the investment, and the result was expressed as a percentage or a ratio. A positive ROI was profitable, and its value could tell us which investments would be preferable to others (Investopedia, 2018b). In Figure 32, the ROI calculations are represented, and again the only negative values were found for 8SR because the milk yield did not change, and no investment would bring any additional profit. Contrary to NPV, the ROI results showed differences between the scenarios. Here the economic constraints of purchasing dairy meal became more visible. In fact, when considering the ROI, investing in dairy meal for a higher milk yield becomes a less attractive option compared to the '2:1 Ratio' or '*Calliandra*'.

It could be concluded that from an economic point of view, '2:1 Ratio' was the most profitable scenario and 'Dairy meal' was the least profitable.

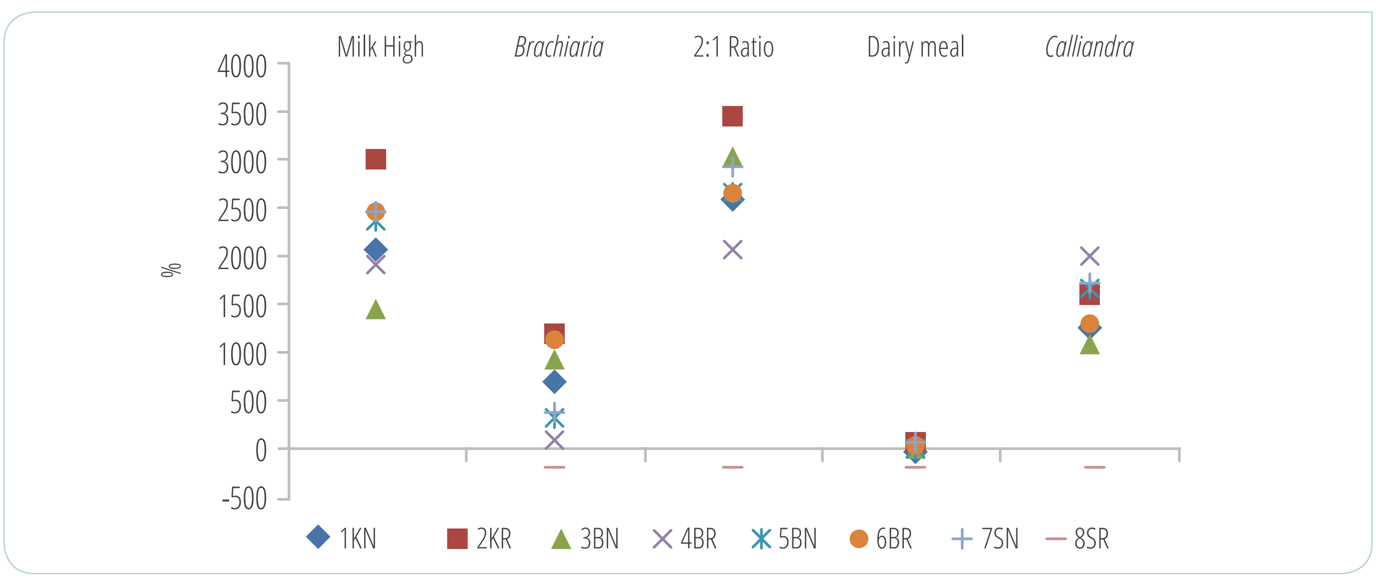


Figure 32 Changes from "Baseline" on Return on investments (ROI) of scenarios in all farms.

Focus group discussion (photo: Vivien Osele/CIAT)

4. Conclusions and recommendations

This study helped us to answer the question "How much land is needed to feed a cow and a family with various feeding strategies across most relevant farming systems?" First, the results presented looked at the land requirement for feeding a productive dairy cow. Through the feed gap assessment, we showed that in the wet season, most farmers provided sufficient feed to cover the animals' energy and protein requirements under current milk production. Feed items were diverse, and the farmers were aware of the influence of different feeding regimes on the health and productivity of their animal. The land required to grow dairy cow feeds varied and depended mainly on the fraction of each feed item in the feed basket. Each feed item was grown on-farm as planted animal feed or dual-purpose crops, or off-farm as collected grasses and purchased concentrates. For example, a farmer who owned as little as 1.1 acres could adequately feed his productive dairy cow without buying any concentrates and the land he used purely for fodder, which was directly in competition with food crops, would be as low as 0.5 acres. The importance of farm planning became apparent through the FGDs. Farmers were willing to put aside on average 0.8 acres to feed their dairy cow. As well as the land size, the way in which the land was managed played an important role, thus the less land a farmer had, the more important clever planning was to him, e.g. planting of Napier in niches and along field borders. Another limitation to increasing productivity and optimally managing the farm was the availability of labor. The bulk of on-farm labor was performed by male and female household members who spent on average 4.5 hours per day on dairy cow related activities. A substantial part of this time was dedicated to feed collection and preparation, i.e. fetching and chopping of feed. When a male household member was present, he would perform these labor-intensive tasks. For all other dairy related activities, no gender bias was observed, i.e. activities were performed by both male and female family members.

After assessing the current situation on the eight CSFs, we explored four feeding strategies and their synergies/trade-offs in terms of land requirements, environmental impacts, food security, and economic profitability. Table 6 shows an overview of the main strengths and weaknesses of such feeding strategies. For each analyzed output, the related best and worst performing scenarios were listed.

Overall, the scenario *'Brachiaria'* was the worst performing while the '2:1 Ratio' scenario was the most promising feeding strategy, followed by '*Calliandra*'. When the financial situation allowed, the scenario 'Dairy meal' was the best strategy for intensification, especially where land was most limiting. *'Brachiaria',* with a visibly higher land requirement due to lower biomass yields than Napier, ranked low for most indicators that were expressed as per acre. Moreover, *Brachiaria* planting has other benefits that could not be quantified in this study, e.g. increasing the diversity of planted fodder, which makes the household more resilient to shocks such as diseases (e.g. Napier stunt and smut). Additionally, *Brachiaria* has lower demands compared to Napier, thus it performs visibly better during drought and on soils with lower quality.

Table 6 Overview of CLEANED outputs

FARM ID	STRONG SCENARIOS	WEAK SCENARIOS
Land requirement		
total (acre)	Dairy meal and 2:1 ratio	*Brachiaria*
per l milk	Dairy meal and 2:1 ratio	*Brachiaria*
Emission intensity		
per acre	*Brachiaria*	Dairy meal
per l milk	2:1 ratio and Calliandra	*Brachiaria*
AME days		
per acre	2:1 ratio and dairy meal	*Calliandra*
Economics		
VOP per acre	Dairy meal	*Brachiaria*
NPV and ROI	2:1 ratio	Dairy meal and *Brachiaria*

There is no universal best-bet scenario. Each scenario implies some trade-offs that must be balanced. The starting point to find a best-bet feeding scenario should be context specific. We need to assess what is there, including climatic conditions, type of cow and the farmer's experience or personal goals. With a good overview of the current situation, the appropriate best-bet scenarios can be calculated. Running an ex-ante scenario with the CLEANED tool can be a solid start to roughly detecting the weaknesses and strengths of the different scenarios and incorporating these findings in the decision-making processes. The tool is, however, not designed to accurately quantify impacts.

In addition to the calculations on the land requirement and the other outputs, this report showed the crucial role of optimally managing the land, finding solutions to limited labor availability, and making trade-offs with food production and limitations in milk marketing. For further research in this field, close collaboration between research institutions, such as CIAT and practical experts such as 'Send a Cow', is essential.

Photo: Vivien Osele/CIAT

Appendices

Appendix 1. Feed baskets

For every CSF, the percentages of each feed item in the feed basket for every scenario are listed for the wet and the dry season separately.

1KN

	FEED BASKET FOR ONE DAIRY COW IN WET SEASON										FEED BASKET FOR ONE DAIRY COW IN DRY SEASON									
	Local mixed grasses	Napier	Common beans vines	Desmodium	Sweet potato vines	Maize stover	Sesbania	Brachiaria	Dairy meal	Calliandra	Local mixed grasses	Napier	Common beans	Desmodium	Sweet potato vines	Maize stover	Sesbania	Brachiaria	Dairy meal	Calliandra
Baseline	15	64	5	10	3	0	3	0	0	0	60	7	10	5	3	10	5	0	0	0
Brachiaria	15	0	5	10	3	0	3	64*	0	0	60	0	10	5	3	10	5	7*	0	0
2:1 ratio	15	50	4	25	3	0	3	0	0	0	47	5	20	10	3	10	5	0	0	0
Dairy meal	10	54	5	10	3	0	13	0	5	0	55	7	10	5	3	0	15	0	5	0
Calliandra	10	54	5	10	3	0	3	0	0	15	55	7	10	5	3	0	5	0	0	15

* In the "Brachiaria" scenario, Napier is replaced with a 50% Napier/*Brachiaria* mix.

2KR

	FEED BASKET FOR ONE DAIRY COW IN WET SEASON									FEED BASKET FOR ONE DAIRY COW IN DRY SEASON								
	Local mixed grasses	Napier	Sugarcane tops	Desmodium	Brachiaria	Maize stover BOUGHT	Sweet potato vines	Dairy meal	Calliandra	Local mixed grasses	Napier	Sugarcane tops	Desmodium	Brachiaria	Maize stover BOUGHT	Sweet potato vines	Dairy meal	Calliandra
Baseline	5	50	0	20	20	0	5	0	0	55	10	5	5	10	10	5	0	0
Brachiaria	5	0	0	20	70*	0	5	0	0	55	0	5	5	20*	10	5	0	0
2:1 ratio	5	45	0	30	15	0	5	0	0	40	5	5	30	10	5	5	0	0
Dairy meal	0	50	0	20	20	0	5	5	0	60	10	5	5	10	0	5	5	0
Calliandra	0	40	0	20	20	0	5	0	15	50	10	5	5	10	0	5	0	15

3BN

	FEED BASKET FOR ONE DAIRY COW IN WET SEASON										FEED BASKET FOR ONE DAIRY COW IN DRY SEASON									
	Local mixed grasses	Napier	Common beans	Sweet potato vines	Dairy meal	Maize stover	Leucaena	Brachiaria	Calliandra	Desmodium	Local mixed grasses	Napier	Common beans	Sweet potato vines	Dairy meal	Maize stover	Leucaena	Brachiaria	Calliandra	Desmodium
Baseline	0	65	6	9	2	15	3	0	0	0	56	10	10	10	2	1 0	2	0	0	0
Brachiaria	0	0	6	9	2	15	3	65*	0	0	56	0	10	10	2	10	2	10*	0	0
2:1 ratio	5	50	4	3	0	10	3	0	0	25	50	5	10	3	0	10	2	0	0	20
Dairy meal	0	65	6	9	5	12	3	0	0	0	56	10	10	10	5	7	2	0	0	0
Calliandra	0	65	6	9	0	2	3	0	15	0	53	10	10	10	0	0	2	0	15	0

4BR

	FEED BASKET FOR ONE DAIRY COW IN WET SEASON										FEED BASKET FOR ONE DAIRY COW IN DRY SEASON							
	Local mixed grasses	Napier	Common beans	Maize green fodder	Calliandra green fodder	Maize stover	Sesbania green fodder	Desmodium	Brachiaria	Dairy meal	Local mixed grasses	Napier	Common beans	Calliandra green fodder	Maize stover	Sesbania green fodder	Desmodium	Dairy meal
Baseline	15	55	5	3	12	5	5	0	0	0	70	0	5	10	10	5	0	0
Brachiaria	15	0	5	3	12	5	5	0	55*	0	70	0	5	10	10	5	0	0
2:1 ratio	10	50	10	0	10	0	5	15	0	0	55	0	10	10	5	5	15	0
Dairy meal	15	55	5	0	12	3	5	0	0	5	70	0	5	10	5	5	0	5
Calliandra	15	55	5	3	15	2	5	0	0	0	70	0	5	15	5	5	0	0

5BN

	FEED BASKET FOR ONE DAIRY COW IN WET SEASON								FEED BASKET FOR ONE DAIRY COW IN DRY SEASON							
	Local mixed grasses	Napier	Desmodium	Sweet potato vines	Calliandra green fodder	Maize stover	Brachiaria	Dairy meal	Local mixed grasses	Napier	Desmodium	Sweet potato vines	Calliandra green fodder	Maize stover	Brachiaria	Dairy meal
Baseline	2	70	10	9	3	0	6	0	65	10	0	5	2	10	8	0
Brachiaria	2	0	10	9	3	0	76*	0	65	0	0	5	2	10	18*	0
2:1 ratio	10	50	25	6	4	0	5	0	50	5	25	5	5	5	5	0
Dairy meal	0	67	10	9	3	0	6	5	70	10	0	5	2	0	8	5
Calliandra	0	60	10	9	15	0	6	0	52	10	0	5	15	10	8	0

6BR

	FEED BASKET FOR ONE DAIRY COW IN WET SEASON									FEED BASKET FOR ONE DAIRY COW IN DRY SEASON								
	Local mixed grasses	Napier	Desmodium	Wild Desmodium	Leucaena	Maize stover	Brachiaria	Dairy meal	Calliandra	Local mixed grasses	Napier	Desmodium	Wild Desmodium	Sesbania	Maize stover	Brachiaria	Dairy meal	Calliandra
Baseline	17	50	10	0.03	0.1	0	0.1	0	0	75	3	3	2	2	10	5	0	0
Brachiaria	17	0	10	3	10	0	60*	0	0	75	0	3	2	2	10	8*	0	0
2:1 ratio	12	40	30	3	10	0	5	0	0	50	3	20	10	5	7	5	0	0
Dairy meal	12	50	10	3	10	0	10	5	0	75	8	3	2	2	0	5	5	0
Calliandra	2	50	10	3	10	0	10	0	15	70	3	3	2	2	0	5	0	15

7SN

	FEED BASKET FOR ONE DAIRY COW IN WET SEASON									FEED BASKET FOR ONE DAIRY COW IN DRY SEASON								
	Local mixed grasses	Napier	Sugarcane BOUGHT	Maize stover	Calliandra green fodder	Desmodium	Sweet potato vines	Brachiaria	Dairy meal	Local mixed grasses	Napier	Sugarcane BOUGHT	Maize stover	Calliandra green fodder	Desmodium	Sweet potato vines	Brachiaria	Dairy meal
Baseline	10	60	5	2	5	8	10	0	0	70	5	4	5	3	3	10	0	0
Brachiaria	10	0	5	2	5	8	10	60*	0	70	0	4	5	3	3	10	5*	0
2:1 ratio	8	50	5	2	5	25	5	0	0	50	5	5	5	3	25	7	0	0
Dairy meal	7	60	5	0	5	8	10	0	5	70	5	4	0	3	3	10	0	5
Calliandra	0	60	5	2	15	8	10	0	0	58	5	4	5	15	3	10	0	0

8SR

	FEED BASKET FOR ONE DAIRY COW IN WET SEASON										FEED BASKET FOR ONE DAIRY COW IN DRY SEASON									
	Local mixed grasses	Napier	Common beans	Sweet potato vines	Calliandra green fodder	Maize stover	Wild Desmodium	Brachiaria	Dairy meal	Desmodium	Local mixed grasses	Napier	Common beans	Sweet potato vines	Calliandra green fodder	Maize stover	Wild Desmodium	Brachiaria	Dairy meal	Desmodium
Baseline	35	35	5	15	2	5	3	0	0	0	65	3	5	10	2	10	5	0	0	0
Brachiaria	35	0	5	15	2	5	3	35*	0	0	65	0	5	10	2	10	5	3*	0	0
2:1 ratio	30	30	5	7	0	5	3	0	0	20	55	0	5	5	0	10	5	0	0	20
Dairy meal	35	35	5	15	2	0	3	0	5	0	65	8	5	10	2	0	5	0	5	0
Calliandra	22	35	5	15	15	5	3	0	0	0	62	3	5	10	15	0	5	0	0	0

*In the *Brachiaria*" scenario, Napier is replaced with a 50% Napier/*Brachiaria* mix.

Apendix 2. Feed and crop parameters

FEED	LITERATURE SOURCE	DM CONTENT (%)	ME CONTENT (MJ/KG DM)	ME (MJ/KG FRESH)	CP CONTENT (% DM)	CP CONTENT (% FRESH)	DE (FRACTION)	ASSOCIATED CROP
Brachiaria hybrid (forage)	1.2.3.6	26.00	7.00	1.82	9.00	2.34	0.53	*Brachiaria* hybrid
Calliandra calothyrsus - green leaf material	1.2.3.5	39.00	7.68	3.00	22.00	8.58	0.50	*Calliandra*
Common beans (*Phaseolus vulgaris*) - bean	1.2.4	90.00	14.15	12.74	25.40	22.86	0.50	Beans
Common beans (*Phaseolus vulgaris*) - vines	1.2	90.00	8.33	7.50	7.62	6.86	0.51	Beans
Dairy meal	1.2.3.7	90.00	10.50	9.45	16.00	14.40	0.80	Purchased
Desmodium (*Desmodium intortum*) green leaf	1.2.3	24.20	8.20	1.98	15.50	3.75	0.50	Green leaf Desmodium
Desmodium (Wild Desmodium)	1.2	19.36	6.56	1.27	12.40	2.40	0.50	Wild Desmodium
Leucaena (*Leucaena leucocephala*) - green fodder	1.2.5	26.20	9.50	2.49	19.93	5.22	0.50	Leucaena
Local mixed grasses (couch/star grass) - green fodder	1.2.3	30.20	10.00	3.02	8.80	2.66	0.50	Local mixed grasses
Maize (*Zea mays*) - green fodder	1.2.3.4	82.00	10.22	8.38	8.90	7.30	0.53	Maize
Maize (*Zea mays*) - stover	1.2.3.4	87.00	9.13	7.94	5.90	5.13	0.53	Maize
Napier grass (*Pennisetum purpureum*) - green fodder	1.2.3	15.00	9.88	1.48	11.00	1.65	0.61	Napier
Sesbania (*Sesbania sesban*) - green fodder	1.2.5	28.90	8.54	2.47	21.30	6.16	0.70	Sesbania
Sugarcane (*Saccharum officinarum*) - tops (green fodder)	1.2.3.8	29.00	6.90	2.00	5.90	1.71	0.50	Sugarcane
Sweet potato (*Ipomoea batatas*) - vines	1.2.3.4	10.80	10.01	1.08	19.40	2.10	0.60	Sweet potato
Napier - *Brachiaria* mix (50%)		20.50	8.44	1.65	10.00	2.00	0.57	Napier/*Brachiaria* mix (50%)

ANNUAL AVERAGES

CROP PRODUCT	MAIN PRODUCT FRESH YIELD (T FW/HA)	MAIN PRODUCT DM CONTENT FRACTION	MAIN PRODUCT DRY YIELD (T DM/HA)	AVERAGE HARVEST INDEX	CROP RESIDUE FRESH YIELD (T FW/HA)	CROP RESIDUE DM CONTENT FRACTION	CROP RESIDUE DRY YIELD (T DM/HA)
Beans	0.90	0..88	0.79	0.50	3.00	0.88	2.64
Brachiaria hybrid	17.00	0.25	4.25	0.90	1.89	0.25	0.47
Calliandra	17.78	0.45	8.00	0.90	1.98	0.45	0.88
Fodder maize	1.33	0.80	1.06	0.47	1.50	0.90	1.34
Green leaf Desmodium	12.50	0.32	4.00	0.90	1.39	1.00	1.39
Leucaena	23.33	0.30	7.00	0.90	2.59	0.30	0.78
Local mixed grasses	13.00	0.25	3.25	0.95	0.68	1.00	0.68
Maize	1.33	0.80	1.06	0.47	3.00	0.90	2.69
Napier	35.00	0.18	6.30	0.90	3.89	0.18	0.70
Sesbania	20.69	0.29	6.00	0.90	2.30	0.29	0.67
Sugarcane	10.80	0.32	3.46	0.71	4.33	1.00	4.33
Sweet potato	8.50	0.23	1.93	0.55	6.95	0.23	1.58
Wild Desmodium	9	0.32	2.88	0.90	1.00	0.32	0.32
Napier/*Brachiaria* mix (50%)	26	0.215	5.275	0.90	2.89	0.22	0.59
Purchased	**0**	**0**	**0**	**0**	**0**	**0**	**0**

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CROP RESIDUE N CONTENT PER AREA (KG N/HA)	MAIN PRODUCT N CONTENT (KG N/KG DM)	CROP RESIDUE N CONTENT (KG N/KG DM)	C (CROP COVER) FACTOR	N FIXATION BY CROP (KG N/HA/YR)	ENERGY (KCAL PER FW 100G)	WATER CONTENT (G PER 100 G)	ENERGY (KCAL PER 100 G DM)
66.00	0.04	0.03	0.10	49.24	337.00	11.75	381.87
94.44	0.02	0.20	0.03	94.82			
0.00	0.03	0.00	0.05	120.00			
9.41	0.02	0.01	0.05	13.75	365.00	10.37	407.23
41.67	0.04	0.03	0.10	102.83			
26.44	0.03	0.03	0.05	132.22			
9.58	0.01	0.01	0.10	27.54			
18.82	0.02	0.01	0.05	18.46	365.00	10.37	407.23
16.10	0.02	0.02	0.03	80.50			
20.00	0.03	0.03	0.05	100.00			
43.26	0.01	0.01	0.17	38.91			
15.80	0.01	0.01	0.05	12.73	86.00	77.28	378.52
8.00	0.04	0.03	0.10	63.04			
55.27	0.02	0.11	0.03				
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**

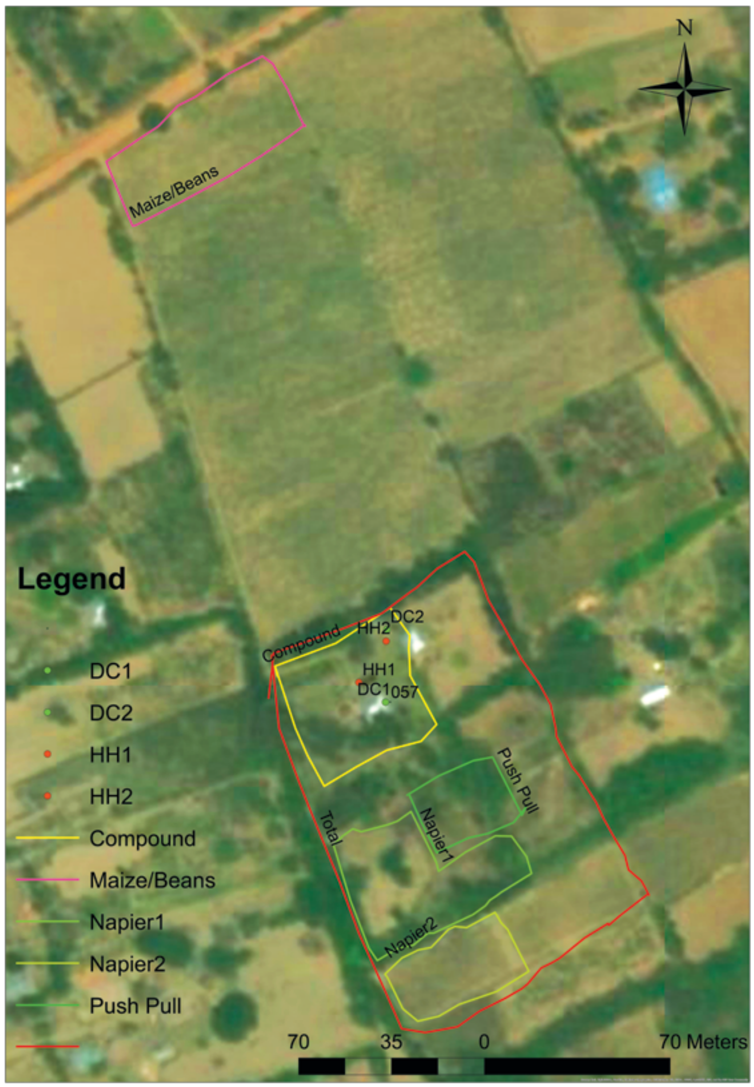
Appendix 3. Annual milk yield calculations

FARM ID	AV. MILK (L/DAY)	PERIOD (1-60)	AV. MILK (L/DAY)	PERIOD (61-120)	AV. MILK (L/DAY)	PERIOD (121-180)	AV. MILK (L/DAY)	PERIOD (181-240)	AV. MILK (L/DAY)	PERIOD (241-300)	AV. MILK (L/DAY)	PERIOD (301-360)	TOTAL (L)
1KN	11	660	9	540	7.5	450	5	300	2.5	150	0	0	2100
2KR	10	600	7	420	4	240	3	180	2	120	0	0	1560
3BN	11	660	8	480	5	300	3	180	2.5	150	0	0	1770
4BR	10	600	8	480	5	300	4	240	2.5	150	0	0	1770
5BN	9	540	7	420	5	300	4	240	2.5	150	0	0	1650
6BR	10	600	7	420	5	300	4	240	2.5	150	0	0	1710
7SN	8	480	6	360	4	240	4	240	2.5	150	0	0	1470
8SR	16	960	12	720	8	480	8	480	4	240	1.5	90	2970

Appendix 4. Economic inputs

CROP (US$/HA)	EXTRA ONE-OFF / ESTABLISHMENT COST (US$/HA)	OPERATIONAL COST (US$/HA/YEAR)
Local mixed grasses	40	24
Napier	180	48
Common beans vines	80	128
Desmodium	290	48
Sweet potato vines	50	98
Maize (*Zea mays*) - stover	76	124
Sesbania	1000	24
Calliandra	1000	24
Brachiaria	310	48
Napier - *Brachiaria* mix (50%)	239	48
Other		
Dairy meal	287	287

Appendix 5. Maps



Map 5BN farm.


N
W
E
S
Maize/Beans
Compound
HH
Napier
Napier2
Legend
PLOTS
Cassava
Compound
Fields
Maize
Maize/Beans
Napier
Napier2
SPV
DC
HH
Maize/Beans
Fields
SPV
Maize
40 20 0 40 Meters

Map 8SR farm.

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Headquarters and Regional Office for South America and the Caribbean

Km 17 Recta Cali–Palmira CP 763537
Apartado Aéreo 6713
Cali, Colombia
Phone: +57 2 4450000
Fax: +57 2 4450073
General e-mail: ciat@cgiar.org

CONTACT
Ruben Echeverría, Director General

Carolina Navarrete, Regional Coordinator
c.navarrete@cgiar.org

Regional Office for Africa

c/o ICIPE
Duduville Campus,
Off Kasarani Road
P.O. Box 823-00621
Nairobi, Kenya
Phone: +254 0709134000
Fax: +254 20 8632001

CONTACT
Debisi Araba, Regional Director
a.araba@cgiar.org

Regional Office for Central America

Planes de Altamira,
de Pizza Hut Villa Fontana 1 cuadra al oeste
Edificio CAR III, 4to. Piso
Apartado Postal LM-172
Managua, Nicaragua
Phone: +505 2 2993011 / 22993056

CONTACT
Jenny Wiegel, Regional Coordinator
j.wiegel@cgiar.org

Regional Office for Asia

c/o Agricultural Genetics Institute (Vien Di Truyen Nong Nghiep),
Vietnam Academy of Agricultural Sciences (VAAS),
Pham Van Dong Street, Tu Liem
(opposite the Ministry of Security – Doi dien voi Bo Cong An)
Hanoi, Vietnam
Phone: +844 37576969

CONTACT
Dindo Campilan, Regional Director
d.campilan@cgiar.org

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