Ex ante impact and trade-off assessment of improved forage use in western Kenya

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Citation

Caulfield M; Paul B. 2021. Ex ante impact and trade-off assessment of improved forage use in western Kenya. CIAT Publication No. 512. International Center for Tropical Agriculture (CIAT). Nairobi, Kenya. 25 p.

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July 2021

Abstract

The dominant cut-and-carry forage grass in East Africa, Napier (*Pennisetum purpureum*), is suffering from increasing problems of stunt and head-smut diseases leading to important decreases in yield. Alternative improved forages have been developed and promoted by research and development organizations globally over the past couple of decades to diversify feed baskets and increase the quantity and quality of available feed. However, the use of these improved forages is associated with different yield potentials, land requirements, effects on livestock productivity, and related impacts on income and food security, which are influenced by agroecology, season, and management. Farmers' preferences depend on their specific production objectives and challenges, and the weighing of these multi-dimensional benefits and trade-offs. The objective of this research was therefore to explore selected impacts and trade-offs as well as the role alternative forage grasses can play in the mixed crop-livestock systems of Kenya. Using data from a survey of 198 rural households in four counties in western Kenya, and on-farm forage and milk production trials, we assessed the use of two improved forage grasses, a *Panicum maximum* hybrid (Maasai) and a *Brachiaria* hybrid (Mulato II), under six different scenarios. We found that the replacement of Napier grass with Maasai forage by households that already produce cow milk has the potential to increase farm income by 10%. Moreover, the land-use savings associated with the greater yield potential of Maasai forage made it possible for nearly 20% of milk producing households to incorporate an additional dairy cow into their farming system with negligible trade-offs, or even positive effects, on food availability. Under the scenario of an additional cow and the use of Maasai forage grass annual farm income rose by 75%. We concluded that, although these potential benefits offered by Maasai grass may not be accessible to all farming households in the study areas due to problems in access to land and barriers to the production and commercialisation of milk of current non-milk producing households, they may be achievable by approximately 20% of them.

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Dennis Nyongesa and his wife have boosted his milk yield and income since using new grass varieties introduced by the Grass to Cash project of the Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT).

1. Introduction

Tropical forages comprise several sown or planted grasses, herbaceous or dual-purpose legumes, and shrubs. They are integrated into the agro-pastoral and silvo-pastoral systems of mixed smallholder farming systems for grazing or as cut-and-carry forages. Grasses have been the forage crop of choice for farming households in the tropics because they require lower maintenance for planting and weeding, they suffer less from pest and disease pressures, they are perennial, and they offer important soil protection properties (Rao et al., 2015). Napier grass (*Pennisetum purpureum*) in particular has long been the dominant crop in cut-and-carry forage systems in East Africa (Bezabih et al., 2019; Maleko et al., 2019; Mwendia et al., 2006). However, increasingly, the crop is being affected by stunt and head-smut diseases leading to important decreases in yield (Asudi et al., 2015; Kariuki et al., 2016; Negawo et al., 2017; Olivier et al., 2019) that threaten already vulnerable rural livelihoods.

In the face of these growing challenges to the dominant forage crop in the tropics, there has been increased interest in exploring and promoting alternative improved forage technologies. In particular, several forage grasses have been identified and indeed promoted by research institutions and governmental authorities as potential alternatives to Napier grass. Some of those that are now becoming commercially important globally are the *Brachiaria* hybrid cultivars Mulato II, Cayman, and Cobra; *Panicum maximum* cultivars Maasai, Mombasa, and Tanzania; *Lablab purpureus* cultivar Rongai; and *Desmodium uncinatum* and *Desmodium intortum* (Rao et al., 2015).

Many of these alternative forage grasses, while providing greater crude protein proportions and metabolizable energy content per kg of dry matter than Napier grass, have lower yield, although it is important to point out that these differences depend heavily on agroecology, season, and management. This potential trade-off between improved forage nutrient content and land-use requirements is particularly important to consider in smallholder mixed farming systems in East Africa (Klapwijk et al., 2014; Njarui et al., 2017; Umunezero et al., 2016) and may be part of the reason why the use of improved forage crops remains below expectations (Haan et al., 2006; Hall et al., 2003; Owen et al., 2012; Pengelly et al., 2003).

In addition to land-use trade-offs, another reason why farming households may not be employing the improved forages promoted by farming extension agents could be that the use of such technologies requires fundamental systemic shifts in approaches to farming. For example, farming households that are unfamiliar with the concept of investing labor and capital in producing feed that was previously acquired for free through communal grazing may be more reluctant to start growing forages. Moreover, it is highly unlikely in these cases that the farming households have the necessary farm infrastructure and capital or the social connections and networks with cooperatives and traders to exploit the potential benefits intensified milk or meat production could bring. The need for such systemic shifts in the farming systems of these households presents major obstacles to stepping up their productivity and income (Tittonell, 2014).

To better understand some of these challenges and the role that alternative forage grasses can play in the mixed crop-livestock systems of western Kenya the current research set out to assess how forage practices and livestock products contribute to current farming systems and the expected trade-offs between farm income, land use, and food availability under different scenarios involving the use of alternative forage grasses.

2. Methodology

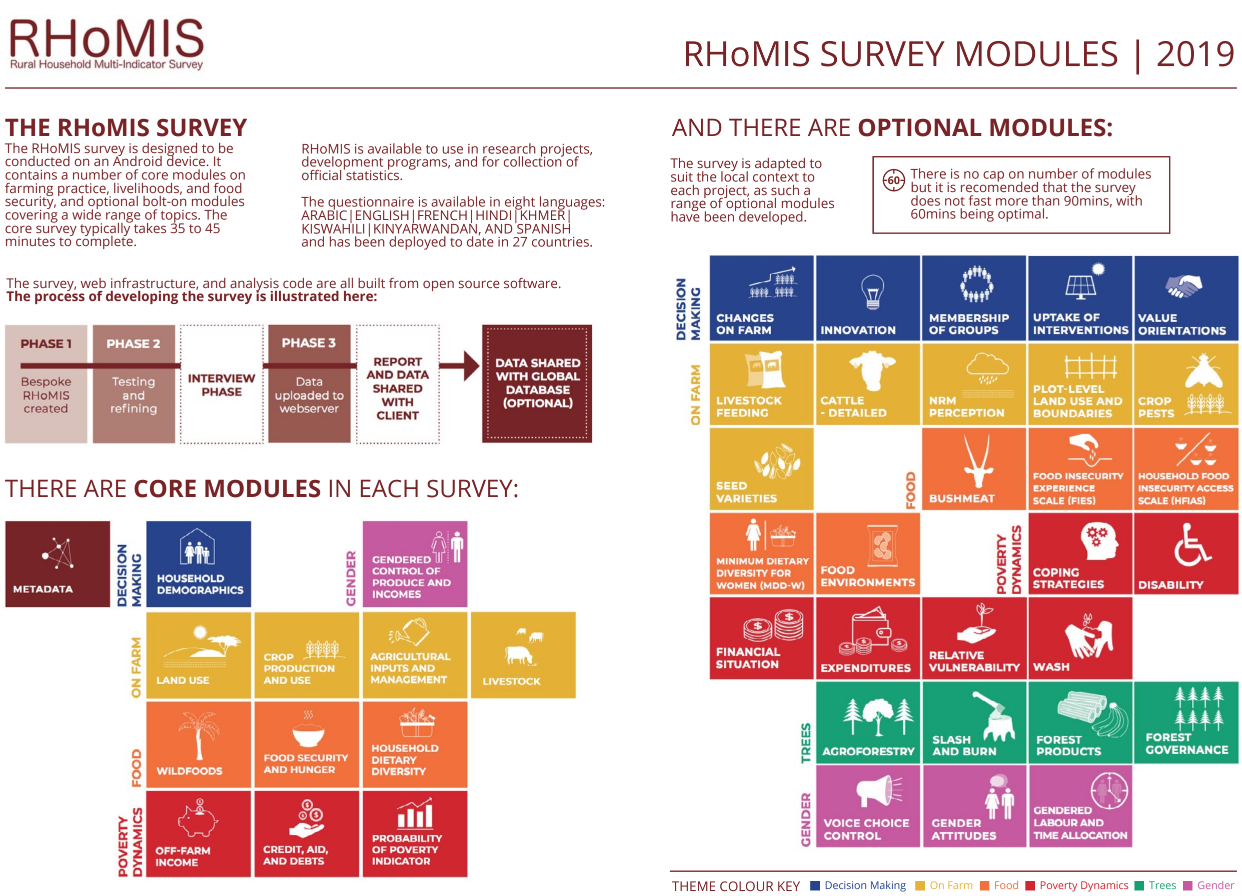
2.1. Rural household surveys and forage and milk production trials

The Rural Household Multiple Indicator Survey (RHoMIS) was used to collect data on 198 smallholder farming households from eight rural villages located in four counties (Bungoma, Busia, Kakamega, and Siaya) of western Kenya. RHoMIS is a standardized farm household survey that collects information on household characteristics and farming systems (van Wijk et al., 2020). To date, more than 30,000 surveys have been collected in 33 countries. The RHoMIS kit was created using open-source software and is administered using Android devices and the ODK software suite (www.rhomis.org). The surveys used in the current research comprised the core modules of RHoMIS and some additional optional modules in order to gather greater detail on livestock management (Fig. 1).

The data from the RHoMIS were complemented in this research by two field experiments. The objective of the first experimental trial was to assess the yield potentials of different forage grasses in situ in the four counties in which the RHoMIS waswas conducted. The experimental design consisted of randomized blocks of three replicates of 11 forage grasses in each of the four counties. The forages were planted in September 2018 and have been growing for two years. The crops were harvested at the point of maturation when they would normally be harvested by farmers. Maturation rates depended on season, varying from 60 to 120 days.

The second experimental trial was designed to assess changes in milk production as a result of the feeding of different forages to dairy cows. The forages assessed were Napier grass, conceived as the control or current farmer practice, and Maasai forage and Mulato II as alternatives to the current farmer practice. The experimental design employed crossover methodology for which each lactating cow was fed for the first 2 weeks on Napier grass, then transferred to experimental feeding interventions (either Maasai or Mulato II) for 1 week, before once again reverting to the current farmer practice for the last 2 weeks. Six cows at each of three study sites (Bungoma, Busia, and Kakamega) participated in the trial, with half of the cows receiving Maasai and half of the cows receiving Mulato II during the experimental feeding week (Mwendia et al., 2020).

Figure 1. Breakdown of the RHoMIS approach and key modules.



2.2. Scenarios, output calculations, and assumptions

Six scenarios were developed to assess the effect the planting and use of alternative forage crops and the incorporation of an additional dairy cow into the livestock herd had on farm income, forage crop land requirements, and food availability as an indicator of food security (Table 1). Although several alternative forage crops could have been selected for the scenarios, because of the availability of data on the effect of Maasai and Mulato II forage crops on milk production in the areas of study compared to the current farmer practice, it was decided to include these two alternative forages within the six scenarios rather than other options. Moreover, because of past governmental programs in some East African countries in which heifers are distributed to vulnerable farming households (e.g., the Girinka Programme in Rwanda) (Klapwijk et al., 2014; Paul et al., 2018) and as a means to assess the potential to upscale current farm-level milk production, two of the six scenarios included the incorporation of an additional dairy cow into the livestock herd of the farming household. Food availability was selected as the variable to represent food security in the modeling as it enables quantitative modeling of changes in household food availability as a result of net changes in land-use distribution and has been shown to correlate positively with other more direct assessments of food security such as Household Dietary Diversity Score (HDDS) and the Food Insecurity Experience Scale (FIES) (Hammond et al., 2017).

Table 1. Summary of changes in livestock management under the six modeled scenarios.

Scenario	Change in livestock management
1	Straight replacement of current forage grass (assumed to be Napier grass) with **Maasai** forage (based on assumption that cut forage accounts for **48% of feed basket**). It is assumed that this will lead to a **20% increase in milk production.**
2	Straight replacement of current forage grass (assumed to be Napier grass) with **Mulato II** forage (based on assumption that cut forage accounts for **48% of feed basket**). It is assumed that this will lead to a **10% increase in milk production.**
3	Straight replacement of current forage grass (assumed to be Napier grass) with **Maasai** forage (based on assumption that cut forage accounts for **100% of feed basket**). It is assumed that this will lead to a **30% increase in milk production.**
4	Straight replacement of current forage grass (assumed to be Napier grass) with **Mulato II** forage (based on assumption that cut forage accounts for **100% of feed basket**). It is assumed that this will lead to a **15% increase in milk production.**
5	Incorporation of an **additional dairy cow** into the livestock herd with continued use of **Napier grass** as the forage grass (based on assumption that cut forage accounts for **48% of feed basket**). Additional milk production from extra dairy cow.
6	Incorporation of an **additional dairy cow** into the livestock herd and the use of **Maasai** forage instead of Napier grass (based on assumption that cut forage accounts for **48% of feed basket**). Additional milk production from extra dairy cow plus a 20% increase in milk production from the use of Maasai forage.

To assess the trade-offs associated with the six scenarios on farm income, forage land area requirements, and food availability (output variables), a simplified conceptual framework of the mixed crop-livestock systems of the study areas was developed (Fig. 2). To calculate the net changes in the output variables, several assumptions were made (Table 2). The net change in annual farm income was calculated based on estimated net changes in milk production rates multiplied by the price of milk sales at the study sites. To determine the net change in milk production under the six alternative scenarios, current milk production rates were multiplied by the proportional change in milk production rates associated with the different forage crop options. In the two scenarios in which an additional cow was incorporated into the livestock herd (scenarios 5 and 6), an annual milk production rate was added to the current milk production rate (2,055 liters) before calculating any proportional changes due to changes in forage crop. For households that consumed less than 2 liters of milk a day, the quantity less than 2 liters was subtracted from the increased milk production as this was assumed to contribute to additional milk consumption in the household. The remaining additional amount of milk production was then multiplied by the selling price of milk in the study areas (US$0.54).

To calculate net changes in cultivated forage area requirements, in the cases where households grew less than the minimal amount of forage crops to satisfy the feed requirements of the number of female adult cattle heads owned and under the assumption that forage crops accounted for 48% of the feed basket, the required forage area was increased to 0.1 ha for the first female adult cow, and then to an additional 0.1 ha for each subsequent dairy cow if the original forage area was below that area. Under the assumption that forage crops accounted for 100% of the feed basket, the minimum forage area was set at 0.2 ha per female adult cow. The revised forage area requirements were then multiplied by the proportional difference between the potential yields of the forage crops. In the two scenarios in which an additional cow was incorporated into the livestock herd, a set amount of forage land was then added to account for the increased feed needs of the extra cow differing by forage type (0.1 ha for the current farmer practice (Napier grass) under scenario 5 and 0.076 ha for scenario 6 using Maasai). The net change in forage area requirements was subsequently calculated by subtracting the original cultivated forage area from the revised cultivated forage area requirements.

To determine net change in food availability, the net change in total farm energy production was calculated by multiplying the net change in cultivated forage area by the potential energy yield of maize (as the staple food crop). The additional quantity of milk produced due to increased milk production up to 2 liters a day was also added. This figure was then divided by household size in male adult equivalent (MAE) units.

All calculations and output plots were carried out within the RStudio environment version 1.4.1103 for R (version 4.0.4) using tidyverse and ggplot2 packages. In the calculations related to farm income, farm land area, and food availability, an outlier was removed due to an extreme value.

Figure 2. Simplified conceptual framework of the trade-offs associated with the use of alternative forage crops in terms of farm income, land-use change, and food availability.

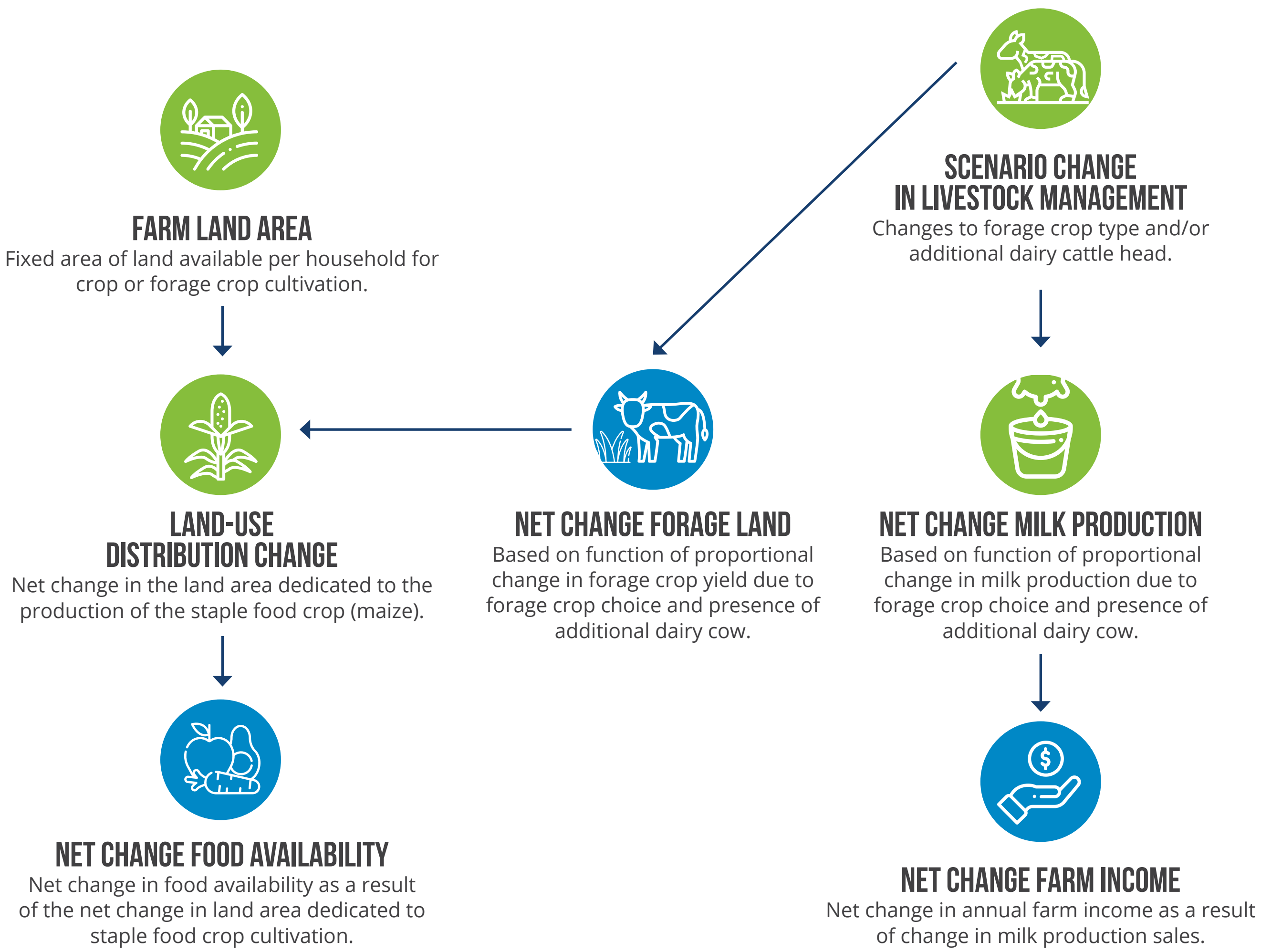


Table 2. Summary of assumptions used in the modeling of trade-offs for different scenarios of livestock management.

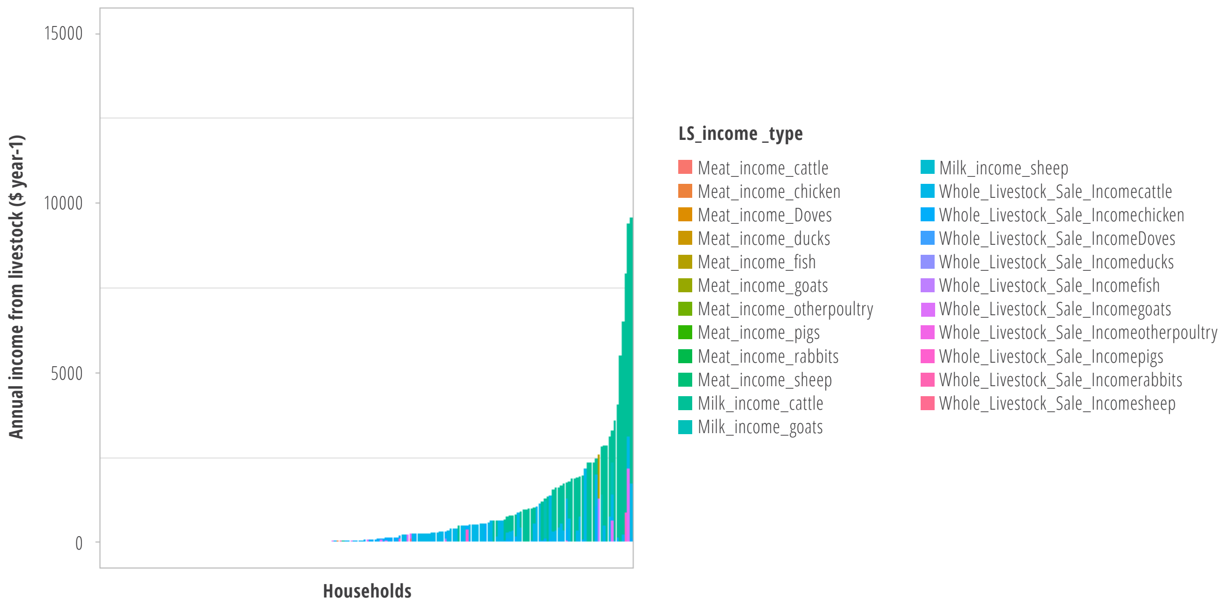
Output variable	Assumption	Evidence upon which assumption is based
Net change in farm income	Current farm livestock management produces 7.5 liters of milk/cow/day.	Data from milk production trials (Appendix 1).
	Feeding dairy cattle with Maasai forage (48% of feed basket) leads to a 20% increase in milk production. Under optimal conditions, milk production can increase by 30% when cows are fed with 100% cut forage.	Data from milk production trials (Appendix 1).
	Feeding dairy cattle with Mulato II forage (48% of feed basket) leads to a 10% increase in milk production. Under optimal conditions, milk production can increase by 15% when cows are fed with 100% cut forage.	Data from milk production trials (Appendix 1) and Mwendia et al. (n.d., in prep.).
	Average lactation period of dairy cow at study sites is 9 months (274 days).	Personal communication from field assistant at study sites.
	Annual milk production rates for current farmer practices: 274 days * 7.5 = 2,055 liters/milk cow/year.	Based on data from milk production trials (Appendix 1) and previous assumption on lactation period.
	Extra milk production is consumed by the household up to the amount of 2 liters of milk per household per day. Any additional milk beyond this amount is sold to the market (not consumed).	Modeling assumption.
	All extra milk produced is sold at US$0.54/liter at study sites.	Personal communication from field assistant at study sites.
Net change in land-use distribution	Annual dry matter yield potential for Napier grass = 16.75 Mg/ha.	Data from forage production trials (Appendix 2).
	Annual dry matter yield potential for Maasai grass = 20.9 Mg/ha Proportional difference in yield between Napier grass and Maasai: 16.75/20.90 = 0.80.	Data from forage production trials (Appendix 2).
	Annual dry matter yield potential for Mulato II = 11.4 Mg/ha Proportional difference in yield between Napier grass and Mulato II: 16.75/11.40 = 1.47.	Data from forage production trials (Appendix 2).
	Feed basket composition includes 48% forage grasses on average across a whole year.	RHoMIS data indicating that the feed baskets of the cows of farming households in the study area tended to contain 35% forage grasses in the dry season and 58% forage grasses in the wet season (Appendix 3).
	Forage grass feed requirements = feed basket forage grass composition multiplied by dry matter feed requirements per cow per year. Dry matter (DM) feed requirements are equal to 3.285 Mg/cow/year. Overall (DM) forage grass requirements are equal to 1.58 Mg/year/milking cow.	Dairy cow crop forage feed requirements = 3.285 Mg/cow/year (Wilkes et al., 2020).
	0.094 ha, rounded to 0.1 ha of land, feeds one dairy cow with sufficient Napier grass for a year when cut forage accounts for 48% of the feed basket (forage grass feed requirements/annual DM forage grass yield potential = 1.58/16.75 => 0.094). Under intensified cut forage feeding where cut forage accounts for 100% of the feed basket, 0.2 ha of land feeds one dairy cow.	Based on previous assumptions.
	0.076 ha of land feeds one cow with sufficient Maasai forage for a year (forage grass feed requirements/annual DM forage grass yield potential = 1.58/20.90 => 0.076).	Based on previous assumptions.
Net change in food availability	Farming households do not purchase or rent-in new land.	Modeling assumption.
	All land saved through increased forage grass yield is converted to staple food crops (maize). All land converted to new cultivated forage land is withdrawn from the staple food crop (maize).	Modeling assumption.
	Maize has an energy value of 3,650 kcal/kg.	Nuss and Tanumihardjo (2010).
	Average maize yield in Kenya = 1.5 Mg/ha/year.	World Bank figures (2017).
	Cattle milk has an energy value of 597 kcal/L.	RHoMIS assumption.

3. Results

3.1. Current farming household characteristics

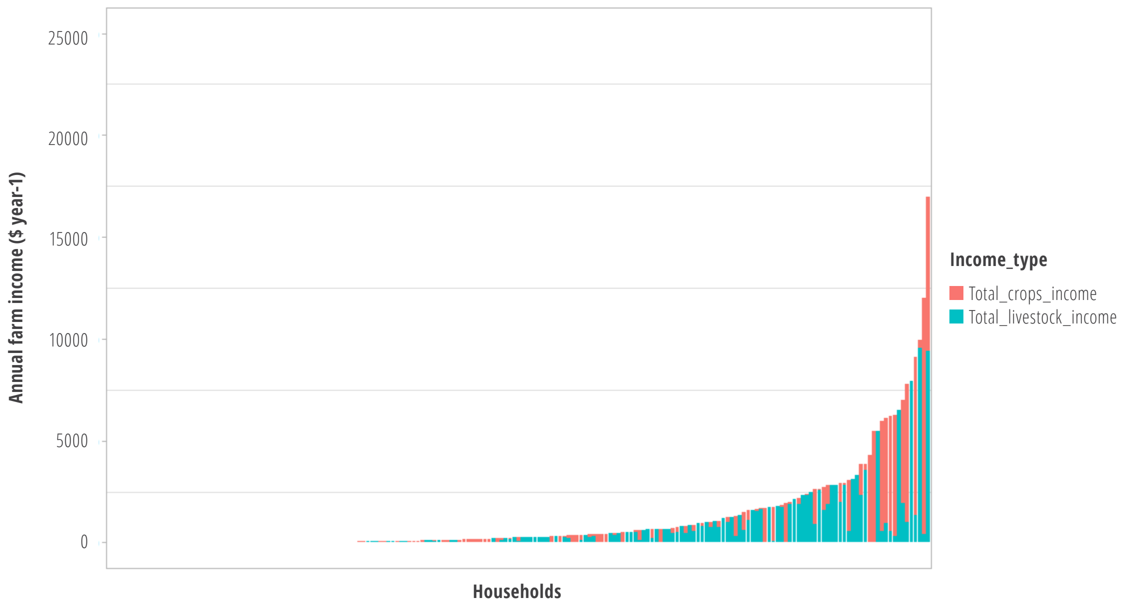
Income from cattle milk sales generated 38% (US$433) of total farm income and 67% of income from livestock product sales. Notwithstanding the importance of income from cattle milk sales overall, only 50 households (25%) reported generating income from cattle milk sales. The other main source of income from livestock products was from whole-livestock cattle sales, accounting for 23% of the income from livestock sources and 13% of total farm income. Sixty-three households (32%) reported not generating income from whole-livestock cattle sales, while 78 households (40%) reported not generating income from livestock product sales (Fig. 3).

Figure 3. Annual farm income from livestock production by livestock product.



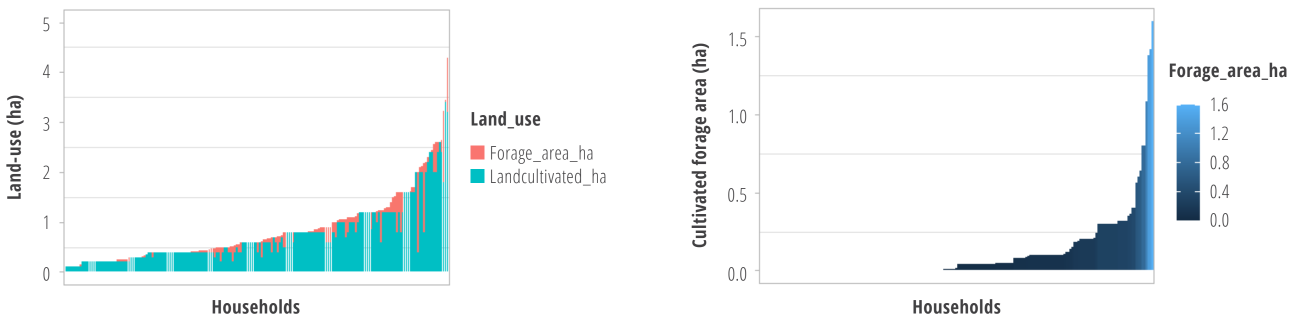
Mean farm income was US$1,152/year. On average, livestock income accounted for more than half (56% or US$649) of farm income, although this proportion was higher for farming households that generated the most farm income and lower for households that generated less farm income. Forty-nine households (25%) reported not generating any farm income (Fig. 4). Among the 96 farming households producing cattle milk, the mean farm income was US$1,804 (more than 56% more than the overall average of farm income).

Figure 4. Annual farm income by farm product type (crops or livestock).



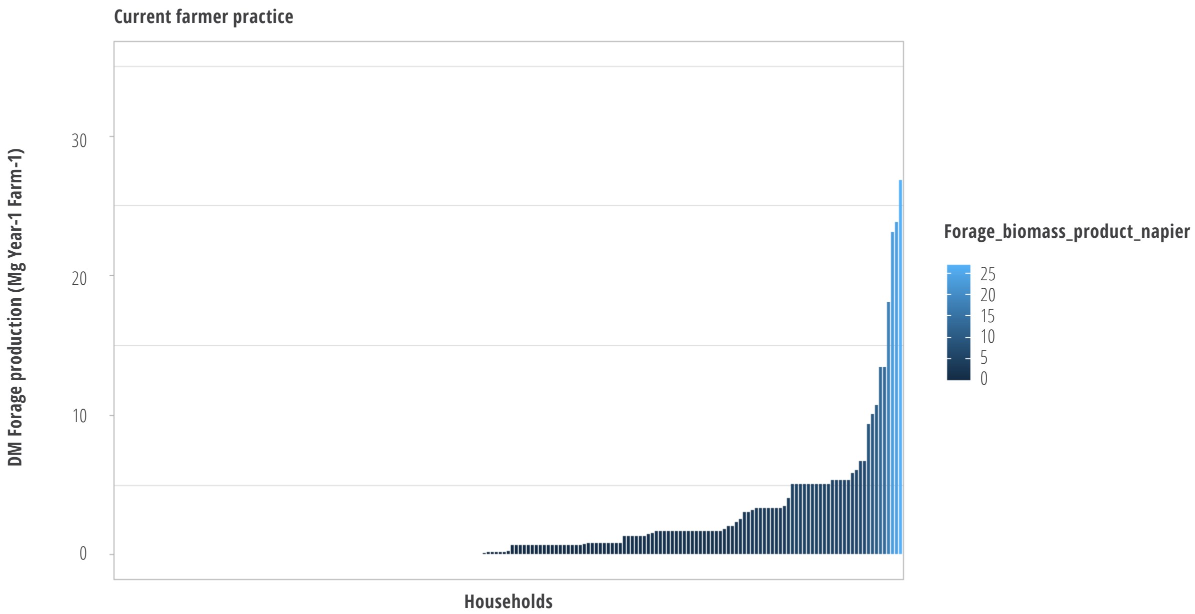
The mean land area dedicated to crop cultivation and forage cultivation across all farming households was 0.83 ha. Although some farming households cultivated significantly less than 0.3 ha, other farms cultivated more than 3 ha of land for either crops or forage crops. Eighty-three farming households (42%) reported that they did not have land specifically dedicated to the cultivation of forage crops. Of the households that produced milk, the mean area of land cultivated for crops and forage crops was 1.01 ha (40% more land than the overall average). Sixteen percent, or 0.16 ha, of this land was designated for the cultivation of forage crops (Fig. 5).

Figure 5. A) Area of land cultivated for crops or forage grasses by land use. B) Area of land cultivated for forage grasses.



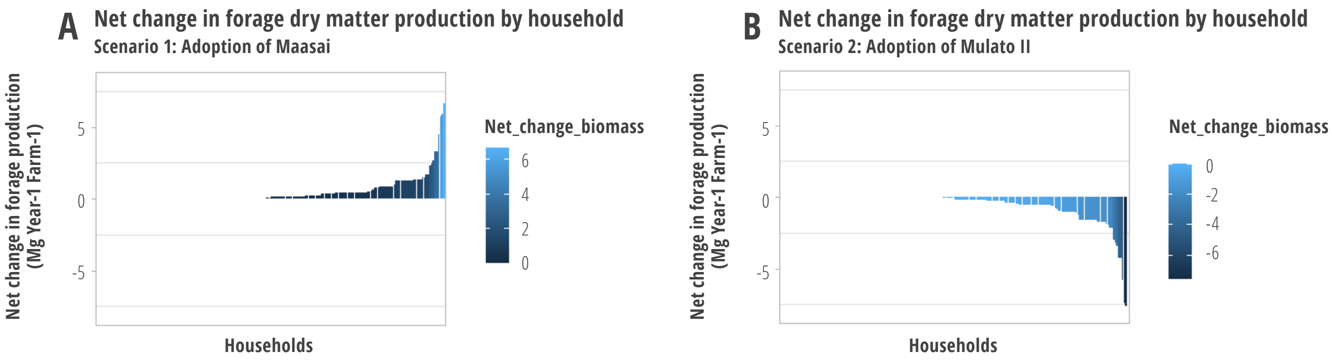
Based on the reported values for forage cultivation area, the estimated annual forage dry matter production rates were calculated. Among the 114 households that specifically set aside land for forage crop cultivation, average Napier grass dry matter productivity potential was 3.2 Mg/year. This rate of DM production varied significantly, with some households being able to produce up to 25 Mg per year (Fig. 6). For the households that produced milk, average Napier grass dry matter productivity potential was 2.6 Mg/year.

Figure 6. Estimated yields of Napier grass dry matter production by household.



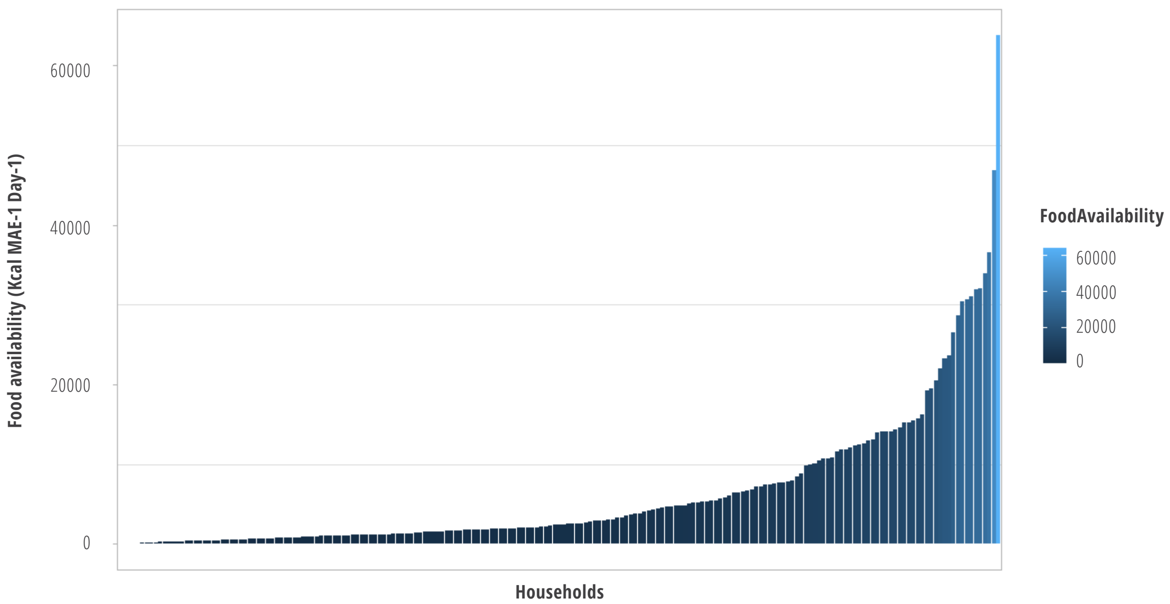
Average estimated dry matter yields of the two improved forage crops assessed displayed contrasting differences vis-à-vis Napier grass. Among households that cultivated forage crops, the estimated yields for Maasai forage were 0.8 Mg more on average than the annual dry matter yields of Napier grass. In some cases, estimated household potential yields for Maasai were greater than 5 Mg/year/farm vis-à-vis Napier grass. For Mulato II, average potential yields for households that already cultivated forage crops were 1.0 Mg/year less than for Napier grass. In some cases, estimated annual yields were more than 6 Mg less than Napier grass estimated yields (Fig. 7).

Figure 7. Estimated net changes in forage grass dry matter production per year, per household by forage grass A) Maasai, and B) Mulato II.



The mean food availability across the study sites was 6,339 kcal/MAE/day. This value varied from 2,458 kcal/MAE/day at the 5th percentile to 26,912 kcal/MAE/day at the 95th percentile. Among households that sold milk, food availability was nearly twice as high as the overall average (8,847 kcal/MAE/day) (Fig. 8).

Figure 8. Food availability by household.



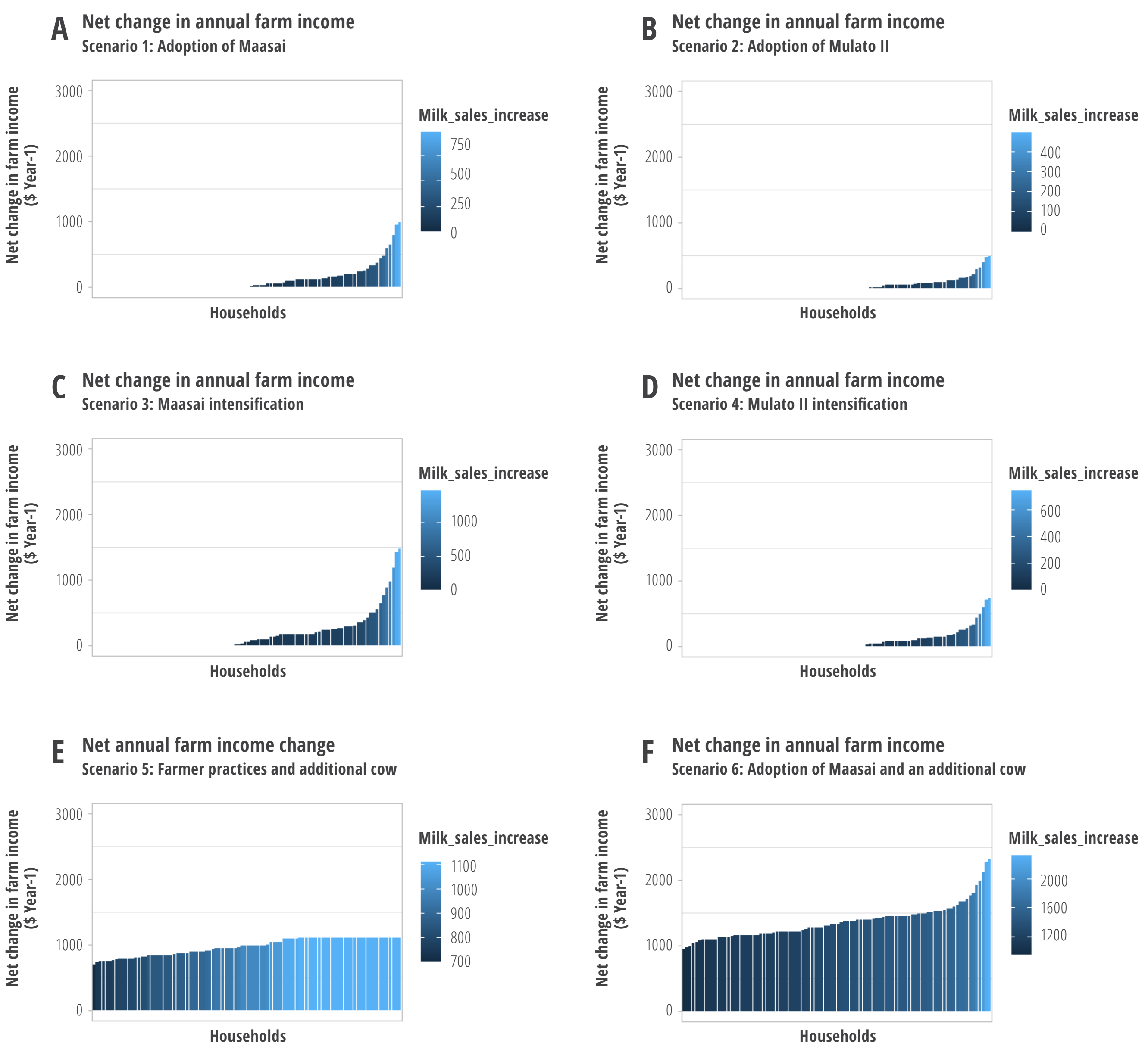
3.2. Scenario modeling

Under scenario 1, in which farming households planted Maasai forage instead of Napier grass, the 96 households that produced cattle milk made US$111 more on average in annual farm income due to the associated increases in milk production with Maasai forage. This represented an increase of 6% compared to the previous farm income levels of the cattle milk-producing households. In scenario 2, in which farming households planted Mulato II forage grasses, milk-selling households generated US$52 (3%) more on average annually compared to current practices (Fig. 9).

Under scenario 3, in which farming households planted Maasai forage instead of Napier grass and increased the use of cut forage in the feed basket to 100%, the 96 households that produced cattle milk made US$177 more on average in annual farm income. This represented an increase of 10% compared to the previous farm income levels of the cattle milk-selling households. In scenario 4, in which farming households planted Mulato II forage grasses and increased the use of cut forage in the feed basket to 100%, milk-producing households generated US$79 (4%) more on average annually compared to current practices (Fig. 9).

In scenario 5, in which households used the current farm practice for feeding cattle (Napier grass) but incorporated an additional milking cow into their livestock herd, there was an average increase in net income of US$971 due to the additional milk sales. This represents a 54% increase in farm income. For milk-producing households under scenario 6, with the incorporation of an additional cow and the planting of Maasai forage, average annual farm income increased by US$1,363, an increase of 75% (Fig. 9).

Figure 9. Net changes in annual household farm income due to changes in milk production under six scenarios: A) Scenario 1, B) Scenario 2, C) Scenario 3, D) Scenario 4, E) Scenario 5, and F) Scenario 6. (Plots include results for only the 96 households that produce milk).

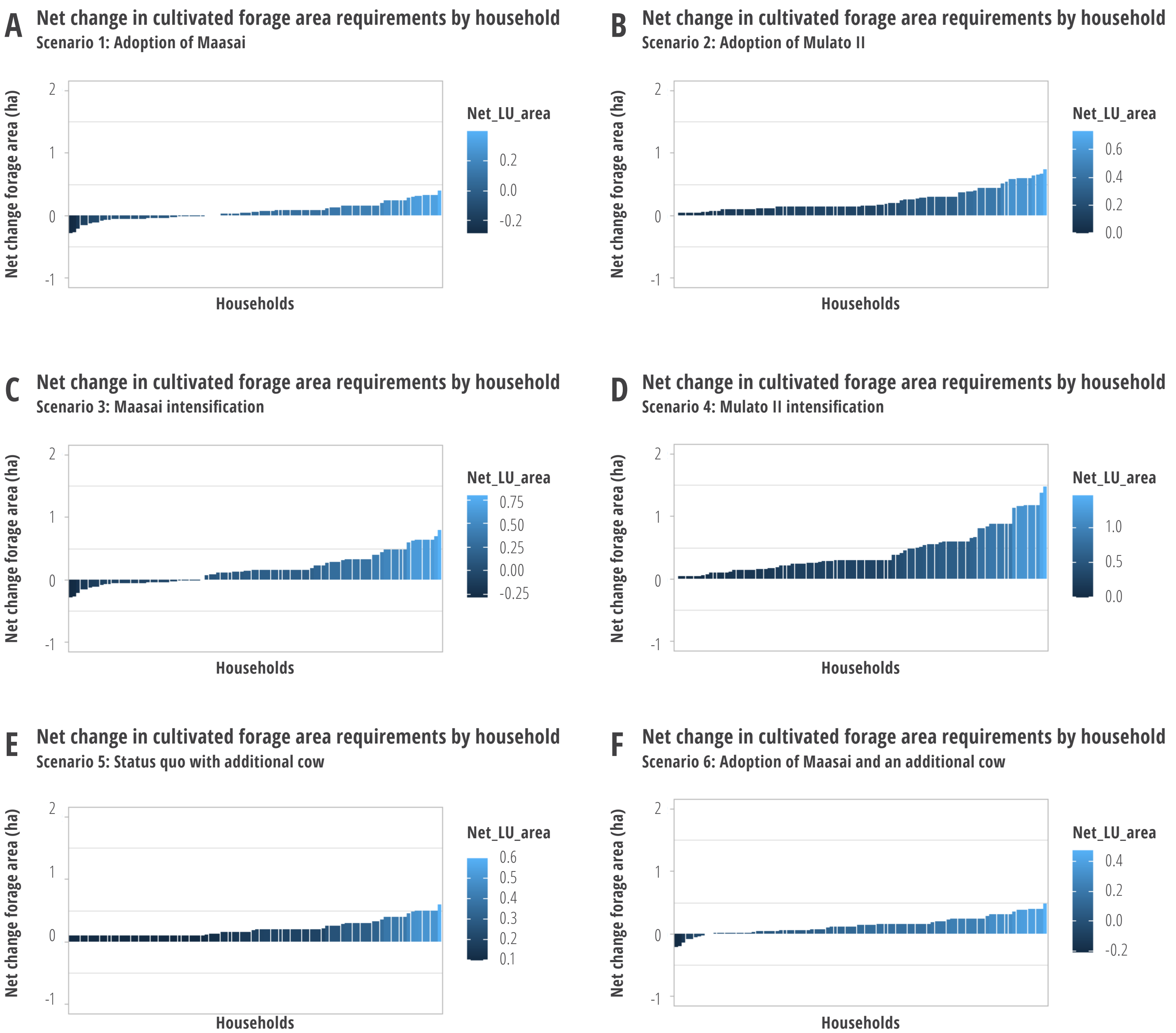


Despite the increased yield potential of Maasai forage, scenario 1 saw a net increase in cultivated forage area requirements of 0.03 ha vis-à-vis the current forage land area used by milk-selling farming households due to the need to meet the minimum forage requirements for the dairy cows. This equated to a 13% increase in required forage area. Under scenario 2, milk-selling households needed to increase their cultivated forage area by 0.24 ha on average because of the lower yields associated with Mulato II grass and the higher cut forage requirements for increased milk production. This equated to a 109% increase in forage land area requirements (Fig. 10).

In scenario 3, increased cut forage requirements due to increasing the cut forage proportion of the feed basket to 100% meant that cultivated forage area requirements increased by 0.12 ha or 55%. Under scenario 4, cultivated forage area requirements rose by 0.41 ha (more than 185%) (Fig. 10).

Under scenario 5, the area of required land for forage cultivation for an additional dairy cow increased by 0.17 ha across all farms, equating to a 77% increase in required forage land area. For households that already sold milk, the increase in forage land area was limited to 0.11 ha. In scenario 6, on the other hand, the net forage land area requirement for an additional dairy cow increased by just over 0.11 ha because of the trade-off in gains in biomass yield of Maasai forage and the requirement for more cut forage. For farms that sold milk, this figure was just under 0.11 ha, equating to a 50% increase in land area dedicated to forage crop cultivation. It is noteworthy that 7 of the 50 households selling milk would experience a net decrease in forage area land requirements under this scenario. This means that, despite the incorporation of an additional dairy cow, the yield benefits of adopting Maasai forage would still enable farms to produce more than enough dry matter to cover the feed requirements of the additional cow (Fig. 10).

Figure 10. Net changes in cultivated forage area requirements by household under six scenarios A) Scenario 1, B) Scenario 2, C) Scenario 3, D) Scenario 4, E) Scenario5, F) Scenario 6. (Plots include results for only the 96 households that produce milk).

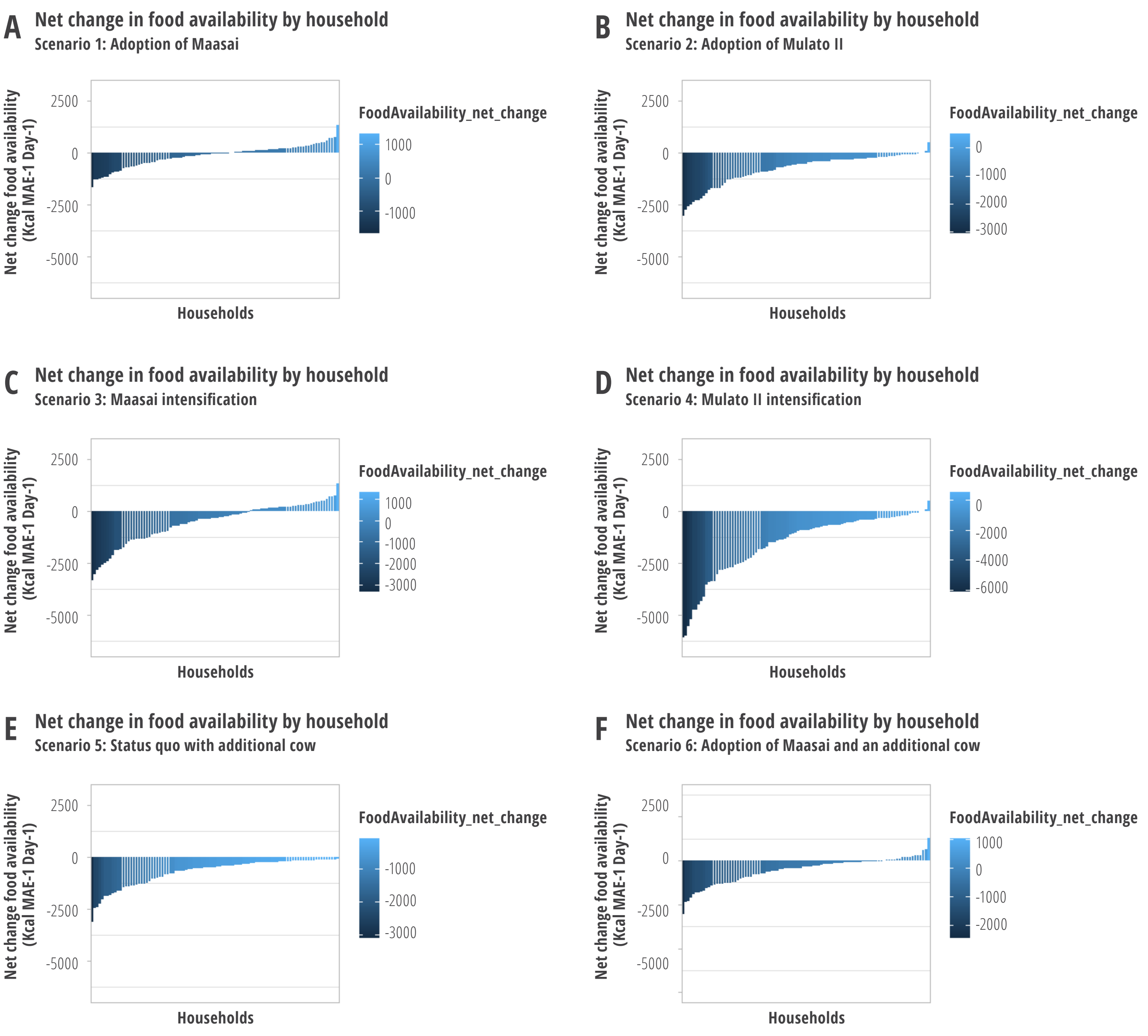


Food availability decreased by 149 kcal/MAE/day overall under scenario 1 for milk-selling households, for which land area requirements for forage crop production increased due to the increase in forage area requirements and the consequent decrease in the area used for the cultivation of the staple food crop (maize). This equated to only a 2% decrease in food availability for these households. It is noteworthy that approximately 44% of the milk-producing households (42) experienced an increase in food availability due to the countervailing effect of increased Maasai forage yield. For scenario 2, food availability decreased across all milk-selling households by an average of 778 kcal/MAE/day. This equated to a 9% decrease in food availability. However, it is notable that two households experienced a slight increase in food availability due to the increase in milk consumption (Fig. 11).

Milk-producing households under scenario 3 saw an overall decrease in food availability of 552 kcal/MAE/day (a decrease of 6%). Similar to scenario 1, however, it is noteworthy that a proportion of these households (35%) experienced a net positive effect on food availability under this scenario. For scenario 4, on the other hand, average food availability decreased across the board by an average of 1,518 kcal/MAE/day, or 17% (Fig. 11).

For scenario 5, in which households had to plant forage crops instead of staple food crops to feed the additional dairy cow, food availability decreased by 715 kcal/MAE/day. This was equivalent to an 8% decrease in food availability. Scenario 6 saw a decrease in food availability of 436 kcal/MAE/day (5%). Notably, 18 milk-selling farms managed to increase food availability under scenario 6 despite incorporating an additional dairy cow into their livestock herd (Fig. 11).

Figure 11. Net changes in food availability by household under six scenarios A) Scenario 1, B) Scenario 2, C) Scenario 3, D) Scenario 4, E) Scenario5, F) Scenario 6. (Plots include results for only the 96 households that produce milk.)



4. Discussion

4.1. Maasai grass, a pathway to higher livestock productivity and farm income

As hypothesized, all scenarios involving the use of alternative forage crops and greater proportions of forage crop in the feed basket led to important increases in farm income of from 3% to 10% in farming households that already produced cattle milk. In the scenarios in which an additional dairy cow was incorporated into the livestock herd, the increases in farm income were seen to be even higher, from 54% to 75% (Fig. 9). Given that Maasai grass was associated with the highest amounts of milk production in dairy cows (Appendix 1), scenario 6, in which an additional dairy cow was coupled with the use of Maasai grass forage, displayed the highest increase in annual farm income (US$1,363). These findings mirror other findings in the region that have observed important benefits in the use of alternative forage crops (Ghimire et al., 2015; Paul et al., 2020a, 2020b; Rao et al., 2015).

However, although all scenarios led to increases in farm income, these increases were coupled with changes in land-use distribution between forage crops and staple food crops (Fig. 10), in many cases leading to important decreases in food availability (Figs. 11 and 12). Given the positive association between food availability and other more direct measurements of food security such as FIES and HDDS, such changes in food availability may indicate worrisome trade-offs between farm income and household welfare under some scenarios (Hammond et al., 2017). In particular, the scenarios that involved the use of Mulato II forage crops instead of the current farmer practice displayed negative effects on food availability ranging between an average decrease in food availability of 9% (scenario 2) and 17% (scenario 4) (Figs. 11 and 12). Furthermore, the incorporation of an additional dairy cow into the livestock herd led to important decreases in food availability by 8% (scenario 5) and 5% (scenario 6).

Notwithstanding these trade-offs, under the two scenarios in which Maasai grass was used as the alternative forage crop (scenarios 1 and 3), the increased yield potential of Maasai meant that for 35-45% of the milk-producing farming households the increases required to feed their dairy cattle with 48% cut forage (scenario 1) or 100% cut forage (scenario 3) were offset by the increases in forage yield, leading to net positive effects on food availability (Fig. 12). Moreover, under scenario 6, in which Maasai forage was used and an additional cow was incorporated into the livestock herd, for 18 households that previously produced milk, the overall net effect on food availability remained positive (Fig. 12).

These results suggest that, for approximately 20% of the population of farming households surveyed (40% of the milk-producing households), the use of Maasai grass as an alternative forage not only provides a pathway toward improved livestock productivity and farm income (up to 10%); these benefits are also coupled with potential benefits to food security. In a minority of cases (18 farming households), this win-win scenario could be achieved while also incorporating an additional dairy cow into the livestock herd, presenting potential farm income gains of 75% while still having net positive effects on food availability. Based on this scenario modeling, we can therefore conclude that improved forages such as Maasai could play a very important role in East African smallholder farming systems in increasing farm productivity and income while ensuring fewer negative trade-offs with other critical components of the well-being of rural households such as food security.

4.2. Trade-offs of potential benefits of improved forage grasses

Although our results underlined the promising potential impacts for the larger scale use of improved forages such as Maasai, they also revealed some important barriers to some households taking these pathways to greater productivity and farm income. Importantly, our rural household survey indicated that only around half of the households produce cattle milk already. This suggests that the other half of the households in the study area are unlikely to be prepared for the commercial production of cattle milk from a farm infrastructure and capital perspective, or from a marketing perspective in terms of social connections and networks with cooperatives and traders. In other words, for farming households such as these to reap the potential benefits offered by improved forage grasses such as Maasai, these farms would have to undergo significant systemic changes, something that is unlikely to happen without important external investments. This reflects the findings in other studies that have emphasized the fact that improved feeding needs to be coupled with several fundamental and systemic shifts in approach to farm and livestock management such as improved access to drinking water and veterinary services, and improved animal husbandry practices (Ndah et al., 2017). Indeed, livestock intensification may not be the priority for many livestock owners. Other roles played by cattle, such as draught power, assets, and risk management, as well as cultural reasons may be more important to the farming households than value production (Descheemaeker et al., 2016; Sumberg and Lankoande, 2013). In such cases, fundamental changes in livestock management approaches may not even be desirable.

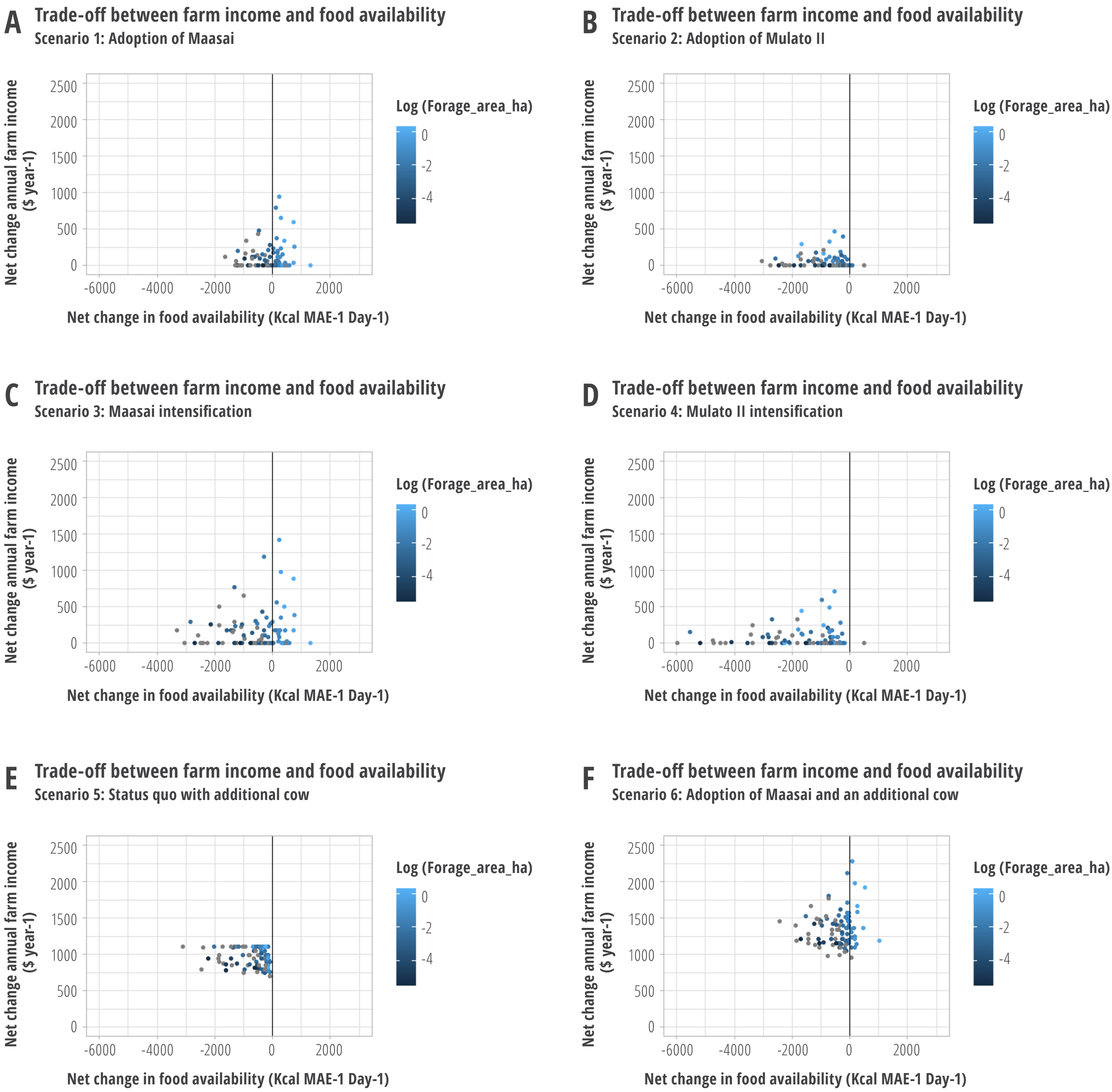
Nelly Adhiambo milking her cows in Busia, Kenya. She has seen the benefit of new forages grasses as a result of the Grass to Cash.

She has increased her milk production in Busia, Kenya as a result of grasses introduced in the Grass to Cash.

Moreover, the potential to benefit from improved forage grasses also seemed to depend upon whether farming households already cultivated forage grasses. Those that did tended to have larger areas of land cultivated overall and also a greater amount of land dedicated to forage grasses (Figs. 5 and 12). The consequences of this asymmetry are borne out under the modeling for scenarios 1, 3, and 6, in which food availability was seen to both increase and decrease depending on the net change in area of cultivated forage. For those households that already had access to sufficient areas of land for forage grass cultivation, increased farm income generated by greater milk production associated with the use of improved forage grasses was coupled with increases in food availability (Fig. 12). However, for households that did not have access to sufficient forage grass land, important decreases in food availability were found (Fig. 12). This reflects the findings of another study from Kenya assessing the determinants of forage adoption among smallholders. In that study, a positive correlation was found between farm size and the adoption of forage grasses (Njarui et al., 2017).

Overall, this suggests that the pathway toward greater livestock productivity and farm income through the cultivation of improved forage grasses may be open, or even desirable, only to those farming households that already produce cattle milk, and that have sufficient land to cultivate forage grasses while at the same time satisfying their food security requirements.

Figure 12. Trade-off visualization between net changes in food availability (x-axis) and farm income (y-axis) by cultivated forage area presented on a log scale to emphasize differences (colored dots) under six scenarios A) Scenario 1, B) Scenario 2, C) Scenario 3, D) Scenario 4, E) Scenario5, F) Scenario 6. (Plots include results for only the 96 households that produce milk.)



Researchers measure and weigh forage grasses in field trials to find better forage feed varieties.

5. Conclusions

The straightforward replacement of Napier grass with Maasai forage in the farming systems that already produce cattle milk has the potential to increase farm income by 6-10% when dairy cows are fed 100% with Maasai grass. The land-use savings coupled with the higher yield potential of Maasai forage also make it feasible for around half of these milk-producing farming households to benefit from net increases in food availability, suggesting that their food security would also increase under these scenarios. Even under the scenario in which an additional dairy cow was incorporated into the farming system, the yield benefits of Maasai grass were able to offset the increased cut forage feed requirements for a small minority of farming households, thus raising farm income by 75% while still providing for negligible, or even positive, effects on food availability. Although these potential benefits will not be accessible to all farming households in the region because of the lack of access to land and the need for more systemic changes in farming systems, our data suggest that these potential benefits might be achievable by approximately 20% of the farming households.

Acknowledgments

We are grateful to our CIAT colleagues Solomon Mwendia, An Notenbaert and Ruth Odhiambo who provided insights informing key assumptions, and James Hammond for feedback and assistance in analysis. The teams from Send a Cow in Kenya (Isaac Ogutu, Alfred Juma) and Ethiopia (Mesfin Zenebe) provided crucial support in field logistics during data collection. Thanks to the survey respondents for their time and willingness to participate in the study. This research received financial support from the German Federal Ministry for Economic Cooperation and Development (BMZ) commissioned and administered through the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) Fund for International Agricultural Research (FIA), grant number 81219431. The work was carried out as part of the CGIAR Research Program on Livestock. We thank all donors who globally support our work through their contributions to the CGIAR System.

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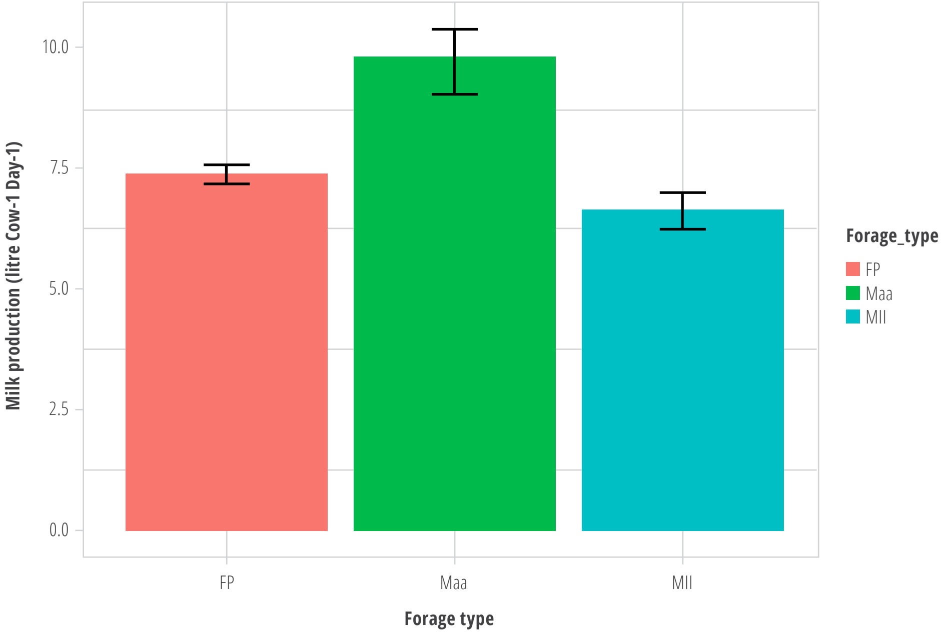
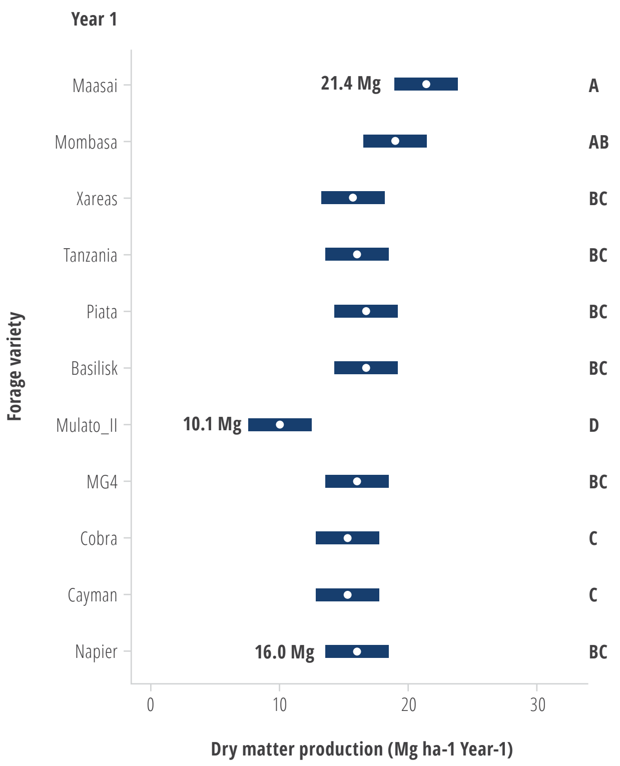
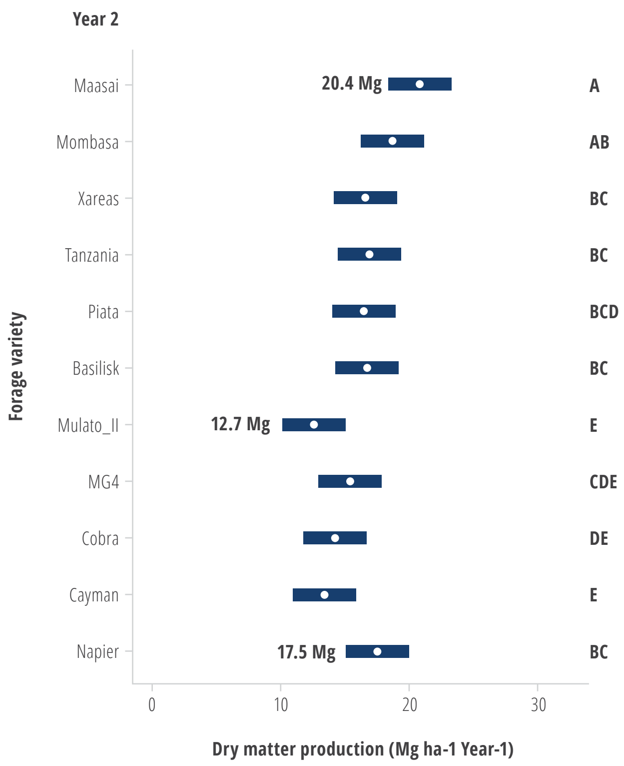
Appendix 1
Milk production by forage grass



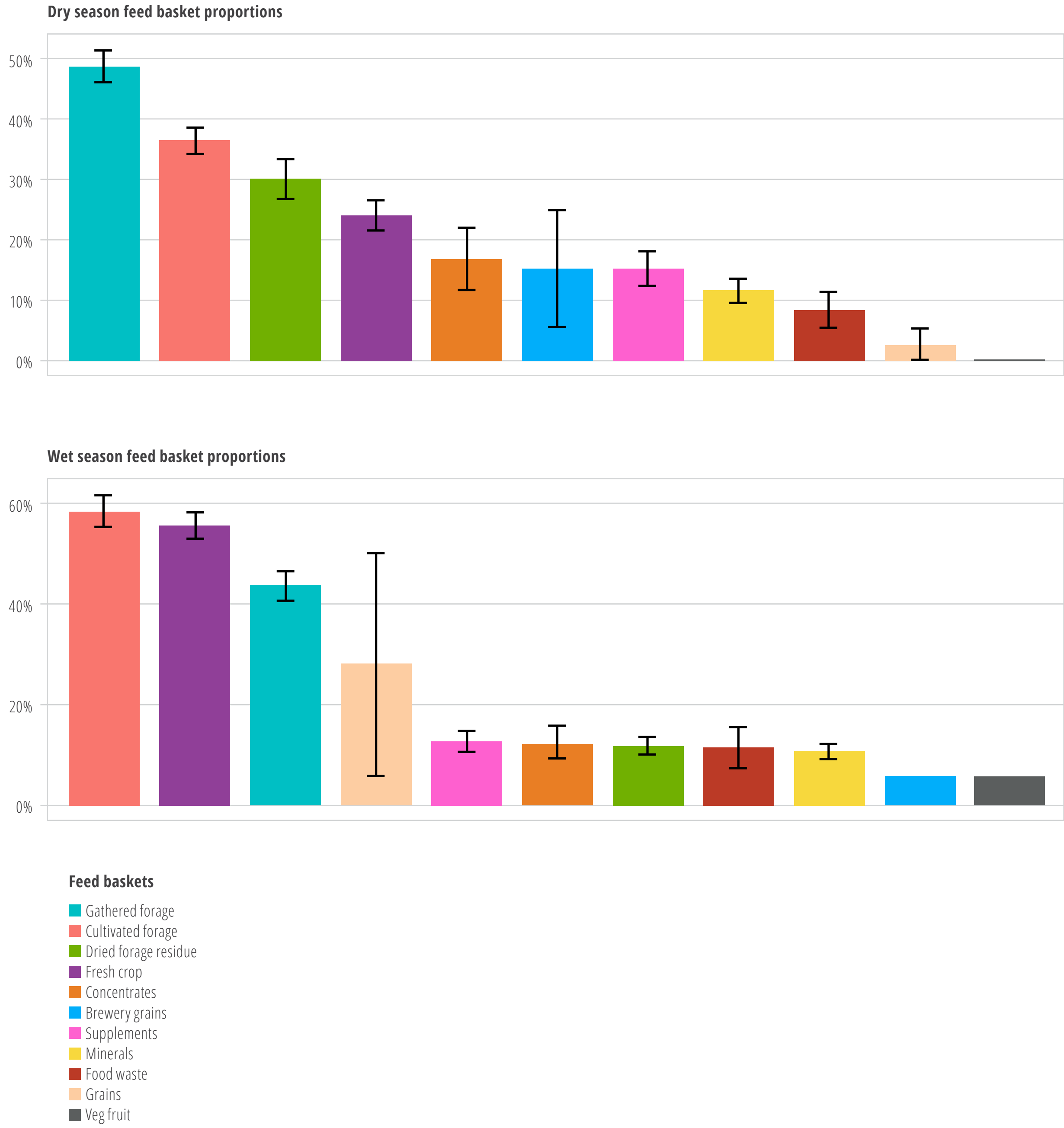
Comments: In a personal communication from the scientist that undertook this research, it was explained that the low milk production levels for the Mulato II experimental treatment might be attributable to inconsistent cattle feeding by the farmers in situ. As such, and aligned with other scientific studies on the effects of Mulato II forage on milk production (e.g., Mwendia et al., n.d., in preparation), it was decided to set the maximum potential milk production increases from the feeding of Mulato II grass to dairy cows at 15% (100% feed basket – scenario 4). For the scenario in which current feed basket proportions were maintained (48%), the potential increase in milk production was set at 10% (scenario 2). For Maasai grass, the maximum potential milk production increases were set at 30% (scenario 3), while the potential milk production increases under current feed basket proportions were set at 20% (scenario 1).

Appendix 2
Forage grass production by year





Appendix 3
Feed basket composition by season



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