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Agricultural Management for Climate Change Adaptation, Greenhouse Gas Mitigation, and Agricultural Productivity

Insights from Kenya

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ABSTRACT

Changes in the agriculture sector are essential to mitigate and adapt to climate change, ensure food security for the growing population, and improve the livelihoods of poor smallholder producers. What agricultural strategies are needed to meet these challenges? To what extent are there synergies among these strategies? This paper examines these issues for smallholder producers in Kenya. Several practices emerge as *triple wins* in terms of climate adaptation, GHG mitigation, and productivity and profitability. In particular, integrated soil fertility management and improved livestock feeding are shown to provide multiple benefits across the agroecological zones examined. In addition, irrigation and soil and water conservation are also shown to be essential in the arid zone. The results suggest that agricultural investments targeted towards triple-win strategies will have the greatest payoff in terms of increased resilience of farm and pastoralist households to climate change, rural development, and climate change mitigation for generations to come.

Keywords: climate change, mitigation, adaptation, resilience, synergies, agricultural land management, livestock feeding

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ABBREVIATIONS AND ACRONYMS

AEZ	agroecological zone
ALRMP	Arid Lands Resource Management Project
CDM	Clean Development Mechanism
ASAL	Arid and Semi-Arid Lands
BAP	Best Agricultural Practices
DM	dry matter
GHG	greenhouse gas
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
MRV	measurement, reporting, and verification
NAMA	nationally appropriate mitigation action
KARI	Kenya Agricultural Research Institute
NGO	nongovernmental organization
ODA	official development assistance
OPV	open-pollinated varieties
PRA	participatory rural appraisal
SCS	soil carbon sequestration
SALM	Sustainable Agricultural Land Management
SLM	sustainable land management
SOC	soil organic carbon
SSA	Sub-Saharan Africa
SWC	soil and water conservation
VCS	voluntary carbon standard

1. INTRODUCTION AND BACKGROUND

The international community faces great challenges in the coming decades including reining in global climate change, ensuring food security for the growing population, and promoting sustainable development. Changes in the agriculture sector are essential to meeting these challenges. Agriculture provides the main source of livelihood for the poor in developing countries, and improving agricultural productivity is critical to achieving food security as well as most of the targets specified under the Millennium Development Goals (Rosegrant et al. 2006). Agriculture also contributes a significant share (14 percent) of greenhouse gas (GHG) emissions, more if related land-use change (particularly deforestation) is included (WRI 2010). At the same time, long-term changes in average temperatures, precipitation, and climate variability threaten agricultural production, food security, and the livelihoods of the poor. While mitigation of GHG emissions can lessen the impact of climate change, adaptation to climate change will be essential to ensure food security and protect the livelihoods of poor farmers.

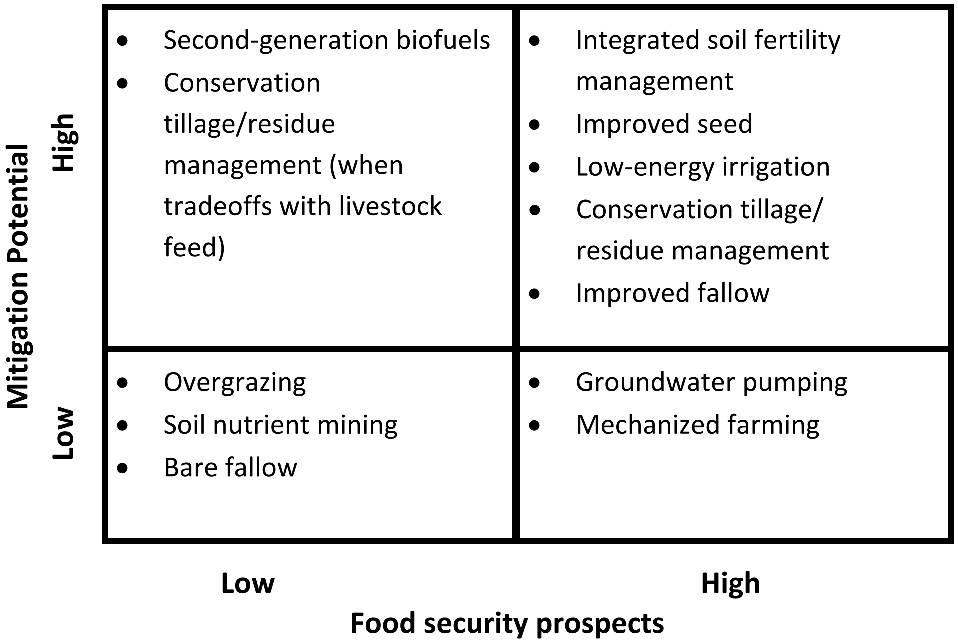
Countries in Sub-Saharan Africa (SSA) are particularly vulnerable to climate change impacts because of their limited capacity to adapt. The development challenges that many African countries face are already considerable, and climate change will only add to these. At the same time, the economic potential for mitigation through agriculture in the African region is estimated at 17 percent of the total global mitigation potential for the sector. Moreover, the economic potential of agricultural GHG mitigation is highest in East Africa, at 41 percent of total potential (Smith et al. 2008).

In Kenya, where the poverty rate is 52 percent (World Bank 2010) and 70 percent of the labor force depends on agricultural production for its livelihood (FAO 2010), poor farmers are likely to experience many adverse impacts from climate change. Therefore, efforts to facilitate adaptation are needed to enhance the resilience of the agricultural sector, ensure food security, and reduce rural poverty.

Adaptation not only is needed to increase the resilience of poor farmers to the threat of climate change, but it also offers co-benefits in terms of agricultural mitigation and productivity. That is, many of the same practices that increase resilience to climate change also increase agricultural productivity and profitability and reduce GHG emissions from agriculture. However, there may also be tradeoffs between increasing farm productivity and profitability, adaptation to climate change, and mitigation of GHGs. To maximize the synergies and reduce the tradeoffs implicit in various land management practices affecting crop and livestock production, a more holistic view of food security, agricultural adaptation, mitigation, and development is required. Mitigation, adaptation, and rural development strategies should be developed together, recognizing that in some cases hard decisions will need to be made among competing goals. Policymakers should aim to promote adaptation strategies for agriculture that have the greatest co-benefits in terms of agricultural productivity, climate change mitigation, and sustainable development.

There is little research to date on the synergies and tradeoffs between agricultural adaptation, mitigation, and productivity impacts. FAO (2009) differentiates between activities with high versus low mitigation potential and those with high versus low food security prospects (Figure 1.1). We suggest instead a framework differentiating tradeoffs and synergies among GHG mitigation, agricultural productivity and profitability, and adaptation to climate change (Figure 1.2).

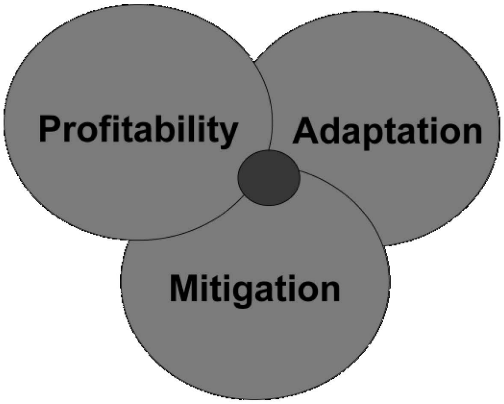
Figure 1.1—Mitigation potential and food security prospects of selected activities



Mitigation Potential	Food security prospects: Low	Food security prospects: High
High	Second-generation biofuels Conservation tillage/residue management (when tradeoffs with livestock feed)	Integrated soil fertility management Improved seed Low-energy irrigation Conservation tillage/ residue management Improved fallow
Low	Overgrazing Soil nutrient mining Bare fallow	Groundwater pumping Mechanized farming

Source: Adapted from FAO (2009).

Figure 1.2—Synergies and tradeoffs among climate change adaptation, greenhouse gas mitigation, and agricultural profitability and productivity



Source: Authors.

Table 1.1 lists several of the land management practices and adaptation strategies discussed in the literature and the implications of these practices for farm productivity and profitability, climate adaptation, and GHG mitigation following our conceptual framework. The number and variety of options reported suggests that there are many promising strategies available to farmers in Kenya and elsewhere in SSA.

Table 1.1—Synergies and tradeoffs between productivity, climate change adaptation, and greenhouse gas mitigation

Management practice	Productivity impacts	Climate adaptation benefits	Greenhouse gas mitigation potential
Cropland management			
Improved crop varieties or types (early-maturing, drought resistant, etc.)	Increased crop yield and reduced yield variability	Increased resilience against climate change, particularly increases in climate variability (prolonged periods of drought, seasonal shifts in rainfall, and the like)	Improved varieties can increase soil carbon storage
Changing planting dates	Reduced likelihood of crop failure	Maintained production under changing rainfall patterns, such as changes in the timing of rains or erratic rainfall patterns	
Improved crop/fallow rotation/rotation with legumes	Increased soil fertility and yields over the medium to long term due to nitrogen fixing in soils; short-term losses due to reduced cropping intensity	Improved soil fertility and water holding capacity increases resilience to climate change	High mitigation potential, particularly crop rotation with legumes
Use of cover crops	Increased yields due to erosion control and reduced nutrient leaching; potential tradeoff due to less grazing area in mixed crop–livestock systems	Improved soil fertility and water holding capacity increases resilience to climate change	High mitigation potential through increased soil carbon sequestration
Appropriate use of fertilizer and manure	Higher yields due to appropriate use of fertilizer/manure	Improved productivity increases resilience to climate change; potential greater yield variability with frequent droughts	High mitigation potential, particularly where fertilizer has been underutilized, such as in SSA
Incorporation of crop residues	Higher yields due to improved soil fertility and water retention in soils; tradeoff with use as animal feed	Improved soil fertility and water-holding capacity increases resilience to climate change	High mitigation potential through increased soil carbon sequestration
Reduced or zero tillage	Increased yields over the long term due to greater water-holding capacity of soils; limited impacts in the short term; tradeoff in terms of weed management and potential waterlogging	Improved soil fertility and water-holding capacity increases resilience to climate change	High mitigation potential through reduced soil carbon losses
Agroforestry	Greater yields on adjacent cropland due to improved rainwater management and reduced erosion	Increased resilience to climate change due to improved soil conditions and water management; benefits in terms of livelihood diversification	High mitigation potential through increased soil carbon sequestration

Table 1.1—Continued

Management practice	Productivity impacts	Climate adaptation benefits	Greenhouse gas mitigation potential
Soil and water management			
Irrigation and water harvesting	Higher yields, greater intensity of land use	Reduced production variability and greater climate resilience when systems are well designed and maintained	Low to high depending on whether irrigation is energy intensive or not
Bunds	Higher yields due to increased soil moisture; potentially lower yields during periods of high rainfall	Reduced yield variability in dry areas; potential increase in production loss due to heavy rains if bunds are constructed to retain moisture	Positive mitigation benefits minus soil carbon losses due to construction of bunds
Terraces	Higher yields due to increased soil moisture and reduced erosion; potential to displace some cropland	Reduced yield variability under climate change due to better soil quality and rainwater management	Positive mitigation benefits minus soil carbon losses due to construction of terraces
Mulching or trash lines	Increased yields due to greater water retention in soils	Reduced yield variability under drier conditions due to greater moisture retention	Positive mitigation benefits
Grass strips	Increased yields due to reduced runoff and soil erosion	Reduced variability due to reduced soil and water erosion	Positive mitigation benefits
Ridge and furrow	Increased yields due to greater soil moisture	Reduced yield variability in dry areas; possible increase in production loss due to heavy rains	Positive mitigation benefits minus initial losses due to construction of ridges and furrows
Diversion ditches	Increased yields due to drainage of agricultural lands in areas where flooding is problematic	Reduced yield variability under heavy rainfall conditions due to improved water management	Positive mitigation benefits through improved productivity and hence increased soil carbon
Management of livestock or grazing land			
Diversify, change, or supplement livestock feeds	Higher livestock yields due to improved diets	Increased climate resilience due to diversified sources of feed	High mitigation potential because improved feeding practices can reduce methane emissions
Destocking	Potential increases per unit of livestock; total production may decline in the short term	Lower variability over the long term, particularly when forage availability is a key factor in livestock output	High mitigation potential because reduced livestock numbers lead to reduced methane emissions
Rotational grazing	Higher yields due to greater forage availability and quality; potential short-term tradeoff in terms of numbers of livestock supported	Increased forage availability over the long term, providing greater climate resilience	Positive mitigation potential due to increased carbon accrual on optimally grazed lands
Improved breeds and species	Increased productivity per animal for the resources available	Increased resilience of improved species or breeds to withstand increasing climate extremes	Varies, depending on the breeds or species being traded

Table 1.1—Continued

Management practice	Productivity impacts	Climate adaptation benefits	Greenhouse gas mitigation potential
Restoring degraded lands			
Revegetation	Improved yields over the medium to long run; improved yields on adjacent cropland due to reduced soil and water erosion	Reduced variability due to reduced soil and water erosion	High mitigation potential
Applying nutrient amendments	Improved yields over the medium to long run		High mitigation potential

Sources: Adapted from FAO (2009); Smith et al. (2008).

In general, management practices that increase agricultural production and reduce production risk also tend to support climate change adaptation because they increase agricultural resilience and reduce yield variability under climate variability and extreme events, which might intensify with climate change. In Kenya, where annual average precipitation volumes are expected to increase with climate change, the greatest impacts on agricultural production are expected from changes in rainfall variability, such as prolonged periods of drought and changes in the seasonal pattern of rainfall (see Herrero et al. 2010). Therefore, adaptation strategies that reduce yield variability during extreme events, such as droughts or floods, or because of erratic rainfall or changing patterns of rain will provide the greatest benefit to farmers.

To a large extent, the same practices that increase productivity and resilience to climate change also provide positive co-benefits with respect to agricultural mitigation of GHGs. There are three main mechanisms for mitigating GHGs in agriculture: reducing emissions, enhancing removal of carbon from the atmosphere, and avoiding emissions through the use of bioenergy or agricultural intensification rather than expansion (Smith et al. 2008). Because there is a positive correlation between soil organic carbon and crop yield, practices that increase soil fertility and crop productivity also mitigate GHG emissions, particularly in areas where soil degradation is a major challenge (Lal 2004).

In Sub-Saharan African countries, such as Kenya, cereal yields have remained stagnant for decades due to continuous depletion of soil organic matter over time from unsustainable land management practices (Lal 2004). In such countries, sustainable land management (SLM) practices such as conservation tillage, cover cropping, water harvesting, agroforestry, and enhanced water and nutrient management can improve soil carbon sequestration (SCS), increase yields, and enhance resilience to climate change (Niggli et al. 2009). Agroforestry practices that produce high-value crops, providing an additional source of farm revenues, offer even more benefits (Verchot et al. 2007; FAO 2009). Thus, SSA has many options for sustainable intensification that offer *triple wins* in terms of climate adaptation, GHG mitigation, and productivity and profitability.

While these practices provide multiple benefits in most cases, there are sometimes some tradeoffs involved with respect to productivity and food security in the short term before long-term benefits can be reaped. For example, leaving crop residues on the field provides benefits in terms of crop yields, climate change resilience, and GHG mitigation through improved soil fertility and carbon sequestration; however, in parts of Kenya where residues are used as a feed supplement, there is a tradeoff with livestock production. Improved crop rotation and fallowing also involve short-term decreases in production due to decreases in cropping intensity. Weeding and waterlogging are the potential tradeoffs of reduced tillage, and production gains from this practice are minimal over the short term.

Other tradeoffs include the costs and risks involved in the restoration of degraded soils, in particular the short-term costs of labor and nutrients, while yields tend to improve only in the medium to long term. Moreover, in the short term, agroforestry practices can also displace some cropland without providing additional benefits, at least during the establishment period. Poor subsistence farmers may not be willing or able to accept the short-term losses associated with some of these practices despite the long-term benefits.

Furthermore, agricultural practices that have benefits for climate change adaptation or productivity enhancement may increase GHG emissions. For instance, expanding agricultural production, a reported adaptation strategy, can increase total farm production and provide benefits in terms of adaptation; however, the cultivation of new lands that were previously under forest, grasslands, or other nonagricultural vegetation can release additional GHGs. In many cases, fertilizer application can also result in increased emissions. This is the case in some regions, such as Asia, where fertilizer application rates are already high. However, fertilizer use in much of SSA is so low that increased application in these areas is likely to mitigate climate change rather than increase emissions. In fact, the benefits of appropriate fertilizer use in SSA are immense—a study of maize and bean yields over an 18-year period in Kenya showed dramatic increases when crop residues were retained and fertilizer and manure were applied to the soils (Kapkiyai et al. 1999). Therefore, increased fertilizer application (in conjunction with soil fertility management) in this context reduces soil mining and supports mitigation, adaptation, and agricultural productivity.

It is important to note that the benefits and tradeoffs discussed above are location specific. Strategies that afford triple wins in dry areas will not offer the same benefits– and in fact may not be appropriate– in other locations. For instance, soil bunds constructed to conserve soil moisture in dry areas would not be appropriate and may in fact increase yield variability in areas with higher rainfall. Conversely, structures constructed to support drainage in high-rainfall areas, such as diversion ditches, would not be appropriate in dry areas. In addition, adopting new farm practices or technologies requires knowledge and experience. Farmers who lack access to information may experience greater yield variability in the short term as they experiment with the new practice.

Moreover, farm decisions do not depend solely on the benefits and tradeoffs involved in various management practices. Rather, farmers must consider the resources needed to implement new practices and technologies on their farms. Thus, while there appear to be many practices available to farmers that provide multiple benefits in terms of productivity, adaptation, and mitigation, the extent to which farmers in Kenya are adopting these practices will vary based on farm household characteristics, the biophysical and socioeconomic environment, and the rural services and incentives associated with the various management practices.

Although it is generally assumed that many efforts toward agricultural mitigation of GHGs will reduce agricultural productivity, in the context of SSA, agricultural practices that offer multiple benefits in terms of climate adaptation, GHG mitigation, and agricultural productivity dominate. Furthermore, linking smallholder farmers to voluntary carbon markets—though fraught with difficulties—can have a large monetary payoff (estimated at up to US$4.8 billion[1] per year for SSA as a whole) if implemented successfully (Bryan et al. 2010). While this does not meet the investment requirements for agriculture in the region, it is an important source of financing and should be used to support agricultural practices that offer the greatest co-benefits. Other potential sources of financing include global multilateral climate funds, official development assistance (ODA) and national investments aimed at sustainable agricultural practices, and programs of payment for environmental services.

This paper examines the extent to which there are synergies between agricultural productivity, climate change adaptation, and GHG mitigation, and it highlights where tradeoffs exist for arid, semiarid, temperate, and humid areas in Kenya. In order to facilitate a comparison of the linkages between management practices that enhance farm productivity, resilience to climate change, and agricultural GHG mitigation, we present the land and livestock management practices as well as adaptation strategies currently employed by farmers. The synergies and tradeoffs with regard to the adaptation potential, GHG mitigation potential, and productivity potential of the various sustainable intensification practices and other adaptation options are then assessed. Such analysis can help policymakers identify the policy levers that are available and effective in achieving these multiple objectives for different agroecological zones (AEZs) in Kenya and beyond.

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[1] All dollar amounts are in U.S. dollars.

2. METHODOLOGY

Household Survey

To identify and assess ongoing and alternative household-level and collective adaptation strategies and land management practices, a total 710 farm households were interviewed from July 2009 to February 2010 in 13 divisions within 7 districts in Kenya (see Table 2.1). The study sites were selected to illustrate the various settings throughout the country in which climate change and variability are having or are expected to have substantial impacts and where people are most vulnerable to such impacts, with the exception of the coastal area. Selection took into account AEZs, production systems (crop, mixed, and pastoralist systems), agricultural management practices, policy and institutional environments, and the nature and extent of exposure and vulnerability to climate change. Selection was also based on the existence or not of World Bank–supported projects for climate change adaptation and GHG mitigation. The selected sites are drawn from a range of AEZs including arid, semiarid, temperate, and humid.[2]

Table 2.1—Study sites

Project	District	Division	Agroecological zone	No. of households
Arid Lands Resource Management Project (ALRMP) and control*	Garissa	Central	Arid	66
		Sankuri	Arid	68
ALRMP	Mbeere South	Gachoka	Semiarid	76
		Kiritiri	Semiarid	21
Control	Njoro	Lare	Semiarid	104
Sustainable Management Services (SMS)/Ecom Agroindustrial Corporation, Ltd.	Mukurwe-ini	Gakindu	Temperate	47
		Mukurweini Central	Temperate	46
		Mukurweini East	Temperate	2
Control	Othaya	Othaya Central	Temperate	45
		Othaya North	Temperate	27
		Othaya South	Temperate	16
Vi Agroforestry	Gem	Wagai	Humid	96
Control	Siaya	Karemo	Humid	96
Total				**710**

Source: Authors.
Note: *In Garissa, project and control households were selected from within the same administrative units. Project households were identified by project officers.

The household survey collected information on demographic characteristics; socioeconomic status (wealth, income sources, and so on); social capital (for example, organizational links); land tenure; crop and livestock management; input use and expenses; productive investments; food consumption patterns and expenditures; access to information, extension, technology, markets, and credit; coping responses to climate shocks; perceptions of climate change; adaptation options undertaken today; and constraints to adaptation. Data for Garissa and Siaya were collected at the end due logistical and climate problems including the drought and flood events that occurred in these districts, respectively, during the time of the survey.

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[2] Coastal areas were not surveyed.

Analytical Methods

Descriptive results of the land management and adaptation strategies employed by survey households are presented by AEZ. Econometric analysis was used to examine the impact of agricultural management strategies on plot productivity using the mean-variance method of Just and Pope (1979). The yields of three main crops grown in the study areas (maize, beans, and coffee) were used as a measure of productivity, and the variance of yield of these crops was used to demonstrate production risk. Land management practices used on more than five percent of plots for each particular crop were selected for the analysis. Although only one adaptation strategy—use of an improved crop variety—was captured in this analysis (because it was the only one available for plot-level analysis), this was also the main adaptation strategy adopted by households in response to perceived climate change. Value of production at the plot level, which incorporates all crops grown on the plot, was also used instead of crop yield to check the robustness of the results and to address problems related to intercropping.

Furthermore, a crop simulation model (DSSAT-CENTURY) was used to estimate the potential dynamic changes of the soil carbon pool under different management practices as well as two different climate change scenarios. We also simulated maize yields under different permutations of seven management practices (two variety choices, fertilizer application, manure application, residue management, rotation with beans, soil and water conservation (SWC) techniques, and supplementary irrigation) and two sets of climate projections out to 2050 (CSIRO-Mk3.0 and MIROC3.2 to represent a possible dry and wet future climate, respectively, with the SRES A2 scenario) for each district using the CERES-Maize 4.5 model. In addition, we examined the potential impacts of improved feeding practices on the productivity and methane emissions of cattle using a ruminant simulation model housed at the International Livestock Research Institute (ILRI).

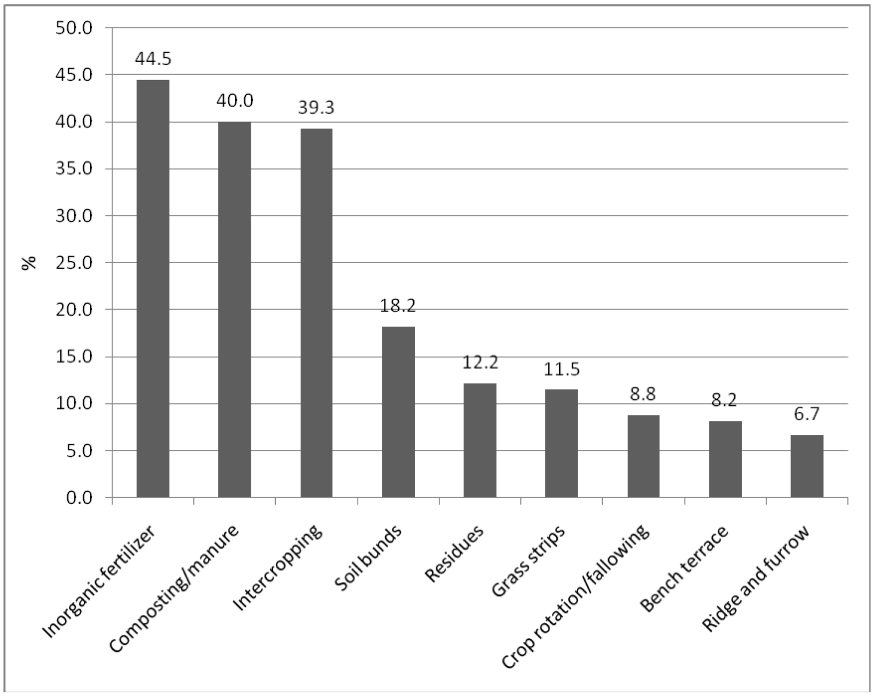
To examine the profitability of different management strategies, data on changes in soil carbon, yield, and livestock productivity from the crop and livestock simulation models were combined with information from the field survey and expert opinions to calculate gross profits for particular sets of management practices compared with a baseline case of no management. We then subtracted production costs (some taken from the survey data and others based on expert opinion) to determine net revenues for each management package to identify win–win–win strategies among agricultural adaptation to climate change, mitigation of GHGs, and profitability across AEZs for Kenya.

3. AGRICULTURAL MANAGEMENT PRACTICES AND CLIMATE CHANGE PERCEPTIONS

Common Land Management Practices

In order to assess the impact of land management practices on farm production, farmers were asked what management practices they are using on cropland and why they chose to adopt those practices, regardless of whether they were adopted as an adaptation strategy. Farmers provided a wide range of responses; those used on more than 5 percent of plots are shown in Figure 3.1. The most common practices employed by farmers included inorganic fertilizer (45 percent), composting or manure (40 percent), intercropping (39 percent), soil bunds (18 percent), residues (12 percent), and grass strips (12 percent).

Figure 3.1—Land management practices used on cropland



Source: Authors.
Notes: Only those practices used on more than 5 percent of plots are presented. Inorganic fertilizer and composting or manure are reported for seasonal crops only. (For perennial crops, inorganic fertilizer was used on 7 percent of plots and manure or composting on 12 percent of plots.) Other practices are reported for both seasonal and perennial crops. Residues indicates that the farmer used either mulching or trash lines.

Common reasons provided by farmers for adopting new management practices included increasing productivity, reducing erosion, increasing soil fertility, and increasing the water-holding capacity of the soil. Reducing erosion, increasing soil moisture, and improving soil fertility are key to increasing productivity in the AEZs studied. This indicates that while many of these practices provide co-benefits in terms of climate change adaptation and GHG mitigation, the farmers' main motivations for adopting new technologies and practices are their productivity impacts and immediate livelihood benefits. This finding is supported by other studies (Tyndall 1996; and Kiptot et al. 2007).

Livestock Feeding Practices

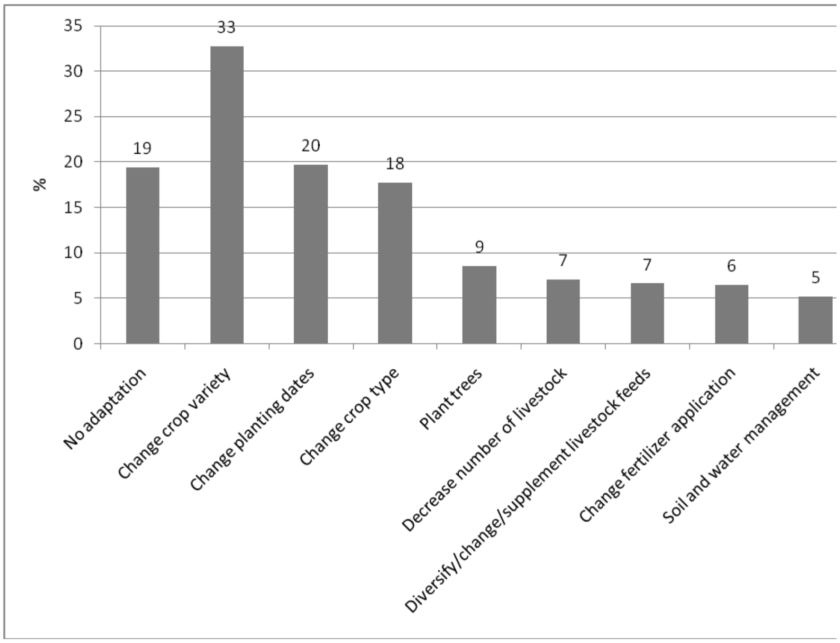
To assess the potential of changes in livestock feeding practices for agricultural mitigation of GHGs, households owning livestock were asked about the types of feeds used during different times of year. Households in the study sites have a homogeneous feeding management system for the different categories of animals. Short-distance rangelands are the primary source of feed during dry and wet seasons, while maize stover, roadside weeds, and cut-and-carry fodders represent other important sources of livestock feed. In general, households experience moderate feed deficits at the beginning of the year and between August and October. More than a third of livestock owners in the study, 36 percent, considered drought to be the key reason for changes in feed resource availability, followed by climate change. Land use change was identified by 18 percent of households as one of the main reasons for change in feed availability, particularly in those districts that have multiple land uses, such as Othaya.

In addition, livestock owners responded that some feed resources that were available 10 years ago are no longer available. Among those they listed were kikuyu grass (*Pennisetum clandestinum*), marer (*Cordia sinensis*), allan (*Lawsonia iner or Terminalia brev*.), deka (*Grevia tembensis)*, and haiya (*Wrightia demartiniana*). On the other hand, some new feed resources have become available over the last 10 years, in particular mathenge (*Prosopis juliflora,* known in North America as mesquite), napier grass (*Pennisetum purpureum*), desmodium (*Desmodium intortum*), and calliandra (*Calliandra calothyrsus*).

Adaptive Responses to Perceived Climate Change

Surveyed farmers had adopted a range of practices in response to perceived climate change (Figure 3.2). The most common responses included changing crop variety (33 percent), changing planting dates (20 percent), and changing crop type (18 percent). Other responses included planting trees (9 percent); decreasing the number of livestock (7 percent); diversifying, changing, or supplementing livestock feeds (7 percent); changing fertilizer application (7 percent); and SWC (5 percent).

Figure 3.2—Changes in agricultural practices reported by farmers in response to perceived climate change

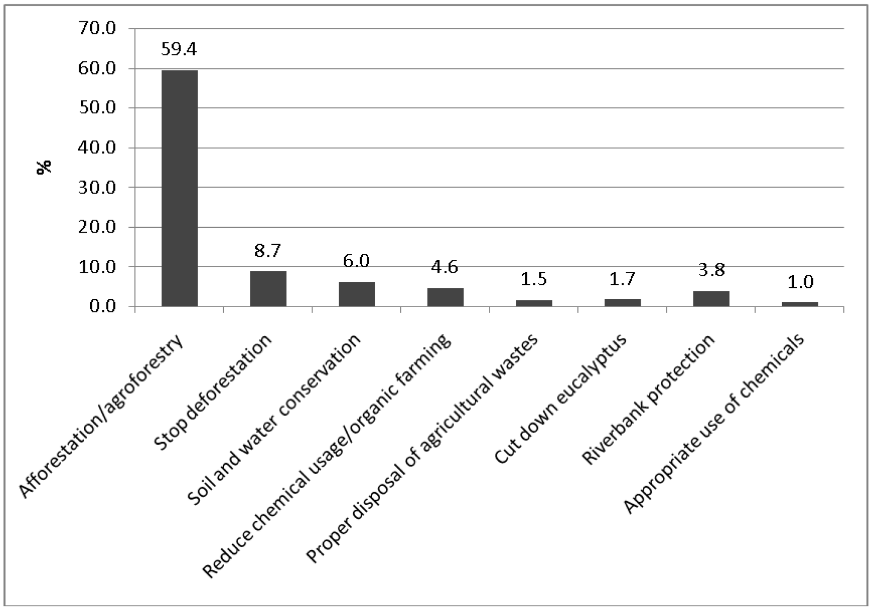


Source: Authors.
Note: Above adaptations only include options reported by more than 5 percent of farmers.

Perceptions of the Practices That Reduce Climate Change

When asked whether they were aware that agricultural practices contribute to climate change, 67 percent of farmers responded yes. Reasons for the high level of awareness likely include extensive media reports as well as government campaigns and speeches. Farmers who responded in the affirmative were then asked which agricultural practices reduce climate change. Results are presented in Figure 3.3. The responses showed that most farmers were aware of the connection between forests or trees and climate change. However, there was less awareness of the connection that other land management activities, as well as crop and livestock practices, have with climate change. Although nongovernmental organizations (NGOs) and government campaigns have contributed to this awareness, it is also traditionally believed that trees take up water from the soil and release it into the air to create clouds. In a companion study based on participatory rural appraisals (PRAs) conducted in some of the study sites, farmers in Njoro talked about the Mau forest as the source of rain and blamed the clearing of the forest for climate change (Roncoli et al. 2010). Fifty-nine and 9 percent of farmers reported that afforestation/agroforestry and avoiding deforestation, respectively, would mitigate climate change. A limited number of farmers listed SWC[3] (6 percent) and reduced or appropriate chemical use (6 percent, combined). Other responses included proper disposal of agricultural chemicals (2 percent), cutting down eucalyptus trees (2 percent), and riverbank protection/preservation of catchment areas (4 percent).

Figure 3.3—Farmers' perceptions of the agricultural practices that reduce climate change



Source: Authors.
Note: Above practices only include responses reported by more than 1 percent of farmers.

Thus, while there is a clear perception of a link between trees and climate change, the perception of the link between specific agricultural land management practices and climate change is rather limited. This is a significant gap that the government, NGOs, and extension agents will need to address if agricultural mitigation is to benefit smallholder farmers in Kenya.

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[3] Here the definition of soil and water conservation includes a range of practices reported by farmers such as cover cropping, minimum tillage, mulching, intercropping, and terracing, although these measures were not commonly found in the study sites. For the analysis below, SWC refers to those practices commonly adopted by farmers in the study sites (soil bunds, ridge and furrow, bench terraces, and grass strips).

4. SIMULATION OF THE IMPACT OF CROPLAND MANAGEMENT PRACTICES ON MAIZE YIELDS AND SOIL CARBON SEQUESTRATION

To assess the implications of various combinations of cropland management strategies for agricultural productivity and soil carbon sequestration (SCS), the CERES-Maize 4.5 model/DSSAT-CENTURY module was used to simulate maize yield and soil organic matter dynamics in smallholder farmers' fields for 40 years for all permutations of seven management practices (two variety choices, fertilizer application, manure application, residue management, rotation with beans, SWC techniques, and supplementary irrigation) and two sets of climate projections (dry and wet)[4] for each district. The cropping calendar of maize for the major (long-rain) growing season in each district, distributed between February and April, followed the survey results. Assuming *no-effort* management with a traditional open-pollinated variety (OPV) as the baseline for each climate, the annual SCS rate (tons of carbon per hectare) was calculated for each case for the 40-year simulation, assuming farmers would adopt and follow the given set of management practices continuously over 40 years.

Given the importance of crop residues, particularly maize stover, for animal feed, we simulated long-term average maize yield for different levels of residue retention on the field across all study sites and for several management practices. This study examined the tradeoff involved in leaving 50 percent and 75 percent of residues in the field.

The results are summarized in Figure 4.1 and Figures 4.2–4.11 present maize yield results and changes in soil organic carbon (SOC) for key maize management practices. Moreover, Table 4.1 presents results for the top five management practice packages per district, climate scenario, and soil type under rainfed conditions, in terms of SCS potential. While management practices considered in Table 4.1 do not include irrigation, reflecting the low adoption of supplementary irrigation in the region, Figures 4.2–4.11 include irrigation together with SWC (SWC + IRG) to test its theoretical benefit in reducing yield variability.

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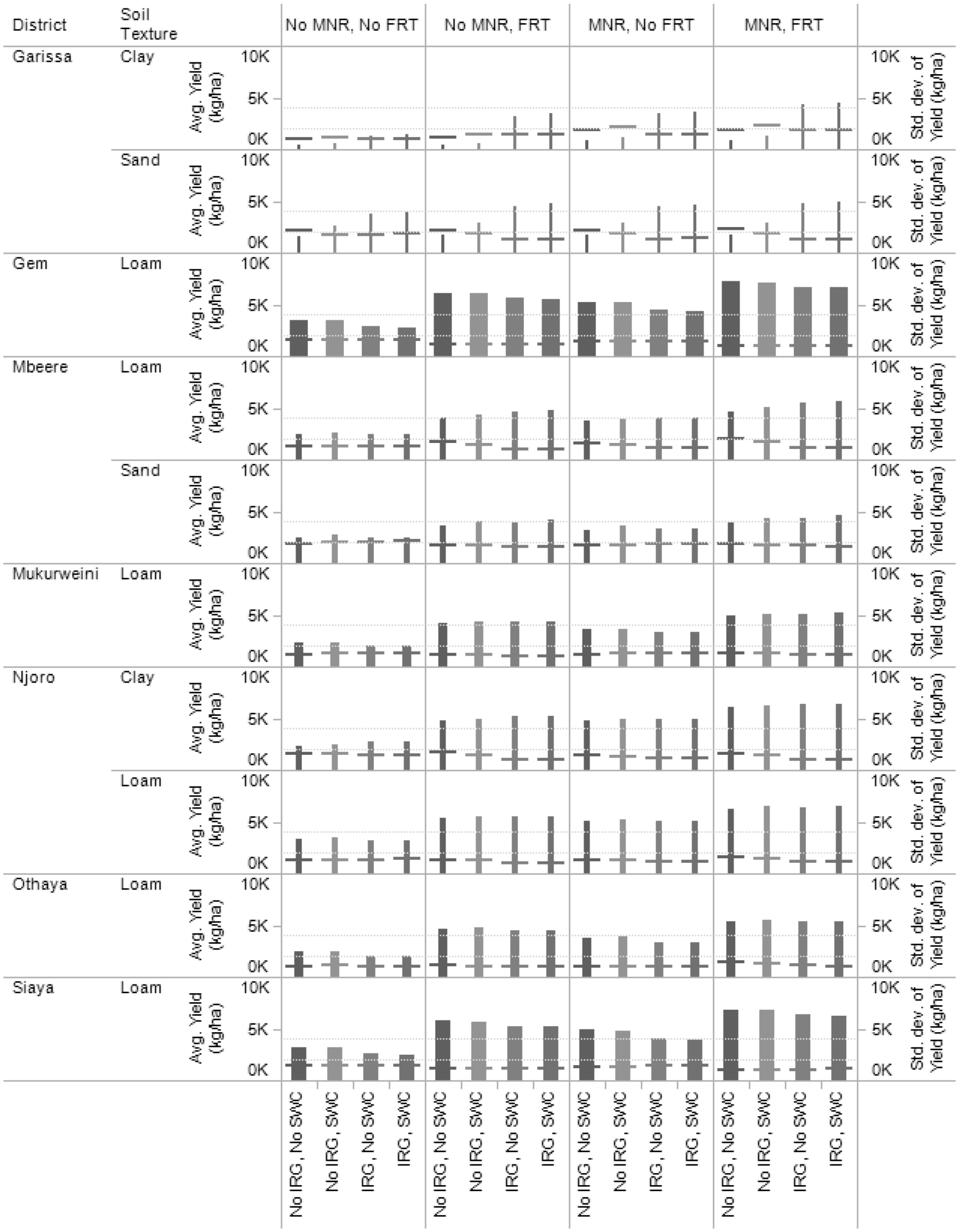
[4] The *dry and wet* climate scenarios are used to identify the two global circulation models (GCMs) used in the study, instead of using the GCM names (CSIRO-Mk3.0 and MIROC3.2) directly. However, the difference in total rainfall for Kenya between the two models is not very large.

Figure 4.1—Average maize yield from 40-year simulation under 16 management practices (4 nutrient management x 4 water management practices) by district, aggregated from the results of all varieties, all soils, all climate conditions, and with and without crop rotation.



Source: Authors.

Notes: The thickness of the yield bar indicates the average amount of seasonal rainfall (thinnest: ≤ 200 mm, thickest: 600 mm). The horizontal bar indicates the level of yield standard deviation. MNR = manure; FRT = fertilizer; IRG = irrigation; SWC = soil and water conservation.

Table 4.1—Top five management practices with soil carbon sequestration potential over 20 years (tons of carbon per hectare) for rainfed maize

			OPV										HYB				
			MNR										MNR				
			No FRT					FRT					No FRT		FRT		
			No RSD		RSD			No RSD	RSD				RSD		RSD		
			SWC		No SWC	SWC		SWC	No SWC		SWC		SWC		No SWC		SWC
District	Soil	Climate	No ROT	ROT	ROT	No ROT	ROT	ROT	No ROT	ROT	No ROT	ROT	No ROT	ROT	No ROT	ROT	No ROT
Garissa	Clay	Dry		3			1	5				2		4			
		Wet			3	5	1			4		2					
	Sand	Dry	4			1					2		3				5
		Wet				2					1		3	5			4
Gem	Loam	Dry			5				1	2	3	4					
		Wet			5				1	2	3	4					
Mbeere	Loam	Dry			5				1	3	2	4					
		Wet			5				1	2	3	4					
	Sand	Dry							1	2	5				4	3	
		Wet							3	1		5			4	2	
Mukurweini	Loam	Dry			5				1	3	2	4					
		Wet							1	3	2	4				5	
Njoro	Clay	Dry			2				3	1	5	4					
		Wet			3				2	1	5	4					
	Loam	Dry			5				1	3	2	4					
		Wet			5				1	2	3	4					
Othaya	Loam	Dry			5				1	2	3	4					
		Wet							1	2	3	4				5	
Siaya	Loam	Dry			5				1	2	3	4					
		Wet			5				1	2	4	3					

Source: Authors.
Notes: Potential rated on a scale of 1–5, with 1 being the highest. OPV = open-pollinated variety; HYB = hybrid variety; MNR = manure, FRT = fertilizer; RSD = residue retention; SWC = soil and water conservation; ROT = rotation with dry beans.

While there is considerable variation across the various packages and districts, several conclusions can be drawn. First, results are generally robust across different future climate scenarios, that is, both the wet and the dry climate change scenarios implemented here. Second, the hybrid variety is not always favored, even with nutrient management practices in most districts. When favored, the hybrid variety is cultivated on sandy soils (Garissa and Mbeere), which have relatively lower bulk density that may promote more root structure and consequently contribute to soil organic matter enhancement. In general, compared with OPV, the hybrid variety demands more water and nitrogen and may not necessarily benefit SCS in smallholder farmers' field conditions. It is important to note, however, that this study used a hybrid variety not specifically calibrated for each local condition due to a lack of phenological data; thus, this may not be a robust result.

Third, the simulation results differ significantly by district, particularly regarding the role of water application. In the arid site (Garissa), maize yields under rainfed conditions are very low due to limited water availability. Irrigation is essential to achieve reasonable yield levels; SWC measures can partially substitute for irrigation and also improve yields. Yields are maximized when SWC and irrigation are combined; results are similar for both soil types and maize varieties. Moreover, application of manure and fertilizers increases SOC, particularly in clayey soils (see Figures 4.2 and 4.8). In the humid sites

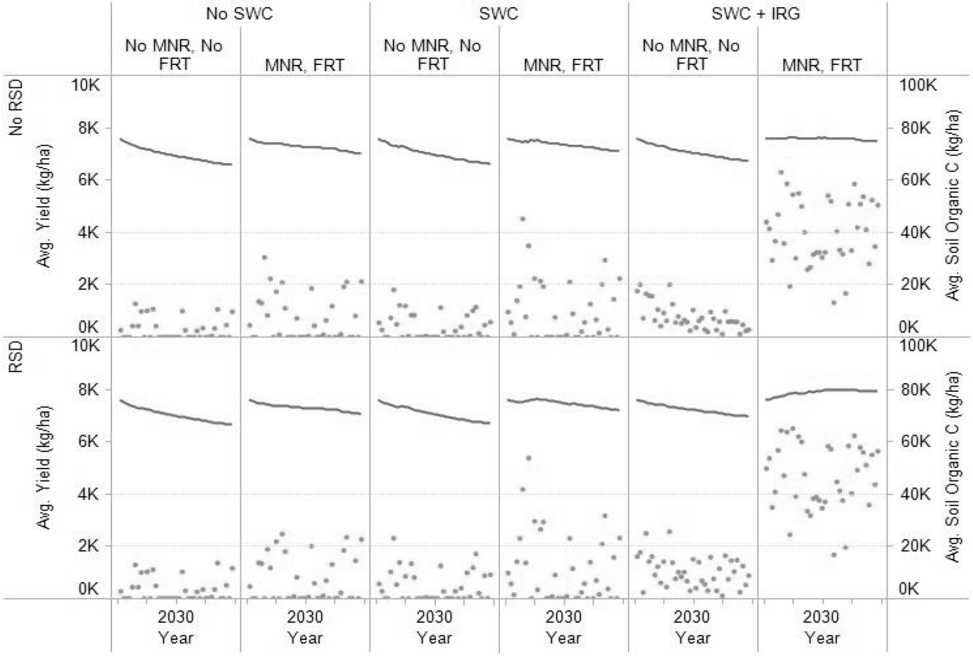
(Gem and Siaya), with relatively high rainfall and low variability, water is readily available in general, while nitrogen is limited. As a result, we find limited effects of SWC techniques, and irrigation in fact lowers average yield levels across simulated management practices, possibly due to increased leaching of nitrogen from the soil (Figures 4.4 and 4.11). In the semiarid sites (Mbeere and Njoro), water is somewhat limited. Therefore SWC practices and irrigation overall increase yield levels (Figures 4.5, 4.6, 4.8, and 4.9). However, yield improvements are much larger from higher nitrogen inputs from both fertilizers and manure. Similarly, in the temperate sites (Mukurweini and Othaya), SWC and irrigation improve yields, but not as significantly as nutrient inputs (fertilizer and manure) (Figures 4.7 and 4.10). Thus, while the use of SWC was strongly favored in Garissa, in almost all packages there was no clear positive or negative pattern regarding the benefit of adopting SWC techniques for enhancing SCS in other districts. Especially when there was no fertilizer application, SWC techniques alone did not contribute to SCS.

Fourth, in terms of residue management (for example, 50 percent of crop residues are left on the field after harvest) we find a high potential for SCS across districts, reflecting the positive role of residues for replenishing soil nutrients (more residue more organic matter input improved soil fertility more biomass production more residues). Only a few packages with high SCS potential included the full removal of residues from the field. This was the case in arid Garissa district under a drier future. In this case, limited soil moisture might hinder microbial activities and decomposition of organic matters.

Fifth, we find that inorganic fertilizer application alone does not enhance SCS. Instead, integrated soil fertility management is required to support agricultural mitigation—that is, inorganic fertilizers should be combined with other soil fertility management practices (manure application, mulching, residue management, or a combination of these). Sixth, the rotation of maize with beans enhances SCS in only a few cases; the majority of the top-ranked packages across districts did not require rotation. Although rotation with legumes generally improves soil fertility, legumes have relatively smaller biomass and their easily decomposable nutrient composition results in relatively less favored options, especially where soil nutrients are well managed through other practices (such as manure and fertilizer applications). That is, while rotation with beans is generally positive for SCS, these benefits are limited compared with more explicit nitrogen input measures, such as the application of inorganic fertilizer, manure, or both.

Overall, the simulated results show that the best-bet package for SCS would generally include integrated soil fertility management, although the optimal combination of nutrient inputs (manure, inorganic fertilizer, and crop residues) depends on a number of factors, including crop type, soil type, and AEZ. The optimal choice of other management practices also varies with soil and climate conditions across the study sites. A comparison of crop simulation results with our household survey shows that many farmers in the study areas already have access to those management practices that can improve SCS as well as soil fertility.

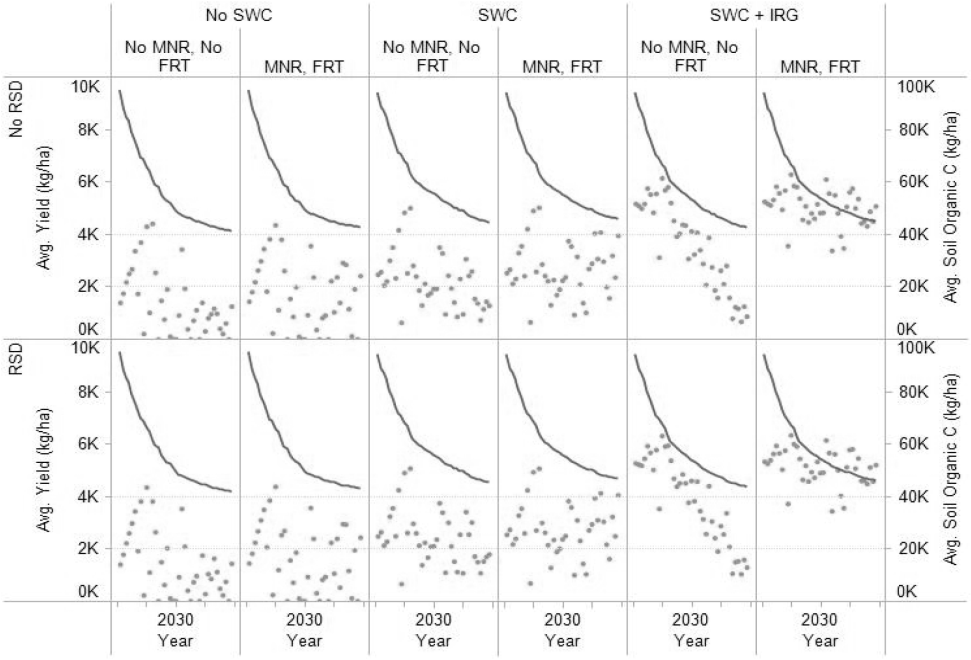
Figure 4.2—Simulated trends of maize yield and soil organic carbon over 20 years in Garissa with clayey soil



Source: Authors.

Notes: Dots represent maize yield; lines represent soil organic carbon. SWC = soil and water conservation; MNR = manure; FRT = fertilizer; IRG = irrigation; RSD = residue retention; SOC = soil organic carbon.

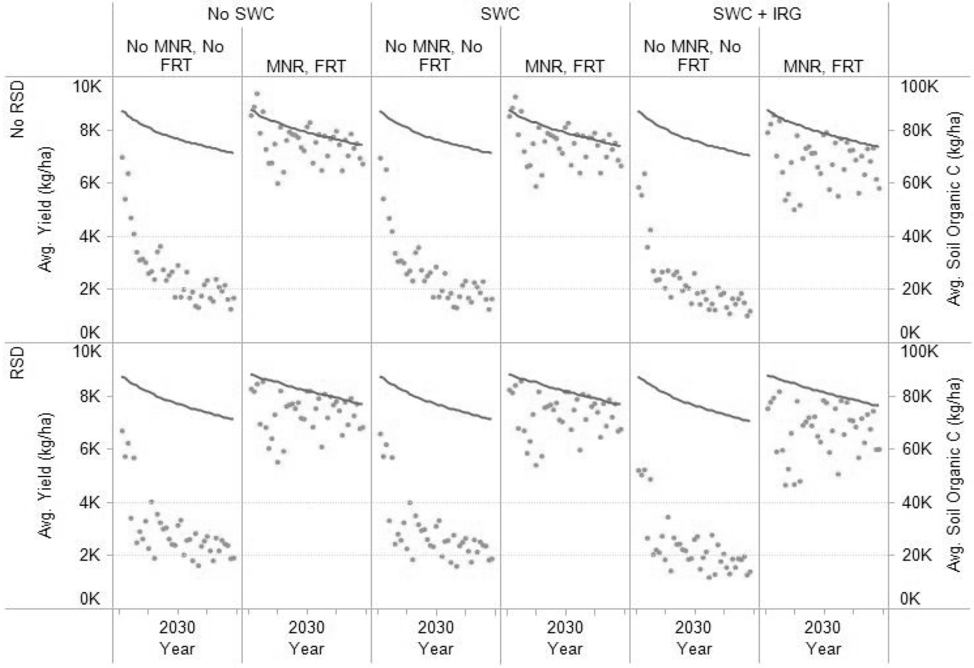
Figure 4.3—Simulated trends of maize yield and soil organic carbon over 20 years in Garissa with sandy soil



Source: Authors.

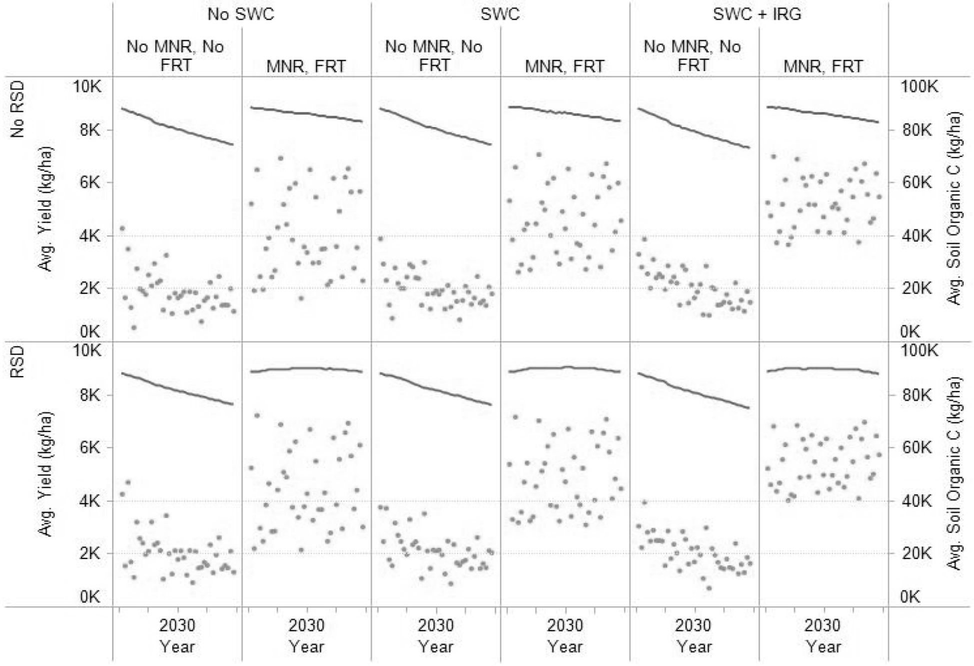
Notes: Dots represent maize yield; lines represent soil organic carbon. SWC = soil and water conservation; MNR = manure; FRT = fertilizer; IRG = irrigation; RSD = residue retention; SOC = soil organic carbon.

Figure 4.4—Simulated trends of maize yield and soil organic carbon over 20 years in Gem with loamy soil



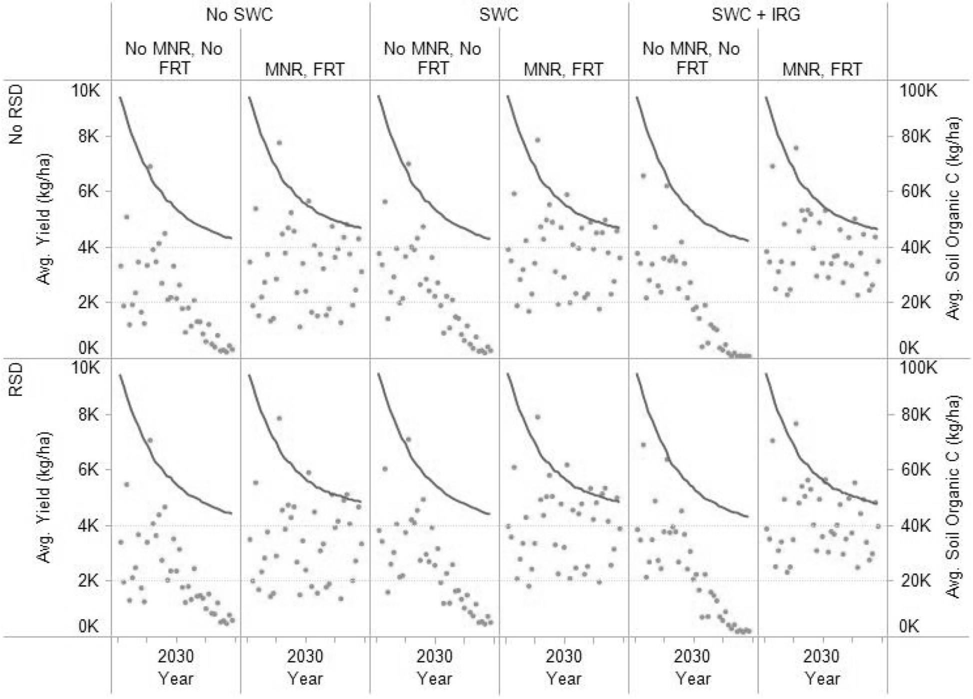
Source: Authors.
Notes: Dots represent maize yield; lines represent soil organic carbon. SWC = soil and water conservation; MNR = manure; FRT = fertilizer; IRG = irrigation; RSD = residue retention; SOC = soil organic carbon.

Figure 4.5—Simulated trends of maize yield and soil organic carbon over 20 years in Mbeere with loamy soil



Source: Authors.
Notes: Dots represent maize yield; lines represent soil organic carbon. SWC = soil and water conservation; MNR = manure; FRT = fertilizer; IRG = irrigation; RSD = residue retention; SOC = soil organic carbon.

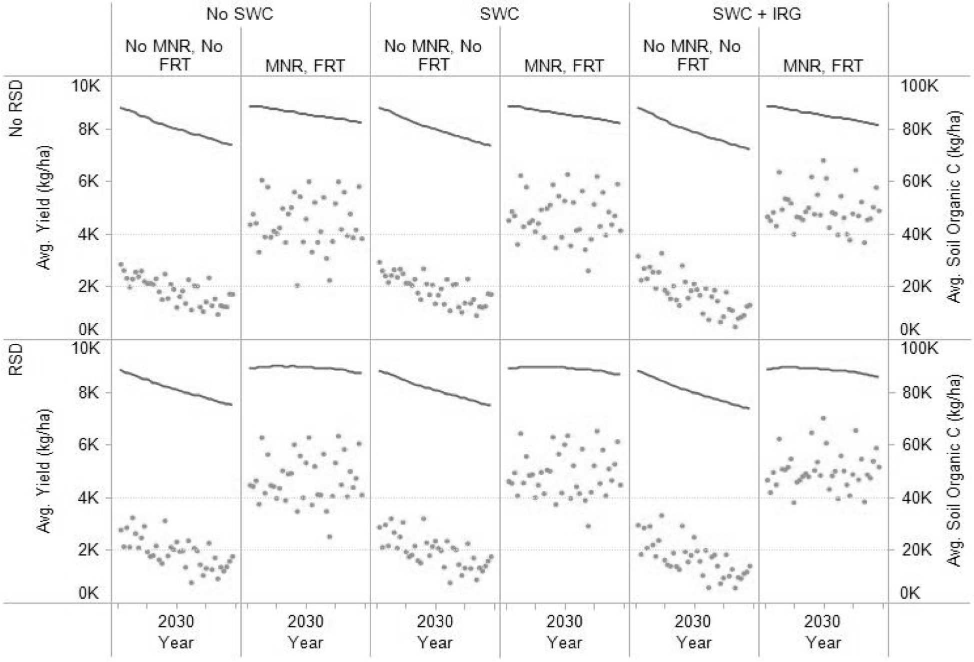
Figure 4.6—Simulated trends of maize yield and soil organic carbon over 20 years in Mbeere with sandy soil



Source: Authors.

Notes: Dots represent maize yield; lines represent soil organic carbon. SWC = soil and water conservation; MNR = manure; FRT = fertilizer; IRG = irrigation; RSD = residue retention; SOC = soil organic carbon.

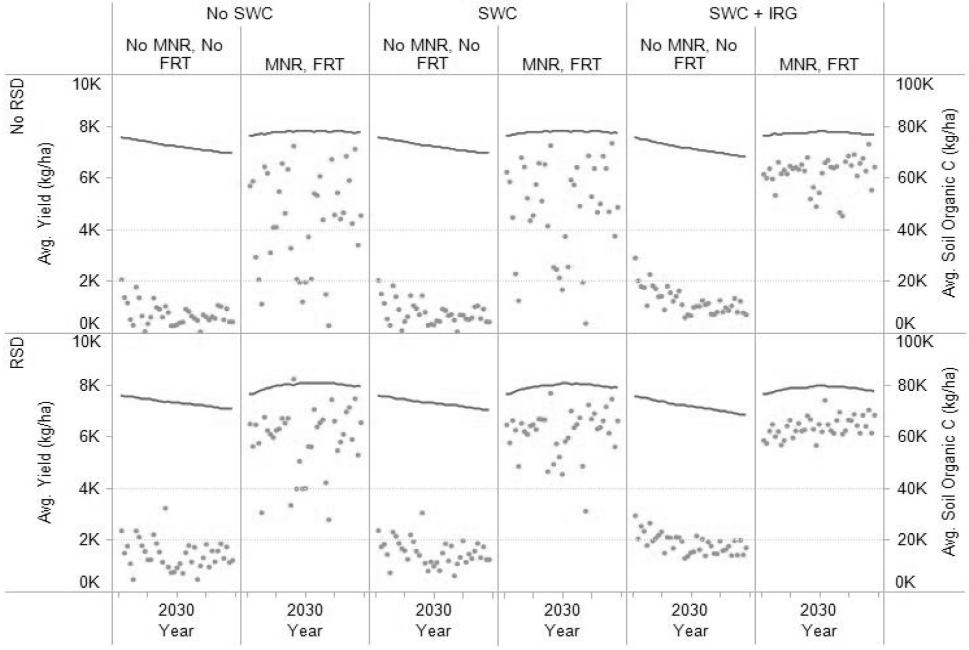
Figure 4.7—Simulated trends of maize yield and soil organic carbon over 20 years in Mukurweini with loamy soil



Source: Authors.

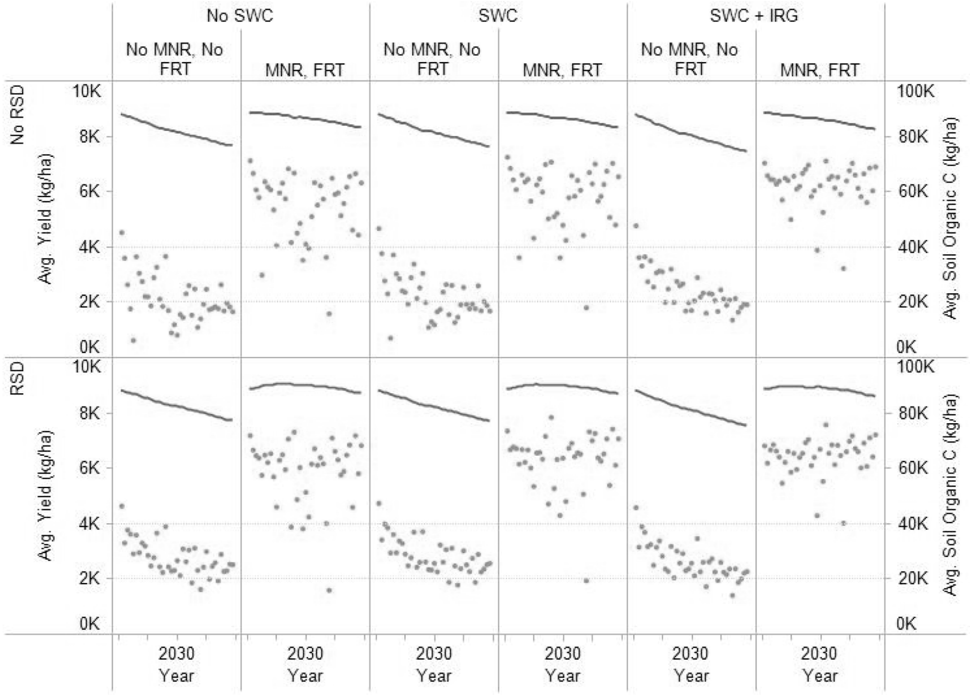
Notes: Dots represent maize yield; lines represent soil organic carbon. SWC = soil and water conservation; MNR = manure; FRT = fertilizer; IRG = irrigation; RSD = residue retention; SOC = soil organic carbon.

Figure 4.8—Simulated trends of maize yield and soil organic carbon over 20 years in Njoro with clayey soil



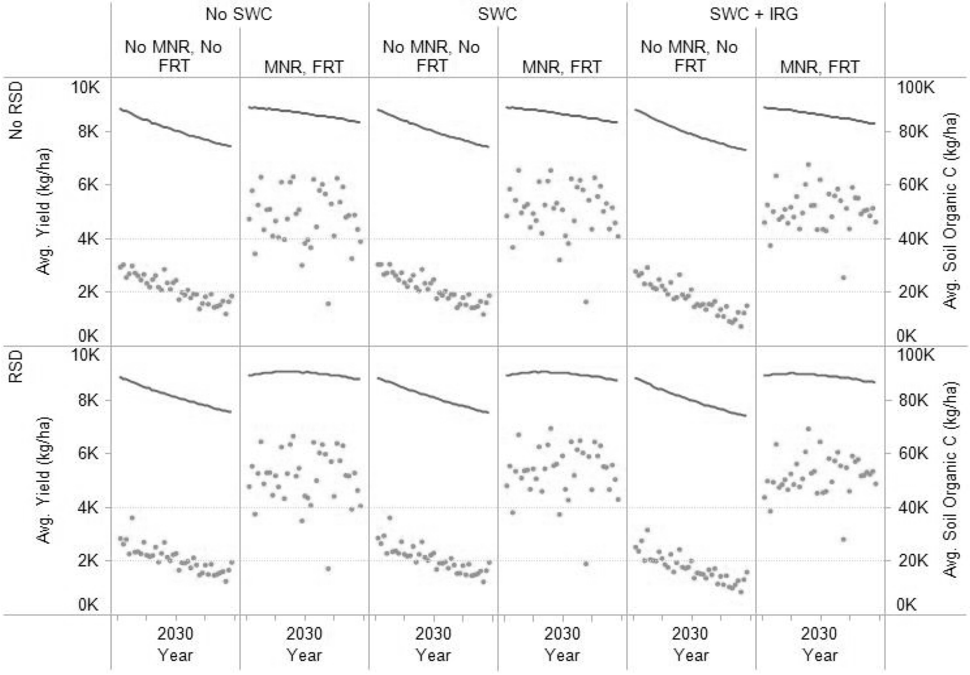
Source: Authors.
Notes: Dots represent maize yield; lines represent soil organic carbon. SWC = soil and water conservation; MNR = manure; FRT = fertilizer; IRG = irrigation; RSD = residue retention; SOC = soil organic carbon.

Figure 4.9—Simulated trends of maize yield and soil organic carbon over 20 years in Njoro with loamy soil



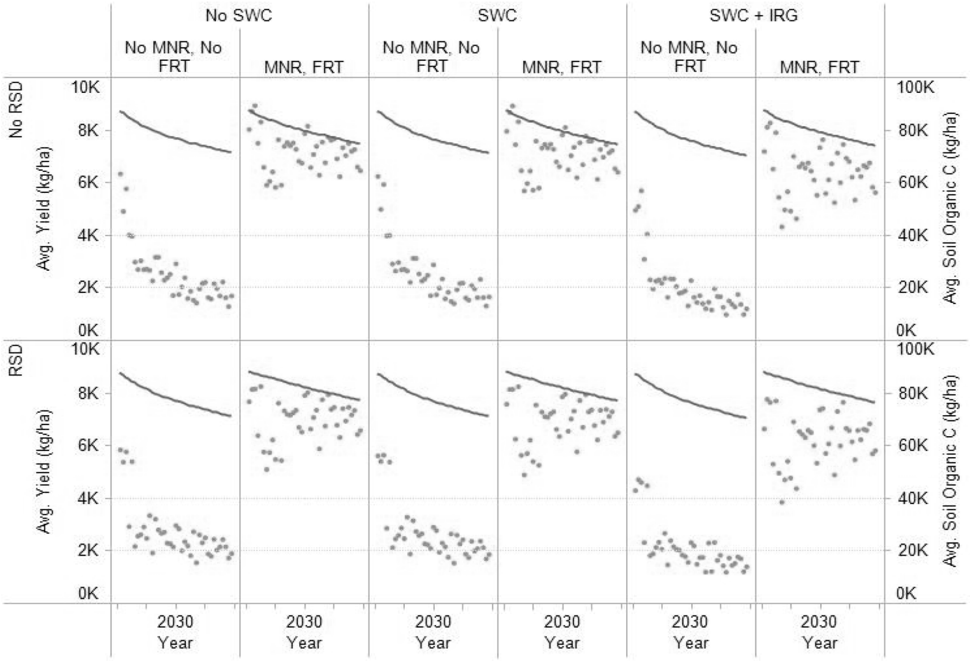
Source: Authors.
Notes: Dots represent maize yield; lines represent soil organic carbon. SWC = soil and water conservation; MNR = manure; FRT = fertilizer; IRG = irrigation; RSD = residue retention; SOC = soil organic carbon.

Figure 4.10—Simulated trends of maize yield and soil organic carbon over 20 years in Othaya with loamy soil



Source: Authors.
Notes: Dots represent maize yield; lines represent soil organic carbon. SWC = soil and water conservation; MNR = manure; FRT = fertilizer; IRG = irrigation; RSD = residue retention; SOC = soil organic carbon.

Figure 4.11—Simulated trends of maize yield and soil organic carbon over 20 years in Siaya with loamy soil



Source: Authors.
Notes: Dots represent maize yield; lines represent soil organic carbon. SWC = soil and water conservation; MNR = manure; FRT = fertilizer; IRG = irrigation; RSD = residue retention; SOC = soil organic carbon.

5. POTENTIAL IMPACTS OF IMPROVED LIVESTOCK FEEDING AS A CLIMATE CHANGE ADAPTATION AND GHG MITIGATION STRATEGY

A governmental push toward market-oriented production is driving production systems in the study areas toward an increased use of improved feeding practices. These practices can help farmers adapt to and at the same time mitigate the adverse impacts of climate change. This part of the report analyzes the potential impacts of improved feeding on the productivity and methane emissions of cattle, the main animal species present in the seven districts under study.

Diets for cattle were constructed using the main feeds as reported in the household survey in quantities devised to match reported dairy production. Alternative diets were then constructed using the main feed ingredients that have been increasing in the seven districts based on survey results. These feed ingredients are also being promoted by several international agencies and projects (for example, the Bill & Melinda Gates Foundation East Africa Dairy Development Programme) as a vehicle for intensifying dairy production. All diets were tested for methane emissions using the ruminant simulation model of Herrero, Fawcett, and Jessop (2002), which predicts feed intake, productivity, manure production, and methane emissions of ruminants. This model has been previously used for estimating productivity and methane emissions of African domestic ruminants (Herrero et al. 2008; Thornton and Herrero 2010) and has been used to estimate methane emission factors for the Intergovernmental Panel on Climate Change (Herrero et al. 2008).

Baseline Diets

From the information generated, the following diets were constructed for cattle in the different districts (Table 5.1). This information is consistent with that from other studies (Zemmelink and Romney 1999; Bebe 2003; Herrero et al. 2008).

Table 5.1—Milk production and main feeds fed to dairy cattle in seven districts of Kenya

District	Ave. milk per cow (kg/yr)	Rangeland grazing	Maize stover	Cut-and-carry fodder	Roadside weeds	Grain supplements
Garissa	275	X				
Gem	548	X	X		X	
Mbeere South	860	X	X	X	X	
Njoro	1,256		X	X	X	X
Mukurweni	2089		X	X		X
Othaya	2,035		X	X		X
Siaya	706	X	X		X	

Source: Authors.

Differences in main feed sources highlight the productive orientation and management of the systems in the various study areas. Njoro, Mukurweini, and Othaya have a more commercial orientation, with stall-fed, high-grade dairy animals with good diets (reflected in high energy densities as a result of the use of concentrates), leading to high milk production. Napier grass will be commonly fed in these mixed crop–livestock systems as a cut-and-carry fodder. On the other hand, the rangeland-based systems point toward more extensive production, where supplementation, mostly in the dry season, is based on crop residues and on the opportunistic use of feed resources like roadside weeds.

Manure production and methane emissions of the baseline diets are presented in Table 5.2. The relationship between the quality of the diet and methane production follows well-established principles: The higher the quality of the diet, the higher the feed intake; hence total methane production is sometimes higher than with poorer diets. However, methane production per unit of animal product will always decrease as the quality of the diet improves. This is the main reason why adaptation options related to supplementation with high-quality forages can also be a GHG mitigation strategy. As expected, the better diets in the more dairy-oriented districts of Njoro, Mukurwe-ini, and Othaya produced the least methane per unit of milk but also produced overall higher quantities of methane because the animals were able to eat more. Cows in the drier agropastoral regions were significantly less efficient in terms of methane produced per unit of milk (up to five times less efficient in some cases), since their diets were poorer and most of the energy was used for maintaining the animals instead of producing milk.

Table 5.2—Manure production and methane emissions of diets for dairy cows (250 kilograms body weight) in seven districts of Kenya

District	Energy density of the diet (MJ ME/kg DM)	Manure per animal (kg/yr)	Methane production (kg CO_2 eq/lactation)	Methane produced per liter of milk (kg CO_2 eq/L)
Garissa	8.4	693	796	2.37
Gem	9.3	730	780	1.42
Mbeere South	9.6	693	824	1.12
Njoro	9.9	693	863	0.72
Mukurweni	10.5	657	936	0.47
Othaya	10.5	657	936	0.47
Siaya	9.4	730	838	1.14

Source: Authors.
Note: MJ = megajoules; ME = metabolizable energy; DM = dry matter.

Manure production ranged from 657 to 730 kilograms per animal (250 kilograms body weight) across districts. This close range was expected because the model was run for animals of a constant body weight, which largely controls the overall magnitude of the intake figures for that range of diet qualities (8.4 to 10.5 megajoules of metabolizable energy per kilograms of dry matter). This means that in overall terms the differences in excretion rates were relatively small, with most impacts related to milk and methane production.

Testing Alternative Feeding Scenarios

Alternative scenarios of diet composition were tested by constructing new supplementation regimes using the new feed sources reported in the seven districts. These feeds are shown in Table 5.3 together with the two scenarios tested for each feed in each district. The simulated 250-kilogram animals consumed between 4.5 and 6 kilograms of dry matter (DM) feed per day in the baseline diets, and the scenarios tested aimed at replacing between 15 and 50 percent of the baseline ration in terms of DM consumed. Scenarios assumed that new feeds would replace maize stover to enable farmers to use the reminder of the maize residues on cropland (providing benefits in terms of soil carbon sequestration as presented in Section 4).

Table 5.3—New feeds most commonly used in the last 10 years in the districts under study and their alternative scenarios of use

District	Main new feed	Scenarios simulated, per day
Garissa	Prosopis	1.5 kg offered in the diet instead of stover
		3 kg offered in the diet instead of stover
Gem	Desmodium	1 kg offered in the diet instead of stover
		2 kg offered in the diet instead of stover
Mbeere South	Napier grass	2 kg offered in the diet instead of stover
		3 kg offered in the diet instead of stover
Njoro	Hay	1 kg offered in the diet instead of stover
		2 kg offered in the diet instead of stover
Mukurweni	Desmodium	1 kg offered in the diet instead of stover
		2 kg offered in the diet instead of stover
Othaya	Hay	2 kg offered in the diet instead of stover
		4 kg offered in the diet instead of stover
Siaya	Napier grass	2 kg offered in the diet instead of stover
		3 kg offered in the diet instead of stover

Source: Authors.

The impacts of alternative diets on milk productivity, manure, and methane production and methane produced per liter of milk are shown in Table 5.4. On average, the supplementation strategies tested increased milk production by 36 percent while also increasing total manure and methane production by 6 and 4 percent, respectively, and decreasing methane production per kilogram of milk produced by 20 percent. Differences varied significantly by district.

As a general trend, the largest positive impacts of supplementation were observed in the districts with the poorest-quality baseline diets (Garissa, Gem, Mbeere, and Siaya). In these districts, milk production increased between 12 and 136 percent while manure and methane production changed between 0 and 16 percent and -5 and 16 percent, respectively. While methane emissions increased overall in many scenarios, efficiency per liter of milk improved in every scenario. Methane production per liter of milk decreased significantly by between -8 and -60 percent. This was expected, since these are the regions where efficiency gaps are largest. This simulation shows that if simple practices and modest supplementation plans can be implemented, methane production in these regions could decline significantly. However, improved feeding practices generally will be profitable only if livestock owners have access to a market for dairy products. This is generally not the case in the more remote arid district of Garissa, where the feeding efficiency gap is largest.

Increasing milk production while reducing methane production per liter of milk was also possible in the districts with higher-quality baseline diets (Mukurweini, Njoro, and Othaya), but improvements were smaller (8 to 49 percent for milk production and -7 to -21 percent for methane per liter of milk, respectively). In addition to the benefits from decreased methane emissions, alternative livestock feeding practices would enable farmers to apply maize stover as residues on their fields, leading to additional agricultural GHG mitigation benefits from SCS.

Table 5.4—Impacts of alternative feeding strategies on annual milk, manure, and methane production and on efficiency of methane production to produce milk in seven districts of Kenya

District	Scenario	Milk production per year, % difference	Manure production per year, % difference	Methane production per year, % difference	Methane per liter of milk, % difference
Garissa	Prosopis				
	1.5 kg/day	64	0	-2	-40
	3 kg/day	136	0	-5	-60
Gem	Desmodium				
	1 kg/day	21	5	-3	-20
	2 kg/day	36	10	0	-26
Mbeere	Napier grass				
	2 kg/day	12	11	3	-8
	3 kg/day	17	16	2	-12
Njoro	Hay				
	1 kg/day	18	-5	6	-10
	2 kg/day	49	-5	18	-21
Mukurweni	Desmodium				
	1 kg/day	9	11	2	-7
	2 kg/day	8	11	0	-7
Othaya	Hay				
	2 kg/day	9	11	2	-7
	4 kg/day	8	11	0	-7
Siaya	Napier grass				
	2 kg/day	42	0	12	-21
	3 kg/day	79	10	16	-35
All districts	Average	36	6	4	-20

Source: Authors.
Note: All results are in percent deviations from the respective baselines.

6. PRODUCTIVITY AND RISK IMPLICATIONS OF MANAGEMENT STRATEGIES

To further examine the implications of various management strategies on crop productivity and to assess their suitability for climate change adaptation, we ran the Just and Pope (1979) production function using survey data. The yields of three main crops grown in the study areas (maize, beans, and coffee) were used as a measure of productivity, with the variance of yield of these crops demonstrating production risk, which we consider an important indicator of resilience to climate change. Previous studies have shown that risk aversion often prevents households from adopting practices that increase overall productivity (Yesuf and Bluffstone 2009). Thus, agricultural practices that reduce production risk are more likely to be adopted and are important for adaptation to climate change.

Ideally we would be able to compare the same set of management practices, or package*s*, that were used in the crop simulation model; however, the number of observations (plots) with the most promising combinations of management practices was limited. We therefore included interactions for common combinations of practices found in the dataset.

While the literature suggests that implementation of SWC measures[5] leads to increased yields (Byiringiro and Reardon 1996; Shively 1998; Kaliba and Rabele 2004; Kassie et al. 2008), our results show few significant impacts of these measures on productivity among surveyed farmers (Table 6.1). None of the SWC measures analyzed had a significant positive impact on yields of maize, beans, or coffee. Only crop rotation or fallowing was shown to have a risk-reducing effect on maize yields (that is, the practice was associated with lower variability of yields). This suggests that this practice is effective at increasing water retention and reducing nutrient losses.

In addition, in some cases, we found some counterintuitive results. Soil bunds were associated with increased variability of bean yields. This could be due to the fact that these structures are found most frequently on plots in the semiarid and humid sites. Given that these structures are intended to increase soil moisture, they may not be as effective in humid areas—therefore, leading to greater yield variability across plots where soil bunds are used. In addition, our results indicate that residues were associated with lower bean yields. This could be due to the fact that residues (applied in the form of mulch or trash lines) may increase the amount of nitrogen in the soils, which is not necessary for beans.

More research is needed to determine why we did not find greater benefits from SWC measures. Possible explanations include that the measures such as terraces, ridge and furrow, grass strips, and trash lines displace some cropland, thus accounting for a reduction in yield over the area of the plot. This would be the case particularly if these measures were recently constructed. In addition, the structures may have been implemented in areas with severely degraded soils, reducing beneficial impacts at least in the short term.

It is also possible that these measures were improperly implemented or that farmers did not choose the appropriate combination of measures given the environmental and agroecological conditions, due to lack of training or experience. Other research has demonstrated that positive effects of SWC measures on production vary by location and that SWC technologies should therefore be selected to suit the environment (Kato et al. 2009).

In order to check the robustness of these findings and to address complications due to intercropping on many of the plots,[6] the same analysis was run using total value of production (rather than the yields of individual crops) as the dependent variable. This analysis also showed no statistically significant impacts of SWC technologies on agricultural production or risk (variance). However, it should be noted that farmers were asked an open-ended question about what land management practices they

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[5] The SWC measures being referred to in this section include soil bunds, bench terraces, grass strips, ridge and furrow. While considered separately in the crop simulation modeling exercise, we also refer to crop rotation/fallowing and retention of crop residues as SWC measures in this section. These are the measures most commonly used on plots in the study sites.

[6] The presence of intercropping complicated the analysis of productivity by crop. To calculate the crop area for intercropped plots, it was assumed that each crop represented 50 percent of the total plot area, which may not be an accurate assumption.

used on their cropland, rather than about specific practices. Thus, farmers may be underreporting the use of these measures.

Table 6.1—Effects of agricultural practices on mean and variance of crop yields of maize, beans, and coffee

	Maize		Beans		Coffee	
Variable	**Mean**	**Variance**	**Mean**	**Variance**	**Mean**	**Variance**
Soil bunds	0.170	0.362	0.213	**0.814*** **	-0.976	-0.46
Bench terraces					-1.892	0.528
Grass strips	-0.270	0.262	0.131	0.481	-0.466	1.167
Ridge and furrow	-0.228	0.420	-0.272	0.239		
Residues	-0.198	0.561	**-0.288***	0.346	2.181	-3.001
Rotation/fallowing	-0.091	**-0.468***	0.037	-0.081		
Soil bunds*grass strips	-0.098	-0.214	-0.102	-0.74		
Soil bunds*residues	0.127	-0.578	0.089	**-1.098****		
Intercropped plot	-0.050	**0.718*****	-0.007	0.15	-0.68	2.223
Amount own seed	**0.113****	-0.169	**0.116*****	**-0.201****	0.098	**-0.859****
Amount purchased seed	**0.134****	0.118	0.018	-0.022	0.271	-0.273
Improved seed variety	**0.364****	-0.425	**0.315***	-0.683	-0.511	-3.359
Labor	**0.209*****	0.207	**0.070****	0.037	0.22	0.641
Animal draft power	-0.005	0.033	0.028	-0.017		
N fertilizer	0.009	**-0.192*****	**-0.087***	0.119	0.188	**-0.757****
P fertilizer	**0.086****	-0.021	**0.105***	-0.113	2.514	2.781
K fertilizer	-0.019	**0.082***	-0.031	-0.048	-2.259	-1.771
No. of observations	931	929	788	786	53	53

Source: Authors.

Notes: Significant results in bold. * p < .1; ** p < .05; *** p < .01. Includes controls for project sites, rainfall season, household characteristics, and soil characteristics.

While we do not find positive effects of SWC measures, the results show that other agricultural practices increase crop yields and reduce production risk. Amount of seed (both own and purchased seed) and amount of labor are associated with higher yields. In particular, own seed, purchased seed, and labor are associated with higher maize yields, and own seed and labor are associated with higher yields of beans. In addition, use of improved varieties is associated with higher yields of maize and beans. Amount of own seed is also associated with lower yield variance of beans and coffee, suggesting that additional seed may provide a buffer against climate variability. If the rains come and then stop, leading to crop failure, farmers with additional seed will be able to plant again, reducing losses.

Fertilizer[7] also shows the expected effect on crop yield and variance. In particular, phosphate (P) has a positive effect on yields of maize and beans. Nitrogen (N) fertilizer reduces yield variance of maize and coffee but shows no effect on mean yields of these crops. Nitrogen fertilizer applied to beans actually has a negative effect on yield. Given that beans are nitrogen fixing, additional input of nitrogen fertilizer only increases vegetative growth rather than seed formation.

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[7] For this analysis, fertilizer includes both organic (manure and compost) and inorganic types. Elemental levels of nitrogen (N), phosphate (P), and potassium (K) are calculated and represented in the production function.

7. PROFITABILITY OF ALTERATIVE MANAGEMENT PRACTICES

Despite the adaptation and agricultural mitigation benefits of many of the sustainable land and livestock feeding practices studied here, farmers are unlikely to adopt these unless they are also financially profitable, that is, they increase income after factoring in any additional costs. This section evaluates the most promising crop and livestock management practices identified above in monetary terms to determine the extent to which these practices provide financial benefits for households in the study sites. Costs were taken from the survey where possible, or based on expert opinion (for example, construction costs of SWC and irrigation structures) or from retail prices for inputs (such as fertilizers).

Profitability of Cropland Management Strategies

In order to examine the profitability of sustainable intensification practices, we selected four packages of practices based on the crop simulation results that provided benefits in terms of SCS and yield increases, compared to a baseline without any improved management practices. In Package 1, 50 percent of crop residues are left on the field. In Package 2, 40 kilograms of nitrogen fertilizer per hectare (split application with 20 kilograms applied during planting at a depth of 5 centimeters and 20 kilograms applied 30 days after planting as a top dressing) and 3 tons of manure per hectare are added. Package 3 includes residues, fertilizer, and manure, and adds SWC practices (represented as increased soil moisture) and crop rotation (rotation with legumes every fourth year). Package 4 includes all the previous management practices plus irrigation (100 millimeters per hectare of furrow irrigation). All package options use the OPV, given its overall better performance in terms of SCS. Results are presented in Table 7.1.

Table 7.1—40-year average annual incremental revenues from SOC and maize yield (crop residues at 50 percent)

		Package 1		Package 2		Package 3		Package 4	
		RSD50		RSD50, FRT, & MNR		RSD50, FRT, MNR, SWC, & ROT		RSD50, FRT, MNR, SWC, ROT, & IRG	
AEZ	Soil	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)	Revenue from carbon* (USD$/ha)	Net revenue from yield** (US$/ha)	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)
Arid	Clay	0	71	2	17	5	202	5	1289
Arid	Sand	1	83	4	-39	6	383	10	1029
Semiarid	Loam	1	214	10	1047	9	1210	5	1160
Semiarid	Sand	1	136	4	368	6	446	6	299
Semiarid	Clay	1	256	7	1763	7	2058	6	2084
Temperate	Loam	1	62	10	953	10	1047	9	873
Humid	Loam	0	136	4	1569	4	1650	4	1198

Source: Authors.
Notes: RSD50 = 50 percent of residues left in field; FRT = fertilizer; MNR = manure; SWC = soil and water conservation; ROT = rotation with dry beans; IRG = irrigation. * Assumes a carbon price of US$10 per ton of CO2 equivalent. ** Assumes a price of US$0.375 per kilogram of maize.

Data on soil carbon and maize yields over a 40-year period generated by the crop simulation model were used to calculate the average increase in revenues from SCS[8] and maize yield improvements[9]

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[8] Revenues are calculated based on increases in soil organic carbon, not including increases in above ground biomass. Changes in SOC over 40 years were converted into tons of CO2e and the increase in CO2e was calculated for each package compared to the baseline. Annual revenues from soil carbon sequestration were calculated by multiplying the increase in CO2e for each package by a payment of US$10 per ton of CO2e divided by 40 years.

for each of these management packages compared with a baseline case of no improved management. We then subtracted production costs (some taken from the survey data and others based on expert opinion) to determine net revenues for each management package.

Labor costs were taken from the survey data for Packages 1 and 2, based on the difference in total labor on maize plots with and without these management packages. We found that residues were actually associated with labor savings, probably due to a reduction in the amount of labor needed for weeding and harvesting activities (the removal of residues). Package 2 was also associated with lower total labor costs but not as much lower as Package 1.

Because there were no maize plots in the study sites that implemented the combination of practices represented in Packages 3 and 4, we assumed there would be no additional cost for plots with SWC structures apart from construction and maintenance of these structures. We also assumed an additional labor cost for irrigation based on the average amount of labor (person days per hectare) spent on irrigation (for those plots in which irrigation is applied). Labor costs were calculated by multiplying the difference in labor (person days per hectare) by the average wage rate for crop production (KES 232 or $2.91 per day), taken from the community survey.

Construction, operation, and maintenance costs of SWC structures and irrigation were based on expert opinion. Given that costs for SWC structures commonly found in the study sites (soil bunds, grass strips, bench terraces, and ridge and furrow) vary by structure, we used average construction costs weighted by the share of maize area covered by these structures. Assuming SWC structures would have to be rebuilt, on average, every five years, we calculated the average yearly cost of SWC by dividing the weighted average construction costs by five.

Fertilizer costs were calculated by taking the elemental amount of nitrogen in each type of fertilizer reported by households in the study sites (UREA, NPK, DAP, CAN). We calculated how many 1-kilogram bags of each type of fertilizer would be needed to reach 40kilograms of nitrogen, and multiplied the number of bags by the cost per bag (using average costs for each type of fertilizer applied to seasonal crops—average price across long and short rainfall seasons). Although the survey contained data on fertilizer prices, these were much higher than retail prices, probably due to error in converting bags to kilograms. We therefore used retail prices in our calculation.

We find that all alternative packages increase SCS[10] and most packages also increase net revenue from maize production compared with a strategy of no improved management practices. An exception is the application of crop residues, manure, and fertilizers on sandy soils in Garissa (arid AEZ), which results in a decline in net profits because the increase in gross profits is more than outweighed by the increase in input costs.

While revenues from the increase in SCS are in the range of $0–$1 per hectare when 50 percent of crop residues are left on maize fields, assuming a carbon price of $10 per ton of CO2, revenues rise to $2–$10 if manure and fertilizers are also applied, and they are highest for loamy soils in the temperate and semiarid areas. If SWC and crop rotation are also incorporated, revenues from carbon alone are $9 per hectare in the semiarid areas with loamy soils and $10 per hectare in the temperate area with loamy soils. If irrigation is also added, carbon benefits are highest on sandy soils in the arid zone, at $10 per hectare, followed by $9 per hectare on loamy soils in the temperate area.

We find the highest increase in net profits from maize production under Package 4 in the semiarid areas on clayey soils. But the increase in net profits is also high on clayey soils in the arid areas and on loamy soils in the semiarid and humid areas. Sandy soils are generally associated with the lowest carbon benefits and the smallest crop production profits. If the only management improvement is leaving crop residues on the field, net profits for maize production increase most on loamy and clayey soils in the semiarid zone; if manure and fertilizers are also applied, the increase in net profits is also high in the humid zone on loamy soils; if rotation and SWC are included, the increase in net profits is also high on loamy soils in the temperate area.

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[9] We use a price per kg of maize of US$0.375.

However, the increase in net revenues in Table 7.1 does not take into consideration the opportunity cost implicit in leaving 50 percent of crop residues (maize stover) on the field. In many parts of Kenya, maize stover is an important source of livestock feed. The cost of purchasing feed replacement must therefore be factored into the analysis of profitability. Although manure is not generally purchased as an input, the amount of manure assumed in the management packages (three tons per hectare) is more than can realistically be produced on the farm. It is therefore also necessary to include an additional cost for manure.

In order to capture the costs associated with livestock, we assumed that one hectare of cropland would support one cow (in terms of feed) and that one cow would provide one ton of manure per hectare per year. Assuming maize stover is the primary source of feed and that one cow would consume 2,008 kilograms of stover per year (5.5 kilograms of DM per day), we calculated the deficit (or surplus as the case may be) in livestock feed if 50 percent of residues are left in the field. Where there is a deficit in feed for livestock, we calculated the cost of purchasing napier grass (KES 4 or $0.05 per kilogram) as a feed replacement. Given that one cow would supply one ton of manure per hectare, we calculated the cost of two tons of manure at a rate of KES 5.5 or $0.07 per kilogram. The results of incorporating costs associated with livestock are presented in Table 7.2.

Table 7.2—40-year average annual incremental revenues from SOC and maize yield, including costs from livestock (crop residues at 50 percent)

		Package 1		Package 2		Package 3		Package 4	
		RSD50		RSD50, FRT, & MNR		RSD50, FRT, MNR, SWC, & ROT		RSD50, FRT, MNR, SWC, ROT, & IRG	
AEZ	Soil	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)
Arid	Clay	0	-16	2	-195	5	7	5	1151
Arid	Sand	1	35	4	-221	6	241	10	892
Semiarid	Loam	1	177	10	910	9	1072	5	1023
Semiarid	Sand	1	116	4	231	6	309	6	162
Semiarid	Clay	1	210	7	1626	7	1920	6	1947
Temperate	Loam	1	12	10	816	10	910	9	736
Humid	Loam	0	116	4	1431	4	1513	4	1061

Source: Authors.

Notes: RSD50 = 50 percent of residues left in field; FRT = fertilizer; MNR = manure; SWC = soil and water conservation; ROT = rotation with dry beans; IRG = irrigation. * Assumes a carbon price of US$10 per ton of CO2 equivalent. ** Assumes a price of US$0.375 per kilogram of maize.

After factoring costs associated with livestock into the analysis, most management packages still increase net profits. The exceptions are Packages 1 and 2 in arid areas with clayey soil and Package 2 in arid areas with sandy soil. In these scenarios, the livestock and other input costs implicit in the packages outweigh the benefits from increased productivity.

To further explore the tradeoff with livestock, we considered a set of management packages that include the application of 75 percent of residues on cropland, leaving only 25 percent of residues for livestock feed. Table 7.3 shows the increase in revenues from SCS and maize yield improvements for this set of packages, not including livestock costs. Compared with Table 7.1 above, we generally find greater revenues from SCS and yield improvements when 75 percent of residues are left in the field, with some exceptions.

Table 7.3—40-year average annual incremental revenues from SOC and maize yield (crop residues at 75 percent)

		Package 1		Package 2		Package 3		Package 4	
		RSD75		RSD75, FRT & MNR		RSD75, FRT, MNR, SWC, & ROT		RSD75, FRT, MNR, SWC, ROT, & IRG	
AEZ	Soil	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)
Arid	Clay	1	84	2	-44	6	393	6	1042
Arid	Sand	1	74	4	11	7	203	11	1353
Semiarid	Loam	2	237	12	1103	11	1264	10	1191
Semiarid	Sand	1	167	5	373	6	470	6	328
Semiarid	Clay	1	463	8	1921	8	2183	7	1958
Temperate	Loam	2	59	12	994	11	1088	11	899
Humid	Loam	0	118	5	1552	5	1637	4	1186

Source: Authors.

Notes: RSD75 = 75 percent of residues left in field; FRT = fertilizer; MNR = manure; SWC = soil and water conservation; ROT = rotation with dry beans; IRG = irrigation. * Assumes a carbon price of US$10 per ton of CO2 equivalent. ** Assumes a price of US$0.375 per kilogram of maize.

With 75 percent residues, revenues from SCS range from $0 to $2 per hectare for Package 1, from $2 to $12 when fertilizer and manure are added, from $5 to $11 with the addition of SWC and crop rotation, and from $4 to $11 when irrigation is added. In general, revenues from SCS tend to increase slightly with 75 percent residue retention compared to packages with only 50 percent residues.

Table 7.4 shows the difference in revenues from yield improvements for each of the management packages when 75 percent of residues (instead of 50 percent) are left in the field. Negative numbers indicate that the increase in revenue from improved management practices is less with 75 percent residues than it is from the same package of practices with 50 percent of residues.

Table 7.4—Difference in 40-year average annual revenues from SOC and yield when 75 percent of crop residues are applied instead of 50 percent

		Package 1		Package 2		Package 3		Package 4	
		RSD		RSD, FRT, & MNR		RSD, FRT, MNR, SWC, & ROT		RSD, FRT, MNR, SWC, ROT, & IRG	
AEZ	Soil	Revenue from carbon* (US$/ha), difference	Net revenue from yield** (US$/ha), difference	Revenue from carbon* (US$/ha), difference	Net revenue from yield** (US$/ha), difference	Revenue from carbon* (US$/ha), difference	Net revenue from yield** (US$/ha), difference	Revenue from carbon* (US$/ha), difference	Net revenue from yield** (US$/ha), difference
Arid	Clay	0	13	0	-61	0	191	0	-247
Arid	Sand	0	-9	0	51	0	-180	1	323
Semiarid	Loam	1	23	2	56	1	54	6	31
Semiarid	Sand	0	31	1	4	0	24	0	29
Semiarid	Clay	0	207	1	157	1	125	1	-126
Temperate	Loam	1	-3	2	40	1	41	1	26
Humid	Loam	0	-18	1	-17	1	-13	1	-12

Source: Authors.

Notes: RSD = residues left in field; FRT = fertilizer; MNR = manure; SWC = soil and water conservation; ROT = rotation with dry beans; IRG = irrigation. * Assumes a carbon price of US$10 per ton of CO2 equivalent. ** Assumes a price of US$0.375 per kilogram of maize.

Factoring in the costs associated with livestock feed and manure, net revenues still increase with management packages when including 75 percent residue retention in most scenarios (see Table 7.5). However, there are more cases in which the management packages with 75 percent residues are less profitable than the same packages with 50 percent residues (see Table 7.6). This shows that the optimal allocation of residues for crop productivity and livestock feed in terms of profitability will depend on the location and local conditions (soil type) as well as the total combination of management practices. In more than half of the scenarios examined, it is more profitable to leave only 50 percent of crop residues in the field, while in the remaining scenarios it is more profitable to leave 75 percent of residues in the field and purchase feed replacement, such as napier grass.

Table 7.5—40-year average annual incremental revenues from SOC and maize yield, including costs from livestock (crop residues at 75 percent)

		Package 1		Package 2		Package 3		Package 4	
		RSD75		RSD75, FRT, & MNR		RSD75, FRT, MNR, SWC, & ROT		RSD75, FRT, MNR, SWC, ROT, & IRG	
AEZ	Soil	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)	Revenue from carbon* (US$/ha)	Net revenue from yield** (US$/ha)
Arid	Clay	1	-10	2	-269	6	177	6	866
Arid	Sand	1	-1	4	-198	7	14	11	1180
Semiarid	Loam	2	168	12	933	11	1099	10	1025
Semiarid	Sand	1	108	5	197	6	296	6	155
Semiarid	Clay	1	392	8	1746	8	2011	7	1782
Temperate	Loam	2	-16	12	817	11	916	11	722
Humid	Loam	0	57	5	1384	5	1472	4	1016

Source: Authors.
Notes: RSD75 = 75 percent of residues left in field; FRT = fertilizer; MNR = manure; SWC = soil and water conservation; ROT = rotation with dry beans; IRG = irrigation. * Assumes a carbon price of US$10 per ton of CO2 equivalent. ** Assumes a price of US$0.375 per kilogram of maize.

Table 7.6—Difference in 40-year average annual revenues from SOC and maize yield when 75 percent of residues are applied instead of 50 percent, including costs from livestock

		Package 1		Package 2		Package 3		Package 4	
		RSD		RSD, FRT, & MNR		RSD, FRT, MNR, SWC, & ROT		RSD, FRT, MNR, SWC, ROT, & IRG	
AEZ	Soil	Revenue from carbon* (US$/ha), difference	Net revenue from yield** (US$/ha), difference	Revenue from carbon* (US$/ha), difference	Net revenue from yield** (US$/ha), difference	Revenue from carbon* (US$/ha), difference	Net revenue from yield** (US$/ha), difference	Revenue from carbon* (US$/ha), difference	Net revenue from yield** (US$/ha), difference
Arid	Clay	0	7	0	-74	0	170	0	-285
Arid	Sand	0	-35	0	23	0	-228	1	289
Semiarid	Loam	1	-9	2	24	1	27	6	2
Semiarid	Sand	0	-8	1	-34	0	-13	0	-7
Semiarid	Clay	0	182	1	120	1	91	1	-164
Temperate	Loam	1	-28	2	1	1	6	1	-14
Humid	Loam	0	-59	1	-47	1	-41	1	-45

Source: Authors.
Notes: RSD = residues left in field; FRT = fertilizer; MNR = manure; SWC = soil and water conservation; ROT = rotation with dry beans; IRG = irrigation. * Assumes a carbon price of US$10 per ton of CO2 equivalent. ** Assumes a price of US$0.375 per kilogram of maize.

Profitability of Improved Livestock Feeding

Table 5.4 illustrates the impacts of alternative feeding strategies on milk, manure, and methane production as well as the efficiency of methane production per liter of milk. To analyze the profitability of the various feeding management strategies, we calculated the cost of emissions for the different scenarios to determine which of the alternative feeding strategies leads to a reduction of emissions. Table 7.7 illustrates the cost of CO2 equivalent emissions for alternative feeding strategies; the alternatives that lead to a reduction in emissions with respect to the baseline situation are in bold. The table shows that overall methane emissions were reduced in only 4 out of 14 alternative feeding scenarios, suggesting that in general improved feeding tends to increase overall emissions. However, importantly, methane emissions per liter of milk are always lower (see also Section 5).

Table 7.7—Cost of carbon emissions for different alternative feeding strategies

District	Cost of CO_2 equiv. emissions for baseline feeding strategy (US$)	Scenarios	Cost of CO_2 equiv. emissions for the scenarios (US$)
		Prosopis	
Garissa		1.5 kg/day	6.45
	6.53	3 kg/day	6.16
		Desmodium	
Gem		1 kg/day	7.52
	7.77	2 kg/day	7.85
		Napier grass	
Mbeere		2 kg/day	9.94
	9.64	3 kg/day	9.90
		Desmodium	
Mukurweini		1 kg/day	9.94
	9.83	2 kg/day	9.17
		Hay	
Njoro		1 kg/day	9.61
	9.06	2 kg/day	10.63
		Hay	
Othaya		2 kg/day	9.68
	9.57	4 kg/day	9.61
		Napier grass	
Siaya		2 kg/day	9.02
	8.07	3 kg/day	10.49

Source: Authors.
Note: Assumes a carbon price of US$10 per ton of CO2 equivalent.

Tables 7.8 and 7.9 show the results from the profitability analysis for milk production in the seven districts. Annual net revenues were derived by subtracting the costs of labor and feed from revenues from the sale of milk. The price per liter of milk is equivalent to $0.352 per liter of milk. The profitability per liter ranges from $0.11 to $0.33. A previous study by Omiti and colleagues (2006) calculated net profits in the range of $0.13 to $0.16 per liter of milk. Table 7.9 compares the profitability of different alternative feeding strategies. Scenarios with increased profitability are in bold.

Table 7.8—Profitability analysis for milk production in the seven districts

District	Cost of feed[a] (US$/yr)	Cost of labor (US/yr)[b]	Net revenue[c] (US$/yr)	Net revenue per liter of milk (US$/yr)
Garissa	n/a[d]	4.7	92.1	0.33
Gem	112	18.8	62.2	0.11
Mbeere	241	30.0	31.3	0.04
Njoro	250	16.6	175.8	0.14
Mukurweni	335	17.8	383.0	0.18
Othaya	297	108.3	311.1	0.15
Siaya	108	31.3	109.6	0.16

Source: Authors.
Notes: [a] This is the cost of feed for one dairy cow. Feed cost information comes from personal communication with Ben Lukuyu; Lukuyu et al. 2009; Nyanga et al. 2009. [b] Labor costs are based on survey results. [c] Assumes a price of $0.352 per liter of milk. [d] Because livestock in Garissa rely on grazing only, there is no cost for feed in the baseline scenario.

Table 7.9—Profitability analysis for milk production in the seven districts based on different alternative feeding strategies

District		Cost of feed[a] (US$/yr)	Cost of labor[b] (US$/yr)	Net revenue[c] (US$/yr)	Net revenue per liter of milk (US$)
	Prosopis				
Garissa	1.5 kg/day	48	7.7	104.1	0.23
	3 kg/day	99	11.1	118.8	0.18
	Desmodium				
Gem	1 kg/day	38	22.7	172.3	**0.26**
	2 kg/day	68	25.5	169.2	**0.23**
	Napier grass				
Mbeere	2 kg/day	155	33.6	150.8	**0.16**
	3 kg/day	173	35.1	146.2	**0.15**
	Hay				
Njoro	1 kg/day	222	19.6	279.9	**0.19**
	2 kg/day	277	24.7	357.0	**0.19**
	Desmodium				
Mukurweni	1 kg/day	235	19.4	547.4	**0.24**
	2 kg/day	264	19.2	511.0	**0.23**
	Hay				
Othaya	2 kg/day	314	118.0	348.8	**0.16**
	4 kg/day	423	117.0	233.2	0.11
	Napier grass				
Siaya	2 kg/day	69	44.4	239.1	**0.24**
	3 kg/day	88	25.5	169.2	**0.23**

Source: Authors.
Notes: [a] This is the cost of feed for one dairy cow. [b] Labor costs are based on survey results. [c] Assumes a price of $0.352 per liter of milk.

Table 7.9 shows that in most cases, alternative feeding practices increase productivity and net profits per liter of milk. One exception is in Garissa, where the cost of purchasing improved feeds reduces net profits per liter of milk (although total net revenues increase slightly given greater quantity of milk produced). Net profits per liter of milk also decrease compared with the baseline for the second scenario in Othaya, given the large cost of purchasing replacement feed.

8. CONCLUSIONS AND POLICY IMPLICATIONS

The results of this study indicate that farmers in Kenya do not fully recognize the interlinkages between agricultural productivity, climate change adaptation, and GHG mitigation. Rather, farm decisions depend largely on productivity considerations, while many farmers are making initial attempts to adjust to climate changes. Moreover, although farmers are aware of the connection between agricultural practices and climate change and of the benefits of planting trees to mitigate climate change, there is less awareness about the mitigation potential of integrated soil fertility management and SWC and their potential synergies with adaptation. This is a significant gap that the government, NGOs, and extension agents will need to address in Kenya and elsewhere in the developing world for agricultural GHG mitigation to become an effective development strategy.

Table 8.1 presents the set of practices identified in the literature (Table 1.1) as promising for adaptation, mitigation, and productivity and adds insights based on the results of this study. This study focused on cropland and livestock management strategies commonly practiced in the study sites, while grazing land management practices and restoration of degraded lands were outside the scope of this study. Many of the practices listed in Table 8.1 are already being implemented in the study sites to increase farm productivity and to help farmers cope with climate change, but the current rates of adoption of some practices that also offer co-benefits with respect to mitigation, such as minimum tillage, cover cropping, and improved fallowing, are low.

The results highlight soil nutrient management (combinations of inorganic fertilizer, mulching, and manure) as a key win–win–win strategy. This strategy increases SCS and boosts yields, thereby increasing farm revenues and providing a buffer against the negative impacts of climate change. The benefits in terms of yield improvements far outweigh the costs of purchasing and applying fertilizer and manure. However, inorganic fertilizer application alone does not increase SCS across all soil types and AEZs. Instead, inorganic fertilizer needs to be combined with other soil fertility management practices, such as manure, mulching, and crop residues. We find that some farmers implement such combinations in all AEZs already. Specific combinations of nutrients will vary depending on the crop type, AEZ, and planting date.

Leaving crop residues on the field has a high potential for both yield improvement and SCS. Applying residues is also associated with lower labor costs because it reduces the time needed for weeding and removing residues from the field. In addition, the benefits are far greater when combined with fertilizer and manure. However, in the rangeland-based systems, where residues are used as a feed supplement during the dry season, farmers may not always choose to leave residues in the field. The optimal allocation of residues—balancing benefits from crop production and livestock costs—depends on the combination of management practices chosen as well as the agroecological and soil conditions. In more than half of the scenarios examined, it was more profitable to leave only 50 percent of crop residues in the field, while in the remaining scenarios it was more profitable to leave 75 percent of residues in the field and purchase replacement feed (napier grass).

While in general nutrient management appears to be a promising strategy across study sites, the results were more complex with respect to other management strategies. Intercropping or rotation of maize and beans are key management practices used in much of Kenya. However, the results show that rotation of maize with beans has only limited SCS and yield benefits.

Table 8.1—Synergies among adaptation benefits, mitigation potential, and crop productivity and profitability: Insights from our study

Management practice	Adaptation benefits	Mitigation potential	Productivity/Profitability
Cropland management			
Improved crop varieties or types	Positive	Mixed	Uncertain
Changing planting dates	Positive	Uncertain	Uncertain
Improved crop rotation, fallowing, or rotation with legumes	Uncertain	Mixed	Mixed
Appropriate fertilizer or manure use	Positive	Positive	Positive
Incorporation of crop residues	Positive	Positive	Positive—tradeoff with livestock feed in certain areas
Agroforestry	Not examined in this study		
Use of cover crops	Not commonly reported in study sites		
Reduced or zero tillage	Not commonly reported in study sites		
Water management			
Irrigation or water harvesting	Positive	Mixed	Positive
Soil and water conservation (bunds, grass strips, ridge and furrow, and the like)	Positive	Mixed	Mixed—positive impacts in areas where soil moisture is a constraint; appropriate selection and combination of technologies important
Livestock/grazing land management			
Improved livestock feeding	Positive	Positive	Positive
Destocking	Positive	Positive	Positive —when combined with improved feeding
Improved breeds or species	Not examined in this study		
Rotational grazing	Not examined in this study		
Restoring degraded lands			
Revegetation	Not examined in this study		
Applying nutrient amendments	Not examined in this study		

Source: Authors.

In addition, while changing crop variety was mentioned as a key adaptation practice, crop simulation results show that for maize, the hybrid variety was not always favored in terms of SCS, even with nutrient management practices. However, further research is needed to determine whether hybrid varieties specifically calibrated to local conditions are more effective at increasing soil carbon and yield.

Changing planting dates and crop types were also mentioned as important adaptation strategies. While the effects of changing planting dates or crop types on soil carbon, productivity, and profitability were not examined in this study, it is probably safe to assume that changing planting dates would have no effect on soil carbon pools or average yields apart from reducing production risk, and that the effect of changing crop type on soil carbon and yield would depend on the crops being substituted.

In terms of water management, SWC techniques—resulting in increased soil water availability prior to planting—and irrigation show mixed results regarding carbon sequestration and yield improvements, even under a drier future. In the arid areas, the use of SWC techniques was strongly favored in almost all management packages, and irrigation was essential to achieve reasonable yield levels given very limited water availability in the arid sites. However, in other districts, there was not a clear positive or negative pattern for SWC practices. In the humid sites, water is readily available yet nitrogen is rather limited. In this situation, SWC techniques had an insignificant effect, and irrigation in fact lowered the average yield levels across simulated management practices, possibly due to an increase in the leaching of nitrogen from the soil. In the semiarid and temperate sites, water is somewhat limited; thus the SWC practices and irrigation overall increased yield levels, and irrigation reduced yield variability, which is important for adaptation to climate change. However, the more notable yield increases were from the nitrogen inputs from manure and fertilizer applications.

The production function results using survey data also did not show significant benefits from SWC measures. This suggests that farmers may not be choosing the appropriate combination of measures given the environmental and agroecological conditions, due to lack of training or experience. Furthermore, other researchers have argued that even when adopted and practiced, SWC measures are necessary but insufficient to address the declining productivity of agriculture. Institutional and policy changes that reduce corruption and increase trust in extension agents' advice, that support lower input and higher output prices, and that provide infrastructure improvements and services are also essential (Ekbom, Knutsson, and Ovuka 2001; Kristjanson et al. 2010).

Overall, the results suggest that irrigation and SWC techniques should be selected to suit the local context. These practices are likely to offer the greatest benefits in areas where soil moisture is a constraint. However, while SWC structures are affordable for many farmers to construct and maintain few farmers are able to make the initial investments required for irrigation.

Promising strategies to capture multiple benefits in terms of adaptation, mitigation, and productivity are also available for livestock producers. Examining the potential impacts of improved feeding practices on the productivity and methane emissions of cattle using a ruminant simulation model showed there is a significant opportunity to produce milk at lower methane emissions per liter in the seven districts under study, through sustainable intensification practices like improved feeding. Large differences exist between the study sites, with the largest potential improvements in the districts with the poorest feed resources available. However, in only 4 of the 14 alternative scenarios did improved feeding practices result in a decline in overall methane emissions, and emission reductions were very small. In cases where overall emissions increased, households would have to also engage in destocking to receive benefits from carbon markets. Maintaining a smaller number of better-quality, more productive animals is a strategy advocated by a number of agencies and NGOs operating in Kenya and one that many households are already adopting in response to climate change.

Improved feeding practices also increased net profits from the sale of milk in most cases. One exception was in the arid site, where livestock are grazed and feed is not purchased. Therefore, the cost of purchasing improved feeds reduced net profits per liter of milk. High levels of replacement feeds, such as presented in the scenario for Othaya, are also not profitable. Households in these areas therefore may require additional incentives to adopt improved feeding practices. Public provision of improved feeds in areas where these practices are not as profitable would facilitate adoption and maximize benefits in terms of increased productivity and GHG mitigation.

Developing agricultural productivity and food security strategies and policies that include climate change adaptation and GHG mitigation aspects requires capacity building at the national level (among policymakers and others) as well as better communication and coordination between ministries. Capacity building in climate-smart agriculture (e.g. development of measurement, reporting, and verification (MRV) systems and baselines; identification and dissemination of locally-appropriate, promising technologies and practices) is also needed among researchers and advisory agents.

Successful adoption of climate-smart agricultural practices also requires farmers to have greater access to information and advice through extension services, as well as additional financial resources, particularly in the case of more costly investments such as irrigation. This was a key issue during the PRA discussions—farmers expressed interest in gaining more information, advice, and training regarding appropriate practices and technologies, such as new crop varieties or agroforestry (Roncoli et al. 2010). The Kenyan government has several options for facilitating adoption of the most promising practices and technologies. Expanding access to credit can encourage the adoption of more costly practices and triple-win technologies. Promoting agricultural intensification through investments in agriculture such as the provision of inputs, capacity development, and additional research and development would further facilitate the adoption of synergistic practices (Smith et al. 2006).

Furthermore, while the opportunities are limited, given the exclusion of many agricultural mitigation activities from carbon markets such as the Clean Development Mechanism (CDM), there are some markets that provide financial incentives to smallholder farmers. For example, this survey covered farmers involved in a program that is taking advantage of mitigation opportunities provided by the Voluntary Carbon Standard (VCS). International climate negotiators should also intensify efforts to include SCS projects in the CDM. A key issue is ensuring that emission reductions meet MRV standards. There are promising technologies to this end—microsatellites with six-meter resolution, inexpensive soil carbon tests—that need to be made available by the time a post-Kyoto agreement comes into effect.

Climate change mitigation has the potential to yield substantial benefits for smallholder farmers in Kenya that can be used to support adaptation and development efforts. However, given the low price of carbon offsets ($5–$20 per hectare); mitigation activities alone do not yield sufficient benefits to warrant their adoption. Carbon finance may never contribute more than 15 percent of global agricultural investment needs, estimated at nearly $210 billion annually to 2050 (Schmidhuber, Bruinsma, and Boedecker 2009; FAO 2009). Rather, agricultural investments (both national and international) should be targeted toward activities that also provide benefits in terms of mitigation, adaptation, and increased productivity and profitability. Investments that advance all three areas—profitability, adaptation, and mitigation—are more likely to be implemented and sustained.

Other financing options to support agricultural adaptation and mitigation should also be further explored, including adaptation funds, mitigation funds (including nationally appropriate mitigation actions or NAMAs) with less strict MRV requirements, and credit mechanisms. In addition, greater support should be given to developers of climate-smart and carbon projects, including assistance in project development and implementation, application of MRV systems, and risk management (such as guarantees or loans), to ensure that smallholders get financial benefits from mitigation activities.

APPENDIX: CROP SIMULATION METHODOLOGY

Seven common management practices were identified for rainfed maize, including variety, inorganic fertilizer, manure application, residue management, mulching, rotation with legumes, and soil and water conservation (SWC) techniques. For each component, use or nonuse cases were characterized based on the household survey results at district level. Following are the description of each management practice component and its code used in the presentation of simulation outputs.

- Maize variety
  - OPV: medium-maturity generic improved open-pollination variety
  - HYB: DeKalb XL71 hybrid variety
- Inorganic fertilizer
  - FRT: 40 kilograms of nitrogen per hectare of inorganic fertilizer, split applied (20 kilograms of nitrogen per hectare on planting at depth of five centimeters and 20 kilograms of nitrogen per hectare on 30th day after planting as top dressing) with no incorporation
  - No FRT: no fertilizer application
- Supplementary irrigation
  - IRG: 100 millimeters per hectare of furrow irrigation split applied on the day of planting and 40th day after planting (for example, 50 millimeters per hectare each application)
  - No IRG: rainfed cultivation with no irrigation
- Manure application
  - MNR: one ton per hectare of animal manure (nitrogen content 1.4 percent) applied on the fallow field three times with 20-day interval, between main growing seasons (total of three tons per hectare per year)
  - No MNR: no manure application
- Residue management
  - RSD: 50 percent of crop residue left on the field after harvest (50 percent of residue removed after harvest)
  - No RSD: all crop residue removed from the field after harvest
  - Three additional levels of residue harvest (harvesting 0 percent, 25 percent, and 75 percent of residue after harvest) simulated for testing the model sensitivity
- Rotation with legume
  - ROT: rotation with dry beans every fourth year (maize–maize–maize–dry bean)
  - No ROT: continuous maize cultivation
- SWC practices
  - SWC: assumes various soil and water conservation techniques practiced on the field so that the soil water availability before planting is 30 percent of field capacity and a small amount (two millimeters per hectare every ten days) of soil moisture is additionally available in the root zone throughout the growing season
  - No SWC: no SWC practices; soil water availability at 10 percent of field capacity before planting

From the 40-year time series simulation results, averaged soil organic carbon content for first five years and last five years were calculated for each climate, soil texture, and management practice combination, and used as the basis for the overall soil carbon stock changes for the time span. For the estimation of SCS, the *no-effort* management case (no residue management, no rotation, no manure, no SWC, no fertilizer application, and the use of OPV) was used as a baseline to be compared with other management practice packages. Then the stock change for a 30-year period (excluding the first and last five years) was scaled down to a 20-year period, to be compatible with the results from other studies.

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