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Green Manure Cover Crops in Benin and Western Kenya - A Review

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Green Manure Cover Crops in Benin and Western Kenya - A Review

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CIAT Publication No. 481
November 2019

Kinyua M; Diogo RVC; Sibomana J; Bolo PO; Gbedjissokpa G; Mukiri J; Mukalama J; Paul B; Sommer R; Kihara J. 2019. Green manure cover crops in Benin and Western Kenya - A review. CIAT Publication No. 481. International Center for Tropical Agriculture (CIAT). Nairobi, Kenya. 41 p. Available at: https://hdl.handle.net/10568/105923

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Acknowledgements

This report is an output of the project "Assessment of benefits and adoption constraints of green manure cover crops in Benin/Ethiopia and Kenya," led by the International Center for Tropical Agriculture (CIAT). The project is funded by the German Federal Ministry for Economic Cooperation and Development (BMZ)/Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) under Contract 81218508, processing number 14.0156.1-101.00. The project was carried out as part of the CGIAR Research Program on Water, Land and Ecosystems (WLE). We thank all donors that globally support our work through their contributions to the CGIAR System.

We thank country staff and partners of the GIZ Global Program on Soil Protection and Rehabilitation for Food Security in Benin and Kenya who have supported this review with information and literature, and who attended an expert workshop. In Benin, we thank Melanie Djédjé, Kado Alphonse Simba, Fulgence Dotonhoue (all GIZ ProSOL), Firmin Amadji (Sol Consult Africa - SolCA) and Jonas Dossou (l'Institut National des Recherches Agricoles du Bénin - INRAB). In Kenya, we thank Gerrit Gerdes and Flora Ajwera (GIZ), Maryleen Micheni (GOPA), Christopher Nyakan, Fanice Wanjala and Fred Akelo (We lthungerhilfe - WHH), Philip Omukono (CESUD), George Ayaga and David Mbakaya (Kenya Agriculture Livestock Research Organization - KALRO). We also appreciate Joshua Mutua, a CIAT travel and logistics staff, for facilitating the research team during farmer surveys and agronomic data collection.

Acronyms and abbreviations

AEZ	agro-ecological zone
AFD	Agence Française de Développement
ARDA	Appropriate Rural Development Agricultural Program
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
CESUD	Community Empowerment for Sustainable Development
CRA	Centre de Recherches Agricoles
FAO	Food and Agriculture Organization of the United Nations
FYM	farm yard manure
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GMCC	green manure cover crops
GOPA	Association for Organization, Planning and Training
GTZ	Gesellschaft für Technische Zusammenarbeit
IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture
INRAB	Institut National des Recherches Agricoles du Bénin [National Institute of Agricultural Research of Benin]
KAFPROD	Kenya Accelerated Food Production
KALRO	Kenya Agricultural and Livestock Research Organization
MoA	Ministry of Agriculture
MRD	Ministry of Rural Development of Benin
PADSE	Programme d'Amélioration et de Diversification des Systèmes d'Exploitation
RACRDs	Regional Action Centers for Rural Development in Benin
RAMR	Applied on-farm Research Project
RD	Research-Development
REFSO	Rural Energy and Food Security Organization
RTIN	Royal Tropical Institute of Netherlands
SCODP	Sustainable Community Oriented Development Program
SEWOH	One World No Hunger initiative
SG 2000	Sasakawa Global 2000
SLM	sustainable land management
SOM	soil organic matter
SSA	sub-Saharan Africa


Photo: CIAT/Georgina Smith

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Mucuna pruriens/maize intercrop with stover retention after maize harvests, Western Kenya (photo: CIAT/Michael Kinyua)

1 Introduction

The purpose of this review is to bring together knowledge on the role of green manure/cover crops (GMCCs) in soil protection and rehabilitation and identify hurdles to adoption by smallholder farmers. The review identifies past and ongoing projects on GMCCs in Benin and Western Kenya, their areas of operation, type of GMCCs and cropping systems involved, adoption status and utilization of such crops as food and soil fertility management.

Cover crops were as early as 1920s defined as crops grown specifically for providing groundcover to protect both soil erosion and plant nutrient losses through leaching and runoff (Parker, 1920; Pieters and McKee, 1938). More recently, FAO (2010) defined GMCCs as plants sown independently, or in association with other crops, to offer soil cover and improve the soils' physical, chemical, and biological characteristics. As such, for a crop to qualify as a cover crop, the following requirements are important: i) easy to establish; ii) has rapid growth rate to realize fast ground coverage; iii) produces high quantity of dry matter; iv) is disease resistant and does not act as a host for diseases of the associated crops; v) easy to manage; vi) economically viable; vii) deep rooting; vii) has little or no competition for moisture and nutrients with the main crop and ix) has multiple uses (Reeves, 1994; Khan et al., 2002; Gachene and Kimaru, 2003).

In both countries, as in most of sub-Saharan Africa (SSA), soils are characterized by low nutrient content (Gachene et al., 1997; Saïdou et al., 2018) and resultant low crop productivity, food insecurity, and malnutrition, especially under smallholder farming systems (Mugwe et al., 2007; FAO, 2010; UN, 2007). Although the use of mineral fertilizers to increase crop productivity is on the rise (Triberti et al., 2016; Diogo et al., 2017), the majority of smallholder farmers have limited access to cash for fertilizer purchase and practice low-input crop production (Ndakidemi, 2006; Klutse et al., 2018). Such continuous crop production coupled with inadequate use of mineral fertilizers (Diogo et al., 2018) has led to increased rates of soil nutrient mining and contributes to soil infertility (Henao and Baanante, 2006).

GMCCs are good complements to other soil health improving practices due to their affordability and soil amelioration effects (Chianu et al., 2011; Zoundji et al., 2016). The major GMCC species promoted in both countries include include velvet bean (*Mucuna pruriens*), joint vetches (*Aeschynomene* spp.), pencil flower (*Stylosanthes* spp.), Lablab bean (*Lablab purpureus*), jack beans (*Canavalia ensiformis*), sunnhemp (*Crotalaria* Spp.), Tick clover (*Desmodium* spp.), and pigeon pea (*Cajanus cajan*). Other regular crops, despite having been utilized for a long time as food crops, have the attributes of green manure cover crops, mentioned above. In this

review, if the primary reason for cultivating such crops is soil fertility improvement through provision of soil cover, increased organic matter through residue retention among other soil benefits, such crops have been considered as GMCCs. Examples of such crops include groundnuts, soybean, and cowpea.

Cover crops improve the organic matter content that is associated with enhanced water holding capacity in sandy soils (Becker et al., 1995). Besides, GMCCs also provide soil cover that protects the soil against water and wind erosion (Parker, 1920; Pieters and McKee, 1938; Hoorman, 2009) and keeps the soil off weeds (Carsky et al., 2001). They also create enabling conditions that promote diversity and functions of belowground biodiversity involved in soil nutrient transformations and cycling (Midega et al., 2013; Vukicevich et al., 2016) and soil aggregation (Hoorman, 2009; Soti et al., 2016). Some GMCC species, such as *Mucuna* and *Canavalia,* reduce nematode prevalence and attack on cereals (Arim et al., 2006). In addition, *Canavalia* is a potential soil bio-remediator for Sulfentrazole herbicides (Madalão et al., 2017).

GMCCs play an important role in nitrogen fixation that reach up to 320 kg N ha^{-1}, depending on the GMCC type, rainfall amount, and soil fertility status (Ojiem et al, 2007). For example, in western Kenya atmospheric nitrogen (N_2) fixation declined by 12% from highly fertile to moderately fertile fields and by 22% from moderately fertile to low fertility fields due to seasonal rainfall fluctuations (Ojiem et al., 2007). *Mucuna*, lablab bean, and groundnut have high N_2-fixation potential across agro-ecological zones (AEZs) and soil fertility gradients (Ojiem et al., 2007). Other benefits derived from GMCC include climate change regulation through carbon sequestration (Olson et al., 2014; Lal, 2015), improved cereal yields (Gachene et al., 2000; Maobe et al. 2000; Salako and Tian 2003; Fofana et al., 2004; Kaizzi et al., 2006), and animal fodder (Weber, 1996). However, contradictory results on yield benefits have also been reported in other studies (Mathuva et al., 1998; Giller, 2001; Kaizzi et al., 2006).

Soil water infiltration test under Lablab purpureus *rotation phase - CIAT staff in Western Kenya (photo: CIAT/Michael Kinyua)*

2 Benin

2.1 Location and agro-ecological zonation of Benin

Benin is located between longitude 1° E and 3°40' E and latitude 6°30' N and 12°30' N in West Africa. It covers an area of 112,625 km^2, of which about one-third is agricultural land. The country has two types of climate: hot and humid/sub-humid in the south and semi-arid (Sudanian climate) in the north, with a region of transition in the middle. The south has two rainy seasons (March to July and September to November) while the north has only one (May to October; Sinsin et al., 2004). The country has 77 administrative districts divided into eight AEZs (MAEP, 2001) ranging from humid to semi-arid lands (Figure 1 and Table 1).

Benin is highly dependent on agriculture, which is a source of livelihood for about 80% of its population and contributes about 38% of its gross domestic product (Gollin et al., 2014). The staple food crops include yams, cassava, beans, rice, and maize, while cotton, cashews, shea nut, pineapples, palm, cocoa, and coffee (Minot and Daniels, 2005) are major cash crops. Of the total production in the 18 districts, two crops cover the most area i.e., maize with about 36% and cotton 65–87%. Cotton is also the major export crop of Benin (MAEP, 2015).

- **Zone 1:** Area of the far North of Benin
- **Zone 2:** Cotton belt of Northern Benin
- **Zone 3:** Food Area South Borgou
- **Zone 4:** West Atacora Zone
- **Zone 5:** Central Cotton Zone
- **Zone 6:** Terre de barre Zone
- **Zone 7:** Zone of depression
- **Zone 8:** Fisheries zone

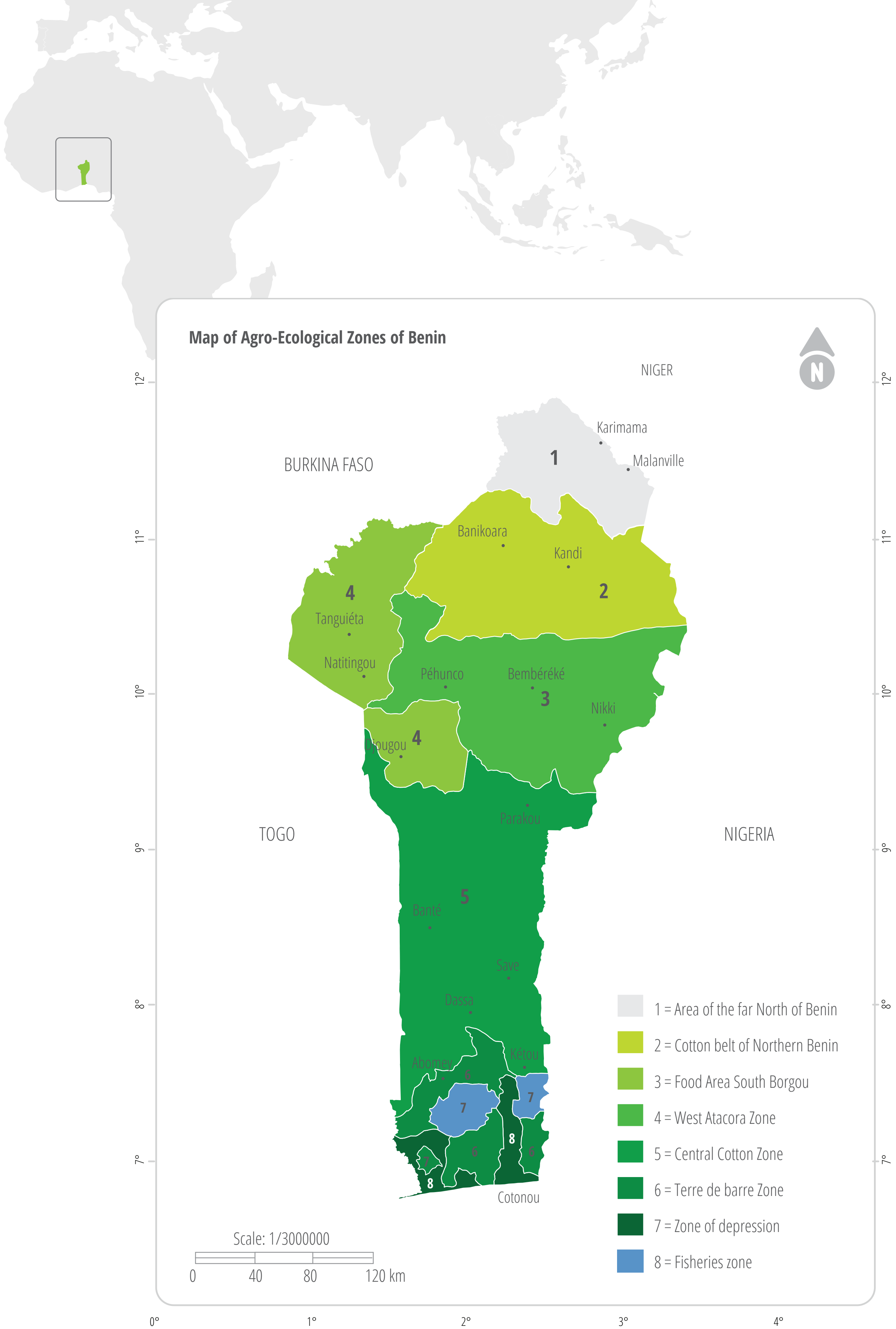

Figure 1 Map of agro-ecological zones of Benin. Source: MAEP (2001).

Table 1 Key characteristics of the eight agro-ecological zones of Benin

ZONE	DEPARTMENTS	ADMINISTRATIVE AREAS	CLIMATE	MAJOR SOIL CHARACTERISTICS	VEGETATION	OTHERS	CROPPING SYSTEM
1	Borgou (Far North)	Karimama, Malanville, Kandi North	Sudano-Sahelian climate with unimodal rainfall of between 700–900 mm per annum	- Fertile alluvial soils	Shrubby savannah sparse thorny acacia *(Acacia sieberiana)*	- Zone exposed to severe erosion - PCV < 140 days	- Basic crops: millet, sorghum and cowpea - Secondary crops: cotton, corn and onion along Niger and Alibory rivers
2	- Atacora - Borgou (North)	North-Kérou, East/ Kouandé, Banikoara, South Kandi, Ségbana, Gogounou	Sudano-Sahelian with unimodal rainfall of between 800–1200 mm per annum	- Very deep soil	- Shrubby trees with acacia and shea trees - Highly degraded by humans	PCV < 180 days	- Corn and millet - Cotton at the start of crop rotation - Ridging often practiced
3	- Atacora - Borgou (South)	Péhunco, East-Djougou, North-TchaourounParakou, N'Dali, Pèrèrè, Nikki, Sinendé, Kalalé, Bembèrèkè	Sudano-Sahelian climate with unimodal rainfall of between 900-1300 mm per annum	- Average fertility - Easily leached	Savanna woodland shrub dominated by *Butyrospermum* (Shea)	PCV = 140 to < 189 days	- Basic crops: sorghum and yam, cotton and maize production expanding *Yam planted at the start of rotation
4	- Atacora	Ouakè, West-Djougou, Copargo, Tanguiéta, Matéri, Kobli, Boukoumbé, Natitingou, Toukountouna, Kouandé	Varies from Sudano-Sahelian to Sudano-Guinean climate - Annual rainfall varies between 800–1300 mm	- Reduced water holding capacity - Fertile soils (except on shallow soils)	Savanna woodland/ shrub with *Butyrospermum* (Shea) and parkia (cheese monger) - Thorny acacia (Boukoumbé and Tanguiéta)	PCV = 180 to < 220 days	Key cowpea production area - Fonio (*Digitaria exilis*) grown especially at Boukoumbé - Yam, sorghum, groundnuts, cassava - Crops grown on tied ridges on the hillside - Crop on bunds on low terraces

ZONE	DEPARTMENTS	ADMINISTRATIVE AREAS	CLIMATE	MAJOR SOIL CHARACTERISTICS	VEGETATION	OTHERS	CROPPING SYSTEM
5	- Atacora - Borgou - Mono - Ouémé - Zou	- Bassila - Tchaourou-South - Aplahoué - Kétou - Bantè, Glazoué, Ouessè, Savalou, Dassa, Savè, Djidja	- Sudano-Guinean with bimodal rainfall in the South and unimodal rainfall in the North - Rainfall varies between 1000–1200 mm per annum (Igué et al., 2017)	- Very variable	Savannah woodland/ shrub dominated by *Danifiaohiori*	- PCV < 240 days	Maize, cowpeas and groundnuts grown in first season - Cotton established at the start of rotation
6	- Atlantique - Mono - Ouémé - Zou	- Allada, Zé, Tori, Bossito, Kpomassè, Djakotomè, Toviklin, Klouékanmè, Bopa, Dogbo-Tota, Houeyogbé - Sakété, Ifangni, Avrankou, Adjarra, Akpro-Missérété, Porto-Novo - Agbangnizoun, Abomey, Bohicon, Za-Kpota, Covè, Zagnanado, Zogbodomey	- Sudano-Guinean climate with bimodal rainfall of about 800–1200 mm in the West and 1000–1400 mm per annum in the East (Igué et al., 2017)	- Deep and easy to work - Most of the soil is currently degraded	- Dense shrub (oil palm and grasses dominant)	- PCV = 240 days	- Main crops are maize (at start of rotation), groundnuts, and cassava - Oil palm majorly grown - Cotton grown in some of the dry areas
7	- Atlantique - Mono - Ouémé	- Toffo - Lalo - Adja-Ouèrrè, Pobè	- Sudano-Guinean climate with bimodal rainfall of about 800–1200 mm in the West and 1000–1400 mm per annum in the East (Igué et al., 2017)	- Very deep soils - Fertile but often waterlogged	Dense semi-deciduous forest with large trees	Fairly high depression area - PCV = 210-240 days	- Maize established at the start of rotation - Cowpea, cassava, and vegetable crops also grown
8	- Atlantique - Mono - Ouémé	- Ouidah, Abomey-calavi, Cotonou, Sô-Ava - Lokossa, Arthiémé, Comé, Grand-Popo - Sèmè-Kpodji, Aguéguée, Dangbo, Adjohoun	- Sudano-Guinean climate with bimodal rainfall of between 1000–1400 mm per annum (Igué et al., 2017)	- Fertile alluvial soils - Infertile sandy soils along the coast	- Prairie grassy savannah - Marshy formations - Some mangroves	- Farming supplemented by fishing - Fluvial lacustrine zones - PCV = 240 days	- Major rotation sequence is maize (main crop) with cowpea or vegetables - Corn and cassava dominant in - non-sandy zones

PCV = Vegetative growth period.
Source: LSSEE, Centre of Agricultural Research of Agonkanmey, INRAB (2016).

Maize biomass sampling in Western Kenya (photo: CIAT/Michael Kinyua)

2.2. GMCC species promoted in Benin

Common GMCC species adopted and promoted in Benin include: *Mucuna, Aeschynomene*, groundnuts, soybean, cowpea, pigeon pea, and *Stylosanthes*. GMCCs already existing in Benin and popularized can be subdivided into two categories: herbaceous legumes used for food (groundnuts, soybeans, cowpea, pigeon pea) and herbaceous legumes used for soil restoration (*Mucuna, Aeschynomene,* and *Stylosanthes*). Below some brief information on these GMCCs is provided.

The species
Velvet Bean

Mucuna pruriens

The species
Velvet Bean

It is a popular leguminous cover crop introduced in 1987 among some 15 farmers through participatory farmer research in the Mono department of Benin (Vissoh, 2006) with the aim of increasing soil fertility. The crop can do well in areas with an altitude of < 1600 masl and > 1000 mm of rainfall. Two management systems have been developed in the sub-humid zone of southern Benin with the aim of integrating *Mucuna* into the cropping systems for soil fertility improvement and weed control. These systems include a) *Mucuna* establishment as a sole cover crop in short fallows for severely degraded fields and, b) *Mucuna* planted as a relay in maize fields that require less rehabilitation. In the bimodal zone of southern Benin, *Mucuna* is planted in March and April to maximize biomass accumulation and groundcover. However, the sowing date can be extended to May if rains are late. On average, *Mucuna* produces between 2 and 10 t ha^{-1} of dry matter and 200–2,000 kg ha^{-1} of grains per season (Cook et al., 2005). *Mucuna* was especially popular among farmers in 1990 due to its ability to suppress Cogon grass (*Imperata cylindrica)* and striga (*Striga hermontica)* weeds (Galiba et al., 1998). Farmers in Atacora, Atlantique, Borgou, Mono, Ouémé and Zou departments working with Sasakawa Global 2000 (SG 2000) reported a complete elimination of *Imperata* after 2–3 consecutive *Mucuna*

Continued...

crops (Galiba et al., 1998). In addition, when used in improved fallows, *Mucuna* significantly improved the subsequent crop yields. For example, after one-year fallow with *Mucuna* , increased maize grain yield was observed in both local (500 kg ha^{-1}) and improved (800 kg ha^{-1}) maize varieties (Versteeg and Koudokpon, 1993). The yield increase is consistent with estimated nitrogen inputs of more than 100 kg N ha^{-1} $year^{1}$ by *Mucuna* through biological nitrogen fixation (Fofana, 2005).

Photo: CIAT / Michael Kinyua

Porcupine jointvetch

A dicot of the Fabaceae family, it is an herbaceous legume adapted to a broad range of soils and climates and thrives also in unfavourable (sandy, infertile, acidic and poorly drained) soil conditions. Introduced from Côte d'Ivoire in 1989, *Aeschynomene* (*A. histrix*) was evaluated in the savannahs of northern Benin in 1998 (Ehouinsou and Aboh, 1998). This evaluation focused on cropping techniques, tolerance of diseases and drought, management methods, biomass production, seed production and crude protein content. The result of the study indicated that *A. histrix* is adapted to the ecology of northern Benin savannahs. *A. histrix* was introduced to Benin for animal feeding and soil regeneration. The crop not only improves soil fertility but also acts as soil cover and produces large quantity of quality fodder especially during the dry season. *A. histrix* can produce 2 to 6 tons of dry matter and about 260 kg ha^{-1} y^{-1} of grains.

Porcupine jointvetch

Aeschynomene histrix

Photo: CIAT Genebank

Soybean

Glycine max

Soybean

It is a grain legume with high productivity of biomass containing about 3.5% N and 0.15% P (Gachene and Kimaru, 2003). Soybean fixes up to 300 kg N ha^{-1} $season^{-1}$ (Hungria et al., 2006) and contributes an equivalent of 112 kg N ha^{-1} to the succeeding crop (Gentry et al., 2001), restores and maintains soil fertility in a sustainable way leading to improved yields (Smaling et al., 2008).

Photo: CIAT / Michael Kinyua

Cowpeas

Vigna unguiculata

Cowpeas

They grow and mature within a period of between 60–80 days (Kamara et al., 2018). Cowpea is a stress-tolerant grain legume, vegetable, and fodder crop that is adapted to wide ranging climate conditions. The estimated N fertilizer replacement value of cowpea can range between 5 kg ha^{-1} (Carsky et al., 1999) and 80 kg N ha^{-1} $year^{-1}$, especially after incorporating cowpea residues or cultivating two legume seasons (Horst and Härdter, 1994). Intercropping cowpeas with cereal crops often reduces legume yields due to shading from the cereal crops (Olufajo and Sigh, 2002). However, a good performance is achieved when cowpea varieties with a spreading cover are cultivated compared to the erect varieties (Ewansiha et al., 2014).

Photo: CIAT / Michael Kinyua

Groundnuts

Arachis hypogaea

Groundnuts

They are drought-tolerant nitrogen fixing legumes cultivated as a cash crop in Benin (Carder-Zou, 1999). The maturity stage of groundnuts ranges between 90–120 days depending on the variety planted (Masters et al., 2015). The crop has a self-pollinating characteristic hence seeds remain viable for a long time. In Zone IV of Benin, farmers intercrop groundnuts with sorghum while in Zone III, groundnut monocropping is practiced due to unsuitability of other crops as a result of striga invasion. Farmers in groundnut production do not generally utilize inorganic fertilizers; however, pod rot is evident in soils with low calcium levels leading to reduced pod filling and yields (Masters et al., 2015).

Photo: CCAFS / V. Meadu

Stylo

It is a perennial legume majorly grown for livestock fodder. It is well adopted in regions of < 1500 masl and rainfall of between 500 and 2000 mm (Cook et al., 2005). The crop is drought tolerant and can do well in soils with low fertility (Jones, 2003). On average, *Stylosanthes* produces about 1–6 t ha^{-1} season^{-1} of dry matter and 50–500 kg ha^{-1} season^{-1} of grains. Studies have reported *Stylosanthes* fallows to improve the grain yields of the subsequent cereal crops by 50–100 % as well as fixing > 100 kg N ha^{-1} annually (Sanginga et al., 1996). The various GMCCs grown in Benin, the year they were introduced, their main uses, and the regions grown are summarized in Table 2 below.

Stylo

Stylosanthes hamata

Photo: www.tropicalforages.info / Wal Scattini

Table 2 Species of GMCCs promoted in different regions of Benin and their main uses

ORGANIZATION	YEAR PROMOTED	GMCC SPECIES	USE(S)	REGION
MRD_RAMR; IITA; RTIN	1987	*Mucuna pruriens*	Weed control, green manure, fodder	Southern Benin: Zouzouvou
RACRDs; SG 2000	1990-1995	*Mucuna pruriens*	Green manure, fodder	Atacora, Atlantique, Borgou, Mono, Ouémé, and Zou
INRAB; RD Savè; PADSE; AFD	1998-2004	*Mucuna pruriens, Aeschynomene histrix*	Weed control, fodder, food	Collines and Alibori
FAO; INRAB; CRA-Center	2005	*Gliricidia sepium, Aeschynomene histrix, Mucuna pruriens, Stylosanthes hamata, Arachis hypogea, Vigna unguiculata,* and *Glycine Max*	Green manure, food	Collines region: Miniffi, Gomé, Akpéro, and Ouessè

2.3 Soil fertility in Benin

The soils of Benin can be divided into two broad categories: (i) soils developed under a dry two-season and two rainy season climate and under dense bush shrub vegetation from the south; (ii) the soils developed under a one-season climate, a dry season and a rainy season, and under savannah vegetation (Adegbola et al., 2016). Soils of the first category have good physical properties, namely: high permeability, great depth, high resistance to erosion, and good-to-medium structural instability index. However, their water reserve is low. The physical properties of the second category of soils are less good: average permeability, fairly low depth, average erosion resistance, average structural instability index to be raised, and low water reserve. These two categories of soils have a common characteristic namely their low water reserve. This serious deficiency of soils in general in Benin is one of the main causes of poor crop yields as soon as the regularity of rainfall is no longer assured. The soil is drying up rapidly and the plants are wilting. Apart from this general insufficiency of the Beninese soils, it must be added that those of the Sudano-Guinean zone, of the savannah, have more physical constraints to development (Igué et al., 2013). Their degradation accelerates as soon as they are cultivated, so they must be exploited with greater delicacy by implementing adapted conservation measures (Azontondé, 1991).


Canavalia ensiformis *rotational phase - farmer in Western Kenya (photo: CIAT/Michael Kinyua)*

The major causes of degradation of the soils of Benin include: poor agricultural practices, clearance of marginal land for farming, charcoal processing, overgrazing, and destruction of biomass by recurrent bush fires or burning (Baba et al., 2016). Soil erosion is a big threat to agricultural production and has resulted in about 72% reduction in crop yields (Ziervogel et al., 2006).

Similar to land degradation, issues of land tenure and security have not been adequately addressed by research and extension services (Igué et al., 2000). The uncertainty in tenure security reduces farmers' confidence on long-term benefits from investments done on land improvement. On the contrary, increasing tenure security would result in farmer access to credits that not only promotes greater investment in short-term inputs but also enhances more investment in land conserving technologies (Saïdou et al., 2007).

Utilizing fallow periods in crop management enhances organic matter accumulation, which helps in gradual restoration of soil fertility. However, the increasing population and poverty is forcing people to reduce fallow periods without replenishing the soils through application of other soil amelioration strategies (Brabant et al., 1996). In addition, land-use changes that are not accompanied by soil protection and rehabilitation measures have also accelerated soil degradation.

The advantages of using legumes as green manures or cover crops are: (1) they enrich the soil with the fixed biological N_2, (2) conserve and recycle soil nutrients, (3) provide soil protection to reduce erosion, and (4) require little or no immediate mineral fertilizer. However, at planned intervals, tillage is required to support the establishment, maintenance, and incorporation of these green manures (Franzluebbers et al., 1998, Groot et al., 1998).

Soils in southern and central Benin have very low cation exchange capacity (Igué et al., 2013). According to this study, 68% of the soils in southern and central Benin have lost their agricultural potential and are in classes III and IV. This phenomenon is due to the nitrogen content, phosphorus, potassium, and the cation exchange capacity in soil. The nitrogen and phosphorus are the most important plant macronutrients whose deficiencies in the soil are limiting crop production threatening rural livelihoods in Benin (Saïdou et al., 2003). About 82% of the soils are ferruginous and associated with high

P fixation (Fatima et al., 2006). Despite the reported nutrient deficiency in the majority of arable lands, utilization of inorganic fertilizers is mostly limited to cotton production. This is because cotton is the major cash crop that has been stimulated through State intervention in most areas of Benin (Saïdou et al., 2012; Honfoga, 2018). In Benin, maize is both a cash and a staple crop. However, fertilizer applied to maize is marginal and comes from residual effects in cotton-cereal rotations (Saïdou et al., 2012). This could be attributed to the market prices for food crops being lower than the expenses incurred from buying fertilizers (Ivo, 2008). Crop response to fertilizer application is also unpredictable, thus reducing their usage by resource poor farmers (Honfoga, 2018). Furthermore, the market-oriented green revolution approach has emphasized on inorganic fertilizer usage while credit to farmers does not allow for employment of site-specific soil fertility management and adoption of mechanisms developed for risk response (Bellwood-Howard, 2014), thus sustainable agricultural intensification has not been achieved.

2.4 Farming systems in Benin

2.4.1 Crops and livestock farming

In Benin, cultivation is mainly subsistence under traditional farming systems (e.g. shifting cultivation), where low-capital inputs such as use of traditional tools, fertilizer, and irrigation are predominant (Mulindabigwi, 2006). Arable farming is practiced in southern, central, and northern regions (Manyong et al., 1996) with different resource endowment.

While the Sudanian zones base their agriculture around maize on ferralitic and ferruginous soils, it is based on sorghum associated with either groundnut or cowpea. It is strongly recommended that both short- and medium-cycle varieties be introduced for the Sudanian zone.

Southern Benin: it covers 10% of the country where 60% of the population resides. The area has high potential despite crop yields reducing over the recent years (Baba et al., 2016). The predominant land-use in the region is crop cultivation, where maize, cassava, beans, sorghum, and vegetables are grown. Cash crops include groundnut, oil palm, and cashew. Food crops are mainly intercropped while oil palm and cotton are generally monocropped. Remote fields are used for cotto n and maize cultivation in a bush fallow system (Manyong et al., 2000). Livestock farming in the region involves free grazing in fields after harvesting of the main crop.

On ferralitic soil, two different management systems have been developed for the integration of *Mucuna* in cropping systems (Manyong et al., 2000). One is a unique fallow cover crop for severely degraded fields. The other is a corn/*Mucuna* relay crop for fields requiring less rehabilitation. For severely degraded and fields infested by *Imperata*, *Mucuna* should be planted in a pure stand at the beginning of the rainy season. Three or four weeks after planting *Mucuna*, a second cut may be necessary to allow *Mucuna* seedlings to defeat *Imperata* because it is a fast-growing weed. Production of 7 to 9 t ha^{-1} yr^{-1} of dry matter is generally observed in the bimodal rain zone (Vissoh et al., 1998). In the dry season, *Mucuna* completes its life cycle leaving a thick mulch free of weeds. This allows a subsequent maize harvest during the long rainy season with little or no preparation or weeding.

Central Benin: The zone characterized by land pressure due to continuous immigration from the southern region resulting in deforestation of primary forests and conversion into agricultural land for growing cotton, groundnut, and maize. For instance, the yam-based cropping system in Zou (Djidja) has resulted in deforestation of the Bokou forest. Cotton cultivation is also expanding; cowpea is its complementary crop. High amounts of fertilizers and other inputs are used (Minot and Daniels, 2005). Livestock farming in the area by pastoralists, especially free grazing after harvest of the main crop, jeopardizes the adoption of GMCCs, e.g. *Mucuna* fallows, leading to conflicts between arable farmers and the pastoralists.

Intercropped Mucuna (Mucuna pruriens) *climbing on maize* (Zea mays) *plants - CESUD field staff* in Western Kenya *(photo: CIAT/Michael Kinyua)*

Northern Benin. The region is also characterized by lower population density than in other zones (Callo-Concha et al., 2012). The farming systems are either based on cotton or livestock production. Cotton production has received a lot of support by the government. However, livestock production is quite established and integrated in the arable farming activities. The increased demand for arable fields has resulted to opening up of more lands in the conserved areas. This has reduced grazing areas leading to over grazing that makes livestock farmers to invade croplands, hence triggering consistent conflicts in land-use (Callo-Concha et al., 2012). On the other hand, the unmet demand for arable land has shortened fallow periods, resulting to continuous cropping, which has increased land degradation (Igué et al., 2000). About 75% of farmers in Northern Benin use inorganic fertilizers, for selected crops, with profitability being achieved mainly in irrigated systems (Laube, 2007).

GMCCs are grown in pure culture and in combination with annual and perennial plants. In all agro-ecological zones, the association and rotation of corn-*Mucuna* with maize cultivation every year and planting of *Mucuna* every two years is noted. Under these conditions, there is no mineral fertilization. Other cropping systems are identical to the first, but with *Mucuna* planting every year. Maize is sown after rainfall greater than 15 millimeters, usually between April 15 and May 15, at a density of 62,500 plants per hectare at a rate of 2 grains per pocket. Harvesting is done between July 30 and August 30.

2.4.2 Soil fertility management practices

Farmers in Benin use several practices to manage the fertility of their land. Previous studies in northern Benin mention this behavior (de Haan, 1997; Wennink et al., 1999), which is also found throughout the Sudano-Sahelian region (Pieri, 1989; McIntire et al., 1992, Jabbar, 1994). The most commonly used practices in the various combinations are crop rotation, direct rotational stocking, mulching, mineral fertilizer inputs or organic fertilizer in the form of manure or compost, and the use of cover crops.

The evolution of soil fertility management practices and strategies highlights the importance of the sustainable land management (SLM) issue. The diversity of practices also reflects the adaptation of farmers to new situations and also the inadequacy of the solutions provided by research and extension. Fallow land, the incorporation of legume biomass, soil cover, organic and mineral fertilization, and crop rotation are the types of practices that are taking place in all areas. But the intensity of use of practices varies according to land pressure, the importance of cotton growing, and the specificities of each agro-ecological zone. The practices are more diversified when the land pressure is stronger and when the fallow disappears. Diversification of practices is also a function of the level of integration of agriculture and livestock on the farm (Floquet et al., 2006).

In areas where land pressure is relatively low, crop residues are not used for soil fertility management. In areas where land pressure is high, mulching fields with crop residues, whether or not followed by direct rotational grazing, contributes to the maintenance of soil fertility.

2.5 GIZ and other projects/programs promoting GMCCs in Benin

In a bilateral cooperation between the Federal Republic of Germany and the Republic of Benin, an initiative called One World No Hunger (SEWOH) was established. In this initiative, there were five projects: ProSOL, ProCIVA, ProSAR, ProFinA, and ProPFR and their general goal was resilient agriculture in the smallholder farms in Benin.

2.5.1 Promotion of GMCCs by ProSOL

ProSOL (through GIZ) is one of the different SEWOH projects that promotes soil protection and restoration to boost food security in Benin. Its main objectives include implementation of soil rehabilitation, integration of SLM politically and institutionally, and enhancing SLM knowledge management and diffusion (Mulindabigwi, 2015). By targeting smallholder farmers, ProSOL works in 4 departments, 18 communes, and 385 villages (Figure 2).

The areas were chosen due to low soil fertility, and their selection was based on the following criteria:

- Level of soil degradation with low, moderate, and high aspects
- Soil fertility level with low, moderate, and strong aspects
- Proportion of farmers that practice rice, soybean, maize, cotton, poultry, or small ruminant-based farming systems.

The main GMCC interventions promoted by ProSOL include the use of residue management (mulching instead of burning), pigeon pea (sole and intercrop), *Mucuna* (sole and intercrop), and intercropping soybean, cowpea, and groundnuts with maize. ProSOL/GIZ through various actors have been promoting a number of sustainable land management practices and GMCCs, which have been a major concern of

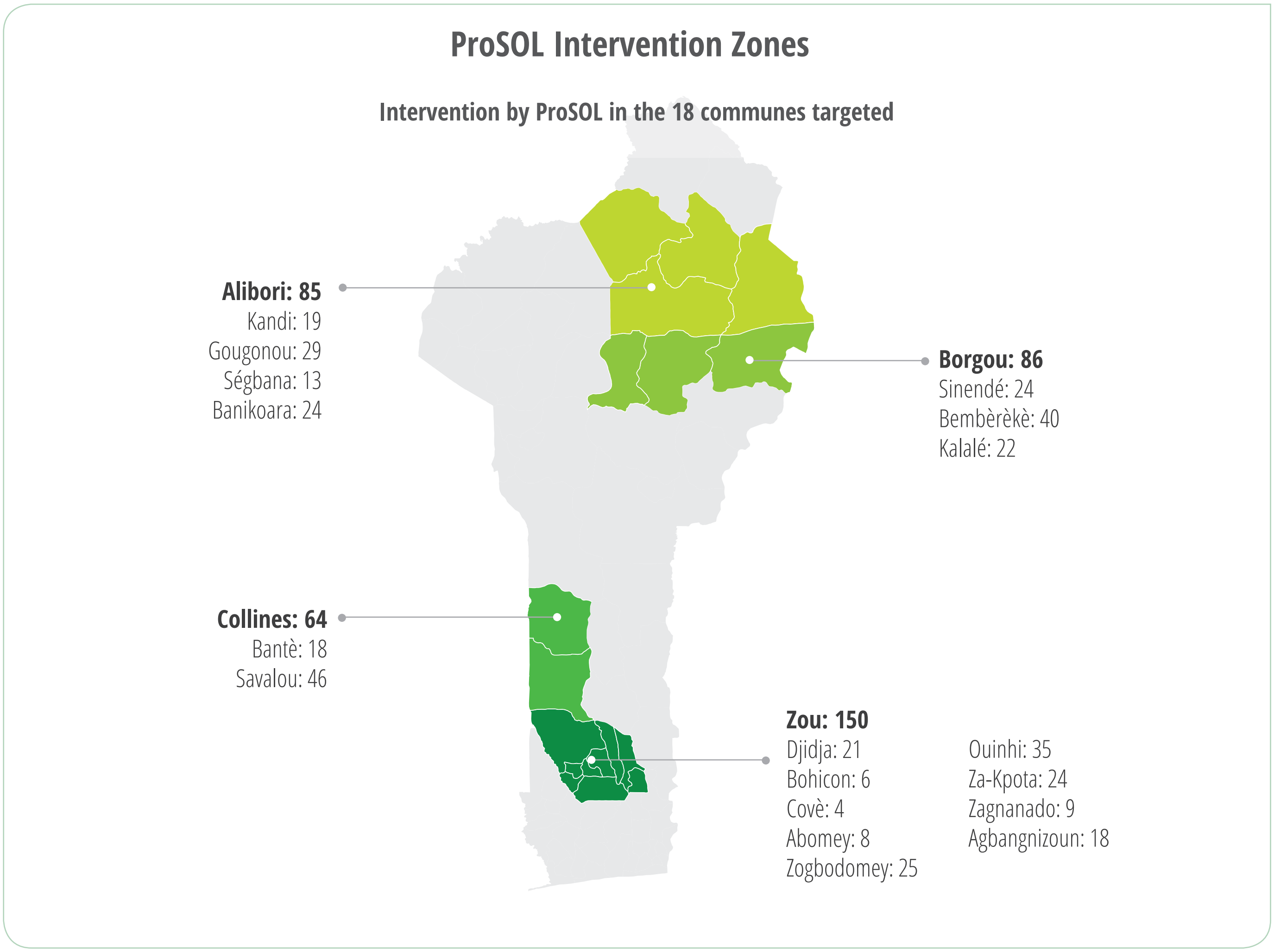

Figure 2 ProSOL intervention zones in Benin. Source: GIZ (2015).

agricultural research. In collaboration with the National Institute of Agricultural Research of Benin (INRAB), they have established a trial in Agricultural Research Center (CRA-Center) on different varieties of pigeon pea, *Mucuna, Aeschynomene,* and *Stylosanthes.* In 2017, ProSOL/GIZ managed to establish 574 and 2,732 ha of *Mucuna* (pure) and pigeon pea (in association) and also rehabilitate 22,000 ha of land. The *Mucuna* cropping systems promoted by ProSOL in Benin include:

- ***Maize-Mucuna intercropping:*** *Mucuna* is planted 21–30 days after maize establishment to reduce competition. In the subsequent season, *Mucuna* is slashed and maize is directly planted.
- ***Mucuna under trees:*** *Mucuna,* being a climber, is established under trees and shrubs and left until seeds development. Although the main goal here is seed production, *Mucuna* still provides soil cover and other soil protection benefits.

Indicators of success for ProSOL/GIZ project are:

1. Twenty thousand (20,000) hectares of small farmland whose soils were highly degraded or having degradation potential are currently rehabilitated or protected.
2. Yields of major crops (maize, soybeans, rice, and cotton) have increased on protected or rehabilitated fields compared to the unprotected.
3. Development of legal texts encouraging the implementation of soil protection and remediation measures with positive impacts on climate change and adaptation have been approved in February 2019 (GIZ, 2015).

The different ProSOL sites are characterised by the conditions illustrated in Table 3 below:

Table 3 General characteristics of ProSOL sites in Benin

DEPARTMENT	COMMUNES	CLIMATIC ZONES	SOILS	VEGETATION	CROPPING SYSTEM
Alibori	Gogounou, Kandi, Ségbana	Sudanian with a single rainy season of 800 to 1,200 mm a year	- Tropical ferruginous soils on crystalline base - High proportion of leached soils and low concretions	- Shaded shrub with *Acacia sieberiana (thorny)* and *Butyrospermum parkii* (Shea butter) - Heavily degraded by anthropogenic activities	- Maize/millet-based but with reduced millet - More developed cotton-based and often use of rotation system - Starting yam-based zone - Often use of ridging tillage
Borgou	Bembèrèkè, Kalalé, Sinendé	Sudanian with a single rainy season of 900 to 1,000 mm per year	- Tropical ferruginous soils with highly variable characteristics - Average fertility - Sensitive to leaching	Tree/shrub savannah dominated by *B. parkii*	- Sorghum/yam-based with high extension of cotton/ maize-based - Yam used in rotation system - Often use of weeding-hills tillage
Collines, Zou	Bantè, Savalou; Djidja	Sudano-Guinean with two rainy seasons in South and one in North 1,000 to 1,200 mm per year	- Tropical ferruginous soils on crystalline base - Tropical ferruginous soils on crystalline block with highly variable characteristics	Tree/shrub savannah dominated by *Danifiaohiori*	- No dominant cropping system - Use of maize, cowpea, and peanut in second season - Peanut and cotton are very important crops in the area - Cotton is used in rotation - Use of weeding-hills and ridging tillage
Zou	Abomey, Agbangnizoun, Bohicon, Covè, Zagnanado, Za-Kpota	Sudano-Guinean two rainy seasons - 800 to 1,200 mm per year in West - 1,000 to 1,400 mm per year in East	- Degraded rhodic ferralsols “terre de barre” - Leached soils and easy for cropping - Mostly degraded soils	Dense shrubby thicket dominated by oil palm and grasses	- Primary crops are maize (used in rotation), peanut and cassava. - Disappearance of yam - Abundant presence of oil palm + vineyard palm - Presence of cotton in some dry areas - Flatland cropping system in West and ridge cropping system in East
Zou	Zogbodome	Sudano-Guinean two rainy seasons 800 to 1,200 mm per year in the West 1,000 to 1,400 mm in the East	- Very deep clay and humus soils - Fertile but often hydromorphic and difficult to work	Semi-deciduous dense forest with tall trees	- Dominated flatland cropping system with maize used in rotation - Maize, cowpea, cassava marshland cropping system

DEPARTMENT	COMMUNES	CLIMATIC ZONES	SOILS	VEGETATION	CROPPING SYSTEM
Zou	Ouinhi	Sudano-Guinean two rainy seasons 1,000 to 1,400 mm per year	- Very fertile alluvial soils - Less fertile sandy soils on the coast	- Grassy Savannah-Prairie - Formation of swampy Raphia - Some mangroves	- Based system = maize (used in rotation) + cowpea and marshland cropping system - Dominance of maize/cassava-based in no sandy zones - Cropping on ridge or on flatland

Source: Igué et al. (2017).

2.5.2 Other organizations working on GMCCs in Benin

The National Institute of Agricultural Research of Benin (INRAB) is the public institution responsible for scientific and technical research. In 2016, GIZ collaborated with INRAB and the International Institute of Tropical Agriculture (IITA) to promote the cultivation of a number of GMCCs and was able to produce a Technical and Information Document on analysis of research and innovation work for sustainable land management in Benin. The document shows a number of technologies the institution has promoted from 1996 to 2015. Notable work by INRAB includes introducing 10 cowpea varieties, studies on *Mucuna* (which took the forefront), and promotion of the following cropping systems:

- Sustainable maize production technique on pigeon pea, *Mucuna, Aeschynomene,* and *Stylo* through direct sowing using a cane and incorporation of the crop at the end of the season
- Sustainable cassava production in a sedentary cropping system with an integration of quickstick (*Gliricidia sepium*) *vegetation* and *Aeschynomene*
- Sustainable production of quality yam in a sedentary cropping system with an integration of *Mucuna, Gliricidia, Aeschynomene,* and *Stylosanthes*
- Production of yam seed by mini-fragmentation (minissett) incorporating *Mucuna* as a cover crop
- Sustainable production of yam in direct sowing systems of tropical Kudzu (*Pueraria phaseoloides*) cover.

2.6 Adoption of GMCCs in Benin

2.6.1 History of the adoption of GMCCs in Benin

In 1987, *Mucuna* was introduced in the village of Zouzouvou, southern Benin, by the "Applied on-farm Research Project" (RAMR) implemented by the Ministry of Rural Development (MRD) of Benin, IITA, and the Royal Tropical Institute of the Netherlands. The aim was to address the serious soil fertility decline in the area through demonstration plots established mainly on local schools. In 1988, the project tested *Mucuna* fallow, fertilizer-N, pigeon pea hedgerows, and alley cropping with 20 farmers where suppression of *Imperata* infestation through *Mucuna* was observed. The farmers also discovered that *Mucuna* was a good livestock fodder. In 1989, INRAB observed that 103 farmers in the nearby villages of southern Benin had planted *Mucuna*. Key works promoting GMCCs occurred around 1996 when the number of farmers testing *Mucuna* technology throughout Benin was 10,000 (Tarawali et al., 1999).

More implementing partners joined in GMCCs technology transfer process for increased soil rehabilitation and fertility in different regions of Benin. For example, Benin's Regional Action Centers for Rural Development (RACRDs) in close collaboration with Sasakawa Global 2000 (SG 2000) accelerated this spontaneous adoption process in six departments, namely Atacora, Atlantique, Borgou, Mono, Ouémé and Zou. According to Manyong et al. (1998), *Mucuna* adoption in Mono province would result to savings of about 6,500 tons of N per year. Despite the high initial adoption rate of *Mucuna* by most farmers in southern Benin, the rate of adoption subsequently dropped due to labour constraints (Azontondé, 2000). Besides *Mucuna*, the partners introduced a variety of other GMCCs such as *A. histrix* and cowpea.

Before *Mucuna*, *Stylosanthes* cultivation had been introduced in Benin in the late 1970s with the main target being increasing livestock fodder in the sub-humid zones of Benin (Amadji et al., 2003). In contrast to the fast adoption of *Mucuna* in southwestern Benin, adoption of *Stylosanthes* by farmers has been relatively low. This was due to low rainfall regime, lack of motivation of livestock keepers, insecure land tenure, limited capability and facilities of extension staff, and unsatisfactory establishment of the crop.

Under the renewed interest in GMCCs observed after 2010, e.g., the GIZ ProSOL project, new perspectives have been introduced, and farmers are changing their farming practices. Previously, crop residues were burned, but not anymore. Currently, cover crops are slashed and left in the field and main crop planted directly without tilling which saves time and labour. Moreover, eco-friendly residue handling technologies such as composting are being promoted.

2.6.2 Constraints of adoption of GMCCs

After completion of various projects on GMCCs in Benin, adoption level of these crops decreases owing to various reasons. The main challenges were: 1) limited access to certified seeds due to poor organization of the seed system; 2) reduced diversity and little knowledge on productivity according to different agro-ecological regions reduced adoption rates (ProSOL, 2015); 3) land tenure system and the difficulty of integrating long-cycle crops such as cassava and yam with GMCCs (Agbokou et al., 2015); 4) high labour demand for maintenance; and 5) poor access to credit and agricultural inputs (Assogba et al., 2017).

According to Vissoh (2006), the most important factors influencing adoption by farmers are weed infestation, land rights, contact with extension services, and other farm-specific variables. On the other hand, Adégbola et al. (2011) showed that the main factors that positively influence the decision of adoption by the producers are the level of formal education, the contact with the extension agents, and the market orientation. Likewise, the voluntary participation of beneficiaries in training actions is a factor that positively influences the adoption of technologies GMCCs (Jasaw et al., 2014). Due to climate variability and risks (Agossou et al., 2012), it becomes imperative for growers to use cover crops to guarantee the sustainable management of their land. Thus, producers' awareness of land degradation (Jasaw et al., 2014) and its impacts on their well-being is a motivating factor for them to adopt the technologies. Declining soil fertility resulting in lower crop yields determines farmers' adoption of GMCCs in their fields.

2.6.3 Causes of no adoption

In Benin, non-adoption of *Mucuna* is related to difficulties in cropping activities due to high density of *mucuna* biomass, inedible grain, hosting rodents and reptiles, aggressive plant suppressing other crops if grown in association, highly flammable biomass when dry, and lack of specialization of *Mucuna* seed production (i.e., no *Mucuna* seed system in place). Establishing a value chain around seed production could be an alternative. On the other hand, self-pollinating characteristic of groundnuts and prolonged viability of the seeds makes large-scale seed production to be commercially unviable because farmers can replant and harvest their own seeds (Tsigbey et al., 2003).

With regard to the adoption of pigeon pea, the adoption rate is low in the north of Benin but moderate in the south (Assogba et al., 2017). In general, the main constraints are: grain does not cook easily, animal damage on produced biomass, dry biomass susceptible to fire, low yield and poor seed quality in the 2nd year of production, lignified stems that are difficult to manage/decompose and non-existence of technical itineraries.

The difficulties of implementing technologies that are technically efficient are very restrictive to implement and are demanding, regardless of the technology considered (Akpinfa et al., 2016, Baba et al., 2016). For example, in the extreme northern and northeastern parts of Benin, characterized by agro-pastoral production systems, the biomass of *Mucuna* is well appreciated by animals and even therapeutic for them. Therefore, conflictual relationships prevail for *Mucuna* use as green manure and animal feeds.

Livestock farming in the area by pastoralists, especially free grazing after harvest of the main crop, jeopardizes the adoption of GMCCs, e.g. *Mucuna* fallows, leading to conflicts between arable farmers and the pastoralists.

Land pressure due to continuous immigration in specific regions, e.g. central Benin, is not only reducing potential for pure GMCCs but also resulting in deforestation of primary forests and conversion into agricultural land for growing cotton, groundnut, and maize.

Weaknesses in outreach strategies: Increasingly, the strategy put in place to promote the adoption of technologies by producers is based on the principle of cascade training (Assogba et al., 2017). Firstly, this consists of training technical support agents who, in turn, are responsible for training producers "models", "relay," or "pilots". The training of producers is conducted around farmer field schools, farm schools, or demonstration plots. The goal is to build local expertise to support producer technical support and better ownership of sustainable land management (SLM) technologies while reducing the costs of disseminating SLM and producer training. However, the method of selection of relay producers, on the one hand, and the return of relay trainings to other producers, on the other hand, do not promote sustainable adoption of technologies. Secondly, the selection of producers is carried out by the technical agents and the leaders of the beneficiary organizations. Their choice is mainly based on the availability of the individual, its open-mindness and ownership of a demonstration plot. This selection method does not give all producers the same chance of selection as relay producers. If resources are concentrated at the level of the demonstration plots for the training of relay producers, these are practically non-existent after training. Thus, the relay producers rarely return the training received and, given the high number of other potential beneficiaries of the actions of the projects, the technical agents concentrate their effort only on the relay producers. This often limits the scope for the real beneficiaries of the project to few relay producers, thus reducing the expected impact of the projects.

Late gender considerations: Projects often do not integrate the gender dimension during their conception phase (Assogba et al., 2017). Also, the consideration of gender varies according to various projects. It translates into the involvement of women in production, processing, and marketing activities or in the extension of SLM technologies as model producers, housing demonstration plots.

Social environment: After great enthusiasm, the use of cover crops in Benin shows limits in the acceptability of these technologies by farmers (Séguy and Bouzinac, 2001). Often, the lack of direct economic return hinders their adoption in a more intensive farming system. The farmer rarely sees long-term fertility conservation as a driver of change (Lynch and Maggio, 2000).

Poverty: The work by Leach and Mearns (1992) established a theoretical causal relationship between poverty and the state of environmental degradation. It is, therefore, questionable whether poor farmers degrade the environment of the cultivated areas and adopt less practice of improved fallow with legumes. The theory has been applied to the particular situation of Benin. The main objective was to determine the influence of farmers' well-being on their production systems and their adoption of agroforestry: the cases of *Mucuna* and earleaf acacia *(Acacia auriculiformis)* in southern Benin (Houngbo et al., 2012). It has been shown that the poorer the farmers, the less they adopt *Mucuna* and then practice soil mining. Although farmers are aware of the positive effects of GMCCs, their adoption rate is generally low. Poorer class farmers adopt less technology than all other farmers. Poverty appears to be a decisive obstacle to the adoption of GMCCs in southern Benin in particular and in Benin in general (Floquet , 1998). Poverty alleviation is, therefore, needed to improve the adoption of sustainable agriculture practices in Benin. This fight can go through the valorization of seeds by producers. Establishing a value chain around seed production could be an alternative.

Land tenure: For most rural populations in developing countries, apart from the labour force, land is the main factor of production, and often remains the only asset with which wealth can be generated and developed (Vendryes, 2014). The issue of land tenure security is often identified in Poverty Reduction Strategy Papers as a major focus for promoting agricultural growth and hence poverty reduction. This vision is based on theoretical reasons that tenure security promotes agricultural investment, access to credit (because land can be used as collateral), adoption of sustainable soil fertility management practices and agricultural productivity (Besley, 1995; Place and Otsuka, 2001; Abdulai et al., 2011).

GMCC context: Each GMCC has specific situations in which it can be adopted, and these need to be identified as a pre-condition. For *Mucuna* and leguminous shrubs, these have been identified as secondary production by the cover crop, high weed pressure to address, soil rich enough to support the main and secondary crop, shorter working time, and positive response of the main crop to the cover crop (Schulz et al., 2001; Hauser et al., 2002).

Canavalia ensiformis pods sampling in Western Kenya (photo: CIAT/Michael Kinyua)

Western Kenya

3.1 The context for GMCC cultivation in Western Kenya

Western Kenya is a tropical region characterized by altitudinal variability and diverse soil types. Rainfall ranges between 1,000 to 2,000 mm per year and is distributed between two rainy seasons in most areas, with long rains in March to July and short rains from September to November. The predominant soil types in the region are Nitisols, Ferralsols and Acrisols (Jaetzold and Schmidt, 1982).

Ferralsols are the most inherently nutrient depleted soils in sub-Saharan Africa. They cover extensive areas on generally well drained, flat land, are associated with old geomorphic surfaces, and are thus strongly weathered.

Similarly, or only little less nutrient depleted are **Acrisols.** They are distinguished from Ferralsols by the accumulation of low activity clays in an argic (= Lat. for clay) subsurface horizon, and thus drainage may be hampered.

Both soils often have low cation exchange capacities (i.e., the capacity to adsorb and retain nutrients like potassium, calcium, and magnesium), a low soil pH accompanied with toxic amounts of aluminum, and deficient levels of micronutrients (boron, manganese, molybdenum).

Nitisols are deep, reddish, and well-drained soils with a nito-argillic (kaolinite dominated) subsurface horizon containing blocky structural elements with shiny faces. They are mainly derived from volcanic ash. The soils are fine textured, rich in iron, but less weathered than ferralsols. Nitisols are generally 'fertile' and unlike ferralsols and acrisols, they have a higher cation exchange capacity despite having low levels of soil available phoshorus.

About 68% of the region has high agricultural potential (Tittonell et al., 2008). Nitrogen (N) and phosphorus (P) are the major limiting nutrients to food production (Shepherd and Soule, 1998). The average farm sizes are between 0.5 and 2 ha. The region has diversified land-use systems ranging from smallholder subsistence farming to commercial farming along the sugar belt in the northern areas (Rotich et al., 1999). The main staple crops grown include maize, beans, cassava, sorghum, and finger millet, while cash crops include tea, sugarcane, cotton, tobacco, coffee, vegetables, fruits, and rice. The main mineral fertilizers used are di-ammonium phosphate (DAP) at planting, and mavuno, calcium ammonium nitrate (CAN) and urea for top dressing while triple super phosphate (TSP) and rock phosphate are less used (Tittonell et al., 2005; Sibusisiwe et al., 2013).

Decline in soil fertility is a major factor that impedes crop productivity in Kenyan smallholder farming systems (Mugwe et al., 2009). In Western Kenya, especially, the majority of the smallholder farmers are resource poor and unable to purchase expensive inputs (Marenya and Barrett, 2007) at the right quantity and time to boost soil fertility (Yawson et al., 2010) and improve their yields.

"The benefit-cost ratio is often too low to encourage farmers to apply fertilizer, because of the relatively high fertilizer price at farm gate, the low market price of food crops like maize and the high year-to-year variability of the agronomic efficiency of fertilizer applied. An overestimation of the risk of failure to break even when applying fertilizer by farmers adds to the dilemma. Furthermore, fertilizer recommendations developed in the past often ignore differences between soils and are highly incompatible with smallholders' resources.

Sommer et al., 2013

Farm yard manure (FYM), alongside being unavailable at the recommended levels, is considered by most smallholder farmers as bulky and labour intensive during preparation and application (Odendo et al., 2006; Ngome et al., 2011).

Intensive mono-cropped cultivation coupled with insufficient fertilizer inputs and short fallows has increased nutrient deficiencies and amplified the prevalence of pests and weeds like striga weed (Khan et al., 2002). Increased striga weed infestation has greatly decimated the agricultural productivity in some areas, occasioning poverty and food insecurity. Farmers, pressed specifically by soil infertility, took up short weedy fallows practiced by 52% of farmers (in about 10–50% total land) for one (24%) or two seasons (35%) to increase the fertility (Swinkels et al., 1997). But green manure cover crops smoothed out striga while also providing an environmentally sustainable yet cheaper route of enhancing soil health.

In Kenya, GMCCs were introduced by the Legume Research Network Project (LRNP) in 1994 as a technology for curbing soil degradation through provision of soil cover and enhancing soil fertility (Mureithi et al., 2003a). Research on cover crops had initially been focusing on their utilization as livestock fodder with little consideration on their use in soil fertility management (Maobe et al., 1996), yet, their role in agricultural yield improvements was inevitable (Gachene et al., 2000). The major cover crops grown in western Kenya include lablab), jack bean, *Crotalaria*, velvet bean, *Desmodium*, groundnut, *Stylosanthes*, canola (*C. juncea*), siratro (*Macroptilium atropurpureum*), and soybean.

Canavalia ensiformis *rotational phase - farmer in Western Kenya (photo: CIAT/Michael Kinyua)*

3.2 GMCCs and their integration in cropping systems in Western Kenya

Lablab

Lablab purpureus

Lablab

It is a herbaceous leguminous crop with multiple uses. It grows well between altitudes of 0 and 1,800 masl. Although susceptible to pests and diseases, lablab is drought tolerant. It is a source of food and fodder, and is easily intercropped with cereals such as maize and sorghum. Within such intercropping, it is inter-seeded 3–4 weeks after maize to reduce competition. The nutrient content in lablab biomass is about 4% N and 0.18% P.

Photo: CIAT / Michael Kinyua

Mucuna

Mucuna pruriens

Mucuna

It is an efficient climber and has high soil fertility amelioration potential. It grows at latitudes between 0 and 1,800 masl. In order to reduce competition with the main crop, *Mucuna* is best established as an intercrop 3–4 weeks after the cereal emergence. The *Mucuna* nutrient content is about 3.6% N and 0.17% P (Gachene and Kimaru, 2003). However, its utilization as food is limited because it contains anti-nutritional compounds such as phenolics, L-Dopa, tannins protease inhibitors, lectins, etc. (Eze et al., 2017). In addition, there is conflicting information regarding its utility as both food and feed leading to underutilization of the crop (Pugalenthi et al., 2005). Because of its competitiveness during growth, the crop can be used for weed suppression. In addition, *Mucuna* is a good nitrogen fixer, improves soil fertility, and controls soil erosion.

Photo: CIAT / Michael Kinyua

Crotalaria

Crotalaria ochroleuca

Crotalaria

It is a fast-growing drought-tolerant legume with excellent nodulation (hence effective N fixation capacity) and nematode suppression properties, and is important in rehabilitation of infertile land, especially if planted as a fallow crop. *Crotalaria* does well at altitudes between 1,300 and 1,800 masl. The legume can be intercropped 3 weeks after planting, matures within 3–4 months, and is adapted to poor soils. Nutrient concentration of *Crotalaria* biomass is 3.0–3.6% N, 0.13–0.14% P, and 0.9–1.6% K (Gachene and Kimaru, 2003). *Crotalaria* fallow, as soil fertility management, recycles about 163 kg N ha^{-1} $season^{-1}$ and 11 kg P ha^{-1} $season^{-1}$ from the biomass and increases total soil C by 1.5–1.6 g C kg^{-1} compared to systems without GMCCs (Thor-Smestad et al., 2002). Some varieties are edible while others can only be used as fodder before flowering because seeds are highly toxic.

Photo: Genebank CIAT

Canavalia

Canavalia ensiformis

Canavalia

It grows well at altitudes between 0 and 1,800 masl (Gachene and Kimaru, 2003). The nutrient concentration in *Canavalia* biomass is about 3.5% N and 0.16% P (Gachene and Kimaru, 2003). It is a useful livestock fodder, good soil cover and ameliorant, tolerant of drought and shade. It is usually sown as a relay crop 4 weeks after maize establishment.

Photo: CIAT / Michael Kinyua

Desmodium

Desmodium intortum; green leaf

Desmodium

It is a cover crop that grows well in altitudes between 0 and 1,900 masl. The nutrient content in *Desmodium* biomass is about 3.4% N and 0.15% P (Gachene and Kimaru, 2003). *Desmodium* plays an important role in weed management in Western Kenya, where it suppresses striga infestation through allelopathic effects of its root exudates (Midega et al., 2013; Khan et al., 2002). *Desmodium*, once established, is efficient in N_2-fixation and soil cover provision.

Photo: CIAT / Michael Kinyua

Soybean

Glycine max

Soybean

It is a grain legume with high biomass productivity. It is commonly regarded a main cash crop. However, soybean has also been promoted as a green manure legume that provides surface cover, soil amelioration (retention of residues), and nitrogen fixation (Mureithi et al., 2003b; Vanlauwe et al., 2003; Onyango et al., 2004; Misiko et al., 2008). In Western Kenya, soybean is mainly produced in Kakamega, Mumias, Bungoma, Busia, Teso, Lugari, Mount Elgon, and Vihiga. Mumias, Busia, and Bungoma districts are the leading soybean producers out of the eight regions (Chianu et al., 2008). The nutrient content in soybean biomass is about 3.52% N and 0.15% P (Gachene and Kimaru, 2003).

Photo: CIAT / Michael Kinyua

Cowpea

Vigna unguiculata L. Walp

Cowpea

It is a stress-tolerant grain legume, vegetable, and fodder crop that is adapted to wide ranging climate conditions. In the late 1990s, some 52 cowpea cultivars were screened in Western Kenya for adaptation, biomass yield, and maturity period. Local cultivars are more productive in terms of biomass yield (Saha and Muli, 2000).

Photo: www.tropicalforages.info/ILRI

Groundnuts

Arachis hypogaea

Groundnuts

They are legumes mostly grown in the lower midland (LM1-4) agro-ecological zones of Western Kenya (MoA, 1996). It is a persistent and drought-tolerant legume though its growth can be retarded if the cumulative monthly rainfall is below 100 mm. In Western Kenya, the crop can produce between 600 and 700 kg/ha/season of grains (Langat et al., 2006) and 2–2.5 t ha^{-1} $season^{-1}$ of dry matter. *A. hypogaea* accumulates more nitrogen than *Mucuna* although the latter is able to fix more N from the atmosphere (Ngome et al., 2011).

Photo: CCAFS / V. Meadu

Stylo

Stylosanthes hamata

Stylo

It is a perennial legume, mainly adapted to sub-humid and humid regions with altitudes of between 1,000 and 1,800 masl and 1,000–2,200 mm rainfall. It is tolerant to both drought (deep penetrating roots) and shade, hence suitable for intercropped systems. Stylo can produce high volumes of organic matter by shedding its small leaves, an attribute that helps it to survive dry seasons in a deciduous state. The legume has better branch ramification when cut about 15 cm above the ground and can produce a dry matter of up to 3 t ha^{-1} when harvested after 4 months of establishment (Macharia et al., 2010).

Photo: www.tropicalforages.info / Wal Scattini

The main GMCC cropping systems in Western Kenya can be distinguished into three:

Intercropping GMCC with maize: practiced in regions receiving bimodal rainfall with two maize crops per year. The GMCCs are planted either concurrently (single row) with maize or two weeks after planting the main crop. Intercropping has about 30% lower GMCC grain production compared to rotational systems (Okoko et al., 1998, Kipkoech et al., 2007).

Relay-cropped GMCC with maize: mainly in regions receiving unimodal rainfall. Maize is mostly planted in April while GMCCs are added in August. To improve insolation of the young GMCC plants, sometimes the lower maize leaves are clipped. Cover crops are left growing after maize is harvested, and are incorporated into the soil at field preparation in the successive season.

Maize-GMCC rotation: mainly in areas receiving bimodal rainfall but with unreliable second season, or where farmers do not cultivate maize in the second season. GMCCs are planted in September and are incorporated during land preparation in the succeeding year.

Other emerging cropping systems where GMCCs are integrated by farmers include:

Intercropped with vegetables: upright growing legumes like *Crotalaria,* and jack bean can be intercropped with vegetables since they do not entwine the vegetables and leave enough light for the, usually low-growing, vegetables.

3.3 GIZ work in Western Kenya

Work by GIZ in Western Kenya can be traced back to early 1990s. In 1993–1998, GTZ in collaboration with the Kenyan government and FAO established a soybean Project (SBP), which was implemented in two phases (1993–1995 and 1996–1998). The focus was to foster development of the soybean sector, variety research i.e., developing soybean varieties for the different agro-ecological zones with production potential, promoting production, processing, and consumption, and offering market information. The key area of research was establishing trials for experimenting adaptability of the various soybean varieties, germplasm acquisition, and examining responses to fertilizers and rhizobium. Yield prospects from six varieties (of 300 lines) assessed in GTZ SBP project (1993–1998) ranged from 600 to 1,900 kg ha^{-1} depending on the agro-ecological conditions.

More recently, GIZ is working on "Sustainable approaches for the broad-based promotion of soil protection and rehabilitation of degraded soils" in Western Kenya with MoA through KALRO, acting as their main implementing partner. GIZ has offered intervention in three counties of Western Kenya, namely Siaya, Kakamega, and Bungoma, where about 247,500 smallholder farmers have been reached. About 33,000 hectares of smallholder-cultivated land, which is affected by degradation, is targeted for rehabilitation or protection. A total of 7,384 hectares have already been rehabilitated. Funding has been directed towards supporting smallholder farmers in application of good soil rehabilitation practices with the aim of reducing erosion and improved soil structure and fertility. Their assistance has enabled a needs-based fertilization (organic and inorganic). In collaboration with partner agencies, GIZ facilitates training programs on best farming practices, e.g., conservation agriculture and integrated soil fertility management (ISFM) within the regional training centres and funds valuable soil analysis equipment, which includes training of KALRO staff. GIZ is carrying out demonstrations on use of lime in combating soil acidity, which has received positive reception by smallholder farmers due to the increased maize and bean yields. In demonstration areas, maize and beans yields have increased by about 36% and 32%, respectively, after soil protection and rehabilitation measures were embraced. Other key partners include GOPA (Association for Organization, Planning and Training), Welthungerhilfe, local NGOs such as Rural Energy and Food Security Organization (REFSO), Anglican Development Services (ADS), and Community Empowerment for Sustainable Development (CESUD).

GIZ is looking forward to generating a handbook on soil protection that will be used in the provision of action-oriented overview of common practices and their impacts for adaptation to climate change and biodiversity conservation by the agricultural advisory service and farmers. The main challenge to their work in Western Kenya is the exceptional climatic and weather events, which prevent yield increase despite the laid measures to revitalize the soil. GIZ produces context-specific technological packages and joint operational plans for soil conservation and rehabilitation of degraded lands where 50% of the planned activities in package are implemented in each of the three districts. They also offer special promotion of women-friendly technologies in soil protection e.g. CA and agroforestry. Besides GIZ, others that worked or are working with GMCCs in Western Kenya are shown in Table 4.

Table 4 Other key partners and organizations that have worked on GMCCs in Western Kenya

PARTNERS	YEAR	GMCC TYPE	OBJECTIVES/CHALLENGES ENCOUNTERED
Sugar companies (Mumias, Sony and Nzoia)	1985–1996	Soybean	- Introducing soybean in sugarcane-based farming systems
Sigma project	1992–1993	Soybean	Not successful - Seed viability problem - Poorly organized marketing
FAO/KAFPROD	1994–1996	Soybean	- Enhancing strong production base - Training and utilization
IFAD/FAO/MoA	1996–1999	Soybean	- Training through farmer field school - Promoting production and utilization
Canadian International Development Agency	1997–1998	Crotalaria	- Impact of *Tithonia* and *Crotalaria* fallows combined with P fertilization on soil fertility and SOM
Rockefeller Foundation and KALRO through Legume Research Network Project (LRNP)	1994	40 GMCCs	- Determine inoculation and P fertilization needs of the species - Evaluate GMCC as a component of Integrated Nutrient Management - Assess GMCC value in controlling *Striga* - Provide information on suitable legumes across 11 ecological regions of Kenya
Rockefeller Foundation and KALRO	2003	*Lablab*, jack bean, *Crotalaria* velvet bean, *Desmodium*, groundnut, lima bean, stylo, siratro, and soybean	- Assess capabilities of GMCC to fix atmospheric N_2 under on-farm conditions across AEZs and soil fertility gradients - Compare N balance of GMCC through N_2-fixation to smallholder farms

PARTNERS	YEAR	GMCC TYPE	OBJECTIVES/CHALLENGES ENCOUNTERED
Rockefeller Foundation and KALRO through Sustainable Community Oriented Development Programme (SCODP)	2005–2009	Soybean	- Soybean increase, commercialization and marketing of soybean
BIOTA-subproject and KALRO	2007	*Desmodium*	- Effect of combined organic and inorganic inputs on maize growth
Bill and Melinda Gates Foundation	2008–2010	Soybean	- Focusing productivity in drought-prone areas (Butere, Mumias, Migori, Teso, and Busia)
German Academic Exchange Service (DAAD)	2009–2010	*Desmodium*	- Maize grain yield after intercropping desmodium varieties - Varying *Desmodium* cutting regimes impacts on maize production and Striga - Economic viability of *Desmodium* spp. and cutting regimes
KALRO, Cornell University (USA), University of Nairobi, Egerton University, Appropriate Rural Development Agriculture Program (ARDAP), Rural Energy and Food Security Organization (REFSO), and AVENE Community Development Organization			- Integrate promising multipurpose grain legumes into farming system (Nandi, Vihiga, and Busia Counties) - Develop, refine, and scale out promising legume options for improved system productivity

Farmer survey in progress (photo: Christopher Nyakan - WHH)

3.4 The adoption of GMCCs technology in Western Kenya

Employing green manure cover technologies in the farming systems can help in increasing cereal yields through improved soil fertility (Fofana et al., 2004; Kifuko et al., 2007). However, adoption of GMCCs by farmers is generally low due to a wide range of biophysical and socio-economic factors that increase the level of complexity and variability of smallholder farming systems (Kipkoech et al., 2007; Ndufa et al., 2007). Utilization of GMCCs in smallholder farming systems has also been associated with several constraints that have hindered or reduced their cultivation in Western Kenya. Some of these constraints include: lack of cultivation knowledge, inaccessibility to seeds, reduced research on new accessions of seeds adaptable to the changing climate, increased labour during cultivation and incorporation, loss of crop season when rotated with food crops, among others. More attention has been given to some of the above mentioned constraints. Identification and address of these constraints is critical to enhance adoption of the GMCC technologies by smallholder farmers.

3.4.1 Inadequate GMCC cultivation knowledge by farmer

Lack of GMCC cultivation knowledge was ranked the top reason why farmers in Bungoma, Siaya, and Teso had low cover crop adoption (Wakhu-Wamunga et al., 2014). In Siaya and Teso, farmers were reluctant to adopting GMCC cultivation and utilization despite the recommendations from agricultural officers. In addition, lack of knowledge on the multiple use of GMCC crops reduced their adoption rates. For example, during a survey in Kakamega and Trans Nzoia regions, farmers had knowledge on a specific Crotalaria species that is utilized as a vegetable but were not aware of species used for soil fertility management (Odendo et al., 2000). This is evident by the existence of projects e.g. “Scaling up farmer-led seed enterprises for sustained productivity and livelihoods in Eastern and Central Africa” by ASARECA and other partners who were promoting the crop for vegetable use and not for soil fertility improvement (Karanja et al., 2012).

Because of the few agricultural extension agents in Western Kenya, the small number of farmers accessing the knowledge on utility of green manure legumes for soil fertility are those hosting green manure trials (Ndufa et al., 2007). This could be one of the reasons for the limited GMCC technology diffusion in the region. In addition, the majority of farmers implementing the GMCC technology have inadequate knowledge of cultivation, production, seed preservation, and storage, which leads to post-harvest losses that discourage their cultivation (Ndufa et al., 2007).

On the part of implementers and promoters of GMCCs, there is lack of knowledge on decomposition, mineralization, nutrient demand-supply synchrony, fertilizer equivalence values of GMCCs, and time of residue incorporation in relation to time of planting the main crop. This may hinder their ability to offer proper recommendations to farmers on the type of GMCC species to cultivate, when, and the amount of residues to apply so as to meet the varying nutrient requirements in specific farmer fields. The soil bio-physical and economic benefits derived from GMCC technology should be exhaustively exploited so that farmers know the profitability of adopting the various GMCCs. Lack of knowledge on nutritive benefits in some of the cover crops such as *Mucuna* could be a major drawback for its adoption considering that the crop is unsuitable for utilization as food (Eze et al., 2017). However, the promoters of GMCC (MoA Bungoma, GOPA) are developing appropriate and cost-effective methods of eliminating such anti-nutritious factors in legume diets (i.e., *Mucuna*).

3.4.2 Inadequate farm labour

Over 60% of farmers in Kakamega and Trans Nzoia experimenting with GMCCs pointed out that green manure legumes technology in the trials did not require much labour due to the small sizes of experimental plots. However, the farmers could foresee that much labour would be required in their own larger farms (Odendo et al. 2000). The labour needs resulted from legumes being established concurrently with the main crop at the onset of rains. Secondly, children no longer supplement the limited household labour because they have to report to school. Labour groups that used to help in reducing workloads during farm management are no longer in existence hence the farmer has to pay for casual labour (Ojiem et al., 2007). In most cases, labour shortage results to delayed start of field activities which derail the realization of full potential of the GMCC adoption.

3.4.3 Accessibility of farm inputs

In as much as a large pool of farmers may want to adopt the GMCC technologies, they are faced with limited legume seed and fertilizer access. In 2018, a scoping mission in Western Kenya revealed that some GMCC seeds have low viability if stored for long, and failure to access fresh seeds affects plant density and establishment. Screening studies on the suitability of different legumes for the varying agro-ecological zones of western Kenya were done for decades and recommendations provided, which in most cases are yet to be applied. For example, in 1998, a survey on 300 lines of soybean recommended Nyala, Duiker, EAI3600, SCSI, Sable, and Gazelle varieties for release as a result of their high grain production potential (Kaara et al. 1998). However, there are very few agro-dealers selling the improved GMCC seeds with the cost of most of the cover crops being higher than farmers can afford (Kiwia et al., 2009). These constraints leave farmers with no option but to recycle the locally available seeds from the previous harvest (Kiptot et al., 2006). A farmer participatory study on groundnut production revealed that grain yields from locally accessed seeds were 30–50% lower than improved seeds (Okoko et al., 1998, Kipkoech et al., 2007). Therefore, if GMCC adoption rate is to increase in the region, a solution has to be provided on the availability and accessibility of improved GMCC varieties that are tolerant of abiotic stresses and adaptable to specific/multiple agro-ecological zones.


Maize biomass sampling (photo: CIAT/Michael Kinyua)

3.4.4 Adaptability of GMCCs to the changing climatic conditions

The suitability and performance of the various GMCC species is dependent on the physical environment in which it is cultivated. As the environmental conditions consistently change, crops that were previously grown by farmers become no longer suitable for these areas. For example, Ojiem et al., (2007) reported how farmers in Bondo district experienced changes in cover crop production over time. Cowpea, which they used to plant as relay in maize systems, is no longer suitable with delays in planting increasing the chances for crop failure (Ojiem et al., 2007). In addition, groundnut production has also declined with farmers getting between 30 and 50% of their potential yield (Kidula et al., 2010). The changing climate has also resulted to unreliable rainfall and emergence of new pests and diseases, which affect the existing cover crops. Therefore, there is a heightened need for better strategies and improved GMCC accessions that can be integrated into the existing cropping systems while concurrently promoting climate-smart soil protection and rehabilitation.

3.4.5 Increasing population with decreasing land holdings

Western Kenya has been experiencing agricultural intensification that has led to continuous crop production and population growth (Valbuena et al., 2015). However, the average farm holding in the region is continuously reducing, thus limiting the utilization of crop rotation, which accelerates soil degradation (Nambiro, 2008). Utilization of cover crops in cereal rotations could lead to loss of a crop season, particularly if the cultivated legume has anti-nutritional value, e.g. *Mucuna*. This would lead to farmers considering continuous cereal cropping or cultivating other crops with nutritional value but that does not necessarily improve soil fertility.

3.4.6 Sustainability of the introduced technologies

After completion of projects promoting the use of GMCC technologies in western Kenya, no strategies are put in place to address on how a critical momentum beyond a project can be maintained in order to sustain the utilization of the introduced technologies. This results to farmer dropping the technologies, hence the expected transformation in smallholder farmer production is not achieved (Okoko, 2000). There is hence a need to plan on how such technologies can be sustained after project completion so as to achieve the ideal objectives of soil rehabilitation and nutrient management.

Taking soil penetration resistance test in conventional tillage system - WHH staff in Western Kenya (photo: CIAT/Michael Kinyua)

Taking soil water infiltration test in conventional tillage system - WHH and CIAT staff in Western Kenya (photo: CIAT/Michael Kinyua)

Conclusions

- GMCCs have a positive influence on crop production and soil fertility.
- In order to continue promoting the GMCCs, there is need to focus on quality GMCC seeds. Improved seeds with high viability should be easily accessible and affordable to farmers. Development of new accessions of leguminous and gramineous cover crops that can tolerate weather variability under different agro-ecological zones and can be utilized in different land use systems.
- Generation and distribution of seeds which are compatible with the cropping systems, e.g. growth behaviour (upright, minimal competition for light and moisture) should suit utilization as intercrops.
- Introduction of GMCCs that favor multiple uses encourages farmer adoption since they can be utilized as soil ameliorant, crop protection, fodder, and feed for the animals.
- There is a need to increase farmer knowledge on cultivation and utilization of GMCC. This could help in eliminating acquired beliefs on some GMCCs that negatively affect their adoption by smallholder farmers.
- Both economic characterization (post-harvest handling, marketing) and niche identification for GMCCs should also form part of future research.
- There should be farmer awareness on improved practices, besides the communal grazing on agricultural fields that causes compaction, and integration of GMCCs in such practices for soil rehabilitation.
- In Benin, the government should ensure public sensitization on the need for a mutual understanding and co-existence between the conflicting arable farmers and livestock keepers.

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