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Towards a Cropping System Sustainability Tool (CROSST)

Pilot results from evaluating green manure cover crops in Benin and Kenya

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Towards a Cropping System Sustainability Tool (CROSST)

Pilot results from evaluating green manure cover crops in Benin and Kenya

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Acronyms and abbreviations

BMZ	German Federal Ministry for Economic Cooperation and Development
CIAT	International Center for Tropical Agriculture
CROSST	Cropping Systems Assessment Sustainability Tool
GDP	gross domestic product
GIZ	Gesellschaft für Internationale Zusammenarbeit
GMCC	green manure cover crops
N	nitrogen
P	phosphorus
SEWOH	One World - No Hunger
SI	sustainable Intensification
SIAF	Sustainable Intensification Assessment Framework
SOM	soil organic matter

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Photo: CIAT/Georgina Smith

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Abstract

Farming practices in sub-Saharan Africa have resulted in declining soil fertility. Hence, Green Manure Cover Crops (GMCC) are promoted for soil improvement and protection. Adoption of GMCCs by farmers, including integration in their cropping systems, requires a good understanding of the multi-dimensional impacts of these crops. We, therefore, developed the Cropping Systems Assessment Sustainability Tool (CROSST), which can compare the performance of different cropping systems with and without the integration of GMCCs. CROSST is an Excel-based tool that assesses both agro-environmental and socio-economic impacts of GMCC technologies. The tool quantifies gross economic margin, productivity (yield), soil health (N and P balances, soil structure, and soil organic carbon), required labour hours, and the trade-offs between these indicators. The tool was pilot-tested in Benin and Kenya under the BMZ-GIZ program on 'Soil Protection and Rehabilitation for Food Security.' Data was collected through literature reviews, focus group discussions and key expert interviews. The compared cropping systems were selected and designed by experts with in-depth knowledge on local contexts of Benin and Western Kenya. The first results indicate that GMCCs improve soil structure/soil organic matter as well as soil N balances in both countries. However, investing in soil improvement can result in loss of profitability, especially when a crop that produces grain for consumption or sale is swapped for a GMCC that produces biomass for soil amendment only. CROSST still needs further data refinement with recent official census as well as independent field measurements. Once validated, it can serve as a decision-support tool for development agencies, implementing partners, and local stakeholders when designing sustainable cropping systems that integrate GMCCs.

Photo: CIAT/Georgina Smith

1 Introduction

Soil degradation poses a serious threat to food production and rural livelihoods in sub-Saharan Africa (Bindraban et al., 2012; Gomiero, 2016; Obalum et al., 2012). Unsustainable agricultural practices have resulted in declining soil fertility due to nutrient depletion – especially nitrogen (N) and phosphorous (P) deficiencies – wind and water erosion, and eventually declining agricultural productivity (Dessie and Mohammed, 2017).

The BMZ Special Initiative 'One World - No Hunger' (SEWOH) addresses some of the greatest challenges facing humanity today. The SEWOH goal is to make a significant contribution to increasing food security by reducing hunger and poverty with a focus on rural development and modernization of agriculture (Mulindabigwi, 2015). SEWOH comprises a range of global programs, which are implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in ten countries. One of the global programs is the Global Program on Soil Protection and Rehabilitation for Food Security, which operates in Benin, Burkina Faso, Ethiopia, Kenya, and India. It aims to support partner countries with the broad-scale implementation of field-tested approaches for soil conservation and rehabilitating degraded soil. At the same time, the aim is to improve the policy-making framework with a view to establishing incentives for sustainable soil use. To support these activities, the program supports exchange and dissemination of lessons learned from partner countries on a systematic basis. Green Manure Cover Crops (GMCC) are part of the portfolio of technologies that are promoted for soil protection and improvement, especially in Kenya and Benin.

GMCCs are crops that protect soil from wind and water erosion, suppress weeds, fix atmospheric nitrogen, scavenge soil nitrogen, build soil structure, reduce surface crusting, improve water infiltration, break hardpan, improve soil/water quality and reduce insect pests (Cherr et al., 2006). Benefits from these crops depend on biomass productivity before the soil is prepared for the next crop (Florentín et al., 2010). When cover crops are buried and tilled into the soil, the green manure that is added enhances soil fertility and structure by feeding soil microbial populations and which also glue together soil particles to form soil aggregates (Cherr et al., 2006; Florentín et al., 2010). When plant material is decomposed by soil microbes, they break down and release nitrogen and other nutrients to the soil. Nitrogen accumulation and release are greater with legumes, which have nitrogen-fixing bacteria in their roots (Giller, 2003).

An assessment framework and tool is needed that can systematically compare existing with novel cropping systems along agro-economic and environmental performance (Cherr et al., 2006). Fertilization, nitrogen mineralization, and eventual crop yield are all affected not only by the management of the individual crops but also by long-term processes that are influenced by crop sequence and the interaction between different crops (Baddeley et al., 2017; Reckling et al., 2016a). Furthermore, sustainable intensification (SI) has become an important paradigm that aims to improve productivity while ensuring environmental sustainability. More food, fiber, and fodder should be produced with fewer resources – for example, by increasing yields per unit of land, water, or fertilizer (Descheemaeker et al., 2016; Falconnier et al., 2017; Giller et al., 2011). To better support farmers and offer a basket of solutions, it is important to be able to analyze agro-environmental trade-offs and synergies in different cropping systems and better understand how farmers assess profits, soil health, and other biophysical and environmental factors (Descheemaeker et al., 2016).

In this study, we present the Cropping System Sustainability Tool (CROSST) that we developed to better understand agro-environmental and socio-economic impacts and trade-offs of GMCC integration in cropping systems. We applied CROSST to selected GIZ intervention areas in Kenya and Benin to illustrate its functionalities with pilot results from the same areas. In the future, CROSST could be further developed and validated to serve as a decision-making support tool for the GIZ soil program, implementing partners, and local stakeholders when considering to integrate GMCCs into cropping systems.

2 Materials and methods

2.1 Conceptual approach

When developing CROSST, we adopted principles from the static rule-based framework developed by Reckling et al. (2016b) that was applied to selected countries in Europe. These included:

(i) Generating crop rotations (using experts' knowledge)

(ii) Selecting agronomic, environmental, and socio-economic parameters

(iii) Assessing and comparing cropping systems with and without green manure cover crops

CROSST was further inspired by the Sustainable Intensification Assessment Framework (SIAF) of Musumba et al. (2017). SIAF comprises five domains of sustainability: social, economic, productivity, human condition, and environment. CROSST can assess the following seven indicators (Figure 1) that fall under the social, economic, productivity, and environmental sustainability domains:

Gross margins	USD/ha	
Labor hours	h/ha	
N balance	kgN/ha	
P balance	kgP/ha	
Yield1 / **Yield2**	kgDM/ha	
Biomass1 / **Biomass2**	kgDM/ha	
Soil organic matter (SOM) /Soil structure	Rank	negative effects – positive effects

Figure 1 CROSST indicators

2.2 Crops, areas, parameters and data collection

Crops and agro-ecological zones for each country were defined during an expert workshop in April 2018 in Nairobi (Table 1). One of the goals of the workshop was to agree on crops and agro-ecological zones the tool should work for, and agree on the indicators of research interest (CIAT, 2018a, 2018b, 2018c).

Table 1 Agro-ecological zones and crops chosen for CROSST in Benin and Kenya

COUNTRY	REGION OF INTEREST	MAIN CROPS	GMCCs
Benin	Different areas of Benin: Sudanian 1, Sudanian 2, Sudano-guinean on ferruginous soils, Sudano-guinean on ferralitic soils	Cotton, maize, yam	Mucuna, pigeon pea, cowpea
Kenya	Western Kenya: lower midlands, midlands, upper midlands	Maize, beans, sweet potatoes	Mucuna, lablab, Canavalia

A parameter can be defined as a characteristic that can help in defining or classifying a particular system (Voinov and Bousquet, 2010). To assess the cropping system, we broke down a system into agronomic, environmental, and socio-economic parameters, which were chosen based on the indicators of interest (Figure 1).

Regarding indicators, gross margin looks at the profit the farmer makes when taking into account the input costs such as seeds, pesticide, fertilizers. The cost of labor and the cost of biomass was set to zero in this study. A positive cash flow indicates that the farmer is making profits, a negative margin means the farmer is making losses. Yield1/2 and Biomass1/2 show much grain and crop residue is being produced, an indicator of how productive the land is. For N/P balance, a negative number indicates that N/P is being mined from the soil, and a positive balance indicates accumulation. For the SOM/soil structure scoring the red represents negative effects and loss of soil structure and SOM and green means there is a positive effect on SOM and soil structure.

The data tables containing all the parameters used and the equations can be found in Mukiri et al. (2019).

Table 2 Data tables, parameters and equations

DATA TABLES	PARAMETERS	EQUATION NUMBER (TECHNICAL DOCUMENT)	INDICATOR
Agro-ecological information	Rainfall amount (mm/yr)	16	N
	Nmin (mg/kg)	16	N
	SoilC g/kg	16	N
	Clay %	16	N
	Seasons per year No.	16	N & P
Agronomic information	Grain yield (lower and upper ranges) kg/ha	1, 14	Yield, Biomass, N, P, Gross margin
	Agriculture classification (cereal, cover crop, tuber, fibre, legume, fallow)	30	Yield, Biomass, N, P, Gross margin
	Harvest index	2, 3	Biomass
	N-concentration in grain g/100g	16	N
	N-concentration in stover g/100g	16	N
	N-fixation rate %	16	N
	P-concentration in grain g/100g	16	P
	P-concentration in stover g/100g	28	P
	SOM scoring + Soil structure ranking	28	SOM

DATA TABLES	PARAMETERS	EQUATION NUMBER (TECHNICAL DOCUMENT)	INDICATOR
Yield change of variations of cropping systems	Yield change %	29	Yield, Biomass, N, P, Gross margin
	Stover yield change %	29	Yield, Biomass, N, P, Gross margin
Labor	Ploughing (h/ha)	10	Labor
	Planting (h/ha)	10	Labor
	Fertilizing (h/ha)	10	Labor
	Manure application (h/ha)	10	Labor
	Residue management (h/ha)	10	Labor
	Weeding (h/ha)	10	Labor
	Spraying chemicals (h/ha)	10	Labor
	Harvest (h/ha)	10	Labor
	Post-harvest (h/ha)	10	Labor
Inputs	Seed 1 (kg/ha)	9	Gross margin
	Seed 2 (kg/ha)	9	Gross margin
	Herbicide type	9	Gross margin
	Herbicide amount (ltrs/ha)	9	Gross margin
	Pesticide type	9	Gross margin
	Pesticide amount (ltrs/ha)	9	Gross margin
Costs / prices	Fertilizers	9	Gross margin
	N content (%)	16	N
	Price (USD/kg)	9	Gross margin
	P content (%)	16	N

A mix of literature review, focus group discussions, expert opinion, and GIZ monitoring and evaluation database was used to populate the CROSST parameters. The data can be found in the supplementary technical document (Mukiri et al., 2019).

2.3 CROSST design and implementation

CROSST was developed in Microsoft Excel (Version Professional Plus 2016) using Visual Basic for Application (VBA) programming code. The source code used to build the model can be found at https://github.com/JENMukiri/GMCC. It is a static model that captures the aggregated annual effects of certain cropping systems over three years (or six seasons). The output of the tool consists of bar graphs, trade-off graphs, and relative scores. CROSST is composed of an input sheet, an output sheet, and nine parameter and calculation sheets.

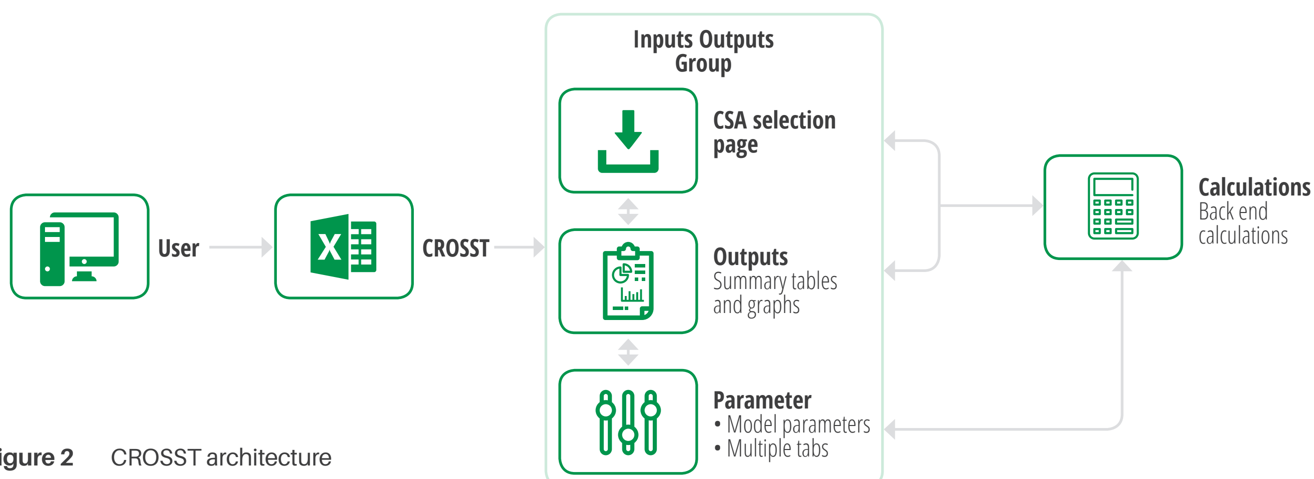

Figure 2 CROSST architecture

- The first sheet name “CSA selection page” is where the users choose the cropping system they want to analyze as well as input data required.
- The second sheet name “Outputs” gives a summary of all the results.
- The third sheet until the eleventh sheet are the parameter and calculation sheets. They are hidden sheets and are only to be accessed by more advanced users e.g. for improving information for crop production in a certain region.

2.4 Cropping systems

For each country and zone, one conventional system was compared to one improved integrated GMCC system to illustrate the functioning of the tool. Data was collected through key expert interviews, literature review, and focus group discussions.

2.4.1 Benin

Benin covers an area of 112,276 square kilometers, of which 32.8% is used for agriculture (FAO et al., 2018).The agricultural sector contributes over 25% to the countries total gross domestic product (GDP) (FAO et al., 2018). The main crops produced in Benin include maize, beans, rice, peanuts, cashews, pineapples, cassava, yams, other tubers, and vegetables and fruits, which are grown for local subsistence and for sale (FAO et al., 2018). Cotton is an important cash crop for export. Other exported crops include cashews, shea nuts and shea butter, pineapples, palm products, and smaller amounts of cocoa and coffee (FAO et al., 2018). The GIZ program ProSOL is currently working in four zones: Alibori and Borgou in the North, and Collines and Zou in the South (Figures 3 and 4). These departments were chosen because of the high level of soil degradation (ProSOL, 2016).

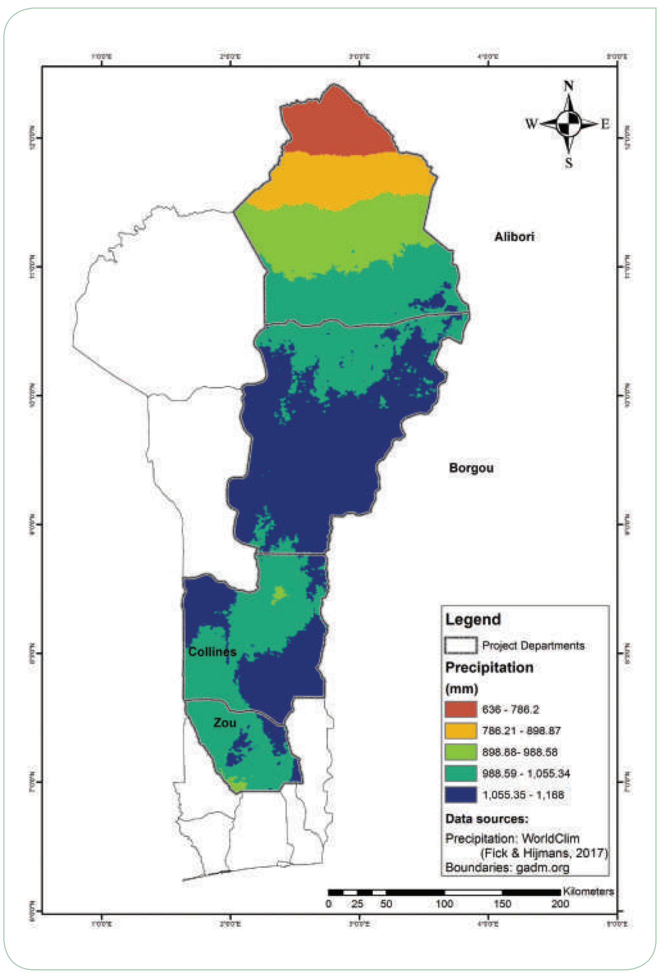

Figure 3 Map of Benin, showing rainfall of the target regions

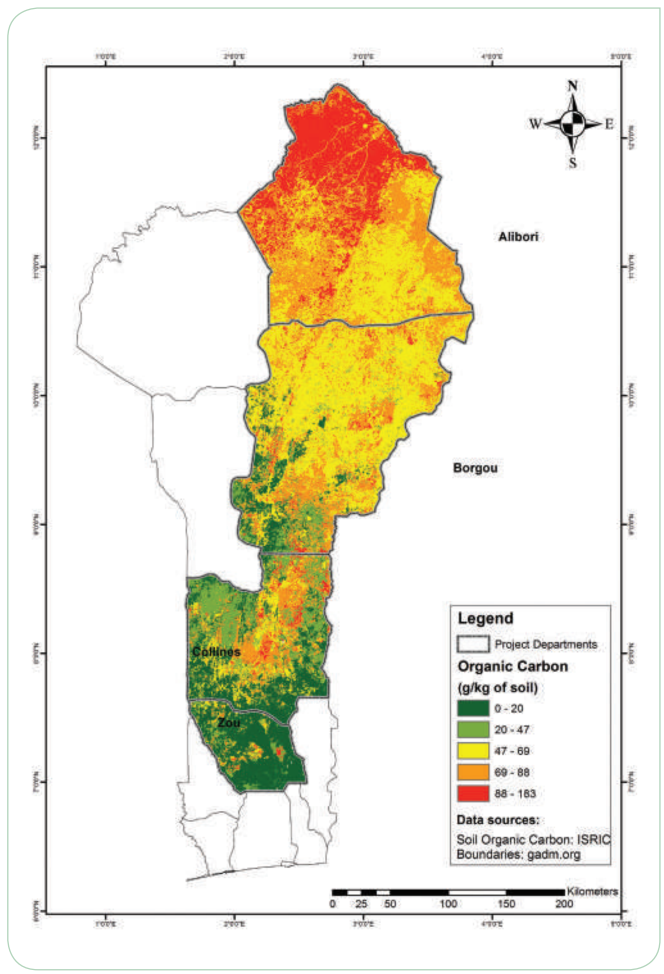

Figure 4 Map of Benin, showing soil organic carbon

Figure 5 Cotton monoculture in the North (photo by: CIAT/Rein van der Hoek).

Alibori (Sudanian zone 1)

Located in the North of Benin, this region has one cropping season a year with annual rainfall of 800 mm. The farming system is mixed crop-livestock, and the farm sizes on average are 5–7 ha (CIAT, 2018a, 2018b, 2018c). Soils are tropical ferruginous on crystalline base, with a high proportion of leached soils and low concretions. Cotton is an important cash crop in the region (CIAT, 2018a, 2018b, 2018c).

During site visits and focus group discussions with farmers in the area, loss of soil fertility was classified as a problem that has been getting worse (CIAT, 2018a, 2018b, 2018c). The conventional practice is cotton mono-cropping with soybean rotation, including burning of crop residues and the application of mineral fertilizers at a rate of 150 kg of fertilizer per hectare of NPK (14-23-14) (Table 3, Figure 5). The cotton market is well developed and farmers usually receive inputs, such as fertilizers and seeds from factories. The costs of these inputs are recovered when the farmers are paid by the factories (CIAT, 2018a, 2018b, 2018c).

For the GMCC practice scenario, we did not burn any of the crop residues, we also applied NPK (15-15-15) to the cotton crop at a rate of 150 kg per ha. These scenarios are represented in Appendix: Cropping Systems Assessed.

Table 3 Conventional practice vs GMCC practice in Alibori as modeled with CROSST

SEASON	CONVENTIONAL PRACTICE	GMCC PRACTICE
1	Cotton	Cotton
2	Cotton	Mucuna
3	Cotton	Cotton
4	Soybean	Mucuna
5	Cotton	Cotton
6	Cotton	Mucuna

Figure 6 Example of maize/pigeon pea intercrop in the North (photo by: CIAT/Rein van der Hoek).

Bourgou

Borgou is also located in the North and, just as Alibori, there is only one cropping season a year and farmers keep both livestock and crops. This area receives more rainfall than Alibori at 900–1000 mm annually (CIAT, 2018a, 2018b, 2018c). The farm size and the crops of importance are similar to Alibori. Soils are tropical ferruginous with high variability and average fertility. The soils here are sensitive to leaching. Maize is an important crop for food consumption (CIAT, 2018a, 2018b, 2018c). The conventional practice was defined as maize/cotton rotation with residue burning and high fertilizer application of 150 kg per ha for the cotton and 200 kg for maize per ha, while the GMCC cropping system included Mucuna and pigeon pea rotations and intercrops without residue burning and only cotton received fertilizer at 150 kg per ha (Table 4; Figure 6). These scenarios are represented in Appendix: Cropping Systems Assessed.

Table 4 Conventional practice vs GMCC practice in Borgou

SEASON	CONVENTIONAL PRACTICE	GMCC PRACTICE
1	Maize	Mucuna
2	Cotton	Cotton
3	Maize	Maize/Pigeon Pea
4	Cotton	Maize/Pigeon Pea
5	Maize	Residue Pigeon Pea + Cotton
6	Cotton	Maize

Figure 7 Conventional farmer practice in the South of Benin (photo by: CIAT/Jessica Mukiri).

Collines

Collines is located in the south of Benin, where only few livestock are kept (CIAT, 2018a, 2018b, 2018c). The average size of a farm is 1.5 ha and with two rainy seasons with annual rainfall at 1000–1200 mm (CIAT, 2018a, 2018b, 2018c). Soils are tropical ferruginous on crystalline base with high variability. Farmers mentioned transhumant livestock destructing fields as a major challenge. Groundnut and maize are important crops in these regions. Just as in the North, common farmers practice included burning of soil residues. The conventional maize/groundnut systems with mineral application of 150 kg a hectare and burning of residues were improved with integrating mucuna and pigeon pea without residue burning and no mineral fertilizer application (Table 5; Figure 7). These scenarios are represented in Appendix: Cropping Systems Assessed.

Table 5 Conventional practice vs GMCC practice in Collines

SEASON	CONVENTIONAL PRACTICE	GMCC PRACTICE
1	Maize	Maize/Mucuna
2	Maize/Groundnut	Maize
3	Maize/Groundnut	Maize/Pigeon pea
4	Fallow	Fallow
5	Maize/Groundnut	Maize/Groundnut
6	Maize	Soya

Figure 8 Maize-pigeon pea intercrop in the South (photo by CIAT/Rein van der Hoek).

Zou

Zou is located in the South. The farming system here is similar to Collines. Soils in this region range from degraded rhodic ferralsols, very deep clay, and humus soils, and very fertile alluvial soils (CIAT, 2018a, 2018b, 2018c). There are two rainy seasons with annual rainfall at 800–1400mm (CIAT, 2018a, 2018b, 2018c). The crops of importance include maize, yam, and cassava. For this study, we set the conventional system at maize/groundnut intercrop with mineral application of 100 kg a hectare and residue burning and improved system with a pigeon pea intercrop with 100% residue retention rate and no mineral fertilizer application (Table 6; Figure 8). These scenarios are represented in Appendix: Cropping Systems Assessed.

Table 6 Conventional practice vs GMCC practice in Zou

YEAR	CONVENTIONAL PRACTICE	GMCC PRACTICE
1	Maize/Groundnut	Maize/Pigeon pea
2	Maize/Groundnut	Maize/Pigeon pea
3	Maize/Groundnut	Maize/Pigeon pea
4	Maize/Groundnut	Maize/Pigeon pea
5	Maize/Groundnut	Maize/Pigeon pea
6	Maize/Groundnut	Maize/Pigeon pea

2.4.2 Kenya

Agriculture plays a key role in Kenya's economy as of 2016 the sector had contributed to over 33% of the country's GDP (MoA Kenya, 2018). Western Kenya is home to over 1.5 million farming households. GIZ work was in three counties in Western Kenya: Siaya, Kakamega, and Bungoma (Figures 9 and 10). Due to time constraints, this study only compared cropping systems in Kakamega. Agriculture is an integral sector in Kakamega county and accounts for over 65 percent of the total earnings. A large proportion of the county population is employed either directly or indirectly in this sector (MoA Kenya, 2018).

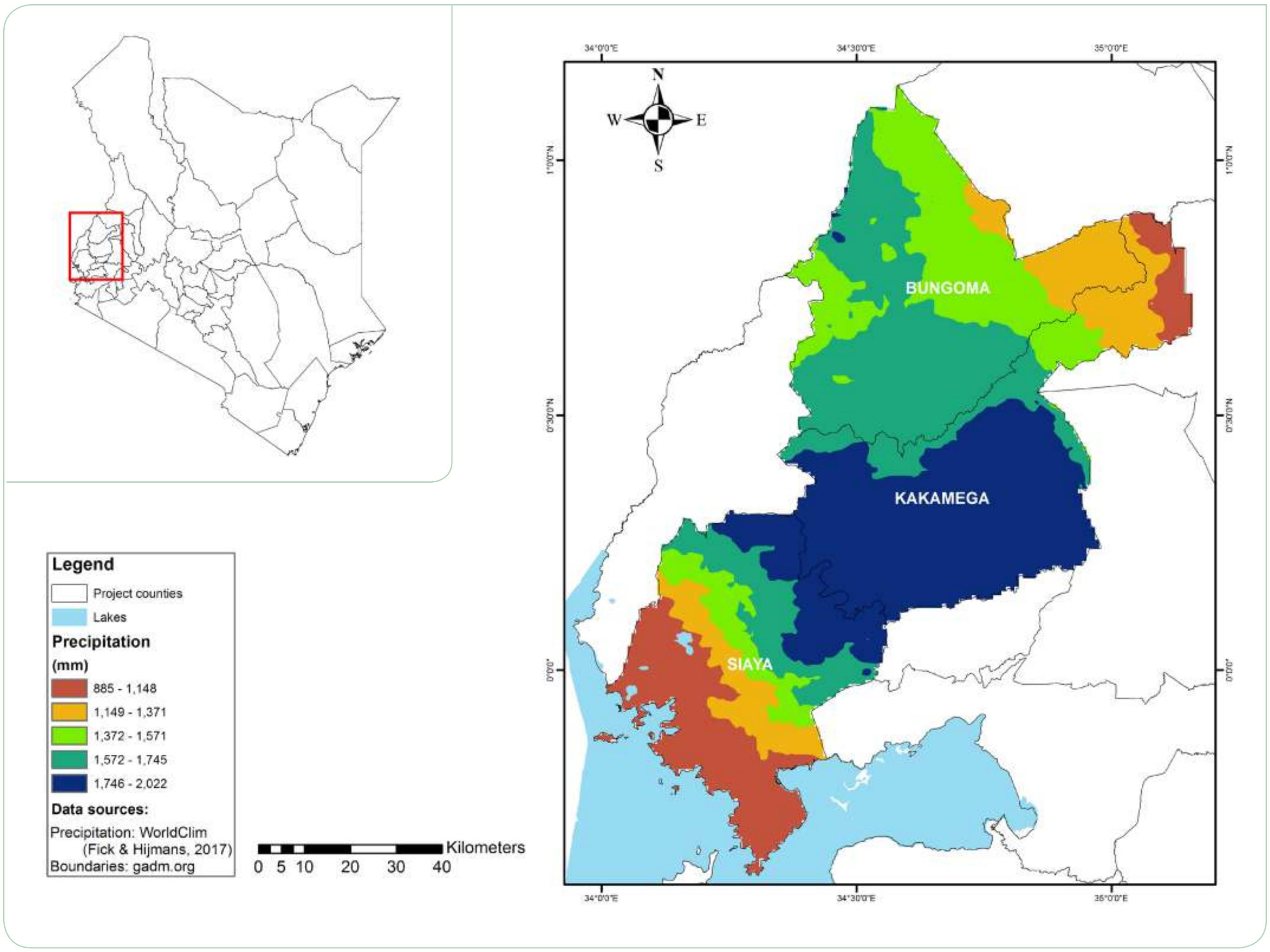

Figure 9 Map of Kenya, showing rainfall of the target regions

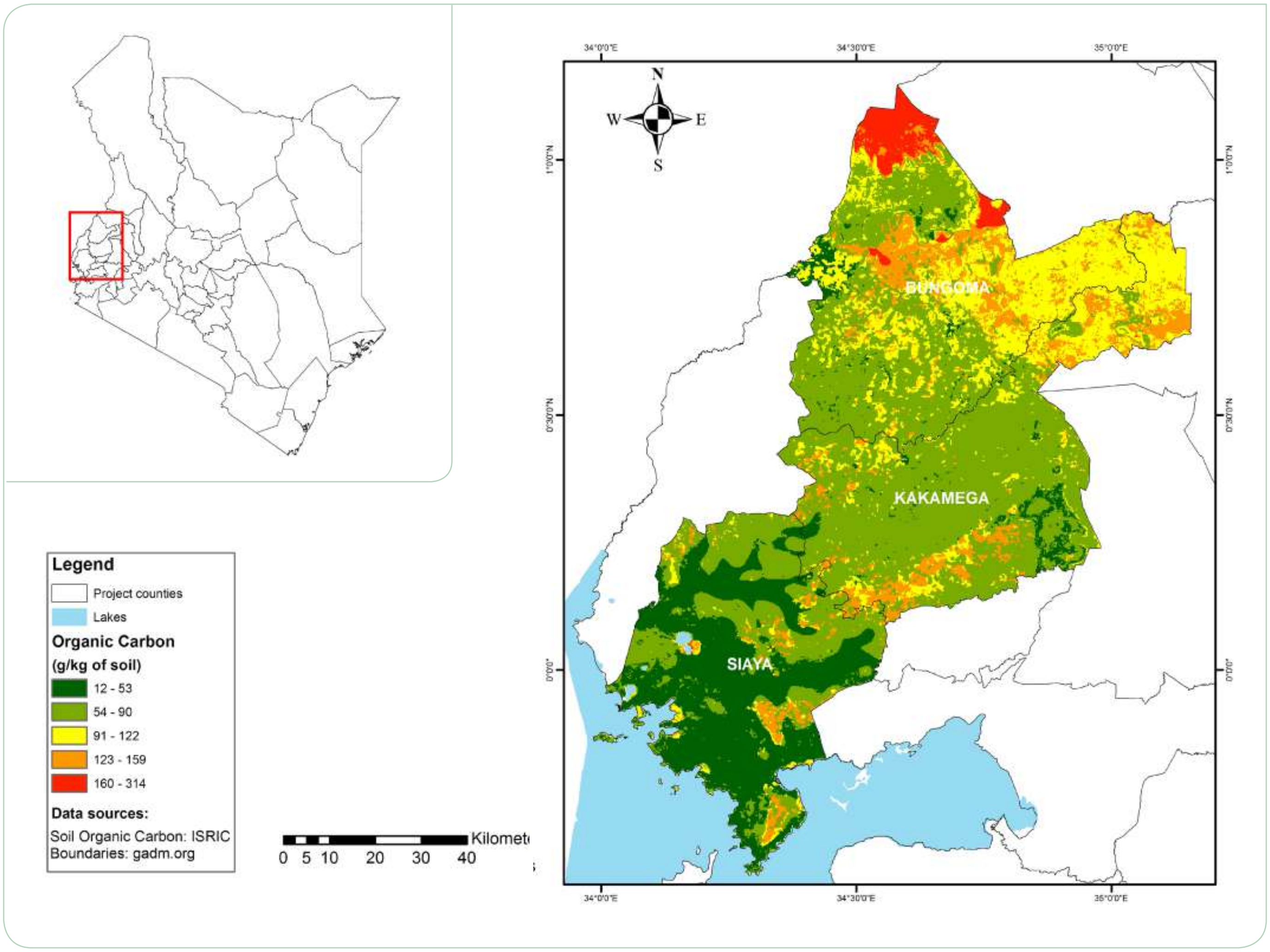

Figure 10 Map of Kenya, showing soil organic carbon in Kakamega

The characteristics of Kakamega are moderate to deep red soils of medium–high fertility and two rain seasons, farm sizes range from 0.2 ha to 2.0 ha (MoA Kenya, 2018). The farmers practice includes feeding crop residues to livestock and application of manure onto fields. Maize and beans are the common cropping system, either as intercrop or in rotation (MoA Kenya, 2018). GIZ and partners in this region are promoting the GMCCs Mucuna, Lablab, and Canavalia in rotation and intercrop.

For this study, we compared a maize-bean rotation with application of 0.75 t DM of manure per hectare and 75% residue removal with maize, maize/lablab intercrop, maize/lablab rotation, and maize/Mucuna rotation; all with 0.75 t DM of manure on maize crop and 75% residual removal from all crop rotation (Table 7; Figures 11 and 12). These scenarios are represented in (Appendix: Cropping Systems Assessed)

Figure 11 GMCC lablab in rotation in Western Kenya (photo by: CIAT/Michael Kinyua).

Table 7 Conventional practice vs GMCC practice in Kakamega

SEASON	CONVENTIONAL PRACTICE	GMCC PRACTICE	GMCC PRACTICE	GMCC PRACTICE
1	Maize	Maize	Maize	Maize
2	Bean	Maize/Lablab	Lablab	Mucuna
3	Maize	Maize	Maize	Maize
4	Bean	Maize/Lablab	Lablab	Mucuna
5	Maize	Maize	Maize	Maize
6	Bean	Maize/Lablab	Lablab	Mucuna

Figure 12 Mucuna in farmers field, Western Kenya (photo by: CIAT/Michael Kinyua).

Photo: CIAT/Georgina Smith

3 Results and discussion

3.1 CROSST approach

In developing the tool, the first step was to generate crop rotations. This was to better understand the crops planted, the crop rotations occurring on the ground, and crop rotations agronomist experts believed to be sustainable. The process differs from our generation of crop rotations (Reckling et al., 2016b). This process included smallholder farmers, agronomists, and development partners who described cropping systems with and without green manure cover crops as carried out by farmers described in section 2.4. This allowed for the generation of practical systems to be assessed within limited time, which differs from Reckling et al. (2016b).

The second step of the tool approach was to gather the agronomic, environment, and socio-economic data needed within the tool. The strength of using expert input was crucial because in these regions there is limited data available or non-existing data, and these experts take into account other physiological and socio-economic factors that might affect productivity in that region (Reckling et al., 2016b). In the tool, only the crops within the given cropping systems were simulated; however, more crops can be added to be analyzed. This tool makes analysis of cropping simple and transparent for all users and allows for quick adjustments if need be.

3.2 Testing the tool

The tool was piloted in Benin and Kenya, and this section looks at the results for the cropping systems described in section 2.4. The indicators of interest are listed per season/year, as sum and as annual average per hectare.

3.2.1 Benin

Alibori and Borgou are the Northern sites for Benin and only have one cropping season every year. Their yields are represented per year. Collines and Zou are in the South of Benin and their yields are represented per season.

3.2.1.1 Alibori

In Alibori, the GMCC system has led to 70% higher N balance and a substantial improvement in SOM/soil structure compared to the farmers' conventional system. Integrating GMCCs in this case can avoid almost all mineral fertilizer application without compromising the nutrient status of the soil. The conventional farming system had 28 more labor hours than the GMCC practice. However, the former is slightly more profitable (13%) as mucuna is not sold but retained on the soil and replaces a cereal/fiber harvest (Tables 8 and 9).

Table 8 Conventional farming practices in Alibori

			YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	SUM	AVERAGE/ HA/YEAR
Cropping System - Conventional			**Cotton**	**Cotton**	**Cotton**	**Soybean**	**Cotton**	**Cotton**		
Soudanienne1	Gross margin	USD/ha	429	342	272	561	517	342	2463	410.5
	Labor hours	h/ha	451	451	451	330	451	451	2585	430.8
	N Balance	kgN/ha	18	20	20	-10	17	20	86	14.3
	P Balance	kgP/ha	11	12	12	-8	10	12	48	8.1
	Yield1	kgDM/ha	1201	989	819	800	1414	989	6211	1035.2
	Yield2	kgDM/ha	0	0	0	0	0	0	0	0.0
	Biomass1	kgDM/ha	2439	2008	1663	1104	2870	2008	12091	2015.1
	Biomass2	kgDM/ha	0	0	0	0	0	0	0	0
	SOM/Soil structure									

Table 9 GMCC farming practices in Alibori

			YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	SUM	AVERAGE/ HA/YEAR
Cropping System - GMCC			**Cotton**	**Mucuna**	**Cotton**	**Mucuna**	**Cotton**	**Mucuna**		
Soudanienne1	Gross margin	USD/ha	434	251	478	251	478	251	2141	356.9
	Labor hours	h/ha	450	354	450	354	450	354	2412	402.0
	N Balance	kgN/ha	24	77	23	77	23	77	301	50.1
	P Balance	kgP/ha	5	-9	5	-9	5	-9	-10	-1.7
	Yield1	kgDM/ha	1212	286	1319	286	1319	286	4707	784.5
	Yield2	kgDM/ha	0	0	0	0	0	0	0	0.0
	Biomass1	kgDM/ha	2462	2607	2677	2607	2677	2607	15639	2606.4
	Biomass2	kgDM/ha	0	0	0	0	0	0	0	0.0
	SOM/Soil structure									

3.2.1.2 Borgou

The farmers' conventional practice in Borgou showed negative results in terms of soil fertility: N is mined from the soil (negative N balance) under maize/cotton rotation, even though mineral fertilizer is applied. SOM/structure is deteriorating over 6 years. Under the GMCC practice of integrating mucuna and pigeon pea, the N balance turns positive and SOM/structure is improving while avoiding almost all mineral fertilizer application. This GMCC system is also more profitable than the conventional practice mainly due to the good price of pigeon pea cropped in relay. The labor hours in the two systems were very similar with the GMCC system taking an additional six hours. However, due to the well-established cotton market and the input loan that farmers are given, it could possibly be an incentive for them to continue with growing the cash crop.

Table 10 Conventional farming practices in Borgou

			YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	SUM	AVERAGE/ HA/YEAR
Cropping System - Conventional			**Maize**	**Cotton**	**Maize**	**Maize**	**Cotton**	**Maize**		
Soudanienne2	Gross margin	USD/ha	245	563	287	181	563	287	2127	354.4
	Labor hours	h/ha	266	450	266	266	450	266	1964	327.3
	N Balance	kgN/ha	-16	17	-18	-4	17	-18	-23	-3.8
	P Balance	kgP/ha	5	10	7	9	10	7	47	7.9
	Yield1	kgDM/ha	1867	1526	2249	1611	1526	2249	11028	1838.0
	Yield2	kgDM/ha	0	0	0	0	0	0	0	0.0
	Biomass1	kgDM/ha	1723	3098	2076	1487	3098	2076	13558	2259.7
	Biomass2	kgDM/ha	0	0	0	0	0	0	0	0.0
	SOM/Soil structure									

Table 11 GMCC farming practices in Borgou

			YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	SUM	AVERAGE/ HA/YEAR
Cropping System - GMCC			**Mucuna**	**Cotton**	**Maize/ Pigeon pea**	**Maize/ Pigeon pea**	**Cotton**	**Maize**		
Soudanienne2	Gross margin	USD/ha	331	598	324	640	514	264	2671	445.1
	Labor hours	h/ha	354	450	280	280	376	258	1998	333.0
	N Balance	kgN/ha	95	22	-21	101	22	-16	202	33.7
	P Balance	kgP/ha	-12	9	-5	-13	10	-4	-15	-2.4
	Yield1	kgDM/ha	377	1609	1947	0	1406	1583	6923	1153.8
	Yield2	kgDM/ha	0	0	0	1254	0	0	1254	209.0
	Biomass1	kgDM/ha	3446	3268	1797	0	2855	1462	12826	2137.7
	Biomass2	kgDM/ha	0	0	0	4198	0	0	4198	699.7
	SOM/Soil structure									

3.2.1.3 *Collines*

In Collines, the farmers' conventional practice is mining N, and SOM/structure deteriorates although not at a rapid pace due to groundnut being part of the rotation. The GMCC cropping system with mucuna and pigeon pea intercropped with maize resulted in better soil health with a positive N balance at an average of 28.2 kgN/ha and improved status of SOM and soil structure. The GMCC system also required additional labor of four hours as compared to the conventional farming system. However, the conventional practice is slightly more profitable (USD50 a season).

Table 12 Conventional farming practices in Collines

			SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SUM	AVERAGE/ HA/SEASON
Cropping System - Conventional			**Maize**	**Maize/ Groundnut**	**Maize/ Groundnut**	**Fallow**	**Maize/ Groundnut**	**Maize**		
SFerrugineux	Gross margin	USD/ha	129	1216	1166	0	1164	163	3838	639.7
	Labor hours	h/ha	266	374	374	0	322	266	1602	267.0
	N Balance	kgN/ha	1	-40	-37	5	-37	-3	-110	-18.3
	P Balance	kgP/ha	7	-7	-7	0	-7	6	-7	-1.2
	Yield1	kgDM/ha	1111	1857	1774	0	1772	1306	7820	1303.4
	Yield2	kgDM/ha	0	1557	1498	0	1497	0	4552	758.7
	Biomass1	kgDM/ha	1025	1714	1638	0	1636	1206	7219	1203.1
	Biomass2	kgDM/ha	0	3466	3335	0	3332	0	10133	1688.8
	SOM/Soil structure									

Table 13 GMCC farming practices in Collines

			SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SUM	AVERAGE/ HA/SEASON
Cropping System - GMCC			**Maize/ Mucuna**	**Maize**	**Maize/ Pigeon pea**	**Fallow**	**Maize/ Groundnut**	**Soya**		
SFerrugineux	Gross margin	USD/ha	892	122	1058	0	891	593	3555	592.4
	Labor hours	h/ha	364	258	364	0	312	330	1628	271.3
	N Balance	kgN/ha	-19	-5	89	5	57	41	169	28.2
	P Balance	kgP/ha	-7	-2	-17	0	-12	-11	-49	-8.2
	Yield1	kgDM/ha	1439	694	1631	0	1342	1126	6232	1038.7
	Yield2	kgDM/ha	729	0	1256	0	1067	0	3052	508.7
	Biomass1	kgDM/ha	1328	641	1505	0	1239	1555	6268	1044.7
	Biomass2	kgDM/ha	230	0	4206	0	2375	0	6811	1135.2
	SOM/Soil structure									

3.2.1.4 Zou

In Zou, consecutive intercropping of maize/pigeon pea has shown positive results for soil health when compared to maize/groundnut intercropping. Soil N is accumulating at an average of 54.1 kgN/ha/season. When it comes to gross margins, the conventional farming system is slightly more profitable by 20%. The GMCC system in Zou required 15% less labor than the conventional system; however, the high gross margin indicates the conventional system has a higher return on labor.

Table 14 Conventional farming practices in Zou

			SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SUM	AVERAGE/ Ha/SEASON
Cropping System - Conventional						**Maize/Groundnut**				
	Gross margin	USD/ha	941	961	982	1005	1029	1053	5971	995.2
	Labor hours	h/ha	310	310	310	310	310	310	1860	310.0
	N Balance	kgN/ha	-24.7	-25.6	-26.5	-27.5	-28.5	-29.5	-162	-27.1
	P Balance	kgP/ha	-6	-6	-7	-7	-7	-8	-41	-6.8
SFerralitiques	Yield1	kgDM/ha	1183	1206	1230	1256	1283	1311	7469	1244.9
	Yield2	kgDM/ha	1221	1246	1272	1299	1328	1359	7724	1287.4
	Biomass1	kgDM/ha	1092	1113	1136	1159	1184	1210	6895	1149.1
	Biomass2	kgDM/ha	2717	2772	2831	2892	2957	3024	17193	2865.5
	SOM/Soil structure									

Table 15 GMCC farming practices in Zou

			SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SUM	AVERAGE/ Ha/SEASON
Cropping System - GMCC						**Maize/Pigeon pea**				
	Gross margin	USD/ha	268	961	371	1207	472	1551	4830	805.0
	Labor hours	h/ha	280	280	228	280	228	280	1576	262.7
	N Balance	kgN/ha	-13	100	-20	125	-27	159	325	54.1
	P Balance	kgP/ha	-3	-11	-4	-14	-6	-18	-58	-9.6
SFerralitiques	Yield1	kgDM/ha	1221	0	1690	0	2152	0	5063	843.8
	Yield2	kgDM/ha	0	1096	0	1376	0	1768	4240	706.7
	Biomass1	kgDM/ha	1127	0	1560	0	1986	0	4673	778.9
	Biomass2	kgDM/ha	0	3670	0	4607	0	5919	14196	2366.0
	SOM/Soil structure									

In all the regions, the GMCC technologies would substantially improve soil structure/soil organic matter as well as soil N balances. This was also expressed in the focus groups with farmers in Benin, as attaining higher yields was attributed to planting GMCCs (CIAT, 2018b). In Alibori, Zou, and Collines, a large increase in the soil N balance under GMCCs came at a small trade-off in economic gross margin. This because a crop grain harvest that can be eaten or sold was swapped for biomass production for soil amendment. In Borgou, this was not the case as GMCCs led to a synergetic effect of soil fertility and profits (Figure 13). This could be part of the trade-offs that pose challenges to GMCC adoption or, in other words, it could point to the need of economic investment to achieve soil protection and rehabilitation. This was confirmed by focus group discussions and several other studies reporting that farmers' top priorities are food security and income, followed by soil fertility. These trade-offs in profitability and labour demands could be hurdles to adoption (Meijer et al., 2015; Assogba et al., 2017; Chibarabada et al., 2017; Nalivata et al., 2017; Vanlauwe et al., 2017).

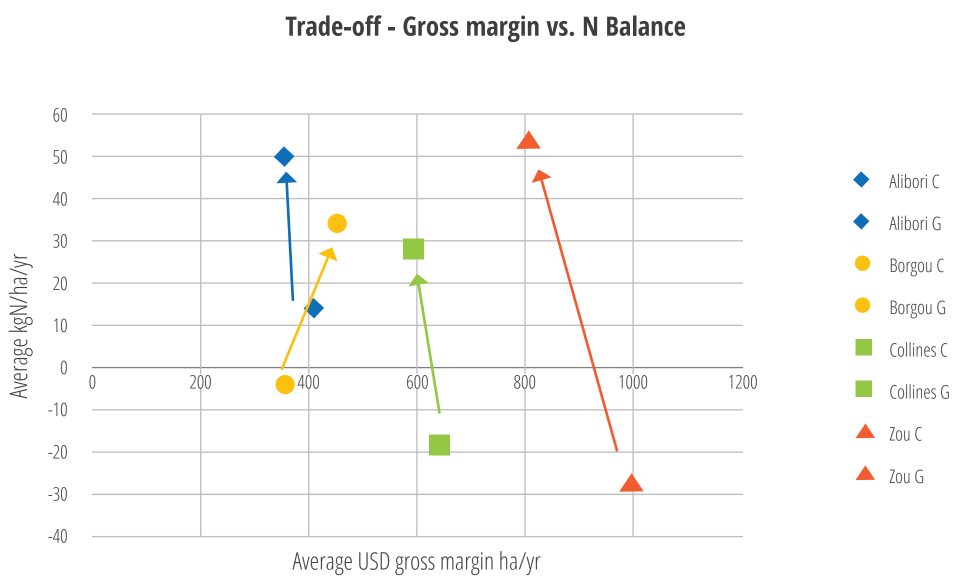

Figure 13 Gross margin vs nitrogen balance - GMCC in Benin

3.2.2 Kenya: Kakamega

In Kakamega, mucuna and then maize with lablab in rotation performed best with regards to soil organic matter, soil structure, and N balance. However, the maize bean system predominantly farmed in this region performed similarly to maize-lablab intercropped system when comparing soil tradeoffs in soil health. The GMCC systems with lablab intercropped with maize or lablab in rotation were the most profitable, with lablab intercropped with maize being most profitable due to more crop harvests. However, this assumes a high market price for lablab, which is an emerging crop in the region. The GMCC system with mucuna was least profitable with average returns of USD323 on average per season.

Table 16 Conventional and GMCC farming practices in Kakamega

CROPPING SYSTEM	INDICATOR		SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5	SEASON 6	SUM	AVERAGE/ HA/SEASON
Cropping System - Conventional			**Maize**	**Bean**	**Maize**	**Bean**	**Maize**	**Bean**		
Upper Midlands	Revenue	USD/ha	503	533	530	533	530	533	3159	526.5
	N Balance	kgN/ha	-36	-6	-39	-6	-39	-6	-133	-22.1
	P Balance	kgP/ha	-5	-1	-5	-1	-5	-1	-17	-2.9
	Yield1	kgDM/ha	1800	760	1890	760	1890	760	7860	1310.0
	Yield2	kgDM/ha	0	0	0	0	0	0	0	0.0
	Biomass1	kgDM/ha	4300	622	4515	622	4515	622	15195	2532.6
	Biomass2	kgDM/ha	0	0	0	0	0	0	0	0.0
	SOM/Soil structure									
Cropping System - GMCC			**Maize**	**Maize/ lablab**	**Maize**	**Maize/ lablab**	**Maize**	**Maize/ lablab**		
Upper Midlands	Revenue	USD/ha	503	806	558	653	619	529	3667	611.1
	N Balance	kgN/ha	-36	-3	-42	-1	-48	1	-129	-21.5
	P Balance	kgP/ha	-5	-7	-5	-5	-6	-4	-32	-5.3
	Yield1	kgDM/ha	1800	990	1985	802	2188	650	8414	1402.3
	Yield2	kgDM/ha	0	585	0	474	0	384	1443	240.4
	Biomass1	kgDM/ha	4300	914	4741	740	5227	600	16521	2753.5
	Biomass2	kgDM/ha	0	775	0	628	0	509	1912	318.7
	SOM/Soil structure									
Cropping System - GMCC			**Maize**	**Lablab**	**Maize**	**Lablab**	**Maize**	**Lablab**		
Upper Midlands	Revenue	USD/ha	503	626	611	626	611	626	3603	600.5
	N Balance	kgN/ha	-36	20	-47	20	-47	20	-70	-11.7
	P Balance	kgP/ha	-5	-5	-6	-5	-6	-5	-30	-5.0
	Yield1	kgDM/ha	1800	720	2160	720	2160	720	8280	1380.0
	Yield2	kgDM/ha	0	0	0	0	0	0	0	0.0
	Biomass1	kgDM/ha	4300	954	5160	954	5160	954	17483	2913.9
	Biomass2	kgDM/ha	0	0	0	0	0	0	0	0.0
	SOM/Soil structure									
Cropping System - GMCC			**Maize**	**Mucuna**	**Maize**	**Mucuna**	**Maize**	**Mucuna**		
Upper Midlands	Revenue	USD/ha	503	0	719	0	719	0	1940	323.3
	N Balance	kgN/ha	-36	136	-58	136	-58	136	256	42.7
	P Balance	kgP/ha	-5	-17	-7	-17	-7	-17	-69	-11.5
	Yield1	kgDM/ha	1800	540	2520	540	2520	540	8460	1410.0
	Yield2	kgDM/ha	0	0	0	0	0	0	0	0.0
	Biomass1	kgDM/ha	4300	4860	6020	4860	6020	4860	30920	5153.3
	Biomass2	kgDM/ha	0	0	0	0	0	0	0	0.0
	SOM/Soil structure									

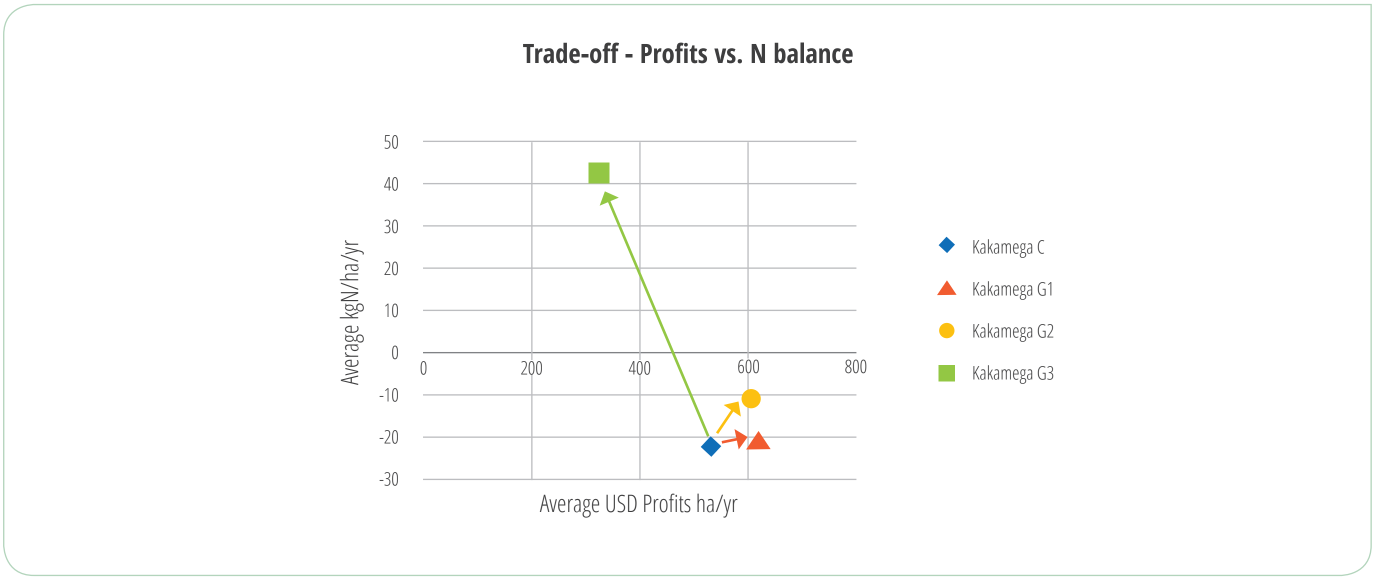

Figure 14 Profits vs nitrogen balance - GMCC in Kakamega

In Kakamega, it is clear that only the system with mucuna is putting back most N into the soil; however, at the largest economic trade-off or investment required. The other GMCC systems could make less increases in N balance but could also slightly increase economic returns.

It is important to note that the gross margins were highest in the south regions of Benin, then Kakamega and lastly northern Benin. For the northern Benin, this is attributed to one cropping season a year. From the data we collected, the prices of crop grain were higher in south Benin than in Kakamega, even though Kakamega has higher rainfall and higher yields with market prices being lower, profitability in this case is higher in southern regions of Benin.

Photo: CIAT/Georgina Smith

4 Conclusions and recommendations

In this study, we presented the Cropping System Sustainability Tool (CROSST) that was developed to better understand agro-environmental and socio-economic impacts and trade-offs of GMCC integration in cropping systems. We applied CROSST to selected GIZ intervention areas in Kenya and Benin to illustrate its functionalities with pilot results from the same areas.

The tool was successful in quantifying the effects of cropping systems with and without GMCCs. This tool also allowed for the participatory interactions with experts, smallholder farmers, and development partners.

Some preliminary conclusions can be drawn from the pilot application of CROSST to the different areas in Benin and Kenya:

- In all regions, the GMCC technologies would substantially improve soil structure/soil organic matter as well as soil N balances.
- Dual-purpose GMCCs such as pigeon pea and lablab are often most popular with farmers as they strike the balance between food security, income, and soil improvement. Farmers often strive to satisfy several objectives instead of maximizing on one.
- Crop economic margins are more complicated than a mere number. Mucuna and lablab might be economically interesting crops as official market prices for beans/seeds are high, but farmers cannot always find the market in their area. Independent of the economic margin, crops such as cotton offer the advantage of guaranteed market as the value chain is well organized.
- The line between GMCC and non-GMCC is not always clear-cut. Crops such as cowpea or soybean are also sometimes considered GMCCs as they also contribute to soil fertility through high N fixation rate.
- The P balance is not directly improved by GMCCs, and needs other methods for improvement, such as manure application or mineral fertilizer.

CROSST has shown to be a promising tool to compare socio-economic and agro-environmental performance and trade-offs of various cropping systems. In this piloting phase, data was mainly retrieved from expert opinion as published data is rare. The model could further be refined with data from recent official census as well as independent field measurements. For the outputs of the model to be robust, a stakeholder validation of outputs and inputs in all target areas, sensitivity and plausibility checks, and ground-truthing is required. An extension of CROSST that would be necessary to reflect GIZ program objectives include for example human health, e.g., health benefits from avoidance of pesticides and herbicides through GMCCs. To enable usability by non-research partners, CROSST would need to move from Excel to a web-based application with an easy-to-use interface.

This study presents a proof-of-concept towards a robust, validated, and user-friendly tool that could serve as a decision-making support tool for the GIZ soil program, implementing partners, and local stakeholders when considering to integrate GMCCs into cropping systems.

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Appendix: Cropping Systems Assessed

5.1 Benin

5.1.1 Alibori

Table 1-A CONVENTIONAL CROPPING SYSTEM

	ZONE	CROPS	MINERAL FERTILIZER-1 TYPE	FERTILIZER-1 AMOUNT (kg/ha)	RESIDUE-1 REMOVAL %	RESIDUE-2 REMOVAL %	MANURE INPUT (t DM/ha)	PESTICIDE APPLICATION	HERBICIDE APPLICATION	MINERAL FERTILIZER-2 TYPE	FERTILIZER-2 AMOUNT (kg/ha)	CROP-1 IS HARVESTED?	CROP-2 IS HARVESTED?
Cropping System - Conventional													
Season 1	Soudanienne1	Cotton	NPK 14-23-14	150	Burn	0	0	Average	None	None	0	TRUE	FALSE
Season 2	Soudanienne1	Cotton	NPK 14-23-14	150	Burn	0	0	Average	None	None	0	TRUE	FALSE
Season 3	Soudanienne1	Cotton	NPK 14-23-14	150	Burn	0	0	Average	None	None	0	TRUE	FALSE
Season 4	Soudanienne1	Soya	None	0	Burn	0	0	None	None	None	0	TRUE	FALSE
Season 5	Soudanienne1	Cotton	NPK 14-23-14	150	Burn	0	0	Average	None	None	0	TRUE	FALSE
Season 6	Soudanienne1	Cotton	NPK 14-23-14	150	Burn	0	0	Average	None	None	0	TRUE	FALSE

Table 2-A GMCC CROPPING SYSTEM

	ZONE	CROPS	MINERAL FERTILIZER-1 TYPE	FERTILIZER-1 AMOUNT (kg/ha)	RESIDUE-1 REMOVAL %	RESIDUE-2 REMOVAL %	MANURE INPUT (t DM/ha)	PESTICIDE APPLICATION	HERBICIDE APPLICATION	MINERAL FERTILIZER-2 TYPE	FERTILIZER-2 AMOUNT (kg/ha)	CROP-1 IS HARVESTED?	CROP-2 IS HARVESTED?
Cropping System - GMCC													
Season 1	Soudanienne1	Cotton	NPK 15-15-15	150	0	0	0	None	None	None	0	TRUE	FALSE
Season 2	Soudanienne1	Mucuna	None	0	0	0	0	None	None	None	0	TRUE	FALSE
Season 3	Soudanienne1	Cotton	NPK 15-15-15	150	0	0	0	None	None	None	0	TRUE	FALSE
Season 4	Soudanienne1	Mucuna	None	0	0	0	0	None	None	None	0	TRUE	FALSE
Season 5	Soudanienne1	Cotton	NPK 15-15-15	150	0	0	0	None	None	None	0	TRUE	FALSE
Season 6	Soudanienne1	Mucuna	None	0	0	0	0	None	None	None	0	TRUE	FALSE

5.1.2 Borgou

Table 3-A CONVENTIONAL CROPPING SYSTEM

	ZONE	CROPS	MINERAL FERTILIZER-1 TYPE	FERTILIZER-1 AMOUNT (kg/ha)	RESIDUE-1 REMOVAL %	RESIDUE-2 REMOVAL %	MANURE INPUT (t DM/ha)	PESTICIDE APPLICATION	HERBICIDE APPLICATION	MINERAL FERTILIZER-2 TYPE	FERTILIZER-2 AMOUNT (kg/ha)	CROP-1 IS HARVESTED?	CROP-2 IS HARVESTED?
Cropping System - Conventional													
Season 1	Soudanienne2	Maize	NPK 15-15-15	150	Burn	0	0	None	None	None	0	TRUE	FALSE
Season 2	Soudanienne2	Cotton	NPK 14-23-14	150	Burn	0	0	None	None	None	0	TRUE	FALSE
Season 3	Soudanienne2	Maize	NPK 15-15-15	200	Burn	0	0	None	None	None	0	TRUE	FALSE
Season 4	Soudanienne2	Maize	NPK 15-15-15	200	Burn	0	0	None	None	None	0	TRUE	FALSE
Season 5	Soudanienne2	Cotton	NPK 14-23-14	150	Burn	0	0	None	None	None	0	TRUE	FALSE
Season 6	Soudanienne2	Maize	NPK 15-15-15	200	Burn	0	0	None	None	None	0	TRUE	FALSE

Table 4-A GMCC CROPPING SYSTEM

	ZONE	CROPS	MINERAL FERTILIZER-1 TYPE	FERTILIZER-1 AMOUNT (kg/ha)	RESIDUE-1 REMOVAL %	RESIDUE-2 REMOVAL %	MANURE INPUT (t DM/ha)	PESTICIDE APPLICATION	HERBICIDE APPLICATION	MINERAL FERTILIZER-2 TYPE	FERTILIZER-2 AMOUNT (kg/ha)	CROP-1 IS HARVESTED?	CROP-2 IS HARVESTED?
Cropping System - GMCC													
Season 1	Soudanienne2	Mucuna	None	0	0	0	0	None	None	None	0	TRUE	FALSE
Season 2	Soudanienne2	Cotton	NPK 14-23-14	150	0	0	0	None	None	None	0	TRUE	FALSE
Season 3	Soudanienne2	Maize/ Pigeon pea	None	0	0	0	0	None	None	None	0	TRUE	FALSE
Season 4	Soudanienne2	Maize/ Pigeon pea	None	0	0	0	0	None	None	None	0	FALSE	TRUE
Season 5	Soudanienne2	Cotton	NPK 14-23-14	150	0	0	0	None	None	None	0	TRUE	FALSE
Season 6	Soudanienne2	Maize	None	0	0	0	0	None	None	None	0	TRUE	FALSE

5.1.3 Collines

Table 5-A CONVENTIONAL CROPPING SYSTEM

	ZONE	CROPS	MINERAL FERTILIZER-1 TYPE	FERTILIZER-1 AMOUNT (kg/ha)	RESIDUE-1 REMOVAL %	RESIDUE-2 REMOVAL %	MANURE INPUT (t DM/ha)	PESTICIDE APPLICATION	HERBICIDE APPLICATION	MINERAL FERTILIZER-2 TYPE	FERTILIZER-2 AMOUNT (kg/ha)	CROP-1 IS HARVESTED?	CROP-2 IS HARVESTED?
Cropping System - Conventional													
Season 1	SFerrugineux	Maize	NPK 15-15-15	150	Burn	Burn	0	None	None	None	0	TRUE	FALSE
Season 2	SFerrugineux	Maize/ Groundnut	NPK 15-15-15	150	Burn	Burn	0	None	None	None	0	TRUE	TRUE
Season 3	SFerrugineux	Maize/ Groundnut	NPK 15-15-15	150	Burn	Burn	0	None	None	None	0	TRUE	TRUE
Season 4	SFerrugineux	Fallow	None	0	None	None	0	None	None	None	0	FALSE	FALSE
Season 5	SFerrugineux	Maize/ Groundnut	NPK 15-15-15	150	Burn	Burn	0	None	None	None	0	TRUE	TRUE
Season 6	SFerrugineux	Maize	NPK 15-15-15	150	Burn	Burn	0	None	None	None	0	TRUE	FALSE

Table 6-A GMCC CROPPING SYSTEM

	ZONE	CROPS	MINERAL FERTILIZER-1 TYPE	FERTILIZER-1 AMOUNT (kg/ha)	RESIDUE-1 REMOVAL %	RESIDUE-2 REMOVAL %	MANURE INPUT (t DM/ha)	PESTICIDE APPLICATION	HERBICIDE APPLICATION	MINERAL FERTILIZER-2 TYPE	FERTILIZER-2 AMOUNT (kg/ha)	CROP-1 IS HARVESTED?	CROP-2 IS HARVESTED?
Cropping System - GMCC													
Season 1	SFerrugineux	Maize/ Mucuna	None	0	0	0	0	None	None	None	0	TRUE	TRUE
Season 2	SFerrugineux	Maize	None	0	0	0	0	None	None	None	0	TRUE	FALSE
Season 3	SFerrugineux	Maize/ Pigeon pea	None	0	0	0	0	None	None	None	0	TRUE	TRUE
Season 4	SFerrugineux	Fallow	None	0	0	0	0	None	None	None	0	FALSE	FALSE
Season 5	SFerrugineux	Maize/ Groundnut	None	0	0	0	0	None	None	None	0	TRUE	TRUE
Season 6	SFerrugineux	Soya	None	0	0	0	0	None	None	None	0	TRUE	FALSE

5.1.4 Zou

Table 7-A CONVENTIONAL CROPPING SYSTEM

	ZONE	CROPS	MINERAL FERTILIZER-1 TYPE	FERTILIZER-1 AMOUNT (kg/ha)	RESIDUE-1 REMOVAL %	RESIDUE-2 REMOVAL %	MANURE INPUT (t DM/ha)	PESTICIDE APPLICATION	HERBICIDE APPLICATION	MINERAL FERTILIZER-2 TYPE	FERTILIZER-2 AMOUNT (kg/ha)	CROP-1 IS HARVESTED?	CROP-2 IS HARVESTED?
Cropping System - Conventional													
Season 1	SFerralitiques	Maize/ Groundnut	NPK 15-15-15	100	Burn	Burn	0	None	Average	None	0	TRUE	TRUE
Season 2	SFerralitiques	Maize/ Groundnut	NPK 15-15-15	100	Burn	Burn	0	None	Average	None	0	TRUE	TRUE
Season 3	SFerralitiques	Maize/ Groundnut	NPK 15-15-15	100	Burn	Burn	0	None	Average	None	0	TRUE	TRUE
Season 4	SFerralitiques	Maize/ Groundnut	NPK 15-15-15	100	Burn	Burn	0	None	Average	None	0	TRUE	TRUE
Season 5	SFerralitiques	Maize/ Groundnut	NPK 15-15-15	100	Burn	Burn	0	None	Average	None	0	TRUE	TRUE
Season 6	SFerralitiques	Maize/ Groundnut	NPK 15-15-15	100	Burn	Burn	0	None	Average	None	0	TRUE	TRUE

Table 8-A GMCC CROPPING SYSTEM

	ZONE	CROPS	MINERAL FERTILIZER-1 TYPE	FERTILIZER-1 AMOUNT (kg/ha)	RESIDUE-1 REMOVAL %	RESIDUE-2 REMOVAL %	MANURE INPUT (t DM/ha)	PESTICIDE APPLICATION	HERBICIDE APPLICATION	MINERAL FERTILIZER-2 TYPE	FERTILIZER-2 AMOUNT (kg/ha)	CROP-1 IS HARVESTED?	CROP-2 IS HARVESTED?
Cropping System - GMCC													
Season 1	SFerralitiques	Maize/ Pigeon pea	NPK 15-15-15	0	0	0	0	None	None	None	0	TRUE	FALSE
Season 2	SFerralitiques	Maize/ Pigeon pea	NPK 15-15-15	0	0	0	0	None	None	None	0	FALSE	TRUE
Season 3	SFerralitiques	Maize/ Pigeon pea	NPK 15-15-15	0	0	0	0	None	None	None	0	TRUE	FALSE
Season 4	SFerralitiques	Maize/ Pigeon pea	NPK 15-15-15	0	0	0	0	None	None	None	0	FALSE	TRUE
Season 5	SFerralitiques	Maize/ Pigeon pea	NPK 15-15-15	0	0	0	0	None	None	None	0	TRUE	FALSE
Season 6	SFerralitiques	Maize/ Pigeon pea	NPK 15-15-15	0	0	0	0	None	None	None	0	FALSE	TRUE

5.2 Kenya: Kakamega

Table 9-A CONVENTIONAL CROPPING SYSTEM

	ZONE	CROPS	MINERAL FERTILIZER-1 TYPE	FERTILIZER-1 AMOUNT (kg/ha)	RESIDUE-1 REMOVAL %	RESIDUE-2 REMOVAL %	MANURE INPUT (t DM/ha)	PESTICIDE APPLICATION	HERBICIDE APPLICATION	MINERAL FERTILIZER-2 TYPE	FERTILIZER-2 AMOUNT (kg/ha)	CROP-1 IS HARVESTED?	CROP-2 IS HARVESTED?
Cropping System - Conventional													
Season 1	Upper midlands	Maize	None	0	75	25	0.75	None	None	None	0	TRUE	FALSE
Season 2	Upper midlands	Bean	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE
Season 3	Upper midlands	Maize	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE
Season 4	Upper midlands	Bean	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE
Season 5	Upper midlands	Maize	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE
Season 6	Upper midlands	Maize/bean	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE

Table 10-A GMCC CROPPING SYSTEM

	ZONE	CROPS	MINERAL FERTILIZER-1 TYPE	FERTILIZER-1 AMOUNT (kg/ha)	RESIDUE-1 REMOVAL %	RESIDUE-2 REMOVAL %	MANURE INPUT (t DM/ha)	PESTICIDE APPLICATION	HERBICIDE APPLICATION	MINERAL FERTILIZER-2 TYPE	FERTILIZER-2 AMOUNT (kg/ha)	CROP-1 IS HARVESTED?	CROP-2 IS HARVESTED?
Cropping System - GMCC													
Season 1	Upper midlands	Maize	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE
Season 2	Upper midlands	Maize/ lablab	None	0	75	0	0	None	None	None	0	TRUE	TRUE
Season 3	Upper midlands	Maize	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE
Season 4	Upper midlands	Maize/ lablab	None	0	75	0	0	None	None	None	0	TRUE	TRUE
Season 5	Upper midlands	Maize	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE
Season 6	Upper midlands	Maize/ lablab	None	0	75	0	0	None	None	None	0	TRUE	TRUE

Table 11-A GMCC CROPPING SYSTEM

	ZONE	CROPS	MINERAL FERTILIZER-1 TYPE	FERTILIZER-1 AMOUNT (kg/ha)	RESIDUE-1 REMOVAL %	RESIDUE-2 REMOVAL %	MANURE INPUT (t DM/ha)	PESTICIDE APPLICATION	HERBICIDE APPLICATION	MINERAL FERTILIZER-2 TYPE	FERTILIZER-2 AMOUNT (kg/ha)	CROP-1 IS HARVESTED?	CROP-2 IS HARVESTED?
Cropping System - GMCC													
Season 1	Upper midlands	Maize	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE
Season 2	Upper midlands	Lablab	None	0	25	0	0	None	None	None	0	TRUE	FALSE
Season 3	Upper midlands	Maize	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE
Season 4	Upper midlands	Lablab	None	0	0	0	0	None	None	None	0	TRUE	FALSE
Season 5	Upper midlands	Maize	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE
Season 6	Upper midlands	Lablab	None	0	0	0	0	None	None	None	0	TRUE	FALSE

Table 12-A GMCC CROPPING SYSTEM

	ZONE	CROPS	MINERAL FERTILIZER-1 TYPE	FERTILIZER-1 AMOUNT (kg/ha)	RESIDUE-1 REMOVAL %	RESIDUE-2 REMOVAL %	MANURE INPUT (t DM/ha)	PESTICIDE APPLICATION	HERBICIDE APPLICATION	MINERAL FERTILIZER-2 TYPE	FERTILIZER-2 AMOUNT (kg/ha)	CROP-1 IS HARVESTED?	CROP-2 IS HARVESTED?
Cropping System - GMCC													
Season 1	Upper midlands	Maize	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE
Season 2	Upper midlands	Mucuna	None	0	0	0	0	None	None	None	0	TRUE	FALSE
Season 3	Upper midlands	Maize	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE
Season 4	Upper midlands	Mucuna	None	0	0	0	0	None	None	None	0	TRUE	FALSE
Season 5	Upper midlands	Maize	None	0	75	0	0.75	None	None	None	0	TRUE	FALSE
Season 6	Upper midlands	Mucuna	None	0	0	0	0	None	None	None	0	TRUE	FALSE

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