Agricultural Land Management: Capturing Synergies between Climate Change Adaptation, Greenhouse Gas Mitigation and Agricultural Productivity—Insights from Kenya

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Report to the World Bank

Report 3b of the project "Adaptation of Smallholder Agriculture to Climate Change in Kenya"

April 20, 2011

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Abbreviations

AEZ	Agroecological Zone
ARLMP	Arid Lands Management Project
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
KARI	Kenya Agricultural Research Institute
NGO	Nongovernmental Organization
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

Executive Summary

Livelihoods of Kenyan farmers are closely interlinked with climate. Fifty-two percent of the population is below the poverty line, mostly in rural areas. While the poorest of the poor live in the northern, arid zones of the country, more than 80 percent of the rural poor are located in the high-potential areas of Lake Victoria and Mount Kenya. Almost three quarters of the Kenyan labor force still depends on agriculture for their livelihoods, and almost all farmers depend on timely and adequate rainfall for crop production and husbandry as only 2 percent of cultivated area is equipped for irrigation. Thus, climate variability and change have and will have an increasing impact on agricultural livelihoods and food security in the country.

Given the small farm size prevalent among Kenyan smallholders, the lack of capital, including the lack of irrigation development, sustainable intensification practices are critical for farmer-driven adaptation in Kenya and elsewhere in East Africa. At the same time, many of the sustainable intensification practices that farmers in Kenya and elsewhere in Sub-Saharan Africa employ also directly contribute to greenhouse gas (GHG) mitigation. However, there is little research to date on the **synergies and tradeoffs between agricultural adaptation, mitigation, and productivity/profitability impacts**.

To address this issue, we implemented a farm household survey during July 2009 to February 2010 for 710 households in seven districts and 13 divisions of Kenya spanning the arid, semi-arid, temperate, and humid agroecological zones (AEZ) of the country. This report analyzes the synergies and tradeoffs among climate change adaptation, mitigation, and productivity/profitability through the assessment of common land management practices implemented in the study sites, climate change adaptation options chosen by farmers, mitigation options for crops and livestock simulated by modeling tools, and productivity/profitability impacts calculated based on survey data.

The most common land management practices used by farmers include application of inorganic fertilizer (45 percent), composting or manure (40 percent), intercropping (39 percent), soil bunds (18 percent), crop residue management (12 percent), and grass strips (11 percent). While some soil and water conservation (SWC) measures were used in all districts, their use varied by agroecological zone, by district/division, and by crop type. The least number of practices were used in the arid zone, while the largest variety of management practices were employed in the semi-arid zone. Farmers in the semi-arid, temperate, and humid regions adopted soil bunds, grass strips, and residues for both seasonal and perennial crops. Farmers in the temperate coffee-producing region also constructed bench terraces on approximately one quarter of their plots planted with perennial crops. Fertilizer use for annual crops was most common in the coffee area, with quarters of farmers using inorganic fertilizers; while 40 percent of farmers in the humid zone and less than a third of farmers in the semi-arid areas applied inorganic fertilizers.

Key **adaptation strategies** chosen include changing crop variety (33 percent), changing planting dates (20 percent), and changing crop type (18 percent). Other, less important strategies include planting trees, reducing livestock, changing livestock feed, changing fertilizer use, and SWC practices. Irrigation, tree planting, and changing crop varieties were mentioned as adaptations farmers would like to make but are unable to due to constraints such as lack of money or access to credit, and lack of water and inputs.

Sixty-seven percent of farmers responded that they believed that agricultural practices contribute to climate change. Moreover, most farmers stated that afforestation and agroforestry would help mitigate climate change. On the other hand, only 6 percent of farmers reported that SWC techniques mitigate climate change and 5 percent stated that reduced chemical usage or organic farming mitigate climate change. Thus, while there is a clear perceived link between deforestation and climate change, there is very little understanding in rural Kenya to date on the link between sustainable intensification practices and climate change mitigation, even though the only land-based agricultural mitigation site in Africa was part of the survey. 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 mitigation to become an effective development strategy.

We estimated the soil carbon sequestration potential and maize yields over a 40-year period for key crop management practices implemented by farm households in the various districts. The results show that many of the management practices that farmers in the study area already use have **positive soil carbon sequestration and yield effects**, and these effects are robust under both a wet and a dry future climate. In particular, leaving crop residues on the field is highly positive for both yield improvement and soil carbon sequestration. The simulations also show that inorganic fertilizer application alone does not increase soil carbon sequestration and maize yields, across all soil types and AEZs. Instead, inorganic fertilizer needs to be combined with other soil fertility management practices, such as manure and/or crop residues.

While in general, the best package of practices for soil carbon sequestration and yield improvements would consist of a combination of manure application, fertilizer application, and residue management, we find complex interactions and differences in final packages for enhanced soil carbon sequestration across the study sites. Assuming a 50-percent residue retention (that is, the remaining 50 percent are removed as animal feed), the results showed that in the arid site, irrigation and/or SWC are essential to achieve reasonable yield levels given very limited water availability. In the humid sites, where water is readily available, but nitrogen is limited; soil water conservation techniques are not effective, and irrigation in fact lowers average yield levels across simulated management practices, possibly due to increased nitrogen leaching from the soil. In the semi-arid and temperate sites, water is somewhat limited; thus soil and water management practices overall increase yield levels. However, larger yield improvements can be obtained from increased nitrogen inputs from manure and fertilizer applications.

Finally, we compared our crop simulation results with those of Joanneum (2007) (Biocarbon project sites) for the temperate AEZ.[1] Compared to that study we find higher soil carbon sequestration benefits from manure and residue management; and lower reductions in soil organic carbon (SOC) under no residue/no manure and residue/no manure cases.

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[1] The reports we received did not include results for the Gem/Siaya site of Vi Agroforestry. Thus, our comparison is limited to the Othaya/SMS site.

Intercropping of maize and beans or rotation of maize and beans is a key management practice used in much of Kenya. However, we find that rotation of maize with beans has only limited soil carbon sequestration benefits. While soil fertility improves, biomass contributed by beans is too low to make a real difference for SOC. In addition, the hybrid variety was not always favored even with nutrient management practices in most districts. In general, compared to an open-pollinated variety, the hybrid variety demands more water and nitrogen and may not necessarily benefit soil carbon sequestration in smallholder farmers' field conditions.

SWC techniques—represented as increased soil water availability prior to planting—show mixed results regarding carbon sequestration, even under a drier future. In the arid areas, the use of SWC techniques was strongly favored in almost all management packages. However in other districts, there was no clear positive or negative pattern regarding the benefit of adopting SWC.

Moreover, in terms of productivity effects, the production function results show no significant yield improvement from SWC for maize, beans, or coffee among the households surveyed. We do find that adding nutrients to the soil, such as inorganic fertilizer, compost, and manure does increase yield and reduce production risk (in terms of yield variance). In particular, phosphate 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. N fertilizer applied to beans actually has a negative effect on yield. Given that beans are nitrogen fixing, additional input of N fertilizer only increases vegetative growth not seed formation.

Examining the potential impacts of improved feeding practices on the productivity and methane emissions of cattle using a ruminant simulation model showed that there is a significant opportunity to produce milk at lower methane emissions per liter of milk in the 7 districts under study through sustainable intensification practices, particularly improved feeding. Large differences exist between the regions under study, with the largest potential improvements in the districts with poorer feed resource availability. Achieving higher efficiency in GHG management will require incentives for farmers to follow a market-oriented dairy focus for their farms and would also require improved market access.

An analysis of the **profitability** of various combinations of agricultural management strategies suggests there are several win-win-win options available for poor smallholders. In particular, nutrient management (the combination of inorganic fertilizer, manure, and crop residues) has positive impacts for SOC, boosts yields, and increases farm profits. Some farmers in all agroecological zones implement this combination already. However, the optimal combination of practices varies depending on the soil type and agroecological zone. For example, in arid areas, net profits are positive only when nutrient management is combined with SWC and/or irrigation.

While revenues from the increase in SCS are in the range of US$1-2 per hectare when 50 percent of crop residues are left on maize fields, assuming a carbon price of US$10 per tCO2e, revenues rise to US$2-24 if manure and fertilizers are also applied and are highest for loamy soils in temperate areas. If SWC and crop rotation are also incorporated, revenues from carbon alone can be as high as US$22 per ha in semi-arid, loamy soils and US$23 per ha in temperate loamy soils. If irrigation is also added, carbon benefits are highest on clayey soils in the arid zone, at US$24 per ha, followed by US$22 and US$21 per hectare in the loamy soils in temperate and semi-arid areas, respectively.

However, there is a **tradeoff** between residues left on the field versus residues used for livestock feeding, particularly in the rangeland based systems, where residues are used as a feed supplement during the dry season. We find that in some cases, it is more profitable for farmers to leave a smaller portion of residues in the field (50 percent versus 75 percent, for example), particularly where the cost of purchasing feed replacement for livestock is greater than the additional revenues from yield improvements.

The analysis also highlighted improved feeding practices as a win-win-win strategy that should be promoted. Not only does increased use of modern feeds enable maize residues to be used on cropland, resulting in higher yields, SCS and profits; this practice also reduces methane emissions per liter of milk[2] and also increases net profits from the sale of milk in most cases. One exception is in the arid site where the cost of purchasing improved feeds reduces net profits per liter of milk. These households, therefore, may require additional incentives to adopt improved feeding practices.

While not examined as part of this report, agroforestry is likely to be another win-win-win strategy, given the large awareness of the importance of this practice in the country (fueled by media and the government), the large support by the government, the large biomass for carbon storage, and important adaptation benefits. However, awareness of the importance of the practice does not mean that farmers are willing to stop cutting trees for fuel or to start planting trees. The government and NGOs must find ways of making the adoption of agroforestry more attractive by providing seedlings, training, and other incentives such as credit. Linking with carbon markets or other payments for environmental services may reduce the incentive to use agroforestry trees for timber and firewood rather than for carbon sequestration and to support agricultural productivity.

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[2] However, in most cases, unless the number of livestock are also reduced (which should be possible given greater productivity per animal) overall methane emissions increase.

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 key 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 and 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 (CAIT 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 can lessen the impact of climate change, adaptation will be essential to ensure food security and protect the livelihoods of poor farmers.

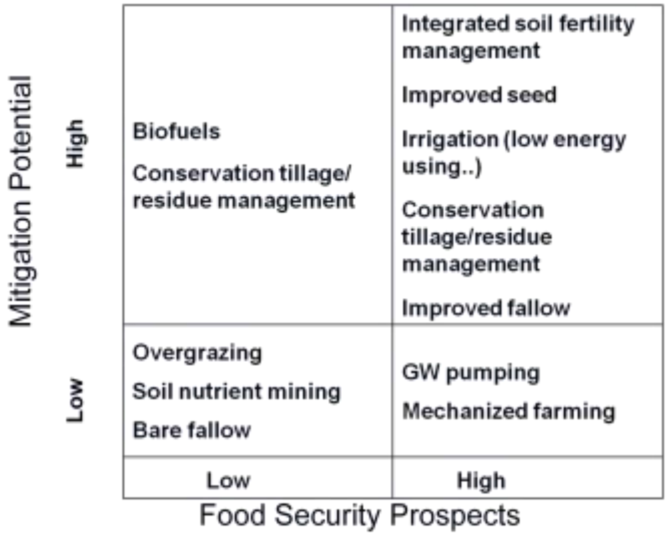
Countries in Sub-Saharan Africa (SSA) are particularly vulnerable to climate change impacts, because of their limited capacity to adapt. The development challenges that many African countries face are already considerable, and climate change will only add to these. At the same time, the economic potential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

In Kenya, where the poverty rate is 52 percent (WDI 2010) and 70 percent of the labor force depends on agricultural production for their 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 agriculture sector, ensure food security, and reduce rural poverty.

Adaptation is not only needed to increase the resilience of poor farmers to the threat of climate change, 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/profitability and reduce GHG emissions from agriculture. However, there may also be tradeoffs between increasing farm productivity/profitability, adaptation, and mitigation. 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). We suggest instead a framework differentiating tradeoffs and synergies among mitigation, agricultural productivity and profitability, and adaptation (Figure 2).

Figure 1: Mitigation potential and food security prospects



Mitigation Potential	Food Security Prospects: Low	Food Security Prospects: High
High	Biofuels Conservation tillage/ residue management	Integrated soil fertility management Improved seed Irrigation (low energy using..) Conservation tillage/residue management Improved fallow
Low	Overgrazing Soil nutrient mining Bare fallow	GW pumping Mechanized farming

Source: Adapted from FAO (2009).

Figure 2: Synergies and tradeoffs among agricultural adaptation, mitigation, and profitability/productivity

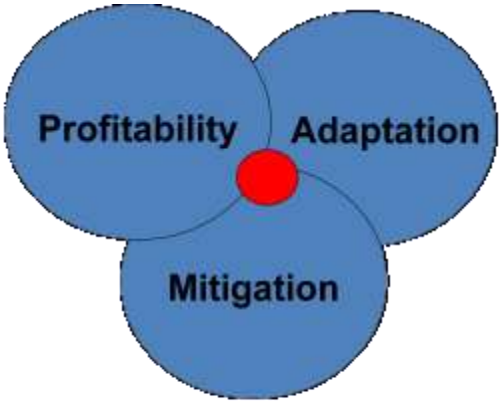


Table 1 lists several of the land management practices and adaptation strategies discussed in the literature and the implications of these practices for farm productivity/profitability, adaptation, and mitigation following our conceptual framework. The number and variety of options reported suggests that there are many promising strategies available to farmers in Kenya and elsewhere in SSA.

We find that, in general, management practices that increase agricultural production and reduce production risk also tend to be support climate change adaptation as 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 also 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. There are three main mechanisms for mitigating GHGs in agriculture: reducing emissions of GHGs, enhancing removals 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 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 adaptation, mitigation, and productivity/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 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/fallowing also involves short-term decreases in production due to decreases in cropping intensity. Furthermore, weeding and waterlogging are potential tradeoffs involved with reduced tillage and production impacts are minimal over the short-term.

Table 1: Synergies and tradeoffs between productivity, adaptation, and mitigation

Management practices	Productivity impacts	Adaptation benefits	Mitigation potential
Cropland management			
Improved crop varieties and/or types (eg. early maturing, drought resistant varieties or crop types)	Increases crop yield and reduces yield variability	Provide increased resilience against climate change, particularly increases in climate variability (e.g. prolonged periods of drought, seasons shifts in rainfall etc.)	Improved varieties can increase soil carbon storage in soils
Changing planting dates	Reduces likelihood of crop failure	Maintains 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 N 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	Increases 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 fertilizer/manure use	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 when fertilizer is 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/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
Water management			
Irrigation/water harvesting	Higher yields, greater intensity of land use	Reduces production variability and climate resilience when systems are well-designed and maintained	Low to high depending on whether irrigation is energy intensive or not

Water management			
Bunds	Higher yields due to increased soil moisture, potentially lower yields during periods of high rainfall	Reduces yield variability in dry areas, may increase 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, may 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/trash line	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	Reduces yield variability in dry areas, may increase production loss due to heavy rains	Positive mitigation benefits minus initial losses due to construction of ridge and furrows
Diversion ditches	Increased yields due to drainage of agricultural lands in areas where flooding is problematic	Reduce yield variability under heavy rainfall conditions due to improved water management	Positive mitigation benefits through improved productivity and hence soil carbon
Livestock/grazing land management			
Diversify/change/supplement livestock feeds	Higher livestock yields due to improved diets	Increased climate resilience due to diversified sources of feed	High mitigation potential, 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, 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 provides greater climate resilience	Positive mitigation potential due increased carbon accrual on optimally grazed lands
Improved breeds/species	Increased productivity per animal for the resources available	Increased resilience of improved species/breeds to withstand increasing climate extremes	Varies, depending on the breeds/species being traded
Restoring degraded lands			
Re-vegetation	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).

Other tradeoffs include the costs and risks involved in the restoration of degraded soils, in particular, regarding the short-term costs in terms of labor and nutrients, while yields tend to only improve 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 non-agricultural 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 reduce 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 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. Win-win-win strategies 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 higher 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 that 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.

While in the group of developed countries, it is generally assumed that many efforts toward agricultural mitigation will reduce agricultural productivity, for example through Conservation Reserve Programs, in the context of SSA, agricultural practices are available that offer multiple benefits in terms of adaptation, mitigation, and agricultural productivity. Furthermore, linking smallholder farmers to voluntary carbon markets—while fraught with difficulties—can have large monetary payoffs (estimated at up to US$4.8 billion 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 payment for environmental services schemes.

This report examines the extent to which there are synergies between agricultural productivity, adaptation, and mitigation and highlights where tradeoffs exist for arid, semi-arid, temperate, and humid areas in Kenya.[3] In order to facilitate a comparison of the linkages between management practices that enhance farm productivity, resilience to climate change, and agricultural mitigation, we present the land and livestock management practices as well as adaptation strategies currently employed by farmers.[4] 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 in Kenya and beyond.

2. Methodology

2.1 Data collection

To identify and assess ongoing and alternative household-level and collective adaptation strategies and land management practices, data were collected from 13 divisions within 7 districts in Kenya (see Table 2). 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 agro-ecological zones, 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. The selected sites are drawn from a range of agroecological zones including arid, semi-arid, temperate, and humid areas.

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[3] Coastal areas were not surveyed.

[4] A previous report (Report 3a) analyzes the adaptation and coping strategies employed by surveyed farmers in more detail.

Table 2: Study sites

Project	District	Division	Agroecological zone	No. of households
ALRMP and Control*	Garissa	Central	Arid	66
		Sankuri	Arid	68
ALRMP	Mbeere South	Gachoka	Semi Arid	76
		Kiritiri	Semi Arid	21
Control	Njoro	Lare	Semi Arid	104
SMS, Ltd.	Mukurwe-ini	Gakindu	Temperate	47
		Mukurwe-ini Central	Temperate	46
		Mukurwe-ini 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**

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

In addition, survey sites were selected to include areas in which complementary World Bank-funded projects are operating, in order to build on ongoing research and data collection efforts and produce results that are relevant to these initiatives. In particular, the study included divisions in Garissa and Mbeere that participate in the Arid Lands Resources Management Project (ALRMP) and are representative of semi-arid and arid low-potential areas with a predominance of pastoralists and agro-pastoralist systems. The study also included districts representative of high-potential crop production areas, where two sustainable intensification projects operate, SMS Ltd. and VI Agroforestry; one of which, VI Agroforestry, is involved in agricultural mitigation activities. Control sites were selected with comparable biophysical and socioeconomic characteristics for each of the program district/divisions. Thus, the sampling frame was not designed to be statistically representative at the level of the district or AEZ. Survey enumerators were selected from each district so that they were familiar with local customs and could speak the local language.

2.1.1 *Description of study sites*

Garissa is an arid district in the Northeastern province covering 7.5 percent of the country's land mass. The bulk of the area is low lying (100-800 msl) and next to the Tana River. Physiographically, the region consists of plains at various levels with scattered inselbergs and plateaus. Floodplains and low terraces are found along Tana River and the climate is arid to very arid (AEZ V-VIII) (Sombroek et al. 1976). The district borders Somalia to the west and is populated by ethnic Somalis. Most households in the area rely on livestock production for their livelihood. Pastoralist households move livestock in search of pasture or extensive grazing in the lowlands. Moreover, households with access to the riverbank irrigate fruits and vegetables for sale in Garissa town and neighboring towns. Frequent droughts and unreliable rains make it difficult to manage rainfed food crop agriculture/pastures for livestock rearing. The river has recently been subject to severe seasonal flooding. The administrative division of Central has an area of 863 km^2 and a population of about 71,000 people (1999 estimate). The administrative division of Sankuri, has an area of 1952 km^2 and a population of approximately 12,000 people (1999 estimate).

Mbeere South (formerly under Mbeere District) is a semi-arid district located in the Eastern Province. It is a hilly area with three agroecological zones: at elevations over 1000 msl, maize, banana and fruits are cultivated; at elevations of 750-1000 msl, millet, sorghum, drought resistant maize, and legumes (beans, pigeon peas, black peas, green grams) are grown; and below 750 msl, livestock production prevails (Roncoli et al. 2010). Gachoka division has an altitude of 570 msl to 1560 msl. Rainfall is bi-modal with long rains from March to June and short rains from October to December. Average rainfall varies from 550 mm to 1100 mm, but is highly unpredictable. Most parts receive less than 600 mm of rainfall. Mbeere is the second largest producer of miraa (Catha edulis) or khat in Kenya, a native flowering plant that contains an amphetamine-like stimulant heavily consumed by men in the Somali-speaking areas. Consumption is not illegal in Kenya but highly discouraged because of its negative effects on the youth. Its use and trade are banned in many countries.

Njoro (formerly under Nakuru District) is part of Rift Valley province, near the semi-arid eastern edge of the Mau forest. The main livelihoods of the people of Njoro are saw-milling, cattle-keeping and farming. Njoro's climate allows its population to grow crops like barley, wheat, potatoes, beans and more recently maize. In fact, maize has overtaken wheat in relative importance. Rainfall averages 800-1000 mm (Walubengo 2007). The area experienced a severe drought in 2009.

Mukurwe-ini (formerly under Nyeri District) forms part of the Central Province, in the fertile highlands southwest of Mt. Kenya. The main cash crop is coffee (and to a lesser degree, tea), produced by smallholders organized in semi-private cooperatives that process and market the coffee. The main food crops are maize, legumes (beans and peas), tubers (potatoes), and vegetables (tomatoes, cabbage, spinach, kale).

Othaya (formerly under Nyeri District) also forms part of the Central Province in the fertile highlands of southwest of Mt. Kenya. It is an agricultural area with agricultural potential similar to Mukurwe-ini.

Gem (formerly under Siaya district) is located in the Nyanza Province in the southwestern part of Kenya, bordering the shores of Lake Victoria. The main crops are cotton, coffee, sugarcane, tobacco, vegetables, beans, bananas, sweet potatoes, and cassava. The area hosts several rivers, streams, and wetlands but they are not widely used for irrigation. Despite the more favorable climate conditions, a recent survey in the Siaya, Vihiga, and Kakamega districts of Western Kenya found that between 58 and 68 percent of the population lived below the poverty line. Local farming systems are characterized by very small landholding size (an average of 0.5 to 1 ha), low external input use and land productivity, declining soil fertility, and an exodus of able-bodied men to secure jobs in urban areas (Place et al. 2007;

Roncoli et al. 2010). Population density in Wagai division, where the study took place, is 289 people/km^2 (2001 estimate).

Siaya district is also part of Nyanza Province in the southwestern part of Kenya. Population density in Karemo division is high at 336 people/km^2 (2001 estimate). Smallholder land size is very small. Poverty is high in areas with low rainfall and poor soil fertility, including Karemo division. The long rains fall between March and June, with a peak in April and May. Short rains typically fall from late September to November. Rainfall averages 8000-1600 mm per payer. The humidity is relatively high with mean evaporation being between 1800 mm to 2000 mm in a year.

2.1.2 Description of the ongoing development programs supported by the World Bank

The Arid Lands Resource Management Project (ALRMP) is a community-based drought management project of the Kenya Government (GoK), which operates in 28 arid and semi-arid districts. The project involves four components: drought management, natural resource management, community driven development, and support to local development. Project activities vary from district to district although some main activities include the following:

- Formulate and implement policies and institutions for drought management
- Coordinate the mobilization of resources for drought management
- Coordinate all stakeholders in drought disaster risk reduction and management
- Empowering communities to effectively manage their own development
- Creating an enabling environment for Arid and Semi-Arid Land (ASAL) development
- Monitoring and evaluation of the drought disaster management program

Sustainable Management Services (SMS), Ltd. works in three project areas covering a total land area of 18,000 ha, split evenly between homestead (housing, animal sheds), coffee and other crops, mostly subsistence. SMS promotes a package of agricultural activities or “best agricultural practices (BAP)” aimed at smallholder coffee farmers with the goals of increased productivity and greater resilience to climate change. The practices promoted by the project include the following:

- Cover crops contribute to the fixation of nitrogen, and provision of mulch
- Soil management involving optimal application of fertilizer with emphasis on composting and optimizing the use of natural available organic fertilizer in order to reduce the use of chemical fertilizers harmful to the atmosphere
- Coffee tree management, including pruning, stumping, de-suckering, generates biomass that can be used for mulching and reduces need for chemical spraying to prevent pest and disease
- Proper collection and handling of pulp and organic waste material for use in soil composting, thereby increasing soil fertility
- Trenching and terracing to reduce water runoff and preserve soils
- Improved crop varieties for resistance to disease and climate threats that are otherwise treated with chemical sprays and fertilizers

- Agroforestry involving the planting of shade trees within the coffee area and along boundary lines

The number of farmers engaged in the project exceeds 25,000, representing a population in excess of 150,000.

Vi Agroforestry promotes the adoption of sustainable agricultural land management (SALM) practices among smallholders in Western Kenya as an engine of economic growth and a means to reduce poverty. The project encompasses 116,387 ha and the target intervention area is approximately 45,000 ha. Farmer groups that participate in the project will also earn income from carbon trading, as the SALM practices increase soil carbon sequestration.

The package of SALM practices to be promoted fall under the categories of cropland management, restoration of degraded landsand livestock management in order of importance. Specific activities include the following:

- Cropland management
  - Agronomy involving crop rotation, use of improved crop varieties, and the integration of cover crops Nutrient management including mulch (weed) management (cow pea, beans, sweet potato), improved fallow, green manure undersowing, manure, compost management, replacing inorganic with organic fertilizer, targeted application of fertilizer
  - Improved tillage and residue management including practices such as minimum soil disturbance, maize residue management in trash lines, drainage channels, contour lines, ridging, improved fallows
  - Agroforestry involving the integration of trees into the existing farming system of intensive cropping of both annual and perennial crops.
  - Water management including water harvesting for agriculture (small dams, ponds, half moons), double dug beds, terracing, erosion control, tie-ridges
- Restoration/ Rehabilitation of degraded lands:
  - Organic amendments such as green manuring and composts on agricultural land has been degraded by erosion, excessive disturbance and organic matter loss
  - Area enclosure, riverbank tree planting, gully control, and various types of fallows (grass planting, natural bush vegetation)
- Livestock management
  - Integration of livestock into cropland management systems is of particular importance and plays an important economic role for smallholders.
  - Sustainable management of grazing in combination with fallowing and/ or rehabilitation of degraded lands

2.1.3 Data collection methods

Three principal methods of data collection were used in the study: household survey, community survey and participatory rural appraisals (PRAs). The household survey collected information on demographic characteristics; socioeconomic status (e.g. wealth status, income sources, etc.), social capital (e.g. 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. The household survey was conducted from July 2009 until February 2010. Data for Garissa and Siaya were collected at the end due to earlier logistics/climate problems. Data covered the previous production year.

The total number of households interviewed was 710. The number of households interviewed per district is shown in Table 2. While initially 96 households were to be sampled per district, survey teams were unable to complete that number of questionnaires in some districts due to budgetary constraints and, in the case of Garissa, difficulty in locating pastoralist households for interview as households had moved away as a result of a drought.

2.2 Analytical methods

Descriptive results of the land management and adaptation strategies employed by survey households are presented. Results are presented by agroecological zones. Selected results are also presented disaggregated by World Bank project and control sites in the same agroecologizal zones. Econometric analysis is 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) are used as a measure of productivity and the variance of yield of these crops demonstrates production risk. Land management practices used on more than five percent of plots for each particular crop were selected for the analysis. While 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) estimates the potential dynamic changes of the soil carbon pool under different management practices as well as climate change scenarios. We also simulate maize yields under different permutations of seven management practices (i.e., two variety choices, fertilizer application, manure application, residue management, rotation with beans, soil water conservation 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 examine the potential impacts of improved feeding practices on the productivity and methane emissions of cattle using a ruminant simulation model housed at ILRI.

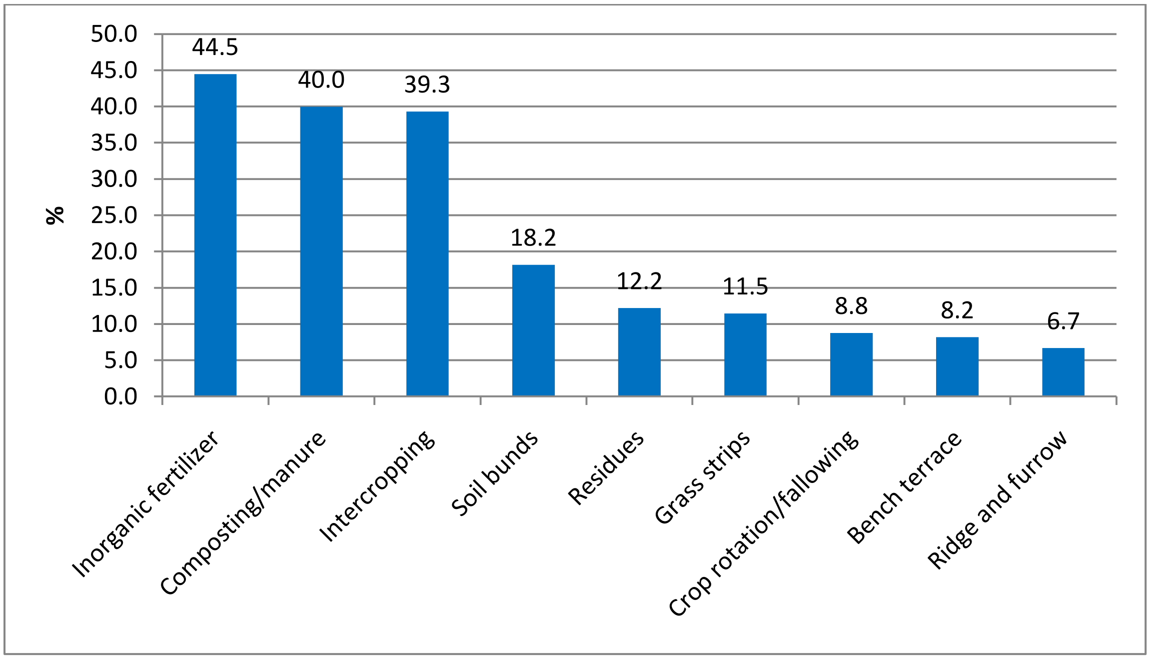
To examine the profitability of different management strategies on soil carbon, yield changes and livestock productivity data from the crop and livestock simulation models are combined with revenue information from the field survey and expert opinions to calculate gross profits for particular sets of management practices compared to a baseline case of no management. We then subtract 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, mitigation, and profitability across agroecological zones for Kenya.

3. Agricultural management practices and perceptions

3.1 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. The most common practices employed by farmers include inorganic fertilizer (45 percent), composting or manure (40 percent), intercropping (39 percent), soil bunds (18 percent), residues (12 percent) and grass strips (11 percent).[5]

Figure 3: Land management practices used on cropland



Note: Only those responses reported by more than 5 percent of farmers are presented. The rate of use of inorganic fertilizer and composting/manure is for seasonal crops only. Other practices are for both seasonal and perennial crops. Residues indicates whether the farmer used either mulching or trash lines.
Source: Authors

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[5] The rates of application of manure/compost and inorganic fertilizer apply to seasonal crops only. For perennial crops inorganic fertilizer is used on 7 percent of plots and manure/compost is used on 12 percent of plots.

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 increase productivity in areas studied. This indicates that while many of these practices provide co-benefits in terms of climate change adaptation and mitigation, the farmers' main motivation for adopting new technologies and practices are their productivity impacts and immediate livelihood benefits. This finding is supported by other studies (Tyndall 1996, Okoba et al. 1998, Kiptot et al. 2007).

Importantly, the land management practices adopted by farmers vary by site as well as by crop. Table 3 shows the share-in-use of the most common land management practices by AEZs for seasonal and perennial crops. Those practices found on 10 percent of plots or more are highlighted.

Table 3: Top land management measures by agroecological zone on seasonal and perennial crops (percent of plots)

Land management practice	**Arid**		**Semi-Arid**		**Temperate**		**Humid**	
	Seasonal crops	**Perennial crops**	**Seasonal crops**	**Perennial crops**	**Seasonal crops**	**Perennial crops**	**Seasonal crops**	**Perennial crops**
Soil bunds	0	0	34	20	14	10	23	20
Bench terrace	0	0	2	1	14	29	1	2
Residues	5	12	13	12	4	5	25	15
Grass strips	0	0	17	17	12	9	10	11
Crop rotation/fallowing	3	-	14	-	9	-	14	-
Ridge and furrow	43	12	2	43	10	25	11	60
Inorganic fertilizer	3	0	29	0	76	15	40	0
Manure	43	28	24	20	63	12	37	5
N (no. of plots)	37	57	842	164	591	539	794	393

Note: Arid includes Garissa ALRMP and control site; semi-arid includes Mbeere South and Njoro; temperate includes Mukurwe-ini and Othaya; and humid includes Gem and Siaya.
Source: Authors

Adoption of soil and water conservation (SWC) measures,[6] such as soil bunds, grass strips, and bench terraces, is very low among crop farmers in the arid region of Garissa. The main SWC measure used in this area is the ridge and furrow technique. Farmers in this area also apply manure to both seasonal and perennial crops and crop residues (mulching or trashlines) to perennial crops. Unlike in the other regions, farmers in Garissa applied very little inorganic fertilizers to seasonal crops. Farmers in the semi-arid, temperate, and humid regions were more likely to adopt SWC measures, such as soil bunds, grass strips, and residues for both seasonal and perennial crops. Farmers in the temperate coffee-producing

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[6] We consider soil and water conservation measures to be any managerial, vegetative or structural measures that reduce erosion and runoff and improve soil quality. For the analyses below, we concentrate on those SWC practices commonly found on plots in the study sites.

region constructed bench terraces on almost one third of their plots planted with perennial crops and 14 percent of plots planted with seasonal crops. As seasonal and perennial crops are sometimes intercropped the rate of terracing of seasonal crops is higher in the temperate zone. The rate of fertilizer application on plots planted with seasonal crops was 76 percent in the temperate zone, 29 percent in the semi-arid areas, and 40 percent in the humid areas. Only 15 percent of perennial plots in the temperate zone received inorganic fertilizers. The reason for the higher application on seasonal crops is the continuous need for nutrient replenishment for each planting season.

Farmers in all AEZs applied some crop residues (as mulch or trashlines) to both seasonal and perennial crops. The rate of application of crop residues was highest in the humid zones with residues applied to 25 and 15 percent of plots planted with seasonal and perennial crops, respectively. In semi-arid areas, residues were applied to 13 and 12 percent of plots planted with seasonal and perennial crops, respectively. In both the arid and temperate areas residues were applied more often to perennial crops than seasonal crops, with 12 and 5 percent, respectively, in arid areas, and 5 and 4 percent, respectively, in temperate areas. Among seasonal crops, residues are applied more to higher-value horticultural crops than staple crops such as maize and beans. While residues have significant potential to increase Soil Organic Carbon (SOC), competing uses, such as for livestock feed, may prevent residues from being left on the field.

As Table 4 shows, land management practices also differ by crop planted. The similarity of practices for maize and beans, for example, soil bunds, residues, grass strips, and crop rotation/fallowing, supports the fact that these two crops are often intercropped.

Finally, application rates of fertilizer and manure are highest on maize plots—fertilizer is used on 53 percent of maize plots and manure is used on 48 percent of plots. On the other hand, fertilizer and manure are used on 26 percent of bean plots, and 20 and 17 percent of coffee plots, respectively.

Table 4: Land management practices used on plots planted with maize, beans, and coffee; percent of plots (percent of plots)

Land management practice	**Maize**	**Beans**	**Coffee**
Soil bunds	26	22	11
Bench terrace	5	4	58
Residues	15	16	6
Grass strips	14	13	19
Crop rotation/fallowing	11	11	N/A
Ridge and furrow	7	7	1
Inorganic fertilizer	53	26	20
Manure/compost	48	26	17
Total no. of plots	1,190	1,022	172

Source: Authors

3.2 Livestock management

3.2.1 Feeding practices

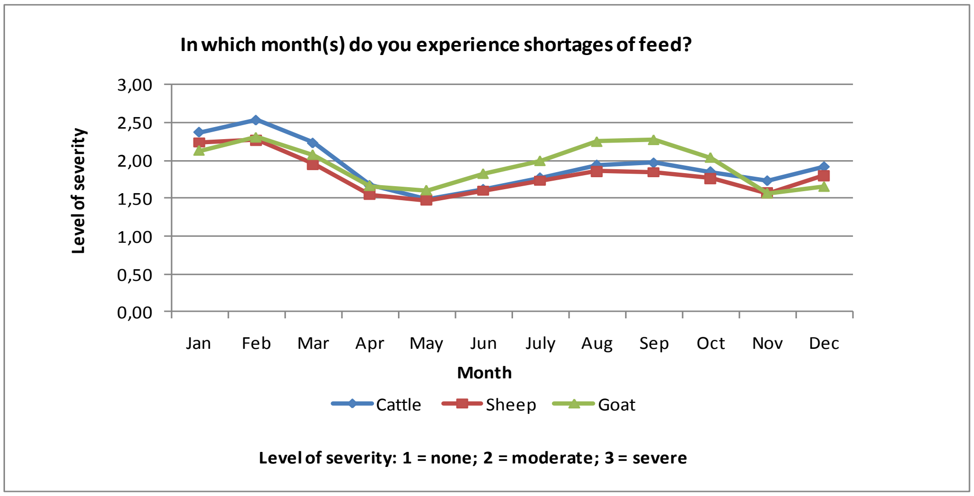
To assess the potential of changes in livestock feeding practices for agricultural mitigation, households owning livestock were asked about the types of feeds used during different times of year. Table 5 illustrates the different types of feed provided to dairy cattle in each district during the first dry season, the first rainy season, and the second rainy season; months associated with these seasons vary across agroecological zones. The numbers in the table indicate the share of households that reported using this type of feed in each district and season. Only feed sources reported by more than 5 percent of households in any one season are shown. Feed sources reported but not shown in the table include kienyeji mash, sorghum and millet grains, millet stover, sorghum stover, and cowpea stover. Tables 2.1 through 2.7 in Appendix 2 present these values for other types of livestock (oxen, cattle, sheep, goat, poultry and pigs).

This table and the Appendix Tables show that 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, maize stover, roadside weeds and cut-and-carry fodders represent other important sources of livestock feed.

3.2.2 Constraints to feeding resources

Households were also asked about feed availability during different times of the year to identify constraints to livestock feeding. Figure 4 presents periods of feed shortages for cattle, sheep, and goat experienced by livestock owners based on survey data. In general, moderate feed deficits affect all types of livestock considered, and are most pronounced at the beginning of the year and between August and October. Sheep are less affected, while goats and cattle experience a significant change in feed availability during the year.

Figure 4: Level of severity of shortage of feed for cattle, sheep and goat across the year



Source: Authors.

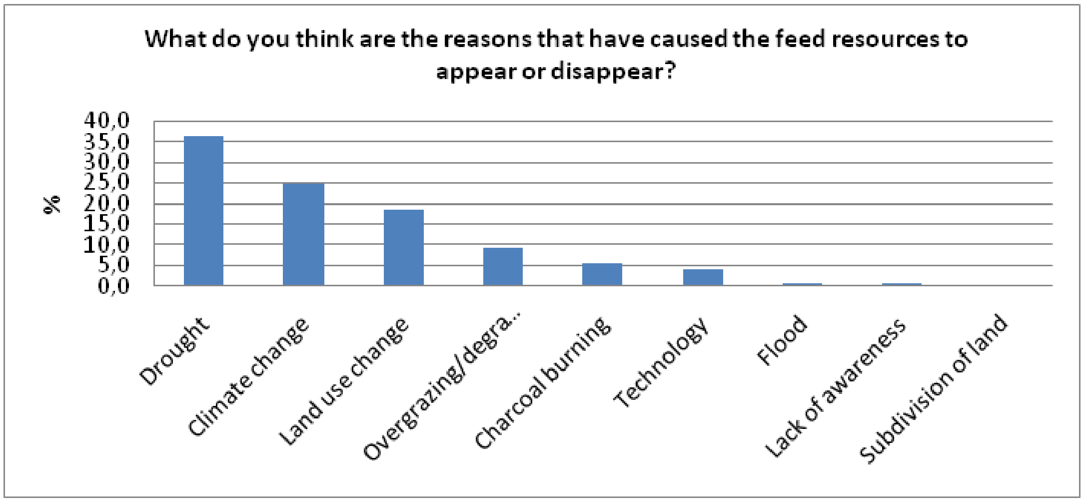
Table 5: Dairy cattle baseline feeds (share of farmers reporting each type of feed by season and district)

		rangeland (short distance)	rangeland (long distance)	crop lands	forest areas	maize stover	legume stover	salt	crop by-products (brans, cakes)	roadside weeds	Cut-and-carry fodders	hays	dairy meal	maize grain
Garissa	1rst Dry season	23	50	8	15				4					
	1rst rainy season	54	23		23									
	2nd rainy season	67	20		7					7				
Gem	1rst Dry season	14	32	9	3	28	1	2	1	3	6	2		
	1rst rainy season	46	11		3	21	4			11	2			
	2nd rainy season	45	12	2	3	25	1			10	2			
Mbeere South	1rst Dry season	15	5		1	29	8	3	2	6	8	1	7	1
	1rst rainy season	33	6		2	7	2	2		28	11		9	
	2nd rainy season	31	8		2	6	2	4	4	23	10		8	
Njoro	1rst Dry season	6	5		1	39	1	7	6	5	11	15	4	
	1rst rainy season	6	3	4	1	4	10	12	3	15	32	3	7	2
	2nd rainy season	5		2		15	10	12	2	13	29	5	8	
Mukurwe-ini	1rst Dry season			1		19		13	5	2	13	5	27	13
	1rst rainy season			5		14	3	13	3	3	22	3	20	10
	2nd rainy season			4		19	2	17	4	3	20	2	18	11
Othaya	1rst Dry season	4		2		12	5	18	7	2	18	6	22	4
	1rst rainy season	5		2	1	17	8	15	6	3	24		17	3
	2nd rainy season	4		2	2	18	8	12	6	2	24		18	4
Siaya	1rst Dry season	24	13	3	3	27	1	1	1	16	5		1	2
	1rst rainy season	37	13	1	3	8	6	2	2	20	6		2	
	2nd rainy season	32	8	2		20	2	3	2	17	8		2	

Source: Authors

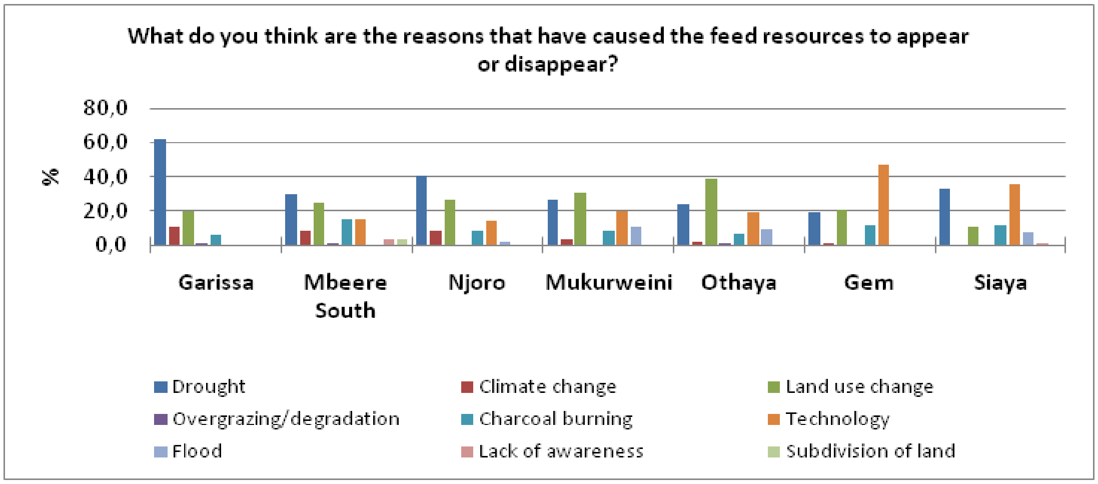
Figure 5 presents key feed production constraints reported by livestock owners and Figure 6 disaggregates constraints by district. More than a third of livestock owners, 36 percent, consider drought to be the key reason for changes in feed resource availability, followed by climate change. Thus, a changing climate is considered key to changes in feed resource availability. Moreover, 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.

Figure 5: Key reasons that have caused feed resources to appear and disappear



Source: Authors.

Figure 6: Key reasons that have caused feed resources to appear and disappear by district



Source: Authors.

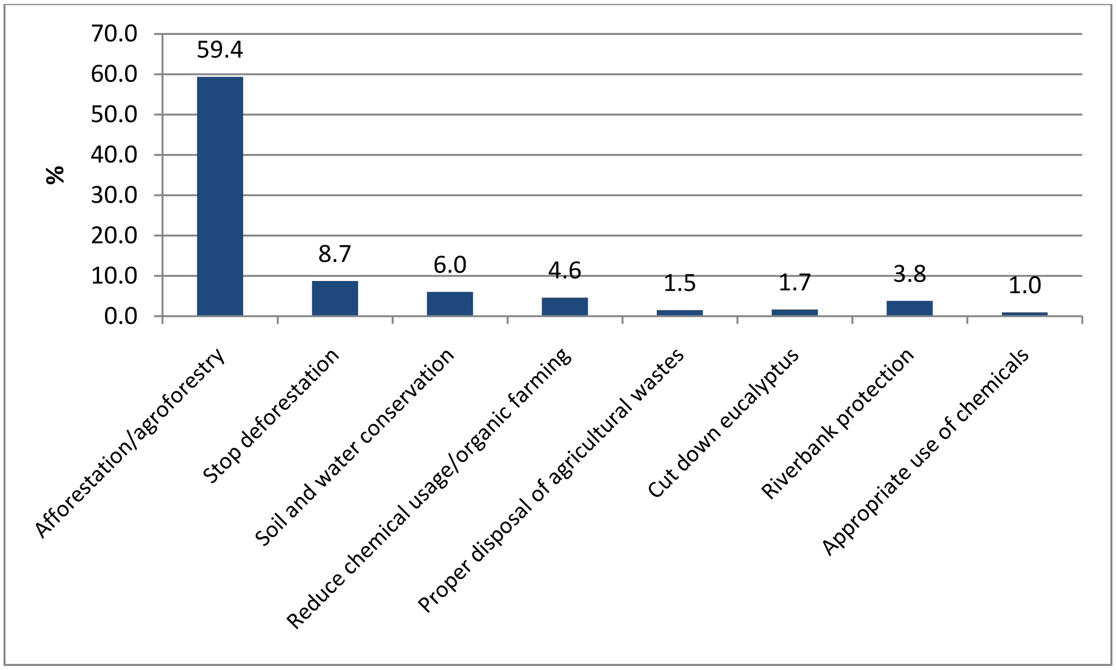
Moreover, perceptions of the reasons for changes in feed resources vary by agroecological zone/district. The role of technology seems to be an important factor in Gem and Siaya, and flood is thought to reduce the availability of feed resources in particular in Mukurwe-ini, Othaya, and Siaya. Drought is identified as the main feed constraint in Garissa and as one of the major drivers of feed availability in Mbeere South, Njoro, and Siaya. These responses also reflect the agricultural potential of different districts.

Moreover, livestock owners responded that some feed resources that were available 10 years ago are no longer available. Among these they listed: kikuyu grass (*Pennisetum clandestinum*), marer (*Cordia sinensis*), allan (*Lawsonia iner* or *Terminalia brev.),* deka (*Grevia tembensis*), haiya (*Wrightia demartiniana*). On the other hand, some new feed resources have become available over the last 10 years, in particular: mathenge (*Prosopis juliflora*), napier grass (*Pennisetum purpureum*), desmodium (*Desmodium intortum*) and caliandra (*Caliandra calothyrsu*).

3.3. 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 where then asked which agricultural practices reduce climate change. Results are presented in Figure 7.

Figure 7: 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.

The responses showed that most farmers are aware of the connection between forests/trees and climate change. However, there is less awareness of the connection between other land management and crop and livestock practices and climate change. Although 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 the companion PRA study farmers in Njoro talked about the Mau forest as the source of rain and blamed the clearing of the forest on 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[7] (6 percent) and reduced or appropriate chemical usage (6 percent). Other responses include proper disposal of agricultural chemicals (2 percent), cutting down eucalyptus trees (2 percent), and riverbank protection/preservation of catchment areas (4 percent). Thus, while there is a clear perception between trees and climate change, the perception 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.

4. Adaptive responses to perceived climate change

Surveyed farmers adopted a range of practices in response to perceived climate change (Figure 8). 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). For additional details, please see Bryan et al. (2010).

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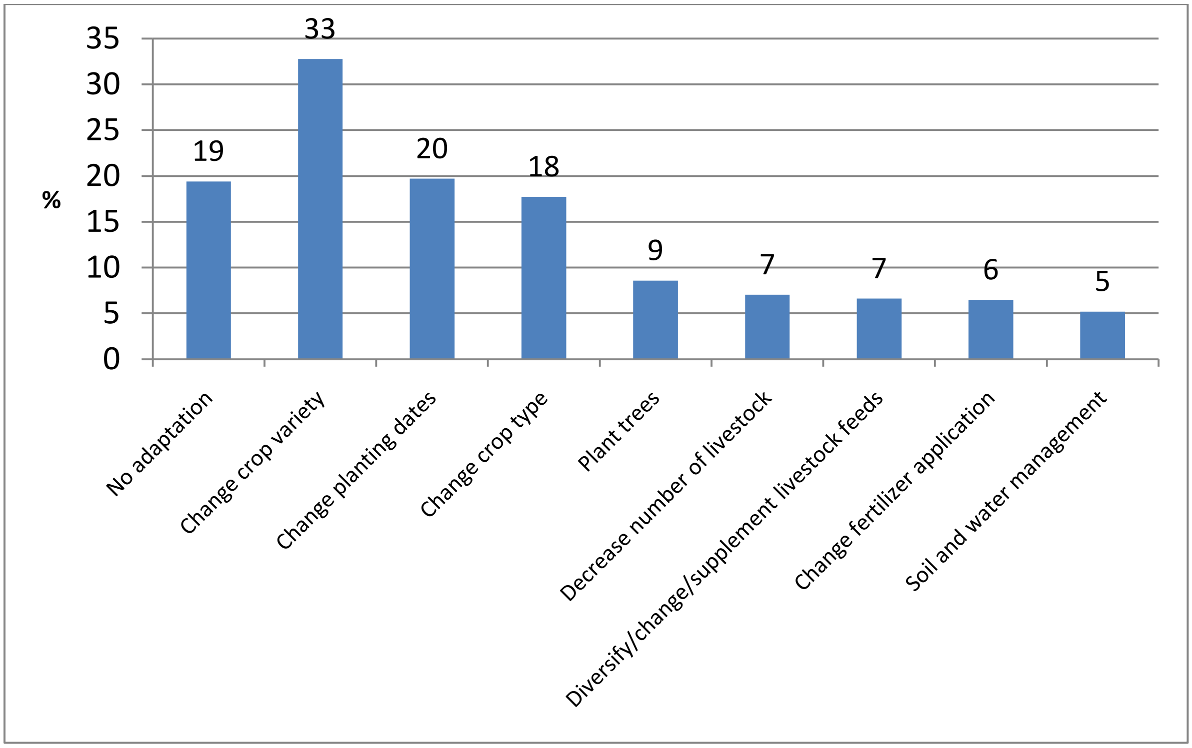
[7] Here the definition of soil and water conservation includes a range of practices reported by farmers such as cover cropping, minimum tillage, mulching, intercropping, and terracing although these measures were not commonly found in the study sites. For the analysis below, SWC refers to those practices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

Figure 8: 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.

5. Simulation of crop agricultural mitigation practices

In order to examine the mitigation potential and productivity implications of various combinations of cropland management practices, we estimate the yield and soil carbon sequestration potential of maize cultivation in smallholder farmers' fields for 40 years for all permutations of seven management practices (i.e., two variety choices, fertilizer application, manure application, residue management, rotation with beans, SWC techniques, and supplementary irrigation) and two sets of climate projections (i.e., dry and wet[8]) 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. Appendix 1 presents additional details on the methodology used as well as the annual trends of the simulated yield and soil organic carbon stock changes for each combination of the simulated management practices. Assuming the "no-effort" management with a traditional Open Pollinated Variety (OPV) as the baseline for each climate, the annual soil carbon sequestration rate (tC/ha) was calculated for each case for the 40-year simulation implying farmers would adopt and follow the given set of management practice

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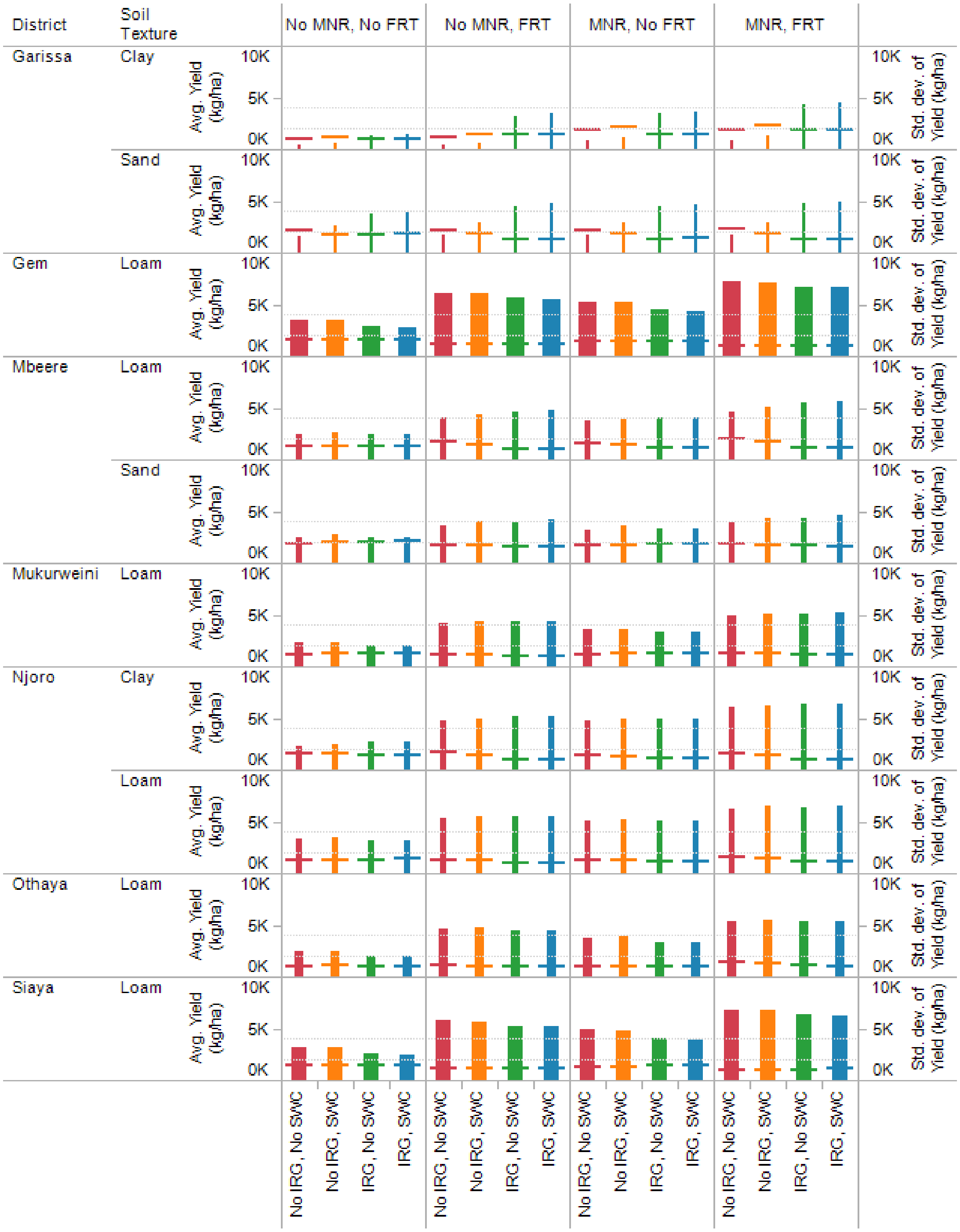
[8] The "dry" and "wet" climate scenarios are used to identify the two GCM's used in the study, instead of using the GCM names (CSIRO-Mk3.0 and MIROC3.2) directly. As shown in Appendix Figure 1.1, the difference in the total rainfall for Kenya is not very large.

package continuously over 40 years. The results are scaled to a 20-year period for comparison with Joanneum (2007).

Given the importance of crop residues, particularly maize stover, for animal feed, we simulated long-term average maize yield with 50 percent of residue retention on field across all study sites and for several management practices.

The results are summarized in Figure 9 and Figures 10-19 present maize yield results and changes in SOC for key maize management practices. Moreover, Table 6 presents results for the top five management practice packages per district/climate/soil under rainfed conditions, in terms of SCS potential. While management practices considered in Table 6 do not include irrigation, reflecting the low adoption of supplementary irrigation in the region, Figures 10 through 19 include irrigation together with SWC (SWC + IRG) to test its theoretical benefit in reducing yield variability.

Figure 9: 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 rotations.



Source: Authors

Note: 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.

Table 6. Top five management practices with SCS potential over 20 years (tC/ha) for rainfed maize (1=highest potential)

			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

Note: MNR=manure, FRT=fertilizer, RSD=residue retention, SWC=soil water conservation, ROT=rotation with drybean, OPV= open pollinated variety; HYB=hybrid variety.

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 scenario implemented here. Second, the hybrid variety was not always favored even with nutrient management practices in most districts. When favored, the hybrid variety was 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 to 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.

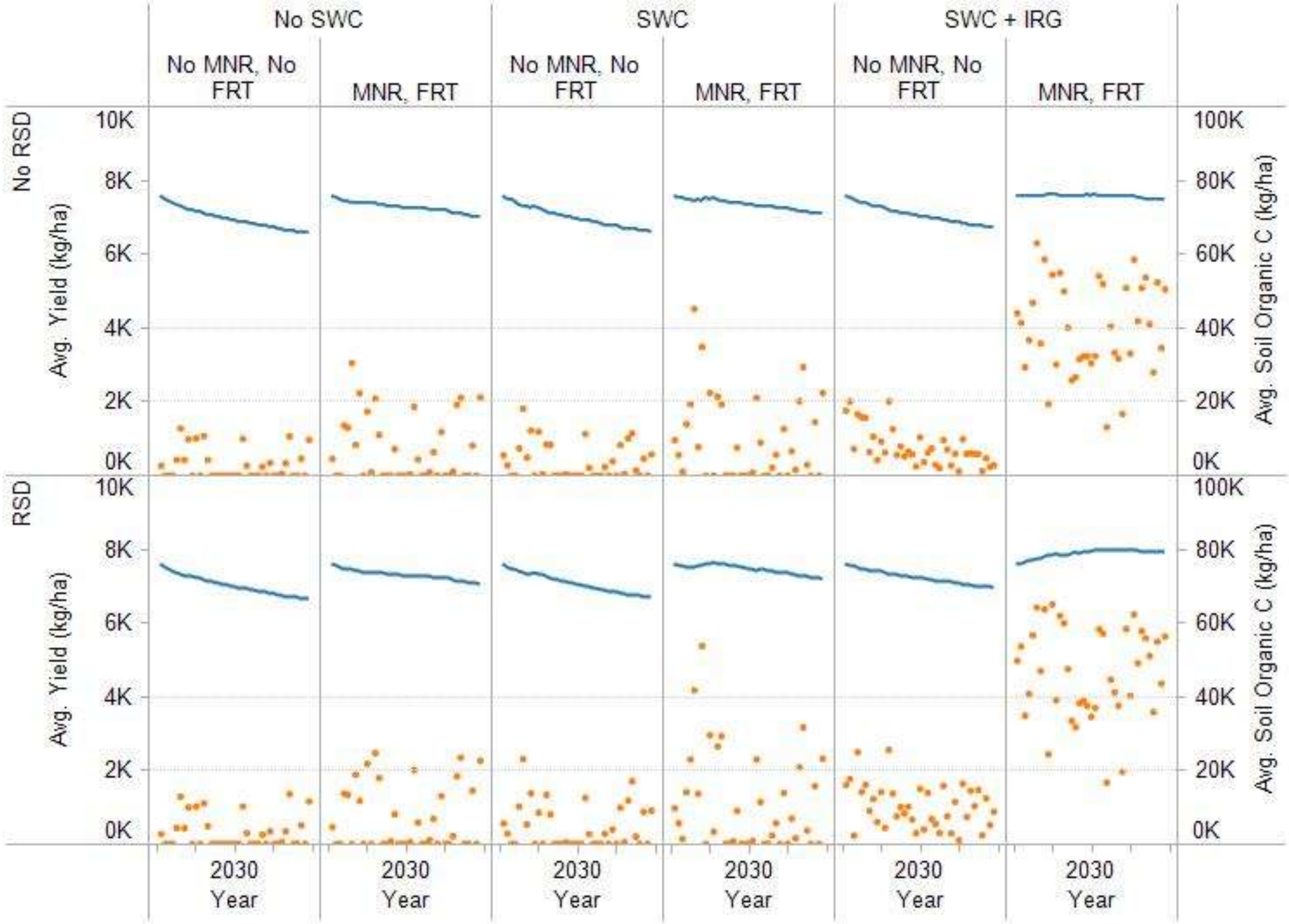
Third, we find that simulation results differ significantly by district, particularly regarding the role of water application. In the arid site (Garissa), maize yields under rainfed conditions are very low due to limited water availability. Irrigation is essential to achieve reasonable yield levels; 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 increase SOC, particularly in clayey soils (see Figures 10 and 11). 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 the increased nitrogen leaching from the soil (Figures 12 and 19). In the semi-arid sites Mbeere and Njoro, water is somewhat limited. Therefore SWC management practices and irrigation overall increase yield levels (Figures 13, 14, 16 and 17). However, yield improvements are much larger from higher nitrogen inputs from both fertilizers and manure. Similarly, in the temperate sites (Mukurwe-ini and Othaya) SWC and irrigation improve yields, but not as significantly as nutrient inputs (fertilizer and manure) (Figures 15 and 18). 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 (e.g., 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 (e.g., 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, i.e. inorganic fertilizers should be combined with other soil fertility management practices (e.g., manure application, mulching, and/or residue management). Sixth, 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 (e.g., manure and fertilizer applications). That is, while rotation with beans is generally positive for SCS, these benefits are limited compared to more explicit nitrogen input measures, such as the application of inorganic fertilizer and/or manure.

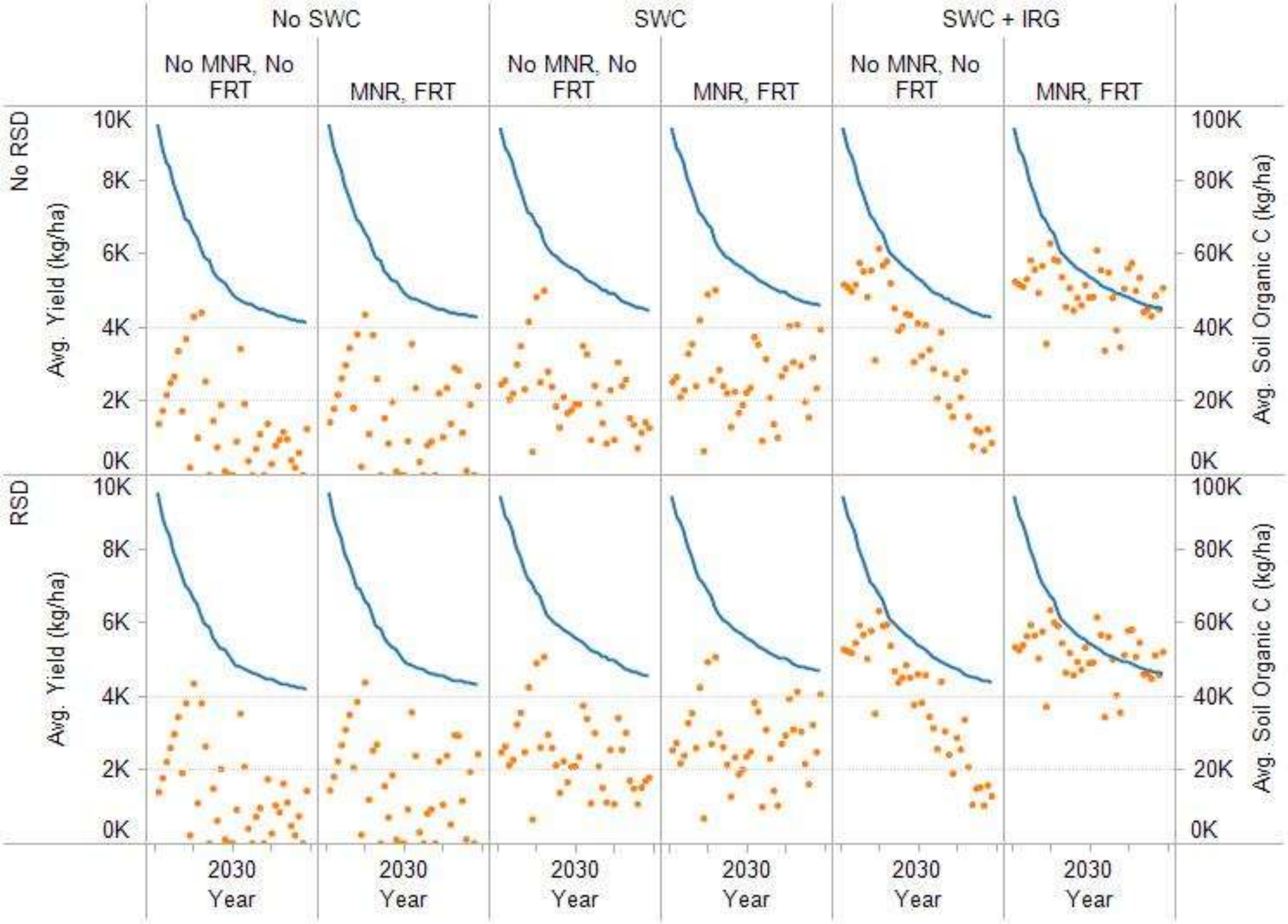
Overall, the simulated results show that the best-bet package for SCS would generally include integrated soil fertility management, although the optimal combination of nutrient inputs (manure, inorganic fertilizer, and crop residues) depends on a number of factors including crop type, soil type, and agroecological zone. The optimal choice of other management practices also varies with the 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 soil carbon sequestration as well as soil fertility management.

Figure 10. Simulated trends of maize yield (circle) and soil organic carbon (line) in Garissa with clayey soil



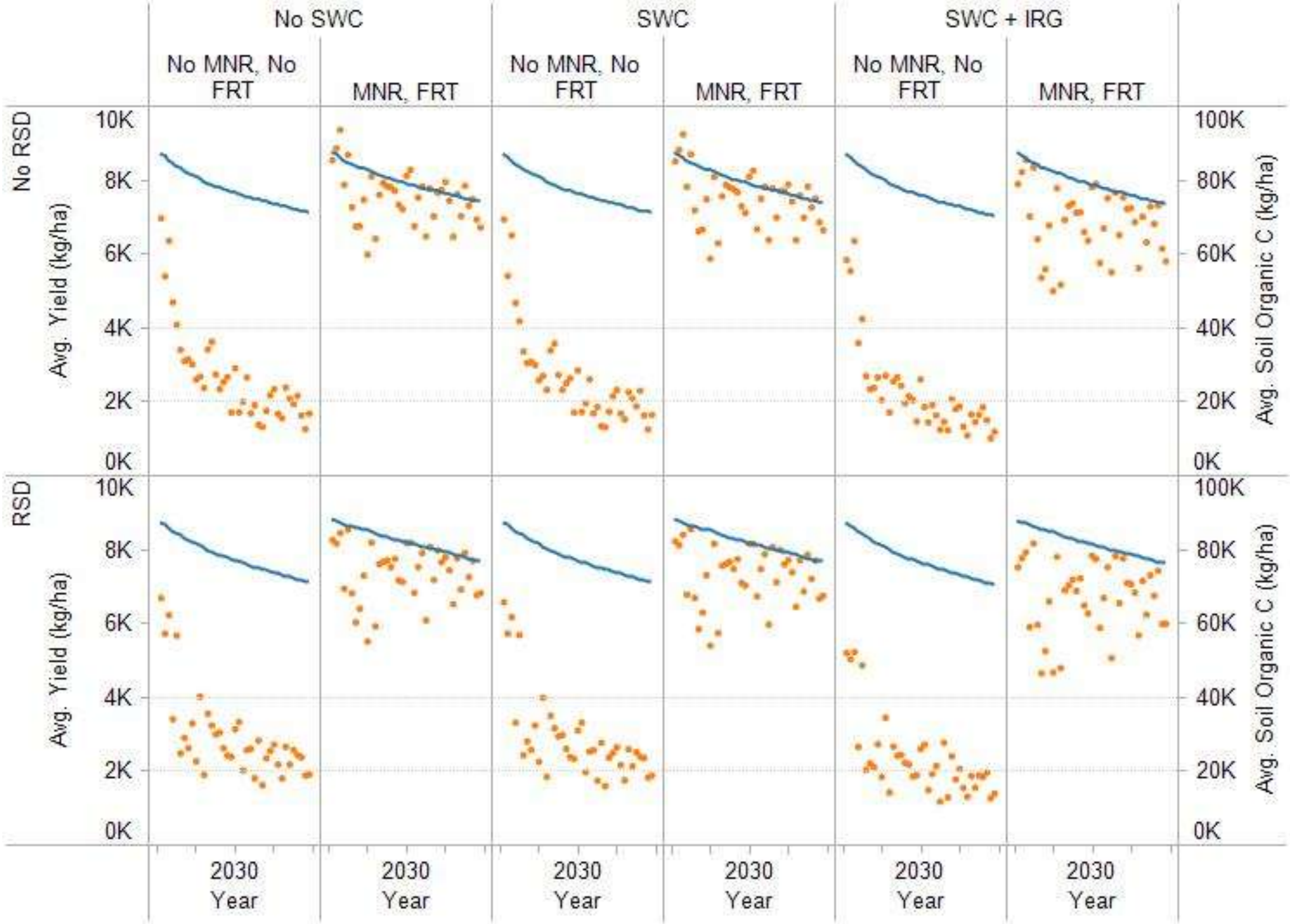
Source: Authors

Figure 11. Simulated trends of maize yield and soil organic carbon in Garissa with sandy soil



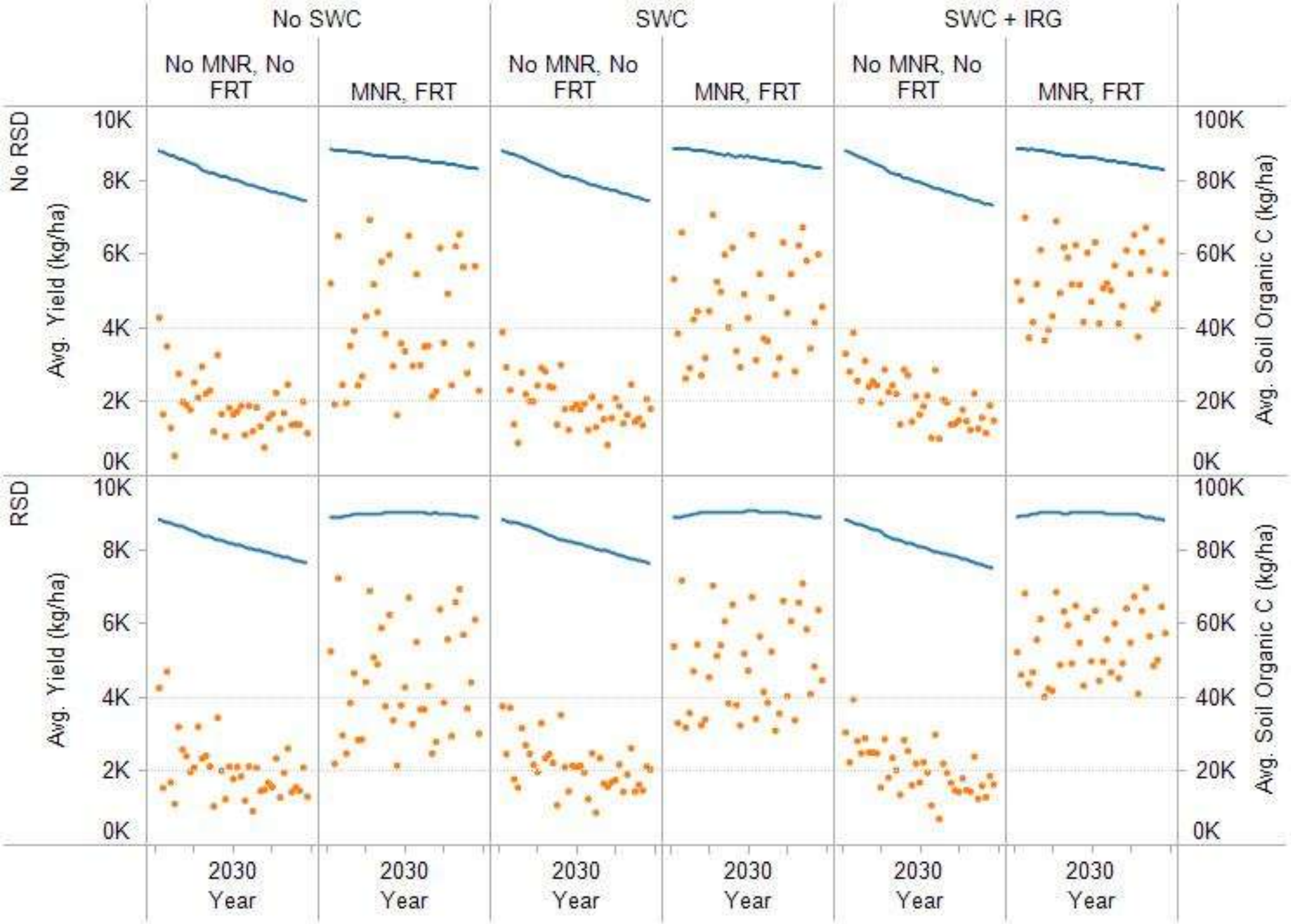
Source: Authors

Figure 12. Simulated trends of maize yield and soil organic carbon in Gem with loamy soil



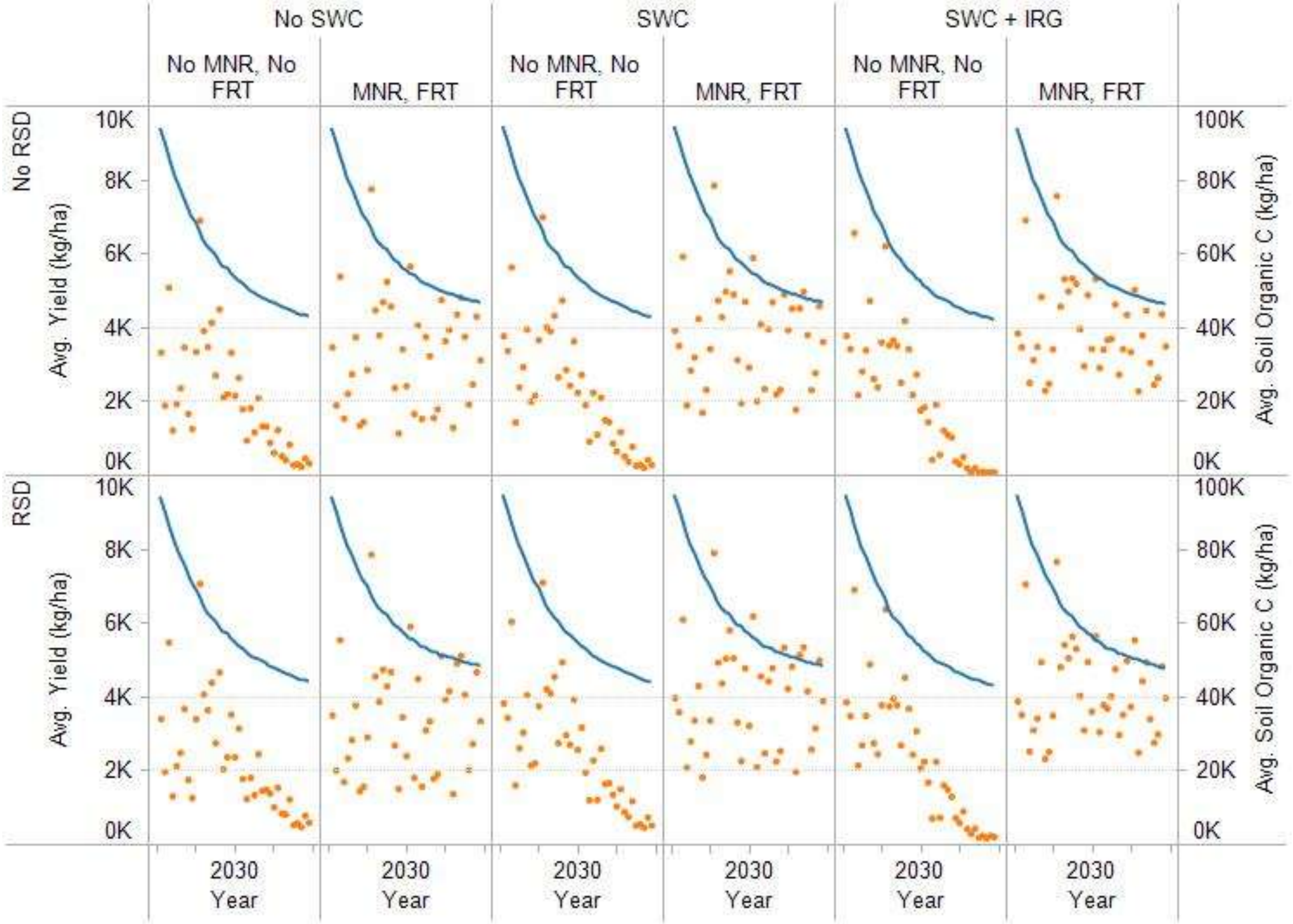
Source: Authors

Figure 13. Simulated trends of maize yield and soil organic carbon in Mbeere with loamy soil



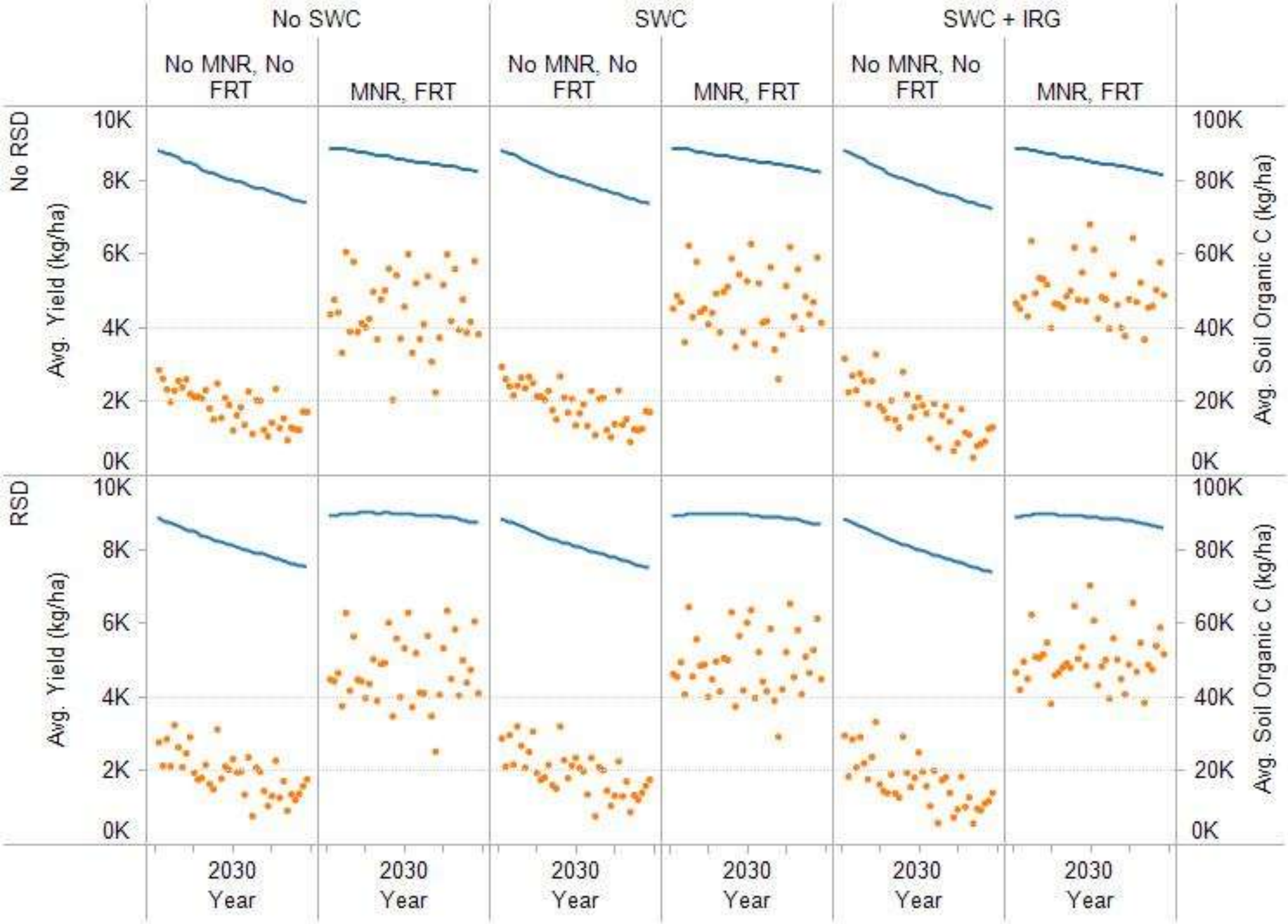
Source: Authors

Figure 14. Simulated trends of maize yield and soil organic carbon in Mbeere with sandy soil



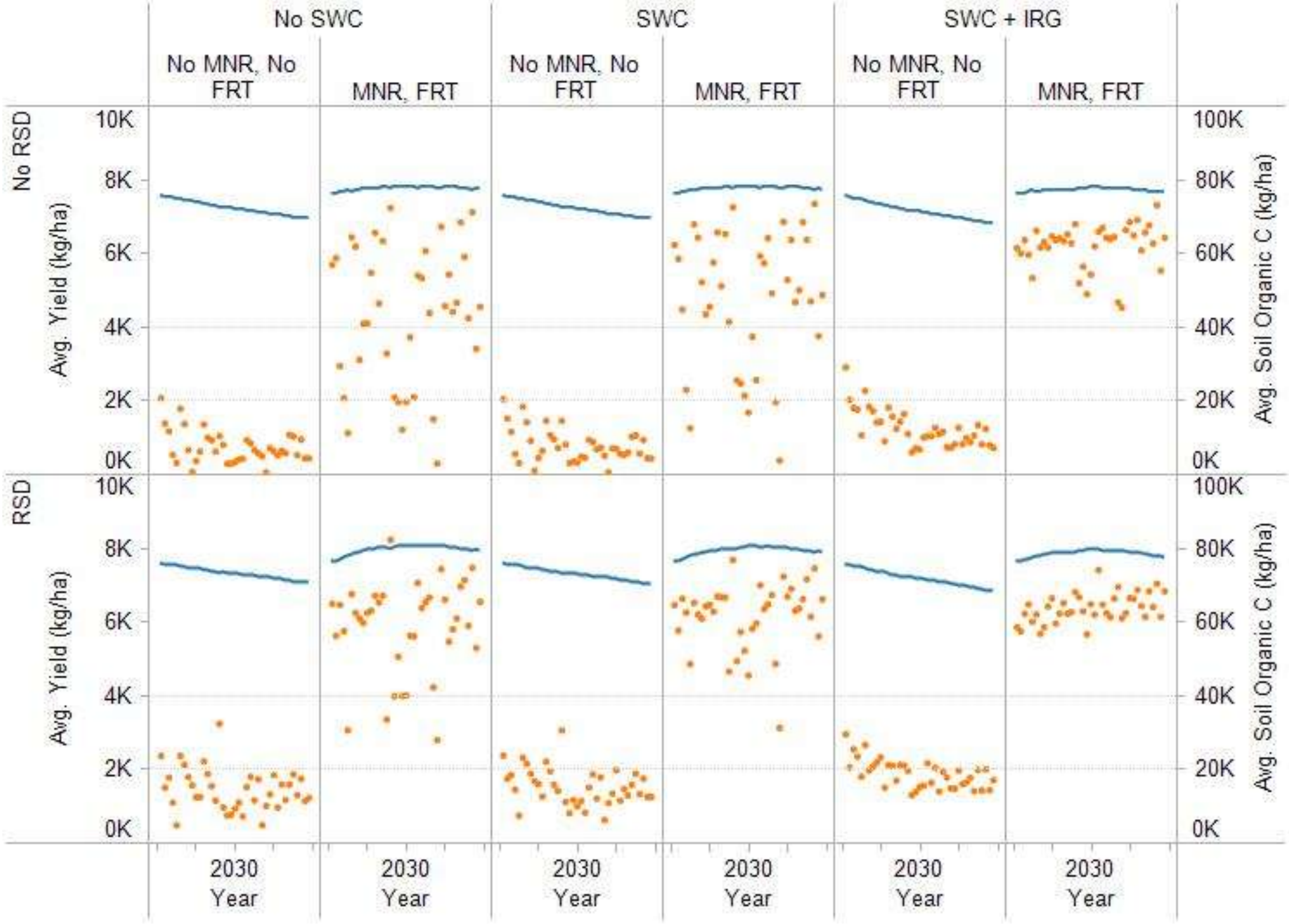
Source: Authors

Figure 15. Simulated trends of maize yield and soil organic carbon in Mukurweini with loamy soil



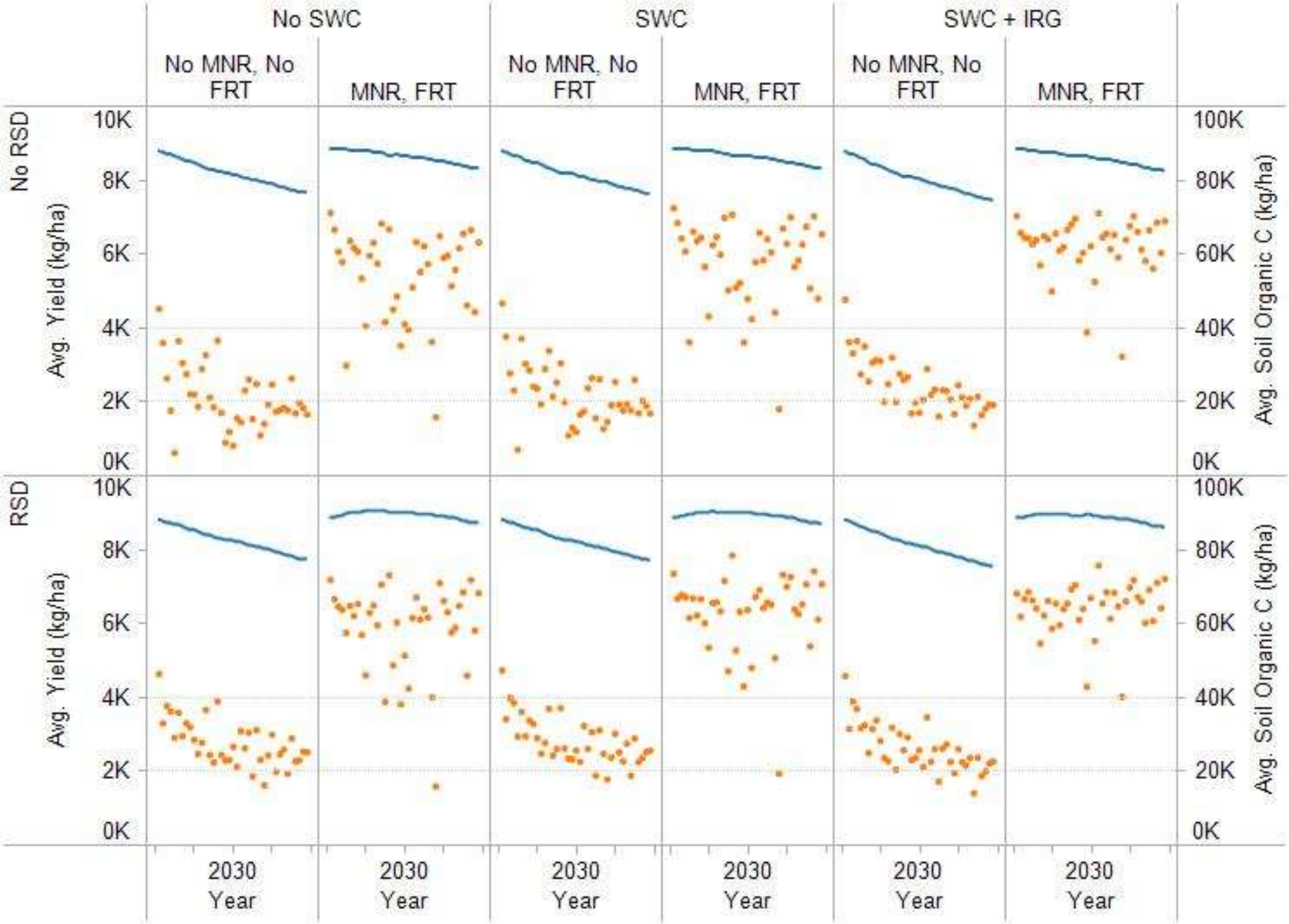
Source: Authors

Figure 16. Simulated trends of maize yield and soil organic carbon in Njoro with clayey soil



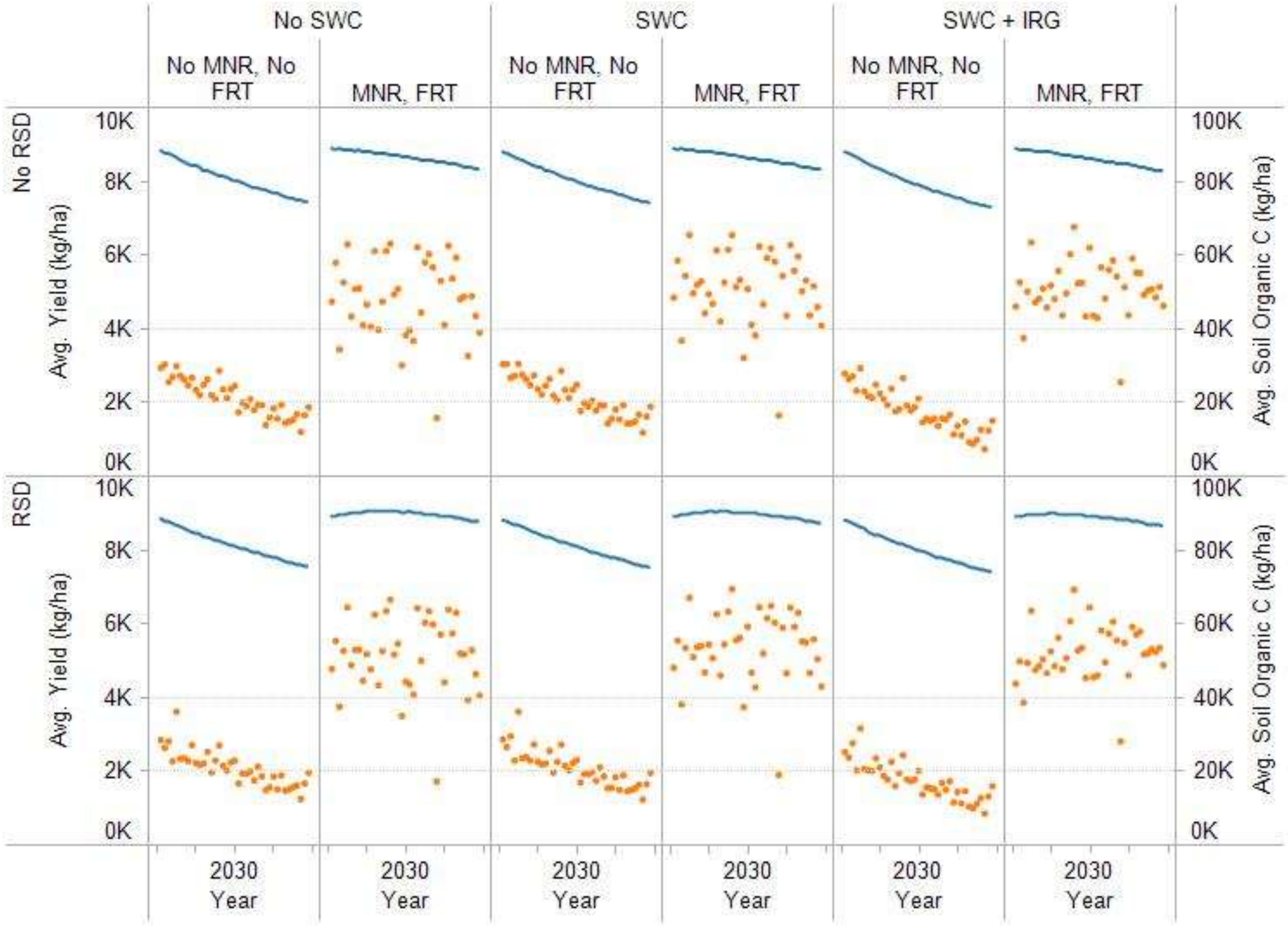
Source: Authors

Figure 17. Simulated trends of maize yield and soil organic carbon in Njoro with loamy soil



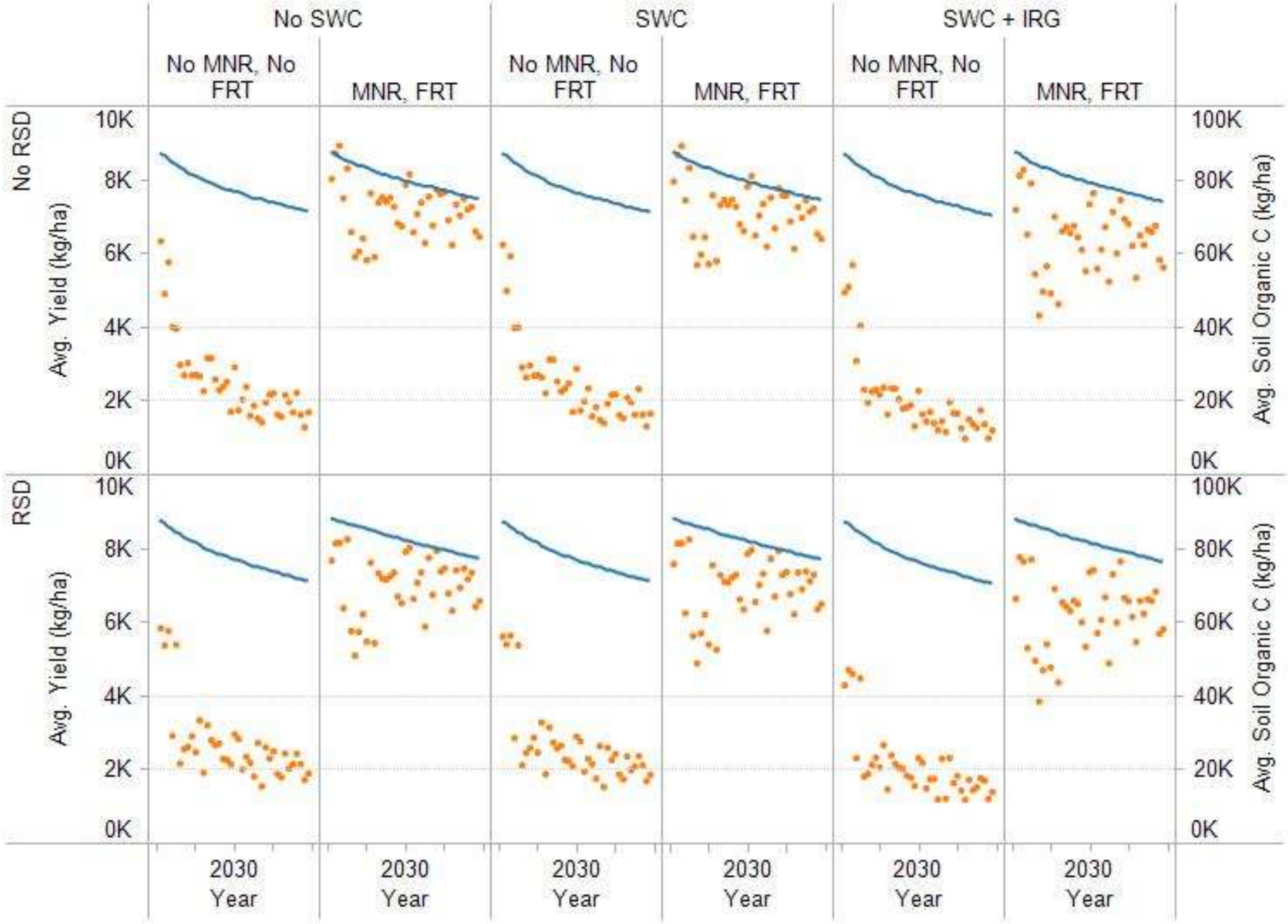
Source: Authors

Figure 18. Simulated trends of maize yield and soil organic carbon in Othaya with loamy soil



Source: Authors

Figure 19. Simulated trends of maize yield and soil organic carbon in Siaya with loamy soil



Source: Authors

We also compared our crop simulation results with those of the Joanneum report (2007) on Biocarbon project sites for the temperate AEZ (Mukurwe-ini and Othaya districts in this study).[9] Compared to the results of the Joanneum study we find higher SCS benefits from manure and residue management; and lower reductions in SOC under no residue/no manure and residue/no manure cases (Table 7).

Table 7. Comparison of the estimated soil carbon sequestration potential (tC/ha/yr) for 20-year period for comparable management practice packages for Mukurweini and Othaya districts

	Management practice		
Source	w/o residue, w/o manure	w/ residue, w/o manure	w/ residue, w/ manure
Joanneum study	-5.15	-3.50	1.60
This study	-2.83	-2.20	1.91

While this study does not examine the mitigation potential of agroforestry, previous studies have estimated the SCS potential of forestry-based carbon sequestration projects in Africa. As with seasonal crops, the SCS potential (as well as economic benefits) of forestry-based carbon sequestration projects vary depending on the quality of land and the land use practices that are adopted (Jindal, Swallow, and Kerr 2008). Dry lands sequester between 0.05 and 0.7 tC/ha per year compared to 0.43 tC/ha per year for Miombo woodlands and 5.9 tC/ha per year for Alnus woodlots (ibid). Another study estimates SCS potential of 4 tons of CO_2 per hectare per year as well as an increase in annual net revenues of US$225 per year (Tennigkeit et al. 2009).

6. Potential impacts of improved livestock feeding as a climate change adaptation and mitigation strategy

A governmental push towards market-oriented production is driving production systems in the study areas towards 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 analyses the potential impacts of improved feeding on the productivity and methane emissions of cattle, the main animal species present in the 7 districts under study. Diets for cattle were constructed using the main feeds as reported in the household survey to match dairy production reported in Table 9 (see also Appendix Tables 2.1 to 2.7). Alternative diets were then constructed using the main feed ingredients that have been increasing in the 7 districts (Table 11) based on survey results. These feed ingredients are also being promoted by several international agencies and projects (for example, under the BMGF 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 et al. (2002), which

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[9] The reports we obtained from Joanneum did not include results for the Gem/Siaya Vi Agroforestry side.

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 IPCC (Herrero et al. 2008).

6.1. Baseline diets

From the information generated, the following diets were constructed for cattle in the different districts (Table 8). This information is consistent with that from other studies (Romney and Zemmelink 2001, Bebe 2006, Herrero et al. 2008).

Table 8 – Milk production and main feeds fed to dairy cattle in 7 districts of Kenya

District	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 S	860	X	X	X	X	
Njoro	1256		X	X	X	X
Mukurweni	2089		X	X		X
Othaya	2035		X	X		X
Siaya	706	X	X		X	

Differences in main feed sources highlight the productive orientation and management of the systems in the various study areas. Njoro, Murkuwe-ini, 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), thus 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 9. The relationship between the quality of the diet and methane production follow 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 climate-mitigation strategy. As expected, the better diets in the more dairy-orientated districts of Njoro, Mukurweni, 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 agro-pastoral regions were significantly less efficient in terms of methane produced per unit of milk (up to five-fold less efficient in some cases) as their diets were poorer and most of the energy was used for maintaining the animals instead of producing milk.

Table 9. Manure production and methane emissions of diets for dairy cows (250 kg bodyweight) in 7 semi-arid 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/lt)
Garissa	8.4	693	796	2.37
Gem	9.3	730	780	1.42
Mbeere S	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

Manure production ranged from 657 to 730 kg per animal (250 kg bodyweight) across districts. This close range was expected as the model was run for animals of a constant bodyweight which largely controls the overall magnitude of the intake figures for that range of diet qualities (8.4-10.5 MJ metabolisable energy per kg 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.

6.2 Testing alternative feeding scenarios

Alternative scenarios of diet composition were tested by constructing new supplementation regimes using the new feed sources reported in the 7 districts. These feeds are shown in Table 10, together with the two scenarios tested for each feed in each district. The simulated 250-kg animals consumed between 4.5-6 kg of feed dry matter per day in the baseline diets, and the scenarios tested aimed at replacing between 15 and 50 percent of the given baseline ration in terms of dry matter consumed. Scenarios assumed that new feeds replaced stover Dry Matter (DM) to enable farmers to use the reminder for SCS (complementing the crop simulation results presented in section 5).

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

District	Main new feed	Scenarios of use
Garissa	Prosopis spp.	1.5 kg offered in the diet
		3 kg offered in the diet
Gem	Desmodium	1 kg offered in the diet instead of stover
		2 kg offered in the diet instead of stover
Mbeere S	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

The impacts of alternative diets on productivity, manure and methane production and methane produced per liter of milk are shown in Table 11. 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 kg 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 that have the poorest diet quality (Garissa, Gem, Mbeere South, and Siaya). In these districts, milk production increases between 12 and 136 percent while manure and methane production changes between 0 and 16 percent and -5 and 16 percent, respectively. While methane emissions increase overall in many scenarios, efficiency per liter of milk improves in every scenario. Methane production per liter of milk decreases significantly by between -6 and -60 percent. This is expected as these are the regions where efficiency gaps are largest. This shows that if simple practices and modest supplementation schemes can be implemented methane production in these regions could decline significantly. However, improved feeding practices generally will only be profitable 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.

Table 11. Impacts of alternative feeding strategies on milk, manure, and methane production and the efficiency of methane production to produce milk in 7 districts of Kenya (all results are in percent deviations from the respective baselines).

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

Source: Authors.

Increasing milk production while reducing methane production per liter of milk was also possible in the districts with higher-quality diets (Njoro, Mukurweni, and Othaya), but improvements are smaller (8-49 percent for milk 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 the field leading to additional agricultural mitigation benefits from soil carbon sequestration.

7. Productivity and risk implications of management strategies

Using the survey data and the Just and Pope production function method, we examine the implications of cropland management strategies that surveyed farmers are already using for crop productivity (mean yields) and production risk (variance of yields). Reducing risk involved in agricultural production is important for increasing resilience to climate change and variability. 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.

While the literature suggests that implementation of SWC measures leads to increased yields (Byiringiro and Reardon, 1996; Shively, 1998; Kaliba and Rabele, 2004; Kassie et al., 2008), the results show few significant impacts of these measures on productivity among surveyed farmers (Table 12). None of the SWC measures analyzed have a significant positive impact on yields of maize, beans, or coffee. Only crop rotation/fallowing was shown to have a risk-reducing effect on maize yields (i.e. 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 are 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 semi-arid 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 are 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 N in the soils which is not necessary for beans.

More research is needed to determine why we did not find greater benefits of 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 could also be 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 demonstrates 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).

Table 12: 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 terrace					-1.892	0.528
Residues	-0.198	0.561	**-0.288***	0.346	2.181	-3.001
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		
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
N	931	929	788	786	53	53

legend: * p<.1; ** p<.05; *** p<.01

Notes: includes controls for project sites, rainfall season, household characteristics, and soil characteristics

Source: Authors.

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 (Ekbom et al. 2001, Kristjanson et al. 2010) are also essential.

In order to check the robustness of these findings and to address the complications in the analysis due to intercropping on many of the plots,[10] the same analysis was run using total value of production

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[10] 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.

(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). These results are shown in Appendix 3. However, it should be noted that farmers were asked an open-ended question about what land management practices they used on their cropland, rather than about specific practices. Thus, farmers may be under-reporting the use of these measures.

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 was 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[11] also shows the expected effect on crop yield and variance. In particular, phosphate 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. N fertilizer applied to beans actually has a negative effect on yield. Given that beans are nitrogen fixing, additional input of N fertilizer only increases vegetative growth rather than seed formation.

8. 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, after factoring in any additional costs and profits. 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 (e.g. construction costs of SWC and irrigation structures) or from retail prices for inputs, such as fertilizers.

8.1 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 the greatest 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 kg/ha of nitrogen fertilizer (split application with 20 kg N/ha applied during planting at 5 cm depth and 20 kg N/ha applied 30 days after

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

planting as top dressing) and 3 tons of manure per ha 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 mm/ha of furrow irrigation). All package options are using the OPV given its overall better performance in terms of SCS. Results are presented in Table 13.

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 soil carbon sequestration[12] and maize yield improvements for each of these management packages compared to a baseline case of no improved management. We then subtract 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 and are 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 (i.e. the removal of residues). Package 2 was also associated with lower total labor costs but not as much 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 assume there would be no additional cost for plots with SWC structures apart from construction and maintenance of these structures. We also assume an additional labor cost for irrigation based on the average amount of labor (person days/ha) spent on irrigation (for those plots in which irrigation is applied). Labor costs were calculated by multiplying the difference in labor (person days per ha) by the average wage rate for crop production (232 KSH or US$2.91 per day), taken from the community survey.

Construction, operation, and maintenance costs of SWC structures and irrigation are 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 re-built, on average, every 5 years, we take the average yearly cost of SWC by dividing the weighted average construction costs by 5.

Fertilizer costs were calculated by taking the elemental amount of N in each type of fertilizer reported by households in the study sites (UREA, NPK, DAP, CAN). We calculated how many 1kg bags of each type of fertilizer would be needed to reach 40kg of N and multiplied the number of bags times 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

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[12] To do so, we assumed that 1,000 kg of SOC increase = 273 kg of CO2e. Potential revenues from soil carbon sequestration are calculated using the following formula: [(change in SOC from baseline*0.273)/1000]*10 USD, assuming payment per ton of CO2e is US$10.

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 soil carbon sequestration[13] and most packages also increase net revenue from maize production compared to a strategy without improved management practices. An exception is the application of crop residues, manure, and fertilizers on sandy soils in Garissa, which results in a decline in net profits as 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 US$1-2 per hectare when 50 percent of crop residues are left on maize fields, assuming a carbon price of US$10 per tCO$_2$e, revenues rise to US$2-24 if manure and fertilizers are also applied and are highest for loamy soils in temperate areas. If SWC and crop rotation are also incorporated, revenues from carbon alone are US$22 per ha in semi-arid, loamy soils and US$23 per ha in temperate loamy soils. If irrigation is also added, carbon benefits are highest on clayey soils in the arid zone, at US$24 per ha, followed by US$22 and US$21 per hectare in the loamy soils in temperate and semi-arid areas, respectively.

Table 13: 40-year average annual incremental revenues from SOC* and maize yield** (USD/ha)

		Package 1		Package 2		Package 3		Package 4	
		RES50		RES50, FERT & MNR		RES50, FERT, MNR, SWC & ROT		FRT, MNR, RES50, SWC, ROT, & IRG	
AEZ	Soil	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)
Arid	Clay	1	71	9	17	15	202	24	1289
Arid	Sand	1	83	2	-39	10	383	8	1029
Semi-arid	Loam	2	214	22	1047	22	1210	21	1160
Semi-arid	Sand	2	136	8	368	6	446	5	299
Semi-arid	Clay	2	256	19	1763	19	2058	17	2084
Temperate	Loam	2	62	24	953	23	1047	22	873
Humid	Loam	0	136	13	1569	12	1650	11	1198

*assumes a carbon price of 10 USD per tCO2e

**assumes a price per kg of maize of 0.375 USD

Source: Authors.

We find the highest increase in net profits from maize production under package 4 on in semi-arid areas on clayey soils. But the increase in net profits is also high on clayey soils in the arid area and on loamy

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[13] Revenues are calculated based on increases in soil organic carbon, not including increases in above ground biomass.

soils in the semi-arid 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 semi-arid 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 is included, the increase in net profits is also high on loamy soils in the temperate area.

However, the increase in net revenues in Table 13 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 (3 tons per hectare) is more than can realistically be produced on the farm. It is, therefore, necessary to include an additional cost for manure.

In order to capture the costs associated with livestock, we assume 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 kg of stover per year (5.5 kg of dry matter per day), we calculate 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 calculate the cost of purchasing napier grass (4 KSH per kg) as a feed replacement. Given that one cow would supply one ton of manure per ha, we calculate the cost of two tons of manure at a rate of 5.5 KSH per kg. The results incorporating costs associated with livestock are presented in Table 14.

Table 14: 40-year average annual incremental revenues from SOC* and maize yield (USD/ha), including costs from livestock**

		Package 1		Package 2		Package 3		Package 4	
		RES50		RES50, FERT & MNR		RES50, FERT, MNR, SWC & ROT		FRT, MNR, RES50, SWC, ROT, & IRG	
AEZ	Soil	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)
Arid	Clay	1	-16	9	-195	15	7	24	1151
Arid	Sand	1	35	2	-221	10	241	8	892
Semi-arid	Loam	2	177	22	910	22	1072	21	1023
Semi-arid	Sand	2	116	8	231	6	309	5	162
Semi-arid	Clay	2	210	19	1626	19	1920	17	1947
Temperate	Loam	2	12	24	816	23	910	22	736
Humid	Loam	0	116	13	1431	12	1513	11	1061

*assumes a carbon price of 10 USD per tCO2e
**price per kg of maize is 0.375 USD
Source: Authors.

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 15 shows the increase in revenues from SCS and maize yield improvements for this set of packages, not including livestock costs. Compared to Table 14 above, we generally find greater revenues from SCS and yield improvements when 75 percent of residues are left in the field, with some exceptions.

Revenues from SCS range from US$ 1-4 per hectare for package 1 (75 percent residues); US$ 2-28 when fertilizer and manure are added; US$ 7-26 with the addition of SWC and crop rotation; and US$ 6-27 when irrigation is added. However, for all packages in arid lands with clayey soils, the increase in soil carbon is less when 75 percent of residues are applied to the field.

Table 15: 40-year average annual incremental revenues from SOC* and maize yield** (USD/ha)

		Package 1		Package 2		Package 3		Package 4	
		RES75		RES75, FERT & MNR		RES75, FERT, MNR, SWC & ROT		FRT, MNR, RES75, SWC, ROT, & IRG	
AEZ	Soil	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)
Arid	Clay	1	84	2	-44	11	393	9	1042
Arid	Sand	2	74	9	11	16	203	27	1353
Semi-arid	Loam	4	237	26	1103	25	1264	25	1191
Semi-arid	Sand	3	167	9	373	7	470	6	328
Semi-arid	Clay	2	463	21	1921	21	2183	19	1958
Temperate	Loam	3	59	28	994	26	1088	25	899
Humid	Loam	2	118	16	1552	15	1637	14	1186

*assumes a carbon price of 10 USD per tCO2e
**price per kg of maize is 0.375 USD
Source: Authors.

Table 16 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 compared to the same package of practices with 50 percent residues.

Table 16: Difference in 40-year average annual revenues from SOC and yield (USD/ha) when 75 percent revenues are applied instead of 50

		Package 1		Package 2		Package 3		Package 4	
		RES		RES, FERT & MNR		RES, FERT, MNR, SWC & ROT		FRT, MNR, RES, SWC, ROT, & IRG	
AEZ	Soil	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)
Arid	Clay	0	13	-6	-61	-4	191	-15	-247
Arid	Sand	1	-9	7	51	6	-180	18	323
Semi-arid	Loam	2	23	4	56	4	54	3	31
Semi-arid	Sand	1	31	1	4	1	24	1	29
Semi-arid	Clay	1	207	2	157	2	125	2	-126
Temperate	Loam	1	-3	4	40	3	41	3	26
Humid	Loam	1	-18	3	-17	3	-13	3	-12

Source: Authors.

Table 17: 40-year average annual incremental revenues from SOC* and maize yield (USD/ha), including costs from livestock**

		Package 1		Package 2		Package 3		Package 4	
		RES75		RES75, FERT & MNR		RES75, FERT, MNR, SWC & ROT		FRT, MNR, RES75, SWC, ROT, & IRG	
AEZ	Soil	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)
Arid	Clay	1	-10	2	-269	11	177	9	866
Arid	Sand	2	-1	9	-198	16	14	27	1180
Semi-arid	Loam	4	168	26	933	25	1099	25	1025
Semi-arid	Sand	3	108	9	197	7	296	6	155
Semi-arid	Clay	2	392	21	1746	21	2011	19	1782
Temperate	Loam	3	-16	28	817	26	916	25	722
Humid	Loam	2	57	16	1384	15	1472	14	1016

*assumes a carbon price of 10 USD per tCO2e
**price per kg of maize is 0.375 USD
Source: Authors.

Factoring in the costs associated with livestock feed and manure, net revenues still increase with management packages including 75 percent residue retention in most scenarios (see Table 17). However, there are more cases where the management packages with 75 percent residues are less profitable than the same packages with 50 percent residues (see Table 18). 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 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 feed replacement, such as napier grass.

Table 18: Difference in 40-year average annual revenues from SOC and yield (USD/ha) when 75 percent revenues are applied instead of 50 (including livestock costs)

		Package 1		Package 2		Package 3		Package 4	
		RES		RES, FERT & MNR		RES, FERT, MNR, SWC & ROT		FRT, MNR, RES, SWC, ROT, & IRG	
AEZ	Soil	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)	Revenue from carbon (USD/ha)	Net revenue from yield (USD/ha)
Arid	Clay	0	7	-6	-74	-4	170	-15	-285
Arid	Sand	1	-35	7	23	6	-228	18	289
Semi-arid	Loam	2	-9	4	24	4	27	3	2
Semi-arid	Sand	1	-8	1	-34	1	-13	1	-7
Semi-arid	Clay	1	182	2	120	2	91	2	-164
Temperate	Loam	1	-28	4	1	3	6	3	-14
Humid	Loam	1	-59	3	-47	3	-41	3	-45

Source: Authors.

For more details on the benefits and costs associated with the selected management packages for each AEZ-soil type combination see Tables 5.1 through 5.7 in Appendix 5.

8.2 Profitability of improved livestock feeding

Table 11 from Section 6.2 above 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 calculate the cost of emissions for the different scenarios to determine which of the alternative feeding strategies leads to a reduction of emissions.[14] Table 19 illustrates the cost of CO2e emissions for alternative feeding strategies; the alternatives that lead to a reduction in emissions with respect to the baseline situation are highlighted 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 6.2).

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[14] We assume a carbon price of 10 USD per t of CO_2.

Table 19. Cost of carbon emissions for different alternative feeding strategies

District	Cost of CO_2e emissions for baseline feeding strategy (USD)	Scenarios	Cost of CO_2e emissions for the scenarios (USD)
		Prosopis	
Garissa		1.5 kg	**6.45**
	6.53	3 kg	**6.16**
		Desmodium	
Gem		1 kg	**7.52**
	7.77	2 kg	7.85
		Napier grass	
Mbeere		2 kg	9.94
	9.64	3 kg	9.90
		Hay	
Njoro		1 kg	9.61
	9.06	2 kg	10.63
		Desmodium	
Mukurweni		1 kg	9.94
	9.83	2 kg	**9.17**
		Hay	
Othaya		2 kg	9.68
	9.57	4 kg	9.61
		Napier grass	
Siaya		2 kg	9.02
	8.07	3 kg	10.49

Source: Authors.

Tables 20a and 20b show the results from the profitability analysis for milk production in the 7 districts. 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 US$ 0.352 per liter. The profitability per liter ranges from US$0.11-0.33. A previous study by Omiti et al. (2006) calculated net profits in the range of US$0.13-0.16 per liter of milk. Table 20b compares the profitability of different alternative feeding strategies. Scenarios with increased profitability are highlighted in bold.

Table 20a. Profitability analysis for milk production in the 7 districts.

District	Cost of feed[a] (USD)	Cost of labor (USD)[b]	Net revenue (USD)	Net revenue per liter of milk (USD)
Garissa	n/a[c]	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

[a] This is the cost of feed for one dairy cow

[b] Labor costs are based on survey results

[c] Because livestock in Garissa rely on grazing only, there is not cost for feed in the baseline scenario.

Source: Authors

Table 20b. Profitability analysis for milk production in the 7 districts based on different alternative feeding strategies

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

Source: Authors

Table 20b 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 to the baseline for the second scenario in Othaya given the large cost of purchasing replacement feed. Feed prices used to calculate the profitability of alternative feeding practices are showing in Appendix Table 5.9.

9. Conclusions and Policy Implications

The results indicate that farmers in Kenya do not fully recognize the interlinkages between agricultural productivity, adaptation, and mitigation. Rather, farm decisions depend largely on productivity considerations while many farmers are making initial attempts to adjust to climate changes. Moreover, while 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 for integrated soil fertility management and soil and water conservation 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 mitigation to become an effective development strategy.

Table 21 presents the set of practices identified in the literature (Table 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 21 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, is low.

The results highlight soil nutrient management (i.e. combinations of inorganic fertilizer, mulching, and manure) as a key win-win-win strategy. This strategy increases soil carbon sequestration 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 soil carbon sequestration across all soil types and AEZs. Instead, inorganic fertilizer needs to be combined with other soil fertility management practices, such as manure, mulching and/or crop residues. We find that some farmers implement such combinations in all agroecological zones already. Specific combinations of nutrients will vary depending on the crop type, agroecological zone, and planting date.

Leaving crop residues on the field has a high potential for both yield improvement and soil carbon sequestration. Applying residues is also associated with lower labor costs as 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).

Table 21: Synergies among adaptation benefits, mitigation potential and crop productivity and profitability—Insights from our study

Management practices	Adaptation benefits	Mitigation potential	Productivity/Profitability
Cropland management			
Improved crop varieties and/or types	√	mixed	?
Changing planting dates	√	?	?
Improved crop/fallow rotation/rotation with legumes	?	mixed	mixed
Appropriate fertilizer/manure use	√	√	√
Incorporation of crop residues	√	√	√ - tradeoff with livestock feed in certain areas
Agroforestry	√	√	? involves greater startup and opportunity costs
Use of cover crops	Not commonly reported in study sites		
Reduced/zero tillage	Not commonly reported in study sites		
Water management			
Irrigation/water harvesting	√	mixed	√
Soil and water conservation (bunds, grass strips, ridge and furrow, etc.)	√	mixed	mixed - positive impacts in areas where soil moisture is a constraint. Appropriate selection/combination of technologies important
Livestock/grazing land management			
Improved livestock feeding	√	√	√
Destocking	√	√	√ - when combined with improved feeding
Improved breeds/species	Not examined in this study		
Rotational grazing	Not examined in this study		
Restoring degraded lands			
Re-vegetation	Not examined in this study		
Applying nutrient amendments	Not examined in this study		

Source: Authors.

A second promising strategy is agroforestry, given the large acceptance of this practice in the country (albeit fueled by media and the government), the large support by the government, the large biomass for carbon storage, and important adaptation benefits. While this study did not examine the implications of agroforestry for soil carbon sequestration and profitability, previous studies have suggested that these projects have significant potential for SCS and can provide economic benefits for local communities. However, agroforestry entails large start up costs that may be prohibitive for many farmers. Indeed the household survey results indicate that resource constraints prohibit poor farmers from making changes that will have benefits over the long term. In addition, not all forest-based sequestration projects are designed to offer benefits to smallholders (but rather commercial plantations) and some may even have adverse effects on local communities (Jindal, Swallow, and Kerr 2008).

Moreover, the opportunity cost of using the trees for firewood or timber is high. The government and NGOs must find ways of making the adoption and use of agroforestry for SOC sequestration and agricultural productivity more attractive by providing seedlings, training, and other incentives such as credit. Linking with carbon markets or other payments for environmental services may reduce the incentive to use agroforestry trees for timber and firewood rather than for carbon sequestration and agricultural productivity.

While in general, nutrient management and agroforestry appear to be promising strategies 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 soil carbon sequestration and yield benefits.

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 soil carbon sequestration even with nutrient management practices in most districts. 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 and productivity/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—represented as 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 is essential to achieve reasonable yield levels given very limited water availability in the arid site. However in other districts, there was not a clear positive or negative pattern for soil water conservation practices. In the humid sites, water is readily available yet nitrogen is rather limited. In this situation, soil and water conservation techniques had an insignificant effect, and irrigation in fact lowered the average yield levels across simulated management practices, possibly due to increased nitrogen leaching from the soil. In the semi-arid and temperate sites, water is somewhat limited; thus the soil and water management practices and irrigation overall increase yield levels and irrigation reduces 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.

Overall, the results suggest that irrigation and SWC techniques should be selected to suite 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 of milk in the 7 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 poorer feed resources available. However, in only 4 of the 14 alternative scenarios do improved feeding practices result in a decline in overall methane emissions; and emission reductions are very small. In cases where overall emissions increase, 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 increase net profits from the sale of milk in most cases. One exception is in the arid site where livestock are grazed and feed is not purchased. Therefore, the cost of purchasing improved feeds reduces net profits per liter of milk. High levels of replacement feeds, such as presented in the scenario for Othaya, are also not profitable. These households, 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 mitigation aspects requires capacity building at national level (among policy makers 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 R&D, 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 which is taking advantage of mitigation opportunities provided by the Voluntary Carbon Standard (VCS). International climate negotiators should also intensify efforts to include soil carbon sequestration projects in the CDM. A key issue is ensuring that emission reductions are measurable, reportable, and verifiable (MRV). There are promising technologies to this end—micro satellites with 6 m 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 (US$2.2 billion in East Africa) that can be used to support adaptation and development efforts. However, given the low price of carbon offsets (US$5-20/ha) mitigation activities alone do not yield sufficient benefits to warrant their adoption. Carbon finance may never contribute more than 15 percent of overall agricultural investment needs, estimated at nearly $210 billion annually to 2050 (Schmidhuber et al. 2009, FAO 2009). Rather agricultural investments (both national and international) should be targeted towards activities that also provide benefits in terms of mitigation, adaptation, and increased productivity/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 project developers of climate-smart/carbon projects, including assistance in project development and implementation, application of MRV systems, and risk management aspects (e.g. guarantees or loans), to ensure that smallholders get financial benefits from mitigation activities.

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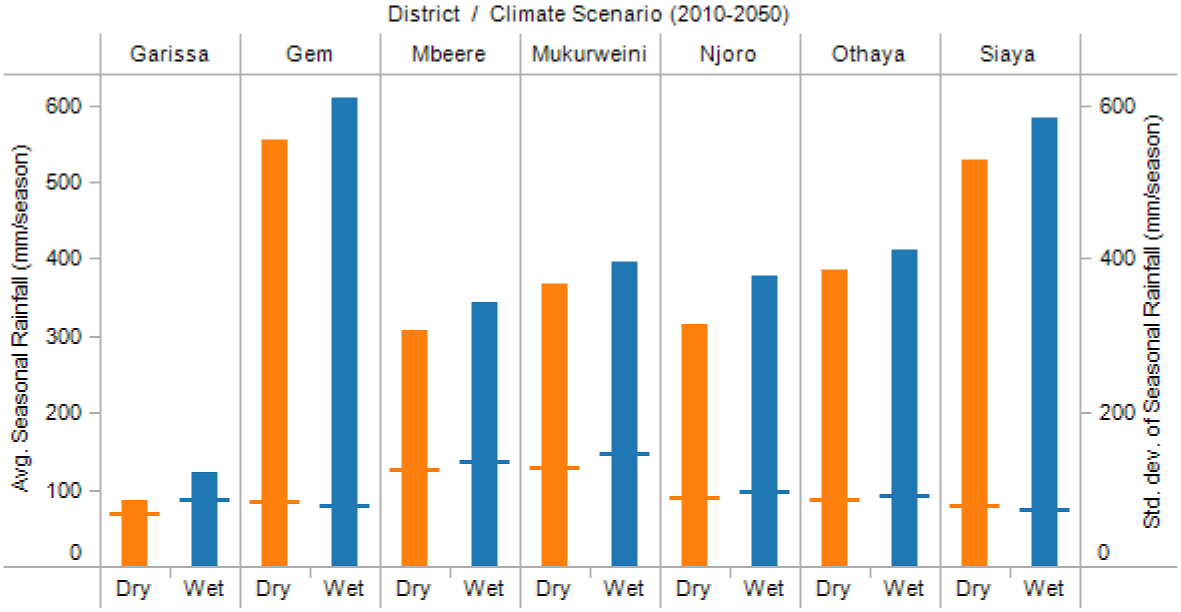
Appendix 1: Crop Simulation Details

Appendix 1.1: Methodology

For simulating maize-based farming systems under various management practice options and their soil carbon sequestration potentials under future climate conditions, the CERES-Maize 4.5 model and DSSAT-CENTURY module was used to simulate maize growth/yield and soil organic matter dynamics, respectively.

Daily weather data for 40-year period (from 2010-2050) was pre-generated by incorporating monthly deltas of climate variables (daily solar radiation, minimum and maximum temperature, and rainfall amount) that were estimated from the FutureClim database (http://futureclim.info) with temporally downscaled and shifted CRU-TS 3.0 historical climatic database (Koo, 2010). Among available spatially downscaled (5 arc-minute; approximately 10 km grids) climate projection datasets of the FutureClim database, two GCM's, CSIRO-Mk3.0 and MIROC3.2, were selected to be used this study to represent a possible dry and wet, respectively, realization of future climate, with SRES A2 scenario (Appendix Figure 1.1).

Appendix Figure 1.1: Average long season rainfall (mm) for each district under two climate projections



Coordinates of all surveyed households in the study areas were overlaid with the 5 arc-minute grids, and each of seven districts (i.e., Garissa, Gem, Mbeere South, Mukurwe-ini, Njoro, Othaya, and Siaya) were enclosed with one grid cell.

Although soil sampling was not made in this study, soil type was surveyed in terms of its texture classification (e.g., clayey, sandy, or loamy). Based on the survey results, three districts were simulated with two dominant soil types (i.e., Garissa with clayey and sandy soils, Mbeere with loamy and sandy soils, and Njoro with clayey and loamy soils), and the other four districts (i.e., Gem, Mukurweini, Othaya, and Siaya) were simulated with the predominant loamy soil. For modeling, the corresponding soil profiles were retrieved from the HarvestChoice HC27 Generic Soil Profile Database (Koo and Dimes, 2010), and they assumed to have the initial condition of medium level soil organic carbon content (between 0.7 – 1.2 percent) and medium level of rooting depth (between 90-150 cm).

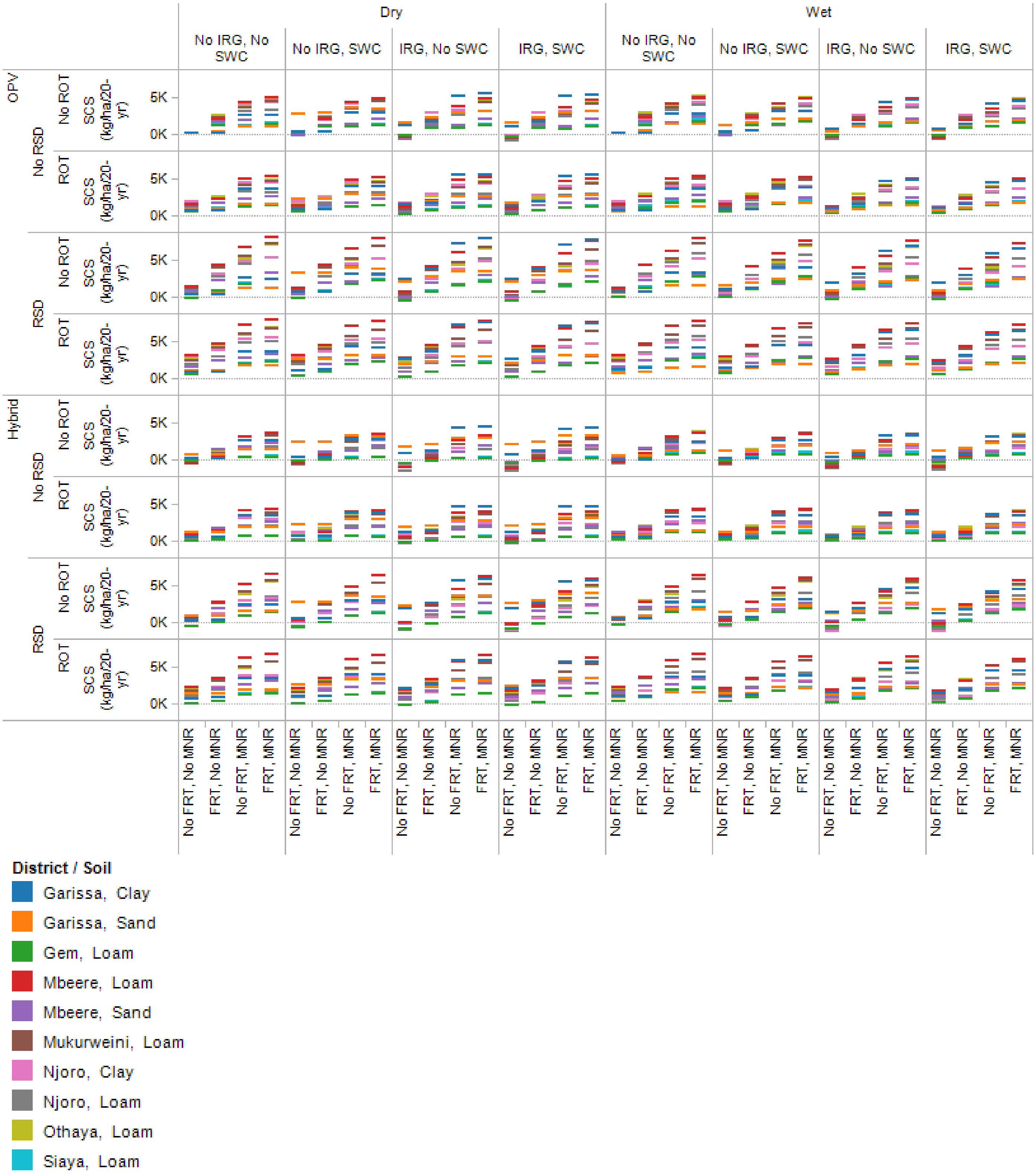
Seven components of common management practices were identified for rainfed maize farming fields, including variety, inorganic fertilizer, manure application, residue management, mulching, rotation with legumes, and soil water conservation techniques. For each component, use or non-use cases were characterized based on the household survey results at district level. Followings are the description of each management practice component and their code used in the presentation of simulation outputs in later sections.

- Maize variety
  - OPV: Medium maturity generic improved open pollination variety
  - HYB: Dekalb XL71 hybrid variety
- Inorganic fertilizer
  - FRT: 40 kg[N]/ha of inorganic fertilizer was split applied (20 kg[N]/ha on planting at 5 cm depth and 20 kg[N]/ha on 30th day after planting as top dressing) with no incorporation
  - No FRT: No fertilizer application
- Supplementary irrigation
  - IRG: 100 mm/ha of furrow irrigation split applied on the day of planting and 40th day after planting (e.g., 50 mm/ha each)
  - No IRG: rainfed cultivation with no irrigation
- Manure application
  - MNR: 1 t/ha of animal manure (nitrogen content 1.4 percent) applied on the fallow field three times with 20-day interval, between main growing seasons (i.e., 3 t/ha per year)
  - No MNR: No manure application
- Residue management
  - RSD: 50 percent of crop residue left on the field after harvest (i.e., 50 percent of residue removed after harvest)
  - No RSD: All crop residue removed from the field after harvest
  - In addition, three more levels of residue harvest (e.g., harvesting 0 percent, 25 percent, and 75 percent of residue after harvest) were simulated for testing the model sensitivity.
- Rotation with legume
  - ROT: Rotation with dry beans every 4th year (i.e., maize-maize-maize-dry bean)
  - No ROT: Continuous maize cultivation
- Soil water conservation (SWC) practices
  - SWC: Assumes various measures of soil water conservation techniques practices on the field so that the soil water availability before planting is 30 percent of field capacity and small amount (2 mm/ha/10-day) of soil moisture is additionally available in the root zone throughout the growing season.

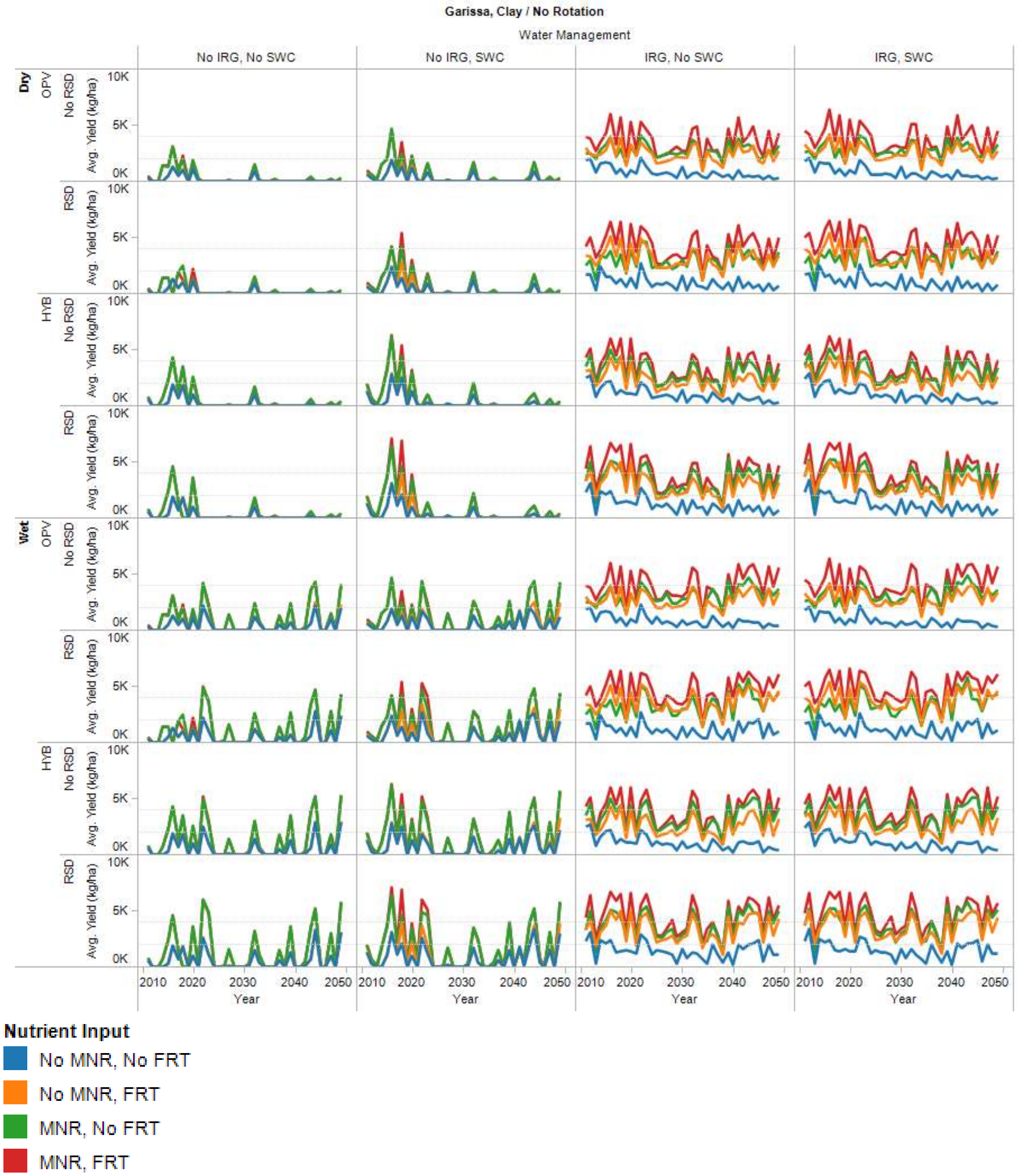
  - No SWC: No SWC practices; soil water availability is 10 percent of field capacity before planting.

From the 40-year time series simulation results, averaged soil organic carbon content for first 5-year and last 5-year were calculated for each climate/soil texture/management practice combination, and used as the basis for the overall soil carbon stock changes for the time span. For the estimation of soil carbon sequestration, "no-effort" management case (i.e., 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 30-year period (excluding the first and last 5 years) was scaled down to 20-year period, to be compatible with the results from other studies.

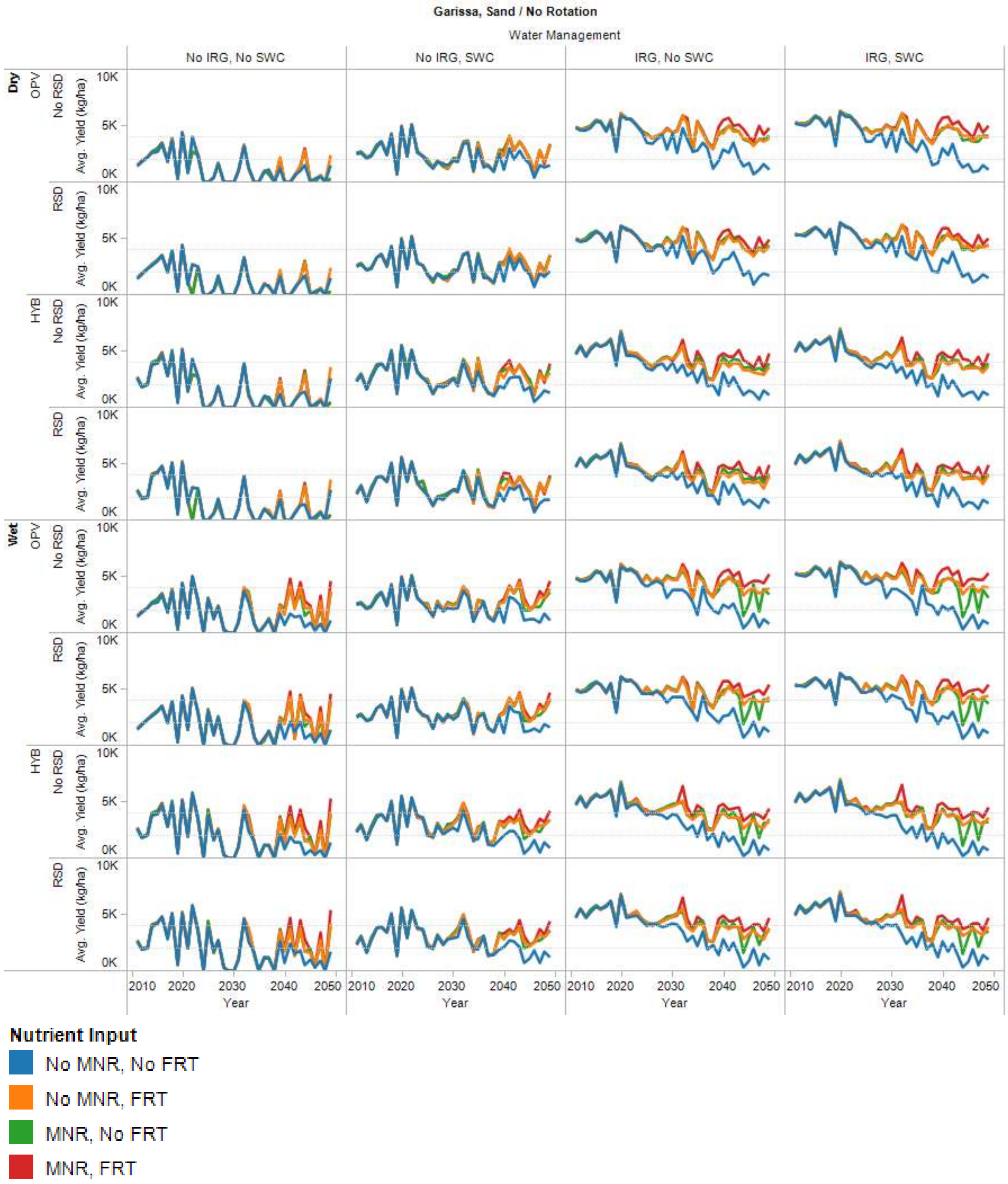
Appendix 1.2: Detailed Results



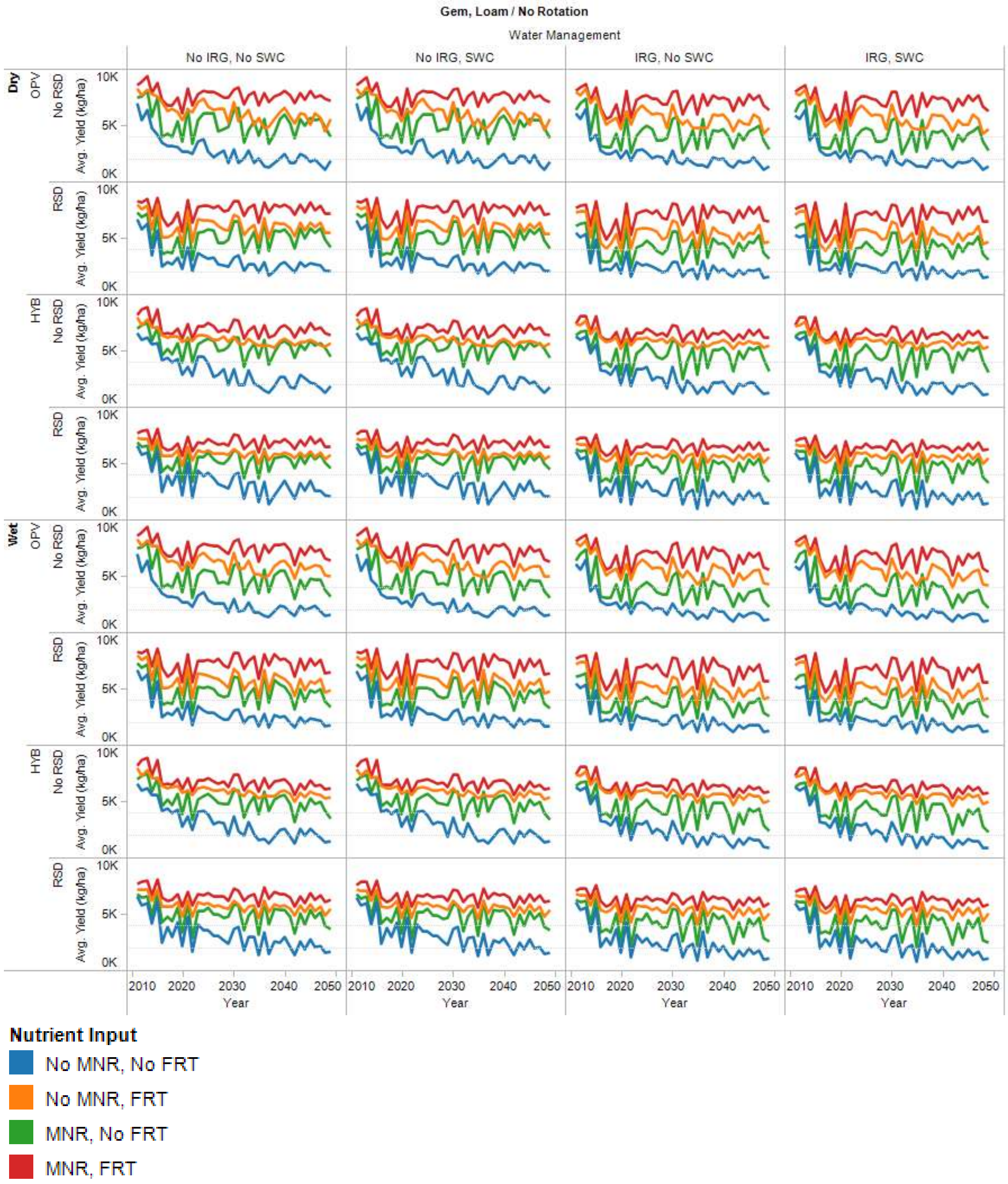
Appendix Figure 1.2. Estimated soil carbon sequestration potential (kg[C]/ha/20-yr) for each management practice package per district/soil/climate



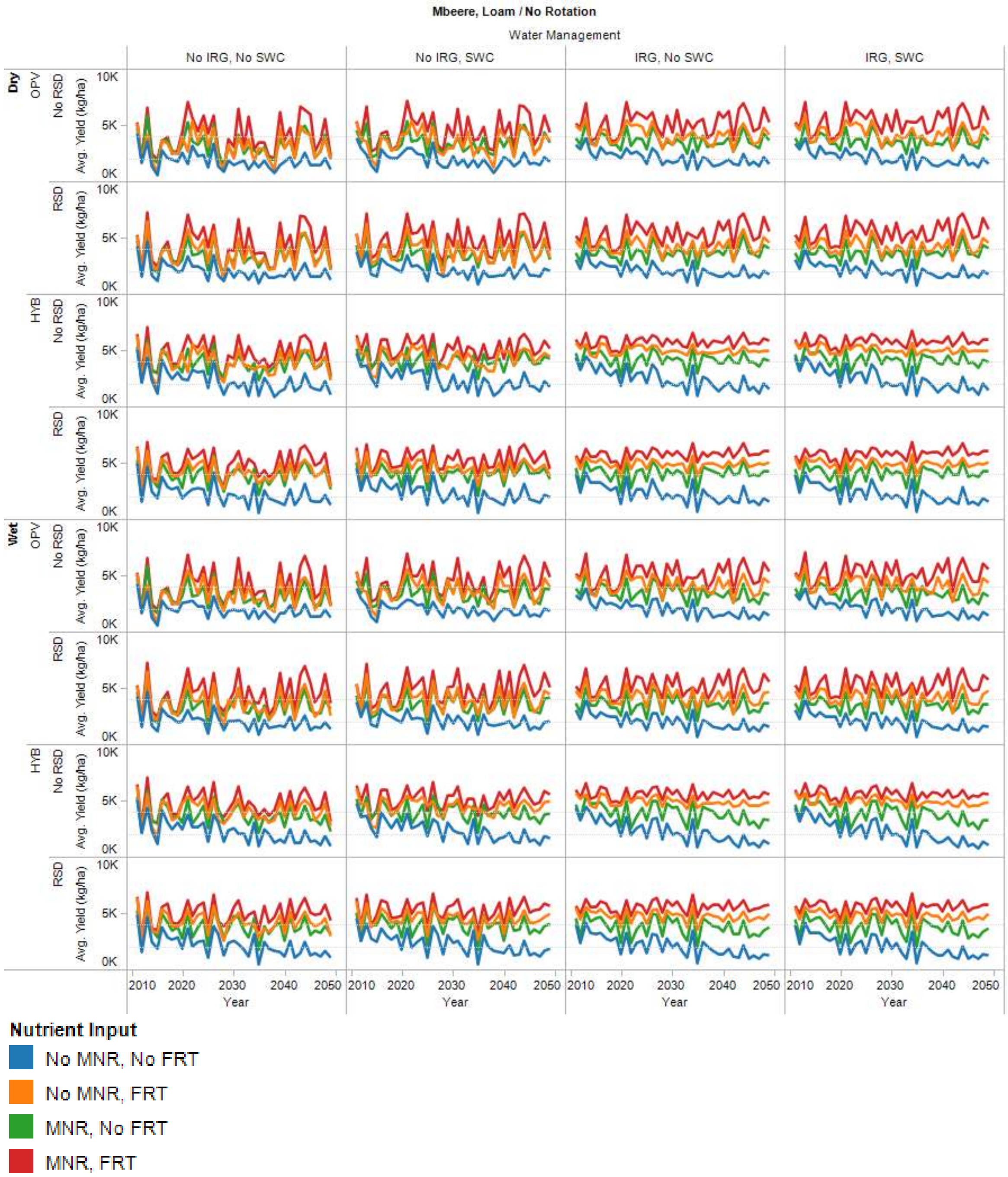
Appendix Figure 1.3. Simulated maize yield trend in Garissa with clayey soil



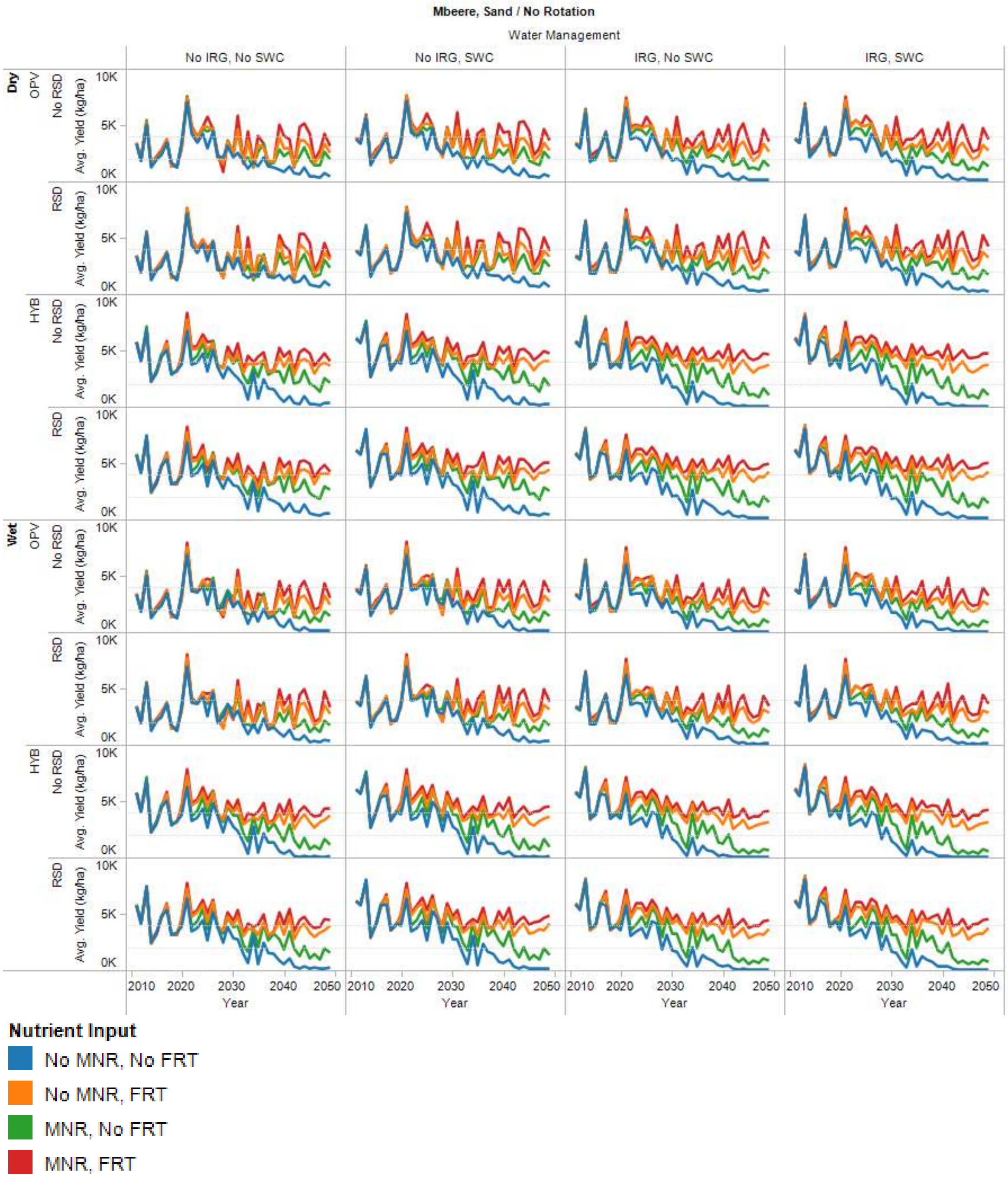
Appendix Figure 1.4. Simulated maize yield trend in Garissa with sandy soil



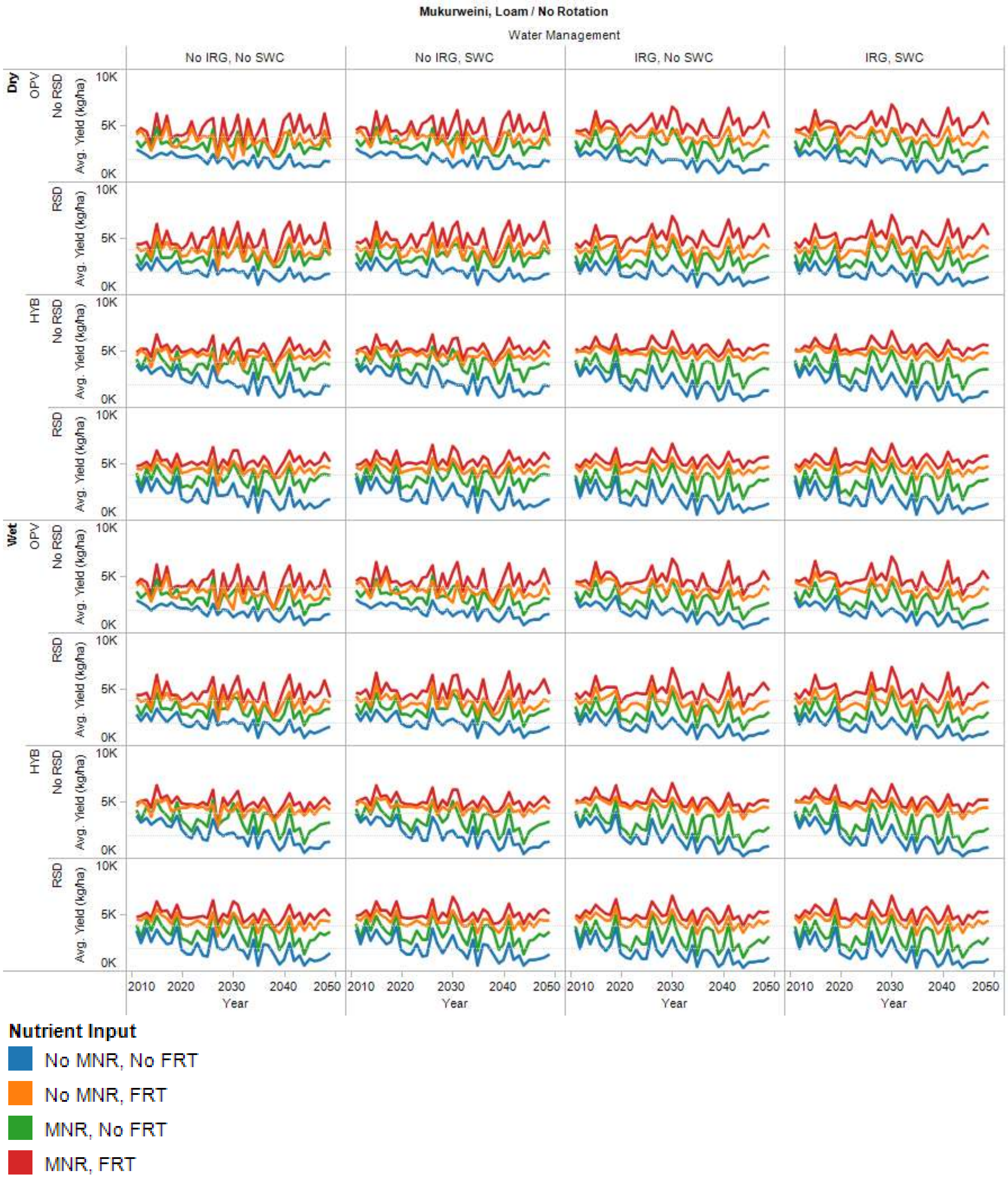
Appendix Figure 1.5. Simulated maize yield trend in Gem with loamy soil



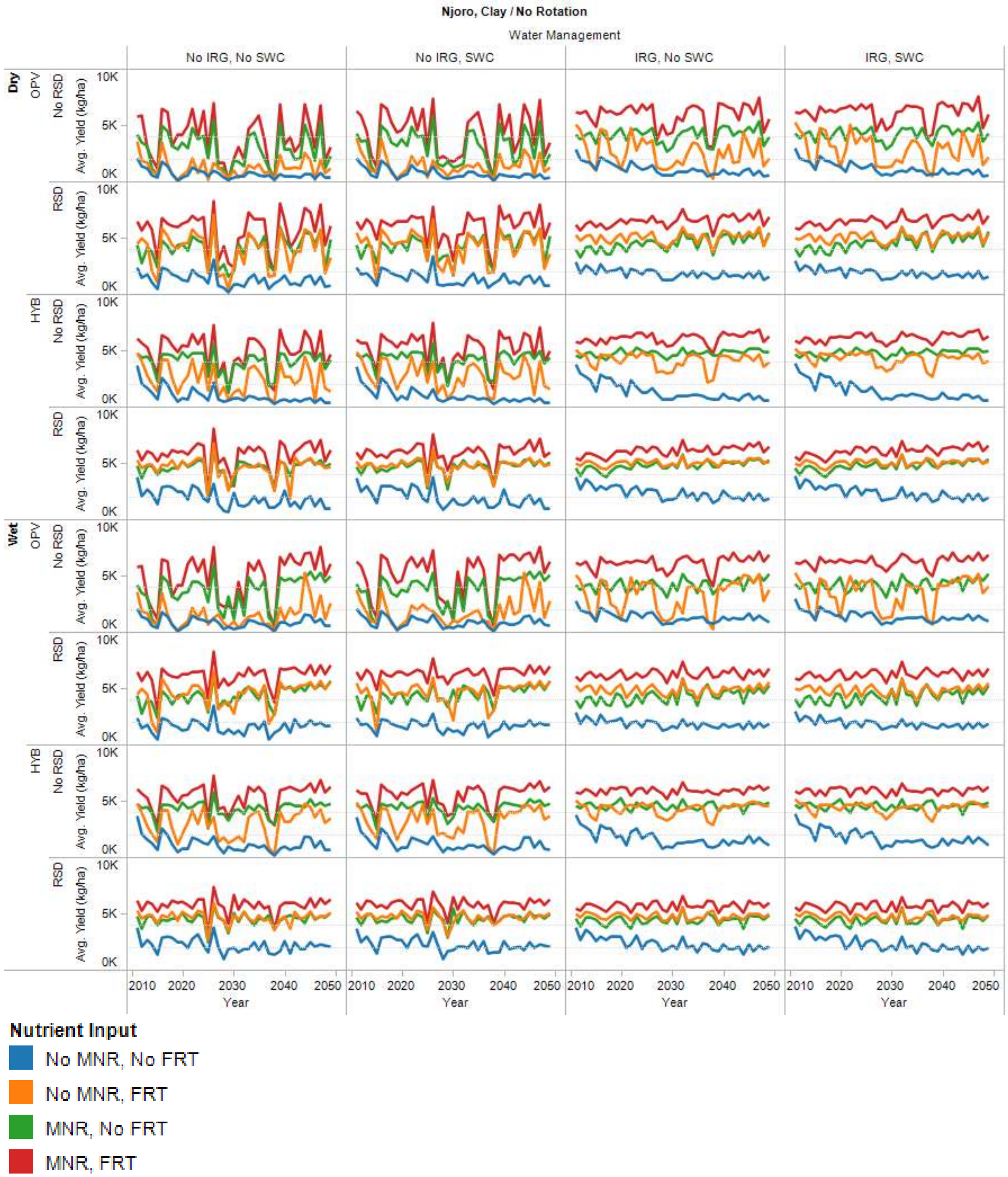
Appendix Figure 1.6 Simulated maize yield trend in Mbeere with loamy soil



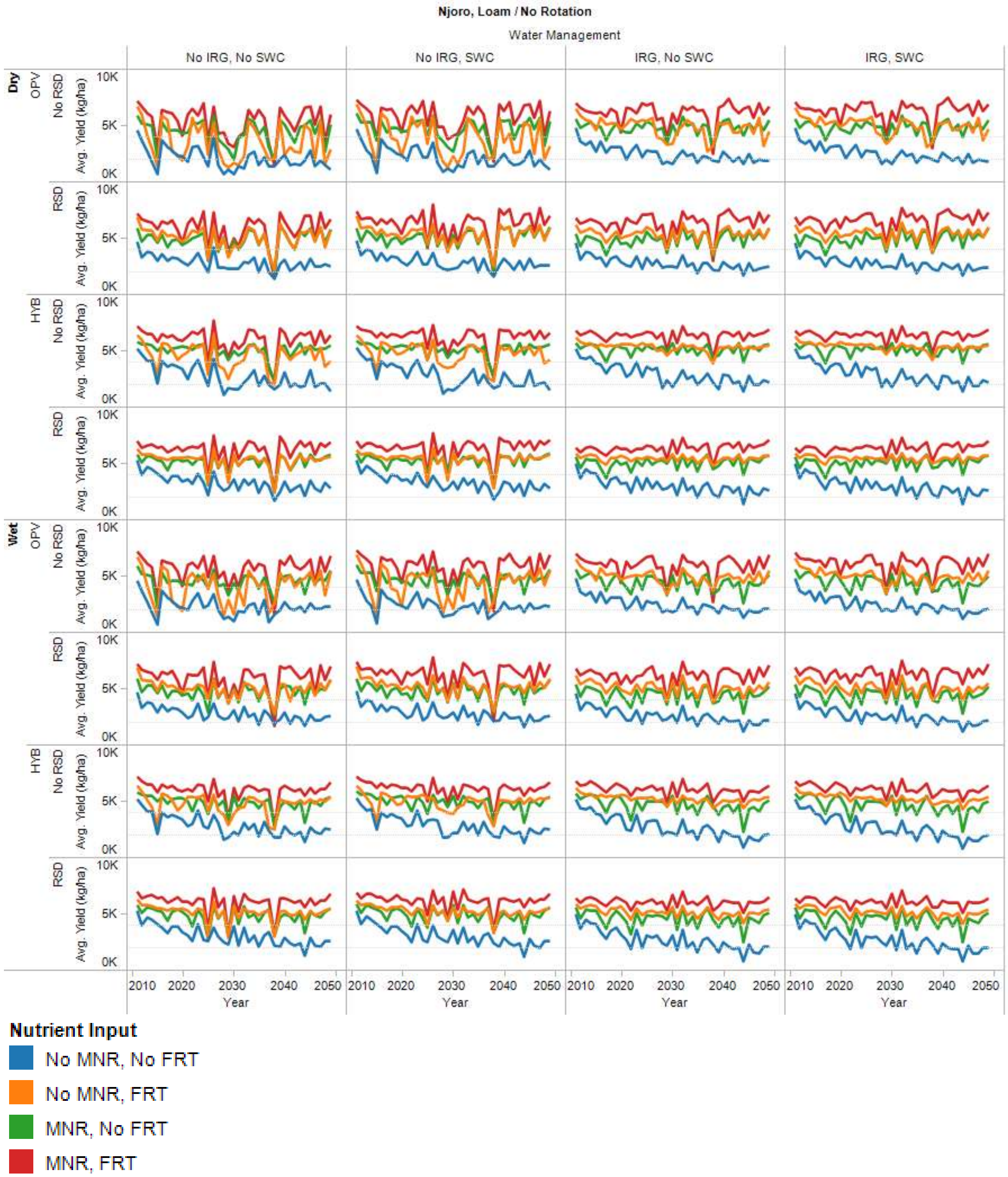
Appendix Figure 1.7 Simulated maize yield trend in Mbeere with sandy soil



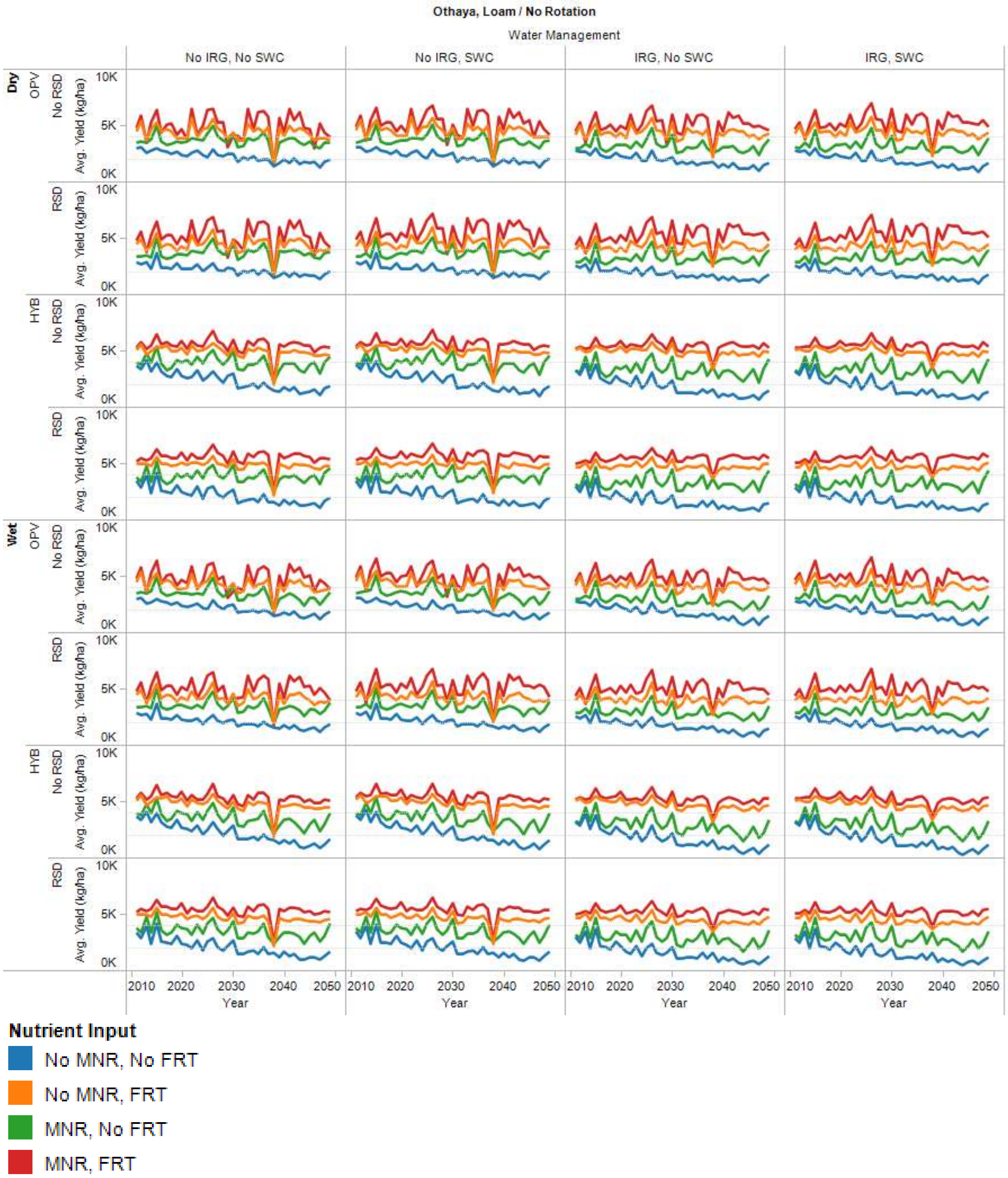
Appendix Figure 1.8 Simulated maize yield trend in Mukurwe-ini with loamy soil



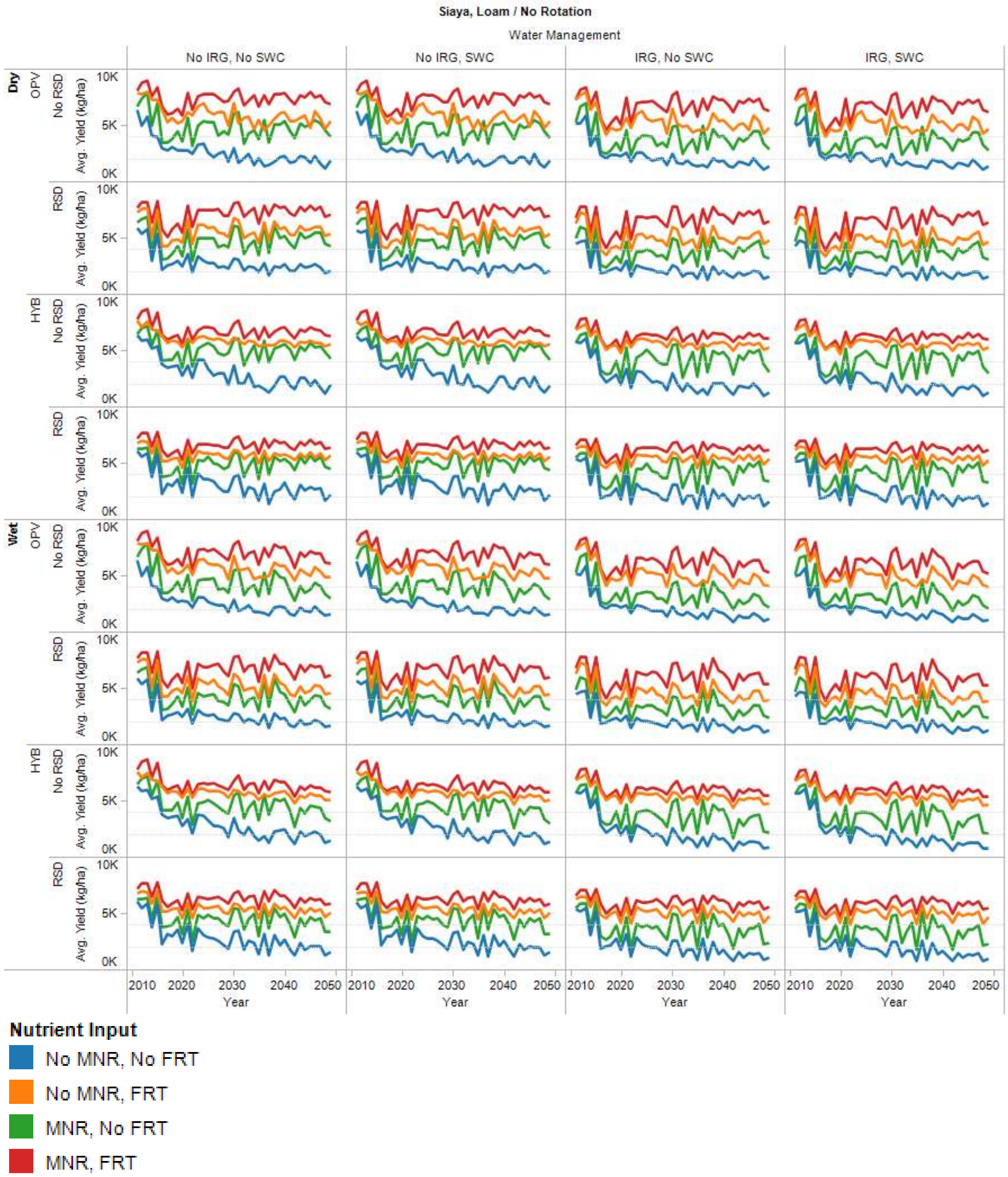
Appendix Figure 1.9 Simulated maize yield trend in Njoro with clayey soil



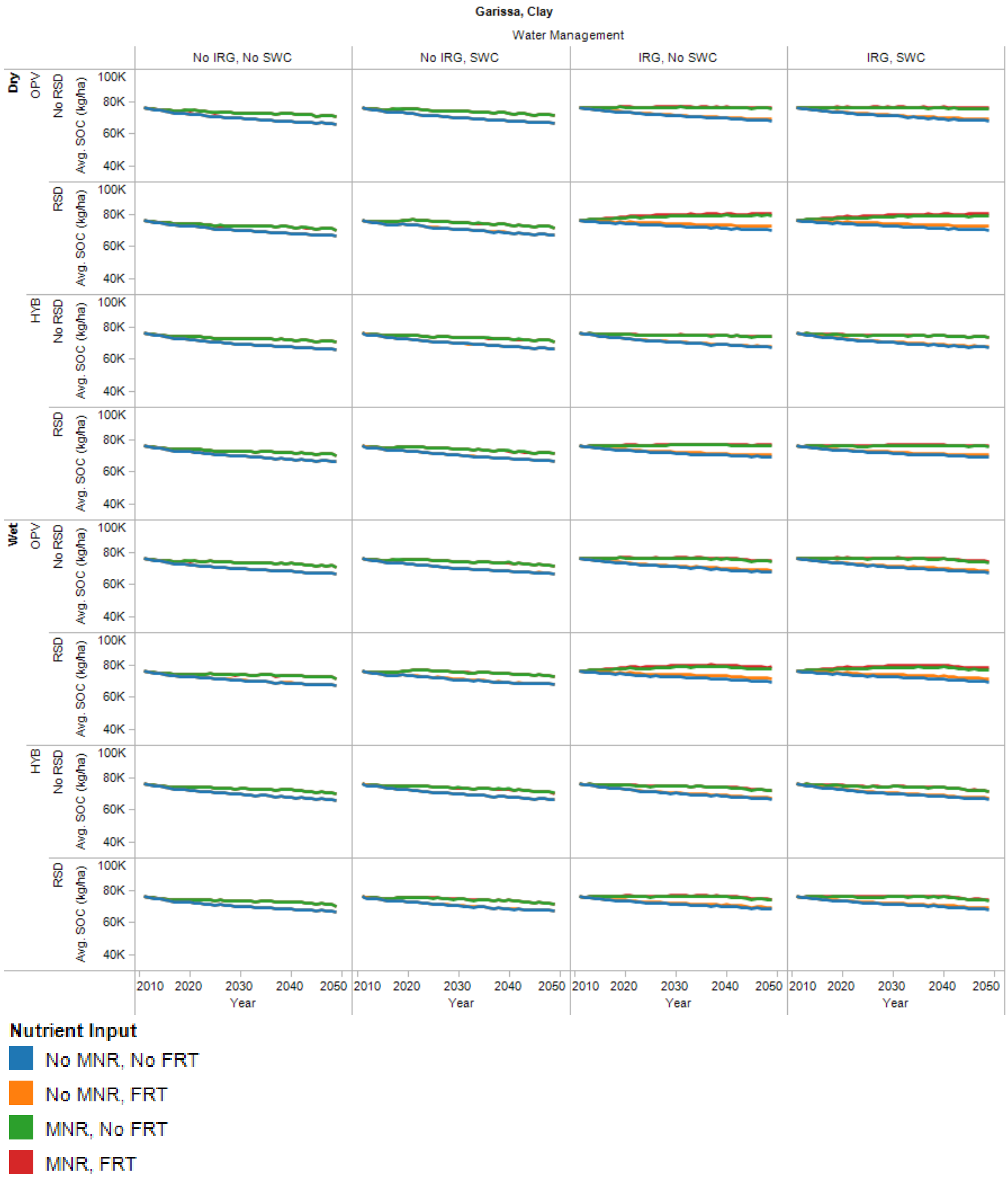
Appendix Figure 1.10 Simulated maize yield trend in Njoro with loamy soil



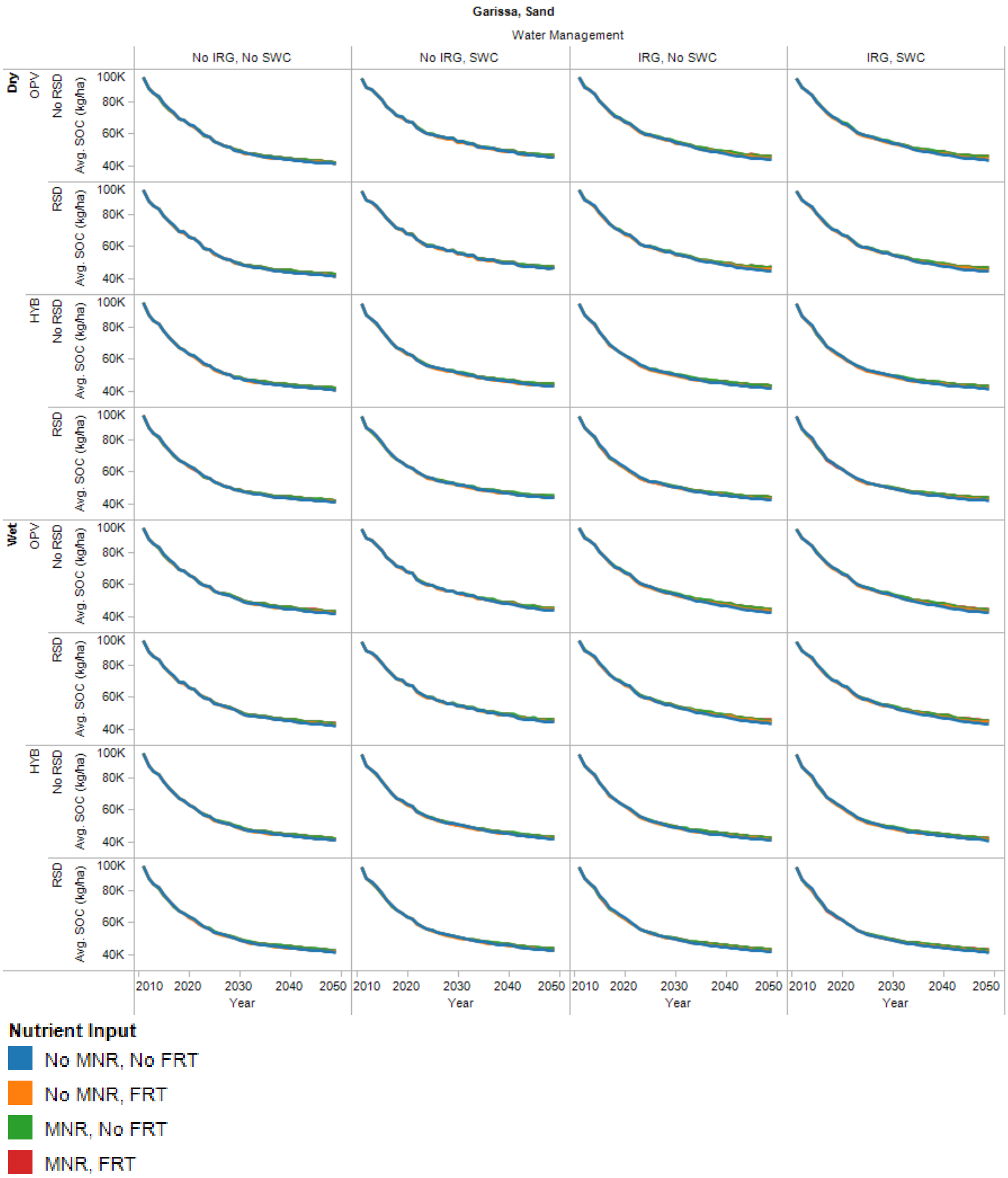
Appendix Figure 1.11 Simulated maize yield trend in Othaya with loamy soil



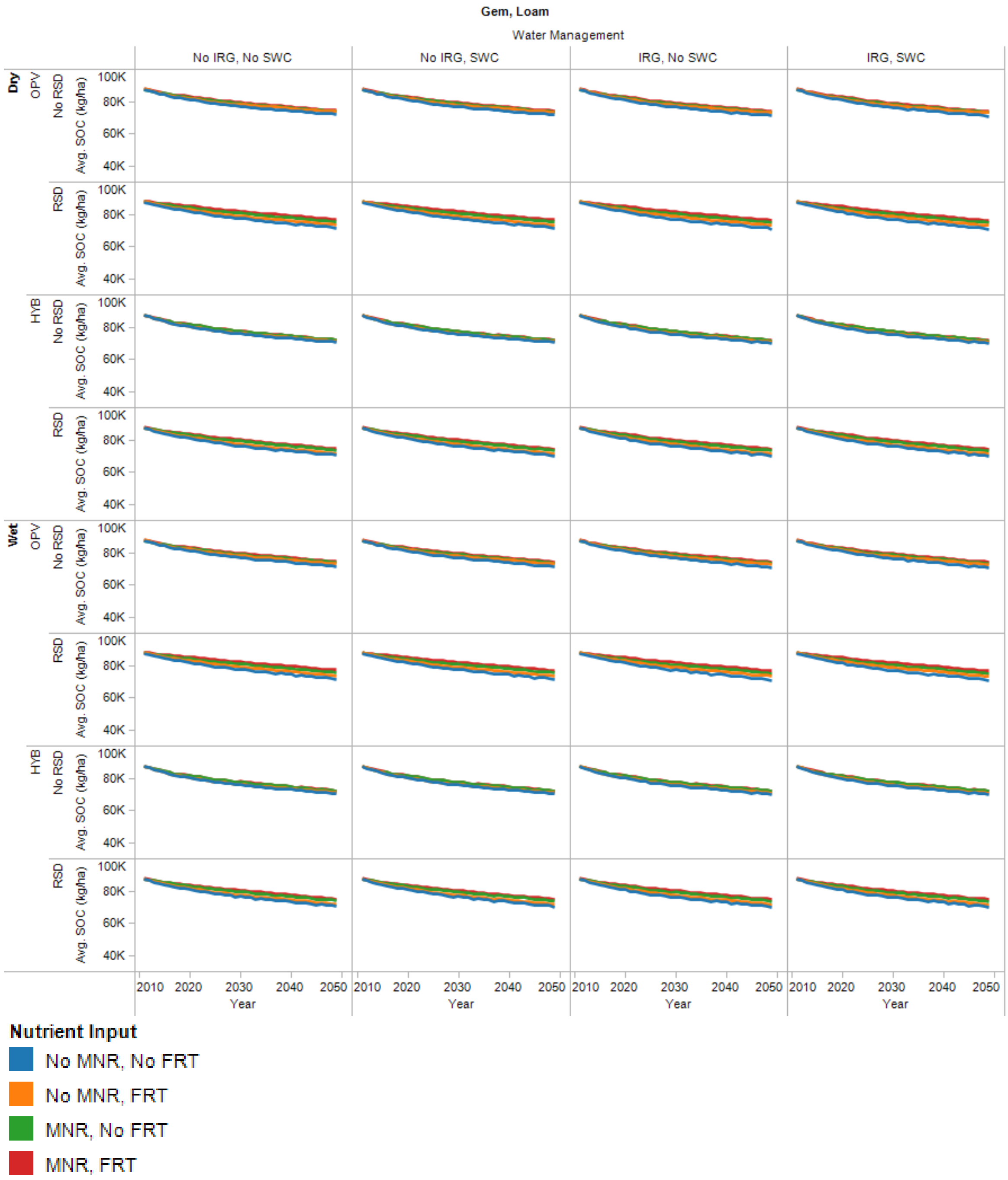
Appendix Figure 1.12 Simulated maize yield trend in Siaya with loamy soil



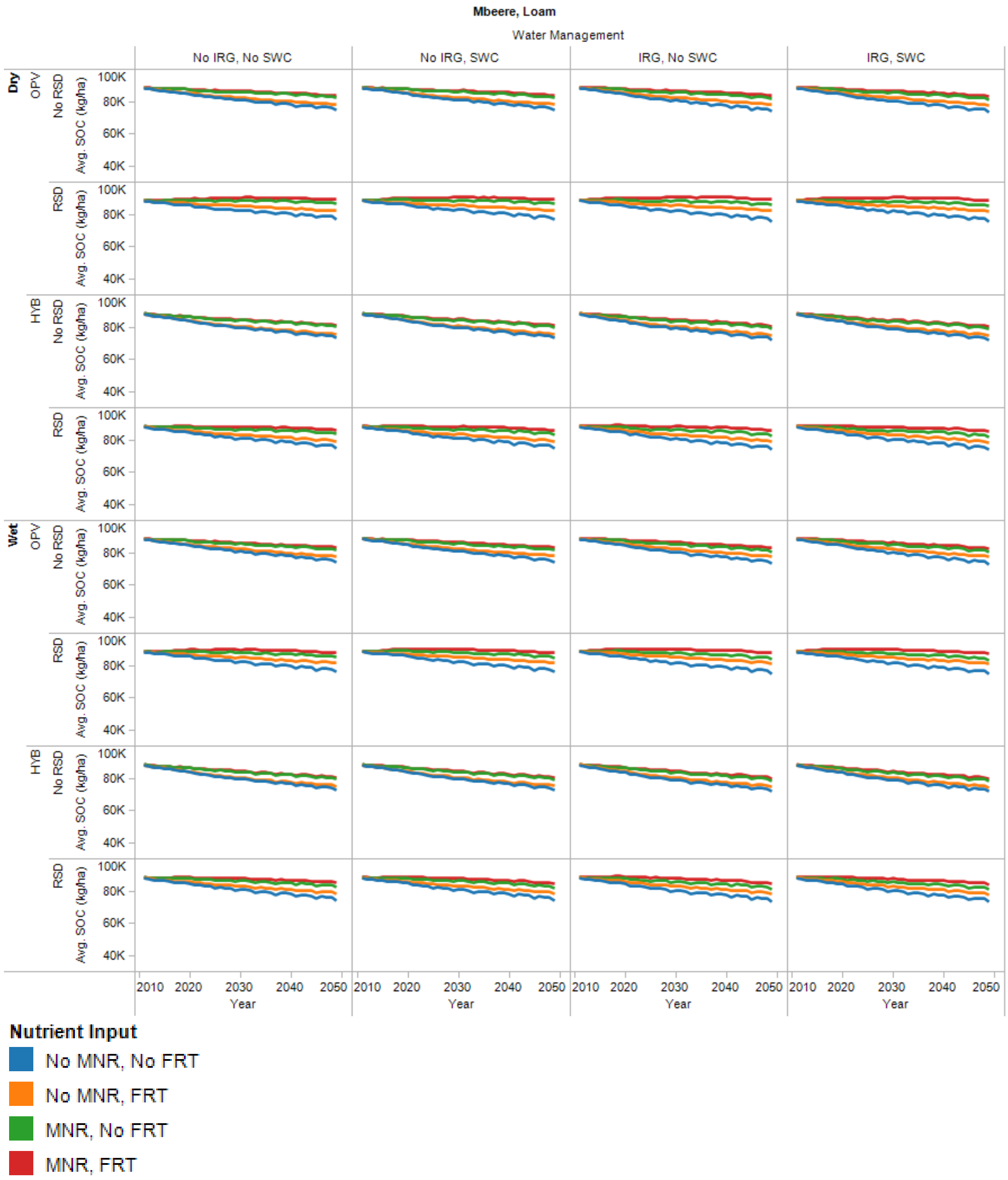
Appendix Figure 1.13 Simulated SOC trend in Garissa with clayey soil



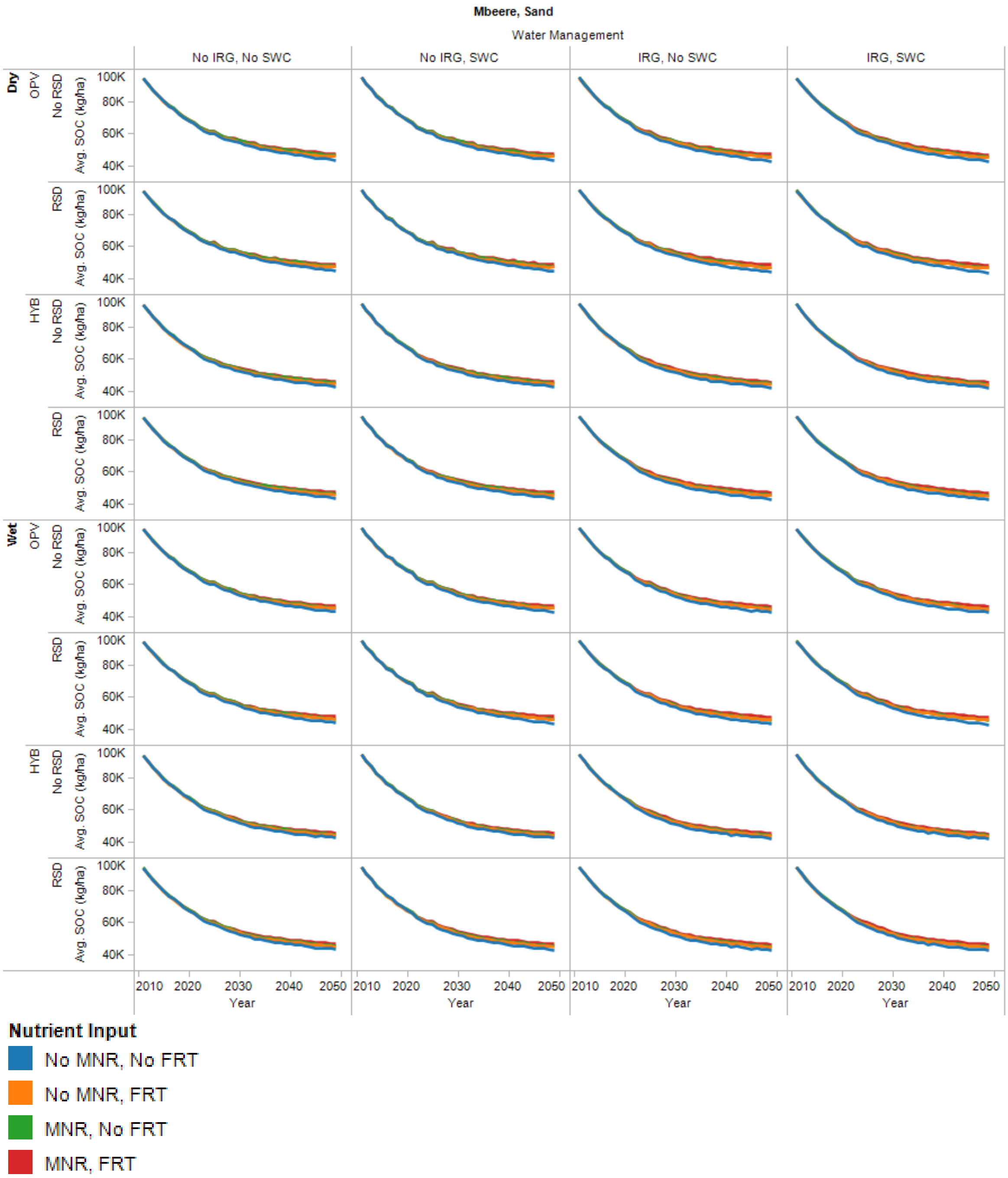
Appendix Figure 1.14 Simulated SOC trend in Garissa with sandy soil



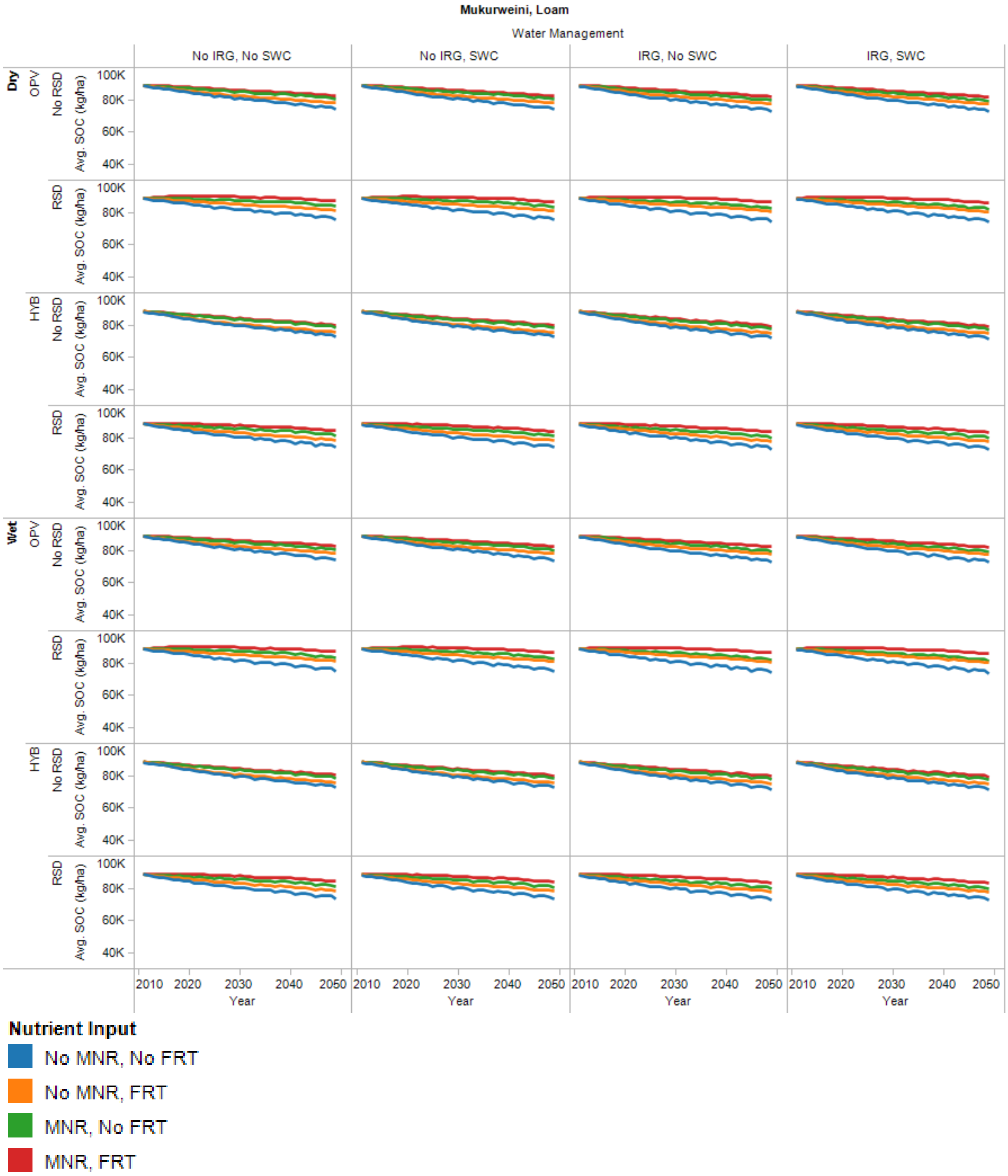
Appendix Figure 1.15 Simulated SOC trend in Gem with loamy soil



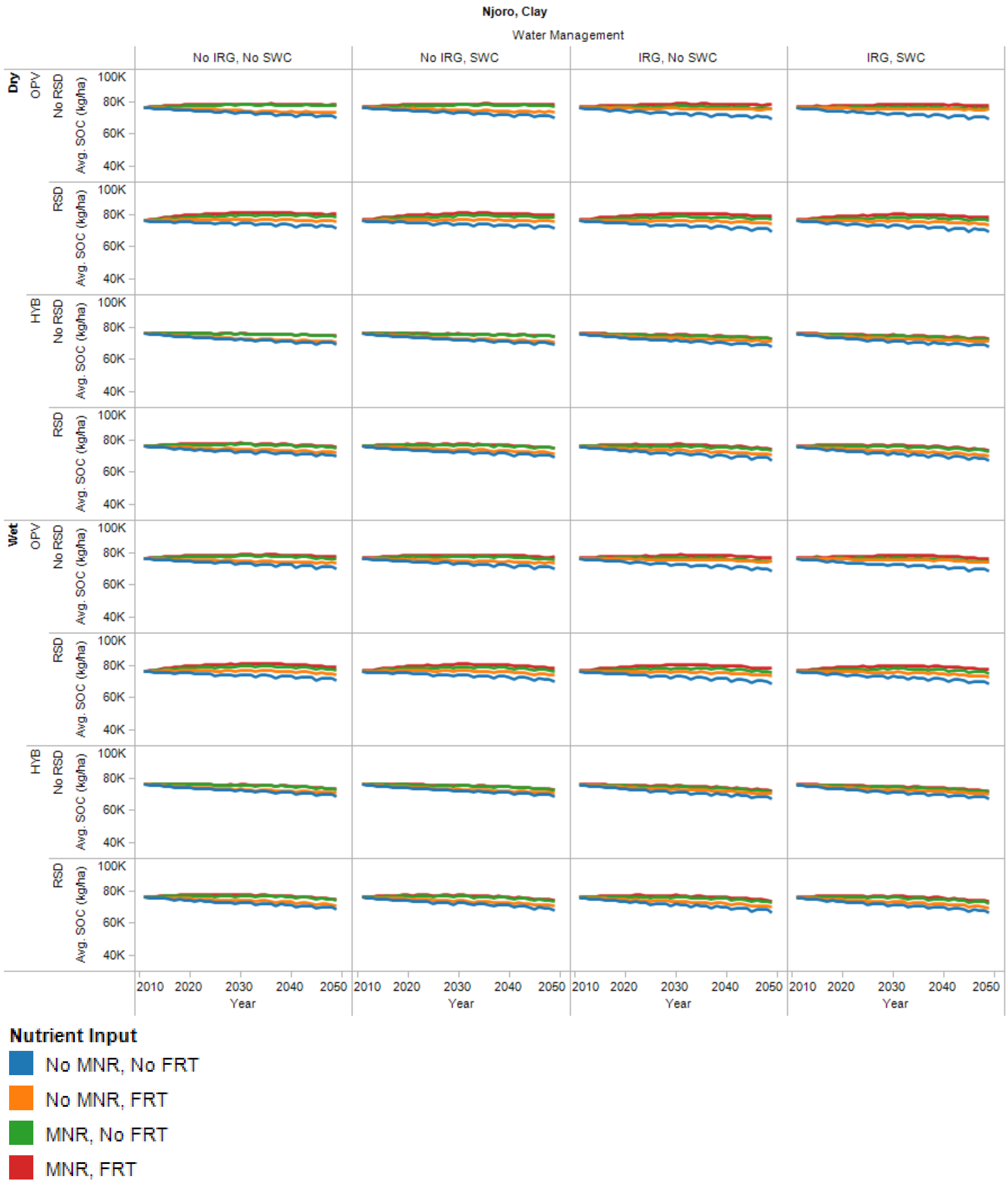
Appendix Figure 1.16 Simulated SOC trend in Mbeere with loamy soil



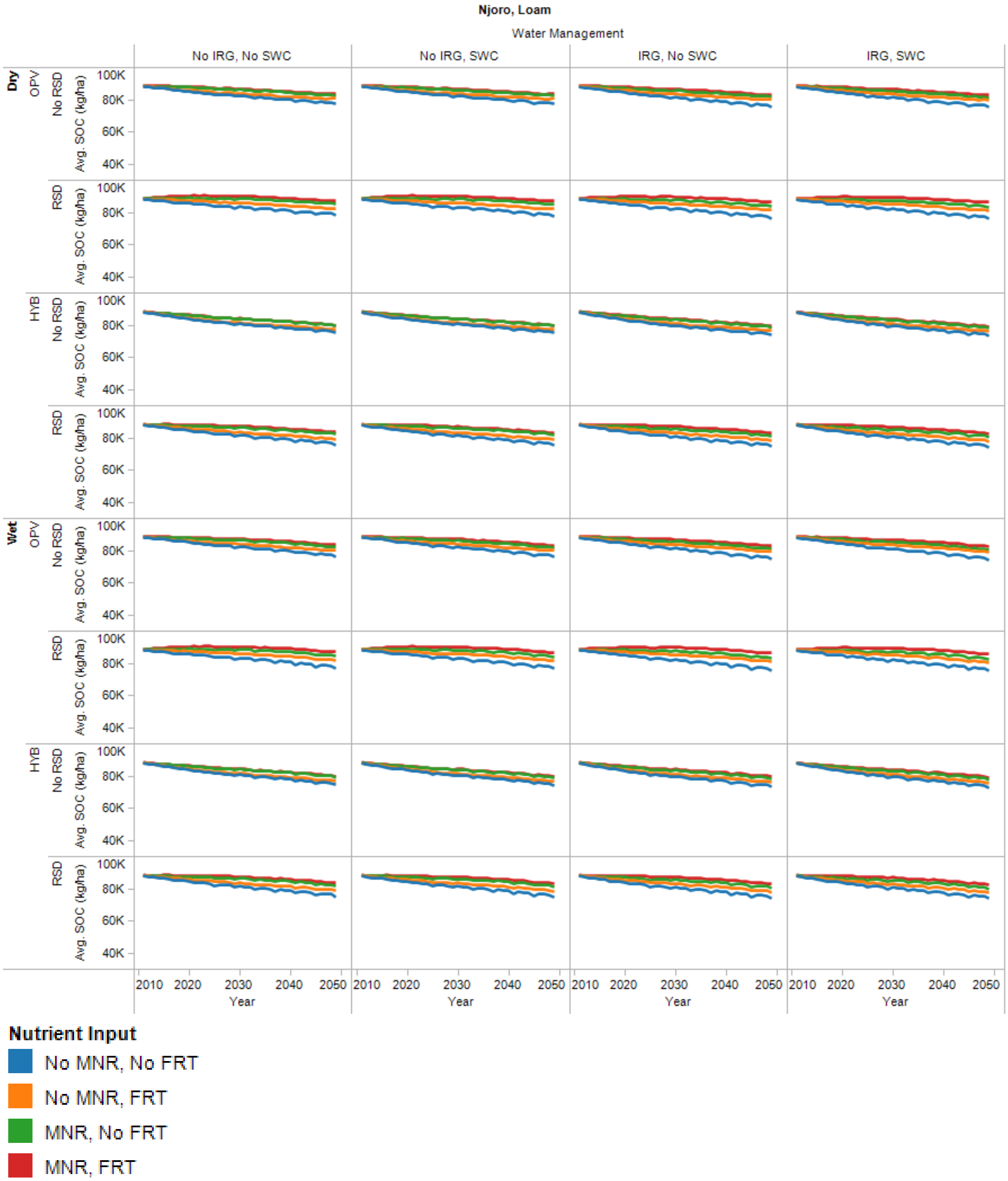
Appendix Figure 1.17 Simulated SOC trend in Mbeere with sandy soil



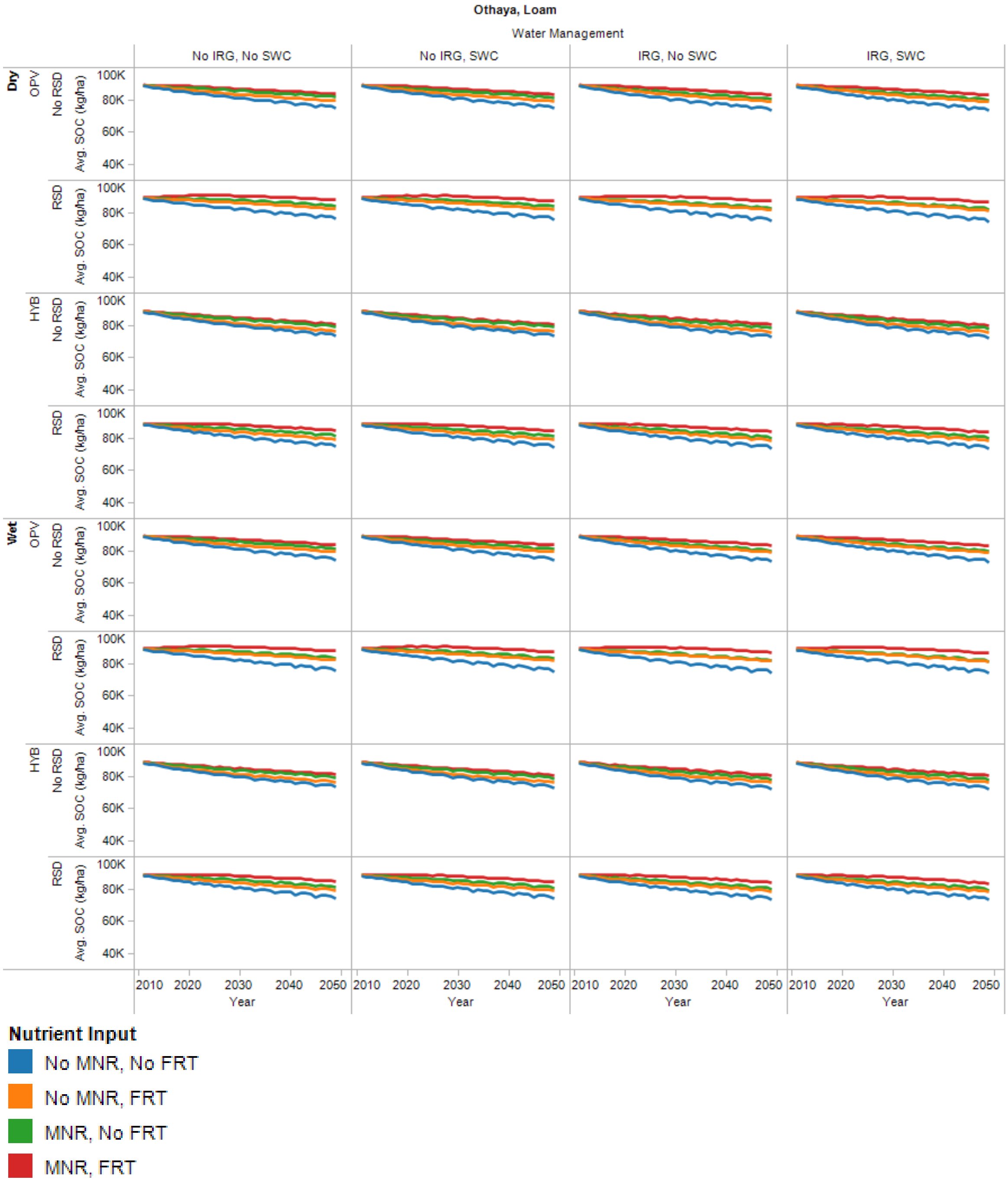
Appendix Figure 1.18 Simulated SOC trend in Mukurwe-ini with loamy soil



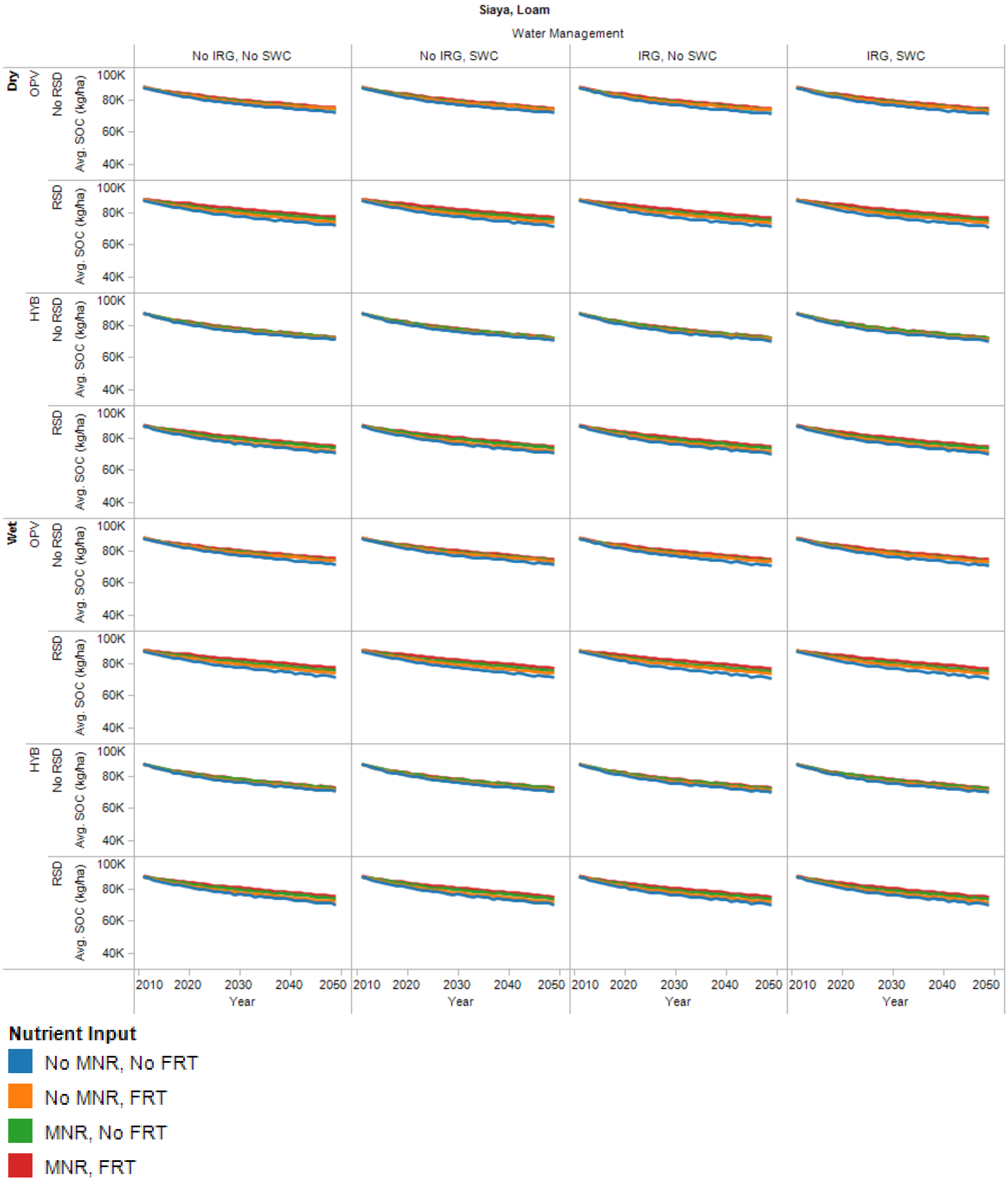
Appendix Figure 1.19 Simulated SOC trend in Njoro with clayey soil



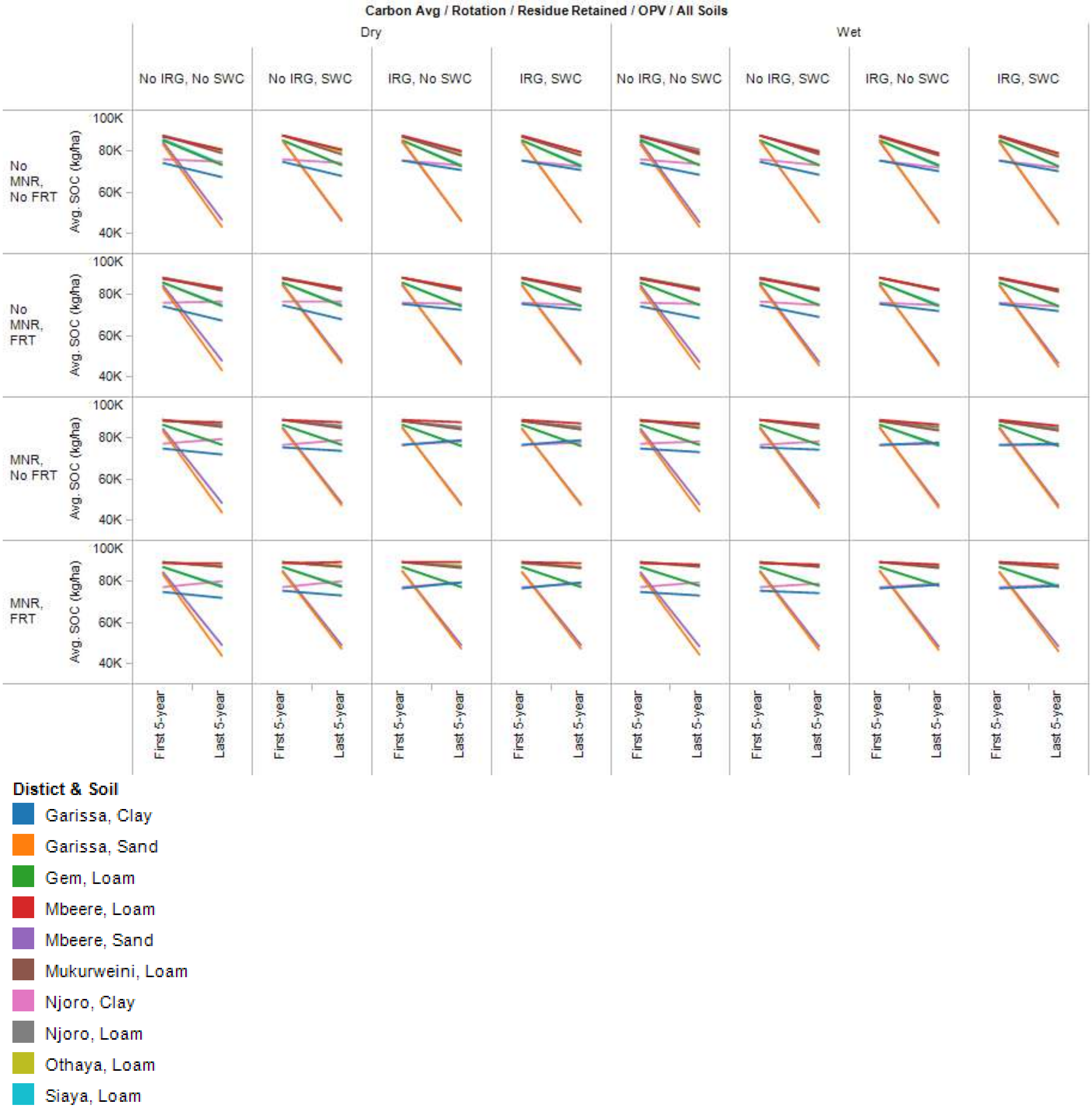
Appendix Figure 1.20 Simulated SOC trend in Njoro with loamy soil



Appendix Figure 1.21 Simulated SOC trend in Othaya with loamy soil



Appendix Figure 1.22 Simulated SOC trend in Siaya with loamy soil



Appendix Figure 1.23 Simulated SOC trend with all soils

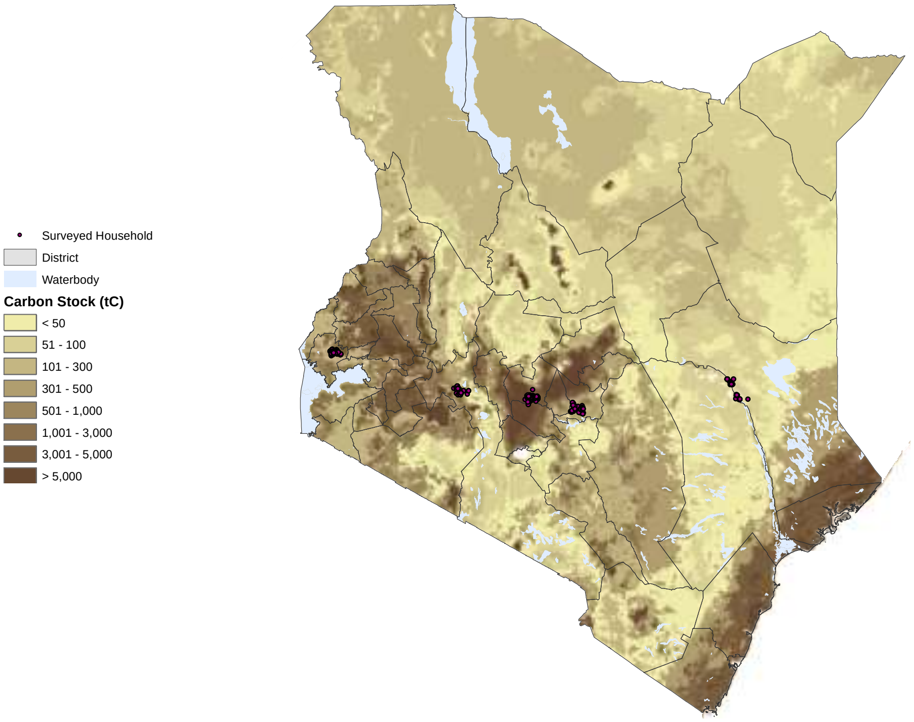
Appendix 1.3: Above ground biomass

A first assessment of the potential of carbon sequestration was implemented by AEZ using the methodology of Baccini et al. (2008) and Goetz et al. (2009) who derived the potential above-ground biomass from satellite imagery. As expected we find that the largest above-ground biomass is located in the humid areas, followed by the semi-humid and semi-arid areas, while the lowest potential is located in the arid areas (Table 6 and Figure 9).

Appendix Table 1.1: Carbon Stocks by AEZ

AEZ	*SUM (tC)*	*AREA (km2)*
Arid	56,655,188	125,391
Humid	107,728,192	25,298
Semi-arid	73,566,304	81,752
Semi-humid to Semi-arid	48,970,072	33,623
Semi-humid	43,697,488	25,882
Sub-humid	64,649,744	26,738
Very Arid	25,376,400	255,147

Appendix Figure 1.24: Estimate of above-ground biostock derived from satellite imagery, Kenya, survey sites and districts



Source: Authors based on Baccini et al. (2008) and Goetz et al. (2009).

Appendix 2: Livestock Feeding Management Practices and Products

Appendix 2.1: Livestock Feeding Practices

Tables 2.1 to 2.7 illustrate the different type of feed provided to cattle, oxen, other cattle, sheep, goat, poultry and pigs in each district during the 1rst dry season, which covers the months from January to February, during the 1rst rain season, which goes from March to May, and during the 2nd rain season starting on October and ending on December.

Appendix Table 2.1: Types of feed provided to cattle, oxen, other cattle, sheep, goat, poultry and pig (number of respondent on 134 interviewed people on Garissa district).

	Other cattle			Sheep			Goat		
	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season
Rangeland(short distance)	6	14	10	2	1		17	19	15
Rangelands(long distance)	13	6	3	1	1	1	13	5	2
Crop lands(specify which crop)	2								
Forest areas	4	6	1	1	1	1	6	12	7
Maize stover							1		1
Legume stover							2		
Sorghum stover									
Millet stover									
Cowpea stover									
Salt									
Crop by products (brans,cakes)	1						1		
Roadside weeds			1			1		2	
Cut and carry fodders								1	2
Hays							1		
Dairy meal									
Maize grains									
Sorghum and millet grains									
Kienyeji mash							17	19	15

Appendix Table 2.2: Types of feed provided to cattle, oxen, other cattle, sheep, goat, poultry and pig (number of respondent on 96 interviewed people on Gem district).

	Cattle			Oxen			Other cattle			Sheep			Goat			Poultry		
	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season
Rangeland(short distance)	2	6	5	2	5	4	16	48	46	3	8	5	6	27	26	19	23	21
Rangelands(long distance)	3	2	2	4	3	2	38	12	12	4	2	3	20	2	3	4		1
Crop lands(specify which crop)	2		1	2		1	10		2			1	1		1	7	7	7
Forest areas	1	1	1	1	2	2	3	3	3				2		1			
Maize stover	5	2	2	4	3	3	33	22	25	2	3	2	3	2	3		1	1
Legume stover	1			1			1	4	1	1	1	1	2	2	2		1	1
Sorghum stover					1	1		1	1		1	1	1	1	1			
Millet stover	1			1			1	1		1								
Cowpea stover																		
Salt		1					2											
Crop by products (brans,cakes)		3					1									2		1
Roadside weeds	1				1	1	3	12	10	1	1		2	2				
Cut and carry fodders	3		2	2	1	1	7	2	2	2	1	1	2	1	1			
Hays	1			2			2			2			2					
Dairy meal																		
Maize grains																38	35	34
Sorghum and millet grains																8	8	7
Kienyeji mash																1	2	2

Appendix Table 2.3: Types of feed provided to cattle, oxen, other cattle, sheep, goat, poultry and pig (number of respondent on 98 interviewed people on Mbeere South district).

	Cattle			Oxen			Other cattle			Sheep			Goat			Poultry		
	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season
Rangeland(short distance)	6	7	5	5	9	8	15	18	16	6	2	4	16	16	13			
Rangelands(long distance)	1	1	1	5	5	5	5	3	4				3	2	2			
Crop lands(specify which crop)													2		1	2	2	2
Forest areas							1	1	1	4			3	3	1			
Maize stover	6		1	12	3	1	29	4	3		2		12	1	1			
Legume stover	1			1			8	1	1				2	2	1	1		
Sorghum stover			1	1			5									2	2	
Millet stover				1			3		1							1	1	
Cowpea stover	1		1	2			5		1					1	1	2	2	1
Salt				1		1	3	1	2									
Crop by products (brans,cakes)							2		2									
Roadside weeds	1	1	1	1	4	4	6	15	12	2	3	2	10	15	13		1	1
Cut and carry fodders	1	1		1	1	2	8	6	5				2	4	4			
Hays	1						1						1	1	2			
Dairy meal							7	5	4				2	1				
Maize grains							1							1		14	13	12
Sorghun and millet grains																3	1	1

Appendix Table 2.4: Types of feed provided to cattle, oxen, other cattle, sheep, goat, poultry and pig (number of respondent on 134 interviewed people on Njoro district)

	Cattle			Other cattle			Sheep			Goat			Poultry		
	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season
Rangeland(short distance)	2		2	6	7	5	16	6	9	3			10	5	6
Rangelands(long distance)				5	3		7	2	3	2			1	1	2
Crop lands(specify which crop)					4	2		2	1				1	2	
Forest areas				1	1		1	1		1					
Maize stover	5	1	2	40	4	16	31	4	13	5			2	2	1
Legume stover				1	11	10	1	7	4		1				
Sorghum stover				1											
Millet stover		2													
Cowpea stover		2													
Salt	2	1	2	7	13	13	4	6		1		1			
Crop by products (brans,cakes)		4		6	3	2	7	3		1			13	7	7
Roadside weeds			1	5	16	14	7	25	17	1	3	3	11	10	3
Cut and carry fodders			3	11	35	30	12	25	23		4	3		2	
Hays	1			15	3	5	7	1	1	2	1				
Dairy meal	1			4	8	8	2	2	2			1		9	9
Maize grains		1			2		1	2					10	7	11
Sorghun and millet grains													1	5	3

Appendix Table 2.5: Types of feed provided to cattle, oxen, other cattle, sheep, goat, poultry and pig (number of respondent on 95 interviewed people on Mukurwe-ini district).

	Cattle			Oxen			Other cattle			Sheep			Goat			Poultry		
	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season
Rangeland(short distance)																		
Rangelands(long distance)																		
Crop lands(specify which crop)		1					1	7	5				1			1	1	1
Forest areas										1							1	
Maize stover	3	4	4	1	2	2	21	20	25		2	1	11	10	6	1		1
Legume stover								5	3				1					
Sorghum stover		1	1					1										
Millet stover																		
Cowpea stover								1										
Salt	1						14	18	22				6	2	4			
Crop by products (brans,cakes)							5	5	5				1	1	1	2	2	2
Roadside weeds	1	1	1				2	4	4				19	6	2			
Cut and carry fodders	2	1	1	1	1	2	14	31	26				11	8	11			
Hays	1	1	2	1			6	4	3				1					
Dairy meal							30	28	24				4					
Maize grains	1			1			14	15	14				9	3	3	11	9	9
Sorghun and millet grains		1					3	4	2				2	3	4	3	5	3

Appendix Table 2.6: Types of feed provided to cattle, oxen, other cattle, sheep, goat, poultry and pig (number of respondent on 88 interviewed people on Othaya district).

	Cattle			Other cattle			Sheep			Goat			Poultry		
	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season
Rangeland(short distance)		1		5	6	4				1	2	1			
Rangelands(long distance)															
Crop lands(specify which crop)				2	2	2			1	1	1	1	1	2	2
Forest areas		1			1	2	2			1					
Maize stover	1			13	19	19		4	3	4	5	7			
Legume stover		1	1	6	9	8			1	1	4	4			
Sorghum stover															
Millet stover				1											
Cowpea stover															
Salt				20	17	12	4	4	3	3	5	5			
Crop by products (brans,cakes)				8	7	6				3	2	2	3	3	2
Roadside weeds				2	3	2	1	1		2	3	1	10		
Cut and carry fodders	2	1	1	20	28	25	3	3	3	7	8	8	3		
Hays				7						2					
Dairy meal				25	19	19				4	3	3		10	10
Maize grains				4	4	4	1							2	3
Sorghun and millet grains													1	1	1

Appendix Table 2.7: Types of feed provided to cattle, oxen, other cattle, sheep, goat, poultry and pig (number of respondent on 96 interviewed people on Siaya district).

	Cattle			Oxen			Other cattle			Sheep			Goat			Poultry		
	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season	1rst Dry season	1rst rainy season	2nd rainy season
Rangeland (short distance)	16	16	11	7	8	4	36	45	34	14	18	14	16	16	10	7	7	8
Rangelands(long distance)	7	6	3	4	4	1	19	16	9	8	7	5	7	7	4	2	2	2
Crop lands(specify which crop)	1			1			5	1	2						1			
Forest areas	2	1		1	2		4	4		2	1		13	12	10			
Maize stover	12	1	7	4	2	5	39	10	21	1	1	6	4	2	7	3	3	3
Legume stover		2			1		1	7	2		5			3				
Sorghum stover			1			1	2		4			2			1			
Millet stover			1			1	1					1			2			
Cowpea stover											1						2	2
Salt							2	3	3									
Crop by products (brans,cakes)	1						2	2	2	1						8	5	19
Roadside weeds	9	10	11	4	3	2	24	25	18	15	12	13	23	20	20			4
Cut and carry fodders	4	4	2				7	7	9			2	1		1			
Hays																		
Dairy meal		1					1	2	2				1	1	1			19
Maize grains							3						16	16	10	17	14	79
Sorghun and millet grains				7	8	4	1	1	1				7	7	4	6	7	21

2.2 Products from livestock

Table 2.8 illustrates the products from livestock. Virtually all households received an income from livestock (i.e. live animal sales, milk sales and sale of other livestock products such as skins, hides and manure). Table 2.8 confirms that in many agro-pastoral systems, the sale or barter of milk (and milk products) is as important as its use for home consumption. Opportunities for milk sales for cattle are related to neighbors, middlemen/trader and market, while milk from camels and goats are primarily sold on the market or consumed by the family.

Appendix Table 2.8: Products from livestock (average and standard error)

		Cattle		**Goats**		**Sheep**		**Camels**	***Slaughtering (meat)***	***Other products***
		Fresh milk (liters)	**Meat (kg)**	**Fresh milk (liters)**	**Meat (kg)**	**Meat (kg)**	**Wool (kg)**	**Fresh milk (liters)**	**Chicken (kg)**	**Eggs (kg)**
Garissa	Amount per one animal	275.6 ± 48.6	10 ± 0	106.8 ± 19.5	8 ± 0	8 ± 0		659.4 ± 260.1		113.3 ± 52.1
	Average per household	720.6 ± 172.6		583.7 ±189.5	24.0 ±16.0	40 ± 0		1585.6 ± 540.2		280.0 ±166.5
Gem	Amount per one animal	548.6 ± 115.3		77.4 ± 6.7					1.5 ± 0.2	41.6 ± 13.1
	Average per household	954.6 ± 217.7		506.9 ± 96.3					3.3 ± 0.9	127.4 ± 41.9
Mbeere South	Amount per one animal	860.0 ± 149.6		165.1 ± 38.7	15 ± 0				4.8 ± 1.9	74.9 ± 29.9
	Average per household	1167.4 ± 207.2		381.6 ± 101.4	15 ± 0				9.8 ± 4.9	275.4 ±109.1
Mukurwe-ini	Amount per one animal	2089.5 ± 231.9		146.7 ± 27.8						233.7 ± 87.7
	Average per household	3023.0 ± 442.5		171.7± 37.8						1233.1 ± 567.1
Njoro	Amount per one animal	1256.8 ± 168.8	150 ± 0	147.3 ± 45.9	8.7 ± 4.1	33.4 ± 10.1	3.2 ± 2.7		4.9 ± 1.2	108.6 ± 20.9
	Average per household	1764.3 ± 247.9		331.6 ± 120.1	18.7 ± 13.4	47.0 ± 11.1			19.7 ± 8.2	555.6 ± 111.5
Othaya	Amount per one animal	2035.1 ± 148.4		522.9 ± 185.0	62.3 ± 43.7				6.6 ± 1.2	330.4 ± 58.5
	Average per household	2682.6 ± 335.7		592.9 ± 190.4	181.3 ±134.4				28.7 ± 7.7	1457.1 ± 281.5
Siaya	Amount per one animal	706.4 ± 97.3	58.0 ± 23.1	200.0 ± 80.0					2.0 ± 0.4	45.7 ± 4.2
	Average per household	1205.8 ± 244.5	70.0 ± 20.5	200.0 ± 80.0					8.0 ± 5.5	166.6 ± 19.8
Total	Amount per one animal	1151.7 ± 66.5	64.3 ± 22.5	134.4 ± 16.6	27.2 ± 15.4	32.2 ± 9.7			4.0 ± 0.6	100.5 ± 11.7
	Average per household	1686.9 ± 117.8	72.9 ± 20.9	486.6 ± 71.3	737 ± 47.5	46.7 ± 10.6			14.7 ± 3.7	440.3 ± 57.4

Appendix 3: Productivity Analysis

Appendix Table 3.1. Mean and variance effects for maize, beans, and coffee

	Maize		Beans		Coffee	
Variable	Mean	Variance	Mean	Variance	Mean	Variance
Area of the plot (ha)	__-0.322***__	__0.284*__	__-0.605***__	0.23	-0.362	1.147
Household size	-0.097	0.288	0.048	-0.048	0.792	-0.637
Education of household head (years)	__0.122*__	__0.346***__	__0.141*__	__0.269**__	__5.238**__	1.336
Gender of plot manager (male)	__0.212*__	0.038	-0.113	0.352	__-3.233**__	__5.558*__
Soil type loam	0.105	__0.786*__	0.086	0.499	__-3.223*__	
Soil type sand	-0.267	0.074	-0.142	0.244		
Slope flat	-0.214	-0.368	0.197	-0.314	__-6.007***__	0.256
Slope moderate	-0.231	-0.423	-0.188	-0.025	__-6.448***__	-0.935
Soil fertility high	__0.300*__	-0.169	__0.535**__	0.377	2.45	-0.156
Soil fertility moderate	0.077	0.029	__0.343***__	0.283	1.003	3.506
Erosion none	-0.162	__1.103**__	0.007	0.641	__4.521**__	-0.289
Erosion mild	0.060	__0.917**__	0.292	0.447	__3.469*__	5.762
Soil bunds	0.170	0.362	0.213	__0.814***__	-0.976	-0.46
Bench terrace					-1.892	0.528
Residues	-0.198	0.561	__-0.288*__	0.346	2.181	-3.001
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		
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
Rainfall season (long)	__0.234***__	-0.295	0.072	0.078		
Mbeere	-0.197	-2.656***	0.077	-3.774***		
Garissa (ALRMP control households)	2.082	0.324				
Garissa (ALRMP households)						
Othaya	-0.093	-4.013***	0.045	-4.501***		
Mukurweini	-0.616*	-3.136***	-0.456	-4.112***		
Siaya	0.059	-4.059***	-0.051	-4.105***		

Gem	0.456*	-4.267***	0.335	-4.372***		
SMS					2.725	-0.246
_cons	3.546***	1.831	3.064***	3.874***	-3.087	-11.593
N	931	929	788	786	53	53

legend: * p<.1; ** p<.05; *** p<.01

Notes: clay is the base category for soil type, low if the base category for soil fertility, steep is the base category for slope, severe is the base category for erosion, Njoro is the base category for site

Appendix Table 3.2. Mean and variance effects for value of production

Variable	**Mean**	**Variance**
Area of the plot (ha)	**0.590*** **	-0.179
Household size	0.088	0.038
Education of household head (years)	0.083	**0.473*** **
Gender of plot manager (male)	0.067	0.215
Soil type loam	**0.338** **	**1.157** **
Soil type sand	0.173	0.141
Slope flat	-0.002	-0.43
Slope moderate	**-0.323* **	**-0.614* **
Soil fertility high	**0.562*** **	-0.075
Soil fertility moderate	0.153	-0.043
Erosion none	0.051	**0.928** **
Erosion mild	0.249	0.536
Soil bunds	-0.172	0.256
Residues	-0.087	0.117
Grass strips	-0.176	-0.374
Ridge and furrow	-0.049	0.304
Rotation/fallowing	0.102	0
Soil bunds*grass strips	0.23	0.357
Soil bunds*residues	0.102	-0.439
Intercropped plot	**-0.384*** **	-0.188
Amount own seed	**0.221*** **	**-0.362*** **
Amount purchased seed	**0.220*** **	-0.081
Improved seed variety	0.068	**-0.623** **
Labor	**0.180*** **	**0.261* **
Animal draft power	0.027	-0.011
N fertilizer	-0.066	-0.099
P fertilizer	**0.111** **	-0.05
K fertilizer	**-0.041* **	0.078
Rainfall season (long)	**0.213*** **	-0.143
Mbeere	-0.196	-4.372***
Garissa (ALRMP control households)	1.816***	-4.417***
Garissa (ALRMP households)	2.728***	-3.752***
Othaya	0.602**	-5.104***
Mukurweini	-0.253	-4.712***
Siaya	-0.058	-4.996***
Gem	0.604**	-5.092***
_cons	6.939***	3.756***
N	1376	1376

legend: * p<.1; ** p<.05; *** p<.01

Notes: clay is the base category for soil type, low if the base category for soil fertility, steep is the base category for slope, severe is the base category for erosion, Njoro is the base category for site

Appendix 4: Differences in Land Management Practices in Program and Control Sites (seasonal and perennial crops)

Appendix Table 4.1: Seasonal crops

	ALRMP	**ALRMP Control**	**Diff.**	**P value**	**ALRMP**	**ALRMP Control**	**Diff.**	**P value**	**SMS**	**SMS Control**	**Diff.**	**P value**	**Vi Agro-forestry**	**Vi Agro-forestry Control**	**Diff.**	**P value**
Land management practices	**Garissa (18)**	**Garissa (19)**			**Mbeere South (621)**	**Njoro (221)**			**Mukurwe-ini (321)**	**Othaya (270)**			**Gem (428)**	**Siaya (366)**		
Soil bunds	0.00	0.00	0.00		**45.41**	**3.17**	**42.24**	**0.00**	14.33	14.07	0.26	0.93	**28.27**	**16.12**	**12.15**	**0.00**
Residues	0.00	10.53	-10.53	0.17	**10.79**	**19.00**	**-8.22**	**0.00**	3.43	4.07	-0.65	0.68	**28.74**	**19.67**	**9.07**	**0.00**
Grass strips	0.00	0.00	0.00		**19.32**	**11.76**	**7.56**	**0.01**	**1.08**	**15.56**	**-14.48**	**0.02**	**14.25**	**5.74**	**8.51**	**0.00**
Ridge and furrow	55.56	31.58	23.98	0.15	1.93	1.36	0.57	0.58	**17.13**	**2.59**	**14.54**	**0.00**	10.05	11.20	-1.16	0.60
Rotation/fallowing	0.00	5.26	-5.26	0.34	**14.98**	**9.50**	**5.47**	**0.04**	**12.15**	**6.30**	**5.85**	**0.02**	**18.22**	**10.11**	**8.12**	**0.00**
Intercropping	5.56	0.00	5.56	0.31	**25.60**	**61.99**	**-36.39**	**0.00**	65.73	65.56	0.18	0.96	**72.66**	**67.21**	**5.45**	**0.09**
Inorganic fertilizer	0.00	5.26	-5.26	0.34	**26.09**	**36.20**	**-10.11**	**0.00**	76.32	75.93	0.40	0.91	**35.98**	**43.72**	**-7.73**	**0.03**
Manure	**27.78**	**57.89**	**-30.12**	**0.07**	23.35	27.15	-3.80	0.26	61.68	64.81	-3.13	0.43	36.21	37.43	-1.22	0.72
Compost	0.00	0.00	0.00		0.97	0.90	0.06	0.94	3.43	2.59	0.83	0.56	1.87	1.37	0.50	0.58

Appendix Table 4.2: Perennial crops

Land management practices	**ALRMP**	**ALRMP Control**	**Diff.**	**P value**	**ALRMP**	**ALRMP Control**	**Diff.**	**P value**	**SMS**	**SMS Control**	**Diff.**	**P value**	**Vi Agro-forestry**	**Vi Agro-forestry Control**	**Diff.**	**P value**
	Garissa (29)	**Garissa (28)**			**Mbeere South (81)**	**Njoro (83)**			**Mukurwe-ini (270)**	**Othaya (269)**			**Gem (225)**	**Siaya (168)**		
Soil bunds	0.00	0.00	0.00		**39.51**	**1.20**	**38.30**	**0.00**	11.11	8.18	2.93	0.25	**24.44**	**13.69**	**10.75**	**0.01**
Bench terrace	0.00	0.00	0.00		1.23	0.00	1.23	0.31	29.26	24.16	5.10	0.18	**0.89**	**3.57**	**-2.68**	**0.06**
Residues	13.79	10.71	3.08	0.73	8.64	15.66	-7.02	0.17	5.56	4.83	0.72	0.71	16.89	11.31	5.58	0.12
Grass strips	0.00	0.00	0.00		**24.69**	**9.64**	**15.05**	**0.01**	8.89	9.67	-0.78	0.76	**16.89**	**3.57**	**13.32**	**0.00**
Ridge and furrow	17.24	25.00	-7.76	0.48	**6.17**	**0.00**	**6.17**	**0.02**	2.59	1.12	1.48	0.20	4.89	5.95	-1.06	0.64
Minimum tillage	3.45	0.00	3.45	0.33	3.70	2.41	1.29	0.63	4.07	6.69	-2.62	0.18	2.67	0.60	2.07	0.13
Intercropping	**24.14**	**0.00**	**24.14**	**0.00**	**34.57**	**50.60**	**-16.03**	**0.04**	**27.78**	**21.56**	**6.22**	**0.09**	62.67	55.95	6.71	0.18
Inorganic fertilizer	0.00	0.00	0.00		0.00	0.00	0.00		**10.74**	**20.07**	**-9.33**	**0.00**	0.00	0.00	0.00	
Manure	34.48	21.43	13.05	0.28	24.69	15.66	9.03	0.15	**8.89**	**15.99**	**-7.10**	**0.01**	4.44	5.36	-0.91	0.68
Compost	0.00	0.00	0.00		**3.70**	**0.00**	**3.70**	**0.08**	1.11	0.37	0.74	0.32	0.00	0.00	0.00	

Appendix 5: Profitability Analysis

Appendix 5.1: Costs and Benefits of Cropland Management Practices by AEZ and soil type

The tables below provide details on the costs and benefits of alternative management packages for each AEZ-soil type combination. The below results are for packages containing 50 percent residues. As was mentioned in the report above, we assume a price of US$ 10 per tCO_2 and a price of US$ 0.375 per kg of maize to calculate revenues from soil carbon sequestration and maize yields.

Appendix Table 5.1: Net revenues from soil carbon sequestration and maize yield improvements in arid areas with clayey soils

	RES50	RES50, FERT & MNR	RES50, FERT, MNR, SWC & ROT	FRT, MNR, RES50, SWC, ROT, & IRG
Revenues from SCS	1	9	15	24
Revenues from yield improvements	6	150	356	1651
Total additional revenues	7	159	371	1675
Difference in labor costs	65	24	24	-109
Fertilizer costs		-158	-158	-158
Construction, operation, and maintenance costs			-20	-95
Replacement feed cost	-87	-75	-58	
Manure cost		-138	-138	-138
Total additional costs	-23	-346	-349	-500
Total net revenues	-15	-187	22	1175

Appendix Table 5.2: Net revenues from soil carbon sequestration and maize yield improvements in arid areas with sandy soils

	RES50	RES50, FERT & MNR	RES50, FERT, MNR, SWC & ROT	FRT, MNR, RES50, SWC, ROT, & IRG
Revenues from SCS	1	2	10	8
Revenues from yield improvements	18	94	537	1392
Total additional revenues	19	96	547	1400
Difference in labor costs	65	24	24	-109
Fertilizer costs		-158	-158	-158
Construction, operation, and maintenance costs			-20	-95
Replacement feed cost	-48	-44	-4	
Manure cost		-138	-138	-138
Total additional costs	17	-315	-296	-500
Total net revenues	35	-219	251	900

Appendix Table 5.3: Net revenues from soil carbon sequestration and maize yield improvements in semi-arid areas with loamy soils

	RES50	RES50, FERT & MNR	RES50, FERT, MNR, SWC & ROT	FRT, MNR, RES50, SWC, ROT, & IRG
Revenues from SCS	2	22	22	21
Revenues from yield improvements	150	1181	1364	1522
Total additional revenues	152	1203	1385	1544
Difference in labor costs	65	24	24	-109
Fertilizer costs		-158	-158	-158
Construction, operation, and maintenance costs			-20	-95
Replacement feed cost	-37			
Manure cost		-138	-138	-138
Total additional costs	28	-271	-291	-500
Total net revenues	180	932	1094	1044

Appendix Table 5.4: Net revenues from soil carbon sequestration and maize yield improvements in semi-arid areas with sandy soils

	RES50	RES50, FERT & MNR	RES50, FERT, MNR, SWC & ROT	FRT, MNR, RES50, SWC, ROT, & IRG
Revenues from SCS	2	8	6	5
Revenues from yield improvements	71	502	600	661
Total additional revenues	73	510	606	667
Difference in labor costs	65	24	24	-109
Fertilizer costs		-158	-158	-158
Construction, operation, and maintenance costs			-20	-95
Replacement feed cost	-20			
Manure cost		-138	-138	-138
Total additional costs	45	-271	-291	-500
Total net revenues	118	238	315	167

Appendix Table 5.5: Net revenues from soil carbon sequestration and maize yield improvements in semi-arid areas with clayey soils

	RES50	RES50, FERT & MNR	RES50, FERT, MNR, SWC & ROT	FRT, MNR, RES50, SWC, ROT, & IRG
Revenues from SCS	2	19	19	17
Revenues from yield improvements	256	1921	2236	2337
Total additional revenues	258	1941	2255	2355
Difference in labor costs	65	24	24	-109
Fertilizer costs		-158	-158	-158
Construction, operation, and maintenance costs			-20	-95
Replacement feed cost	-46			
Manure cost		-138	-138	-138
Total additional costs	19	-271	-291	-500
Total net revenues	212	1645	1939	1964

Appendix Table 5.6: Net revenues from soil carbon sequestration and maize yield improvements in temperate areas with loamy soils

	RES50	RES50, FERT & MNR	RES50, FERT, MNR, SWC & ROT	FRT, MNR, RES50, SWC, ROT, & IRG
Revenues from SCS	2	24	23	22
Revenues from yield improvements	-3	1087	1201	1236
Total additional revenues	-1	1111	1224	1258
Difference in labor costs	65	24	24	-109
Fertilizer costs		-158	-158	-158
Construction, operation, and maintenance costs			-20	-95
Replacement feed cost	-49			
Manure cost		-138	-138	-138
Total additional costs	15	-271	-291	-500
Total net revenues	14	840	933	758

Appendix Table 5.7: Net revenues from soil carbon sequestration and maize yield improvements in humid areas with loamy soils

	RES50	RES50, FERT & MNR	RES50, FERT, MNR, SWC & ROT	FRT, MNR, RES50, SWC, ROT, & IRG
Revenues from SCS	0	13	12	11
Revenues from yield improvements	71	1702	1804	1561
Total additional revenues	71	1715	1816	1572
Difference in labor costs	65	24	24	-109
Fertilizer costs		-158	-158	-158
Construction, operation, and maintenance costs			-20	-95
Replacement feed cost	-20			
Manure cost		-138	-138	-138
Total additional costs	45	-271	-291	-500
Total net revenues	116	1444	1525	1072

Appendix 5.2: Profitability of improved livestock feeding practices

Appendix Table 5.8 illustrates the cost of management, feed, and other general costs associated with livestock. Most of the activities are performed by the owner while others are delegated to professional support such as veterinary treatment (e.g. tick removal, tsetse fly protection and supply of medicine). Appendix Table 5.9 shows the feed prices used to calculate the profitability of alternative feeding practices.

Appendix Table 5.8: Costs of livestock management

Livestock	**Management (care) costs**							**Other costs**				
	Watering	**Feeding**	**Herding**	**Veterinary treatment,[a]**	**Housing**	**Grazing**	**Breeding**	**Buildings**	**Electricity**	**Tools**	**Machinery**	**Veterinary**
Cattle	258.3 ± 49.3	301.7 ± 57.4	317.1 ± 85.0	76.8 ± 19.9	276.0 ± 76.0	377.0 ± 125.9	136.3 ± 50.0	90.7 ± 23.8	41.2 ± 28.5	13.5 ± 3.2	41.1 ± 16.2	19.8 ± 3.9
Goats	370.3 ± 99.9	357.4 ± 116.3	396.6 ± 113.7	216.4 ± 74.9	392.5 ± 124.0	613.3 ± 231.7	614.2 ± 285.8	91.3 ± 46.5		19.2 ± 9.8		16.9 ± 3.6
Oxen												18.3 ± 19.9
Sheep	356.9 ± 192.8	389.5 ± 208.2	421.0 ± 227.5	94.9 ± 56.0	274.1 ± 157.6	367.1 ± 210.9	359.4 ± 235.1	81.7 ± 58.6		12.8 ± 5.7		27.8 ± 3.8
Pigs								19.3 ± 5.3		20.1 ± 6.7		11.0 ± 12.5
Poultry	113.3 ± 32.5	128.2 ± 31.2		356.9 ± 192.8				24.4 ± 3.9	137.4 ± 130.7	18.2 ± 12.7		67.0 ± 3.5

[a] tick removal, tsetse fly protection, medicine

Appendix Table 5.9: Feed prices used to calculate profitability of alternative feeding practices

Feed	Cost per kg (USD)
Prosopis	0.09
Napier grass	0.05
Hay	0.15
Desmodium	0.08
Cut and carry fodder	0.15
Grain supplements	0.2
Maize stover	0.2

Sources: Ben Lukuyu personal communication; Lukuyu et al. 2009; Nyanga et al. 2009.