Green manure cover cropping

Green manure cover cropping and carbon sequestration in Tanzanian small-holder agriculture.

Oskar Sjöberg

Bachelor's thesis

Sustainable Coastal Management

Raseborg 2020

BACHELOR'S THESIS

Author: Oskar Sjöberg
Degree Programme: Sustainable coastal management
Supervisor(s): Lars Fridefors

Title: Green manure cover cropping and carbon sequestration in Tanzanian small-holder agriculture.

Date: May 6, 2020 Number of pages: 36 Appendices: 1

Abstract

Small holder farmers in Tanzania face great challenges as the soil fertility decreases and they therefore consequently also experience a decrease in yields. The reasons for this can partly be traced back to climate change but also to a decline in nutrients and organic matter in the soil. The main research question of this study is if green manure cover cropping is an effective method for soil improvement and carbon sequestration? The thesis was commissioned by FIDA International.

To answer the research question a literature study, interviews with professionals and a survey done among local small holder farmers were conducted. As a part of the literature study, previous research on green manure cover crops, carbon sequestration and adaptation was analysed. The interviews with the three professionals were done by me on-site in Tanzania. The survey was conducted by a local man as structured interviews with 44 participants in the Arusha region.

In conclusion, green manure cover crops are an effective way to fight climate change and soil degradation. Long-term research should continue in a national Tanzanian context where the most important climate zones and soil types are included with the most important species and their combinations. In addition to the research, the mindsets of local small holder farmers and stakeholders should be affected for wider adaptation. This can be achieved through increased awareness and knowledge sharing through the use of lead-farmers and demonstration farms.

Language: English Key words: green manure, cover cropping, carbon sequestration, sustainable agriculture, small-holder agriculture, Tanzania

Foreword

This thesis has been a very interesting and in a good way challenging process for me. This process has forced me to get out of my own comfort zone and to study a topic which was not very familiar to me from the beginning. I'm happy and thankful that I was presented this opportunity by FIDA International to do my thesis work on GMCC and in Tanzania which is a dear country for me.

I would like to thank Daniel Korpela, Country Programme Manager at FIDA International for proposing this topic to me, and together with being my supervisor while doing my internship in Tanzania, supporting and giving med enthusiastic and valuable input into the research process. I would also like to thank the FIDA team in Tanzania, especially Lomayani Laizer, Project Coordinator, and Samson Mhir, Project Coordinator for being good colleagues in Tanzania, but also for their valuable input. From the FIDA team in Tanzania I would also especially want to thank Elijah Kitadu, Intern, for working close with me and successfully preparing, implementing and reporting the survey results.

I would like to thank Neil Rowe-Miller, Agriculture and Livelihoods Technical Advisor in Eastern Africa at Tearfund, Erwin Kinsley, Director at Echo East Africa Impact center, Roland Bunch, California State University and David C Johnson, New Mexico State University for their valuable input.

From Novia I would like to thank my supervisor Lars Fridefors, Senior Lecturer, my teacher Stefan Heinänen and all other teachers.

Last but not least I would like to thank my family for the love and support.

Table of contents

1 Introduction

1.1 Background

The target group of this thesis is Tanzanian small holder farmers, the topic is green manure cover crops (GMCC) and carbon (C) sequestration. The target group and topic are chosen due to a personal interest in the region and the topic, and also because of the specific research question suggested by FIDA International. The soil has always been an important resource for the farming population. When the soil is resilient and nutritious, it is good to grow crops in, allowing the population to get food on the table and also to get an income for sustainable living. The declining soil fertility is a great challenges for local farmers as the African population is greatly dependent on small holder farmers growing food for their own consumption and for selling the crops to other villagers (Kimaru 2003). If the crop yields continue to decline, and the population growth continue to climb there will be very serious challenges for the locals. As there usually is no governmental social security system available, people are forced to make ends meet. So, if the local farmer is not able to grow food because of degrading soil and lack of nutrients there will be serious lack of food as we have seen happening in many places. One major threat for the Tanzanian soil is climate change (Arndt 2012). This is causing decline in soil fertility which causes reductions in agricultural production and hinder the development of the rural parts of Tanzania (Olsson 2019). The soil is low on organic matter and is also low on nutrients like nitrogen and phosphorous (Hamisi n.d.). This affects the agricultural crops and consequently the food security risking the lives of the Tanzanian people. As there is a limited supply of manure compost for improving the agricultural soil, and the limitations in the practical, environmental and economic aspects of transporting it, other alternatives must be found and implemented. The use of synthetic fertilizers is not a good alternative for several reasons including emissions, the cost of acquiring it for local small-holder farmers and the lack of soil improvement characteristics (Shetto 2007). GMCC have shown good results concerning improvement of soil fertility and production (Bunch 2019). In addition to increasing the soil organic matter, fixing nitrogen, improving drought resistance, preventing erosion and improving biodiversity, GMCC also have great potential to fight climate change (Arndt 2012; Bunch 2019). By sequestering C by fixing atmospheric carbon dioxide (CO_2) through photosynthesis in plants and returning it back into the soil increasing the soil organic carbon (SOC) stocks. GMCC plays an important role in increasing the level of soil SOC which in itself has an important role in the sustainability of the agroecosystem (FAO 2011). SOC plays an important role for soil structure, water dynamics, microbial activity, biodiversity, atmospheric C/nutrient cycling and SOC pools (Zomer 2017). When the level of SOC decreases all of the beforementioned benefits are reduced and the consequences are severe, including noticeable decline of crop yields (Bunch 2019). From a sustainability perspective, small holder-farmers using GMCC reduce the consumption of non-renewable resources, for example in production of synthetic fertilizers, and increase the use of renewable resources. The increasing problem of climate change and CO_2 emissions requires many innovative ways of C sequestration, one of them being sequestration in agricultural soils by using GMCC. These methods will probably attract both investors and critics, and because of this, it is of greatest importance to understand and exactly estimate the possible gains and losses of using GMCC in mitigating crop yield decline and climate change.

1.2 Definition of aim

The aim of this study was to research the effectiveness of soil improvement, adaptation and C sequestration using GMCC in Tanzanian small holder agriculture. The research was done by researching and reviewing the theory behind C sequestration, studying earlier research, conducting interviews with stakeholders and by comparing different geographical and biological aspects of C sequestration/GMCC. The research was limited to studying small-holder agriculture in Tanzania. It was also limited to studying specific GMCC generally and traditionally used in Tanzania small holder agriculture.

Research question:

Is green manure cover cropping an effective method for soil improvement and C sequestration?

1.3 Outline

This thesis starts with defining the problem that will be researched. It continues with methods and a theoretical background study regarding the C cycle including photosynthesis, decomposing and respiration. Following that comes a chapter on soil C sequestration. After this the thesis covers the GMCC, GMCC methods, advantages-disadvantages, common Tanzanian species and GMCC C sequestration. The research and the result section ends with the survey done in Tanzania among small-holder farmers on GMCC and by adaption of GMCC management systems in a Tanzanian context. The thesis ends with discussion, conclusions and recommendations.

2 Materials and methods

In this theoretical case study three different research methods were used, a literature review, a survey and interviews. Even though I would have preferred a more practical approach, the method for this research was chosen because it was not possible in the framework of this research to do any practical experiments in Tanzania. As a result of this, the research was done through analysing existing literature, interviews, personal communication with researchers and a survey. For this research I did not find any well documented research focusing on GMCC in a Tanzanian or in an East-African context. There is a quite a lot of research done in North America and also in South America, especially concerning Brazil. The sources were filtered, and relevant sources related to GMCC and those that could be converted to ton per hectare per year (t/ha/yr.) were selected. Three studies were found of which one was global, one was conducted in Benin and the last one conducted in Brazil. Through email correspondence with renowned researchers in the field, Roland Bunch PhD (California State University) and David C Johnson PhD (New Mexico State University), I got information from two sources that could be applied in a Tanzanian context, unfortunately the results were not scientifically documented, or at least I could not get my hands on the documentation.

The interviews conducted with professionals locally in Tanzania were done with Neil Rowe-Miller on the 22.10.2019 (Agriculture and Livelihoods Technical Advisor in Eastern Africa at Tearfund), Erwin Kinsley on the 17.10.2019 (Director at Echo East Africa Impact center) and Lomayani Laizer on several occasions (Project Coordinator, FIDA International). The interviews were mostly open discussions and were therefore not analysed systematically. The result can therefore be seen as supporting information for the other results and the discussion. The persons interviewed were identified, as persons with experience and competency, together with my internship supervisor Daniel Korpela (Country Program Manager, FIDA International). The questions asked the beforementioned persons covered GMCC adaptation, GMCC C sequestration and about relevant questions for the survey etc.

In the survey, local Tanzanian farmers were interviewed to get their opinion on GMCC farming and its benefits. The survey was prepared by me with the help of Samson Mhir (Project Coordinator, FIDA International) who assisted with the questions to make them relevant and Mr Elijah Kitadu (Intern, FIDA International) who translated them to Swahili. The survey was done in the Arusha region between the 9.2.2019 and 12.12.2019. The survey was done by Elijah Kitadu who hired a motorcycle driver and a guide in every village to locate the farmers. The survey included taking pictures, taken by Elijah Kitadu, in every location, some of which are presented in figure 15 and 16. The goal of the survey was to identify how aware the respondents were of GMCC and in which way the use of GMCC had influenced their farming practices and outcome. The survey was done using KoboToolBox (Harvard Humanitarian Initiative, www.kobotoolbox.org/) which is a smartphone-based application that saves respondent responses, positions, pictures and other information into a central database. This database was exported to excel and analysed to gather the necessary information. After the survey was completed Kitadu wrote a report of the possibilities and challenges when doing this survey, these conclusions have been included in this paper.

3 Theoretical background

3.1 Carbon cycle

The C cycle shown in figure 1, is a biogeochemical cycle where C cycles through all four of the major elements: atmosphere, hydrosphere, lithosphere and biosphere. In these SOC pools C is stored for a different average time, in lithosphere it is long, in atmosphere it is short and in biosphere/hydrosphere it is intermediate. (Botkin 2005). Processes of respiration turns C into CO_2 and to compensate for that photosynthesis collects the CO_2 from atmosphere and turns it into carbohydrates in the plants. Yearly one fifth of the CO_2 in the atmosphere is cycled in and out from both land biota and with the oceans (Houghton 2009). Giffords (2003) research (as cited in Abdullahi 2018), supported that the amount the plant is using when generating energy for its own growth process is 45% of the maximum amount of C a plant can produce. The more the plant is using for production of carbohydrates, the more is transferred to the soil as stable SOC pools and the rest is lost back to the atmosphere as respiration.

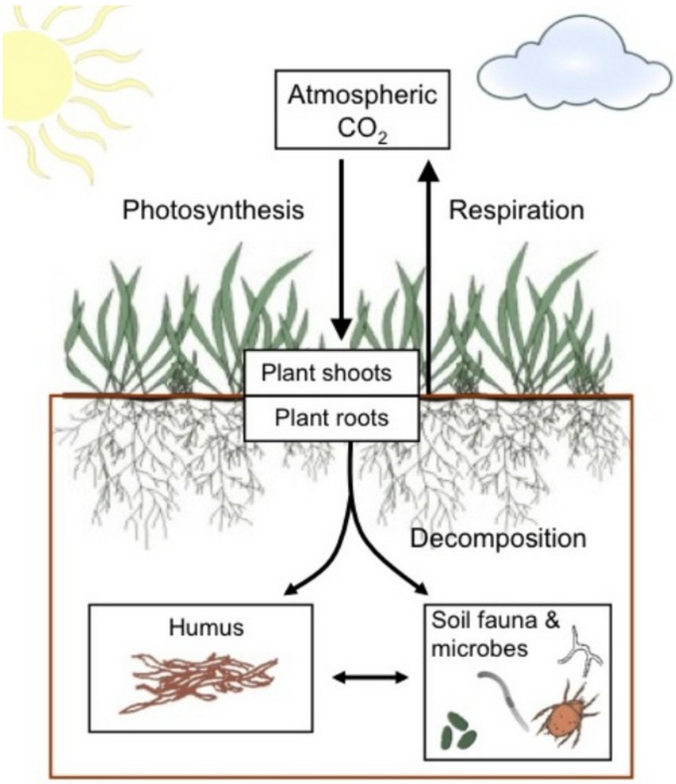


Figure 1 C inputs from photosynthesis and C losses by respiration controls the C balance in the soil. (Ontl and Shulte 2012)

3.2 Soil organic carbon

Soil organic matter (SOM) is very important because it has an important role in soil structure stabilization, holding and releasing of nutrients and water level management, which does not only affect the productivity of agriculture but also environment preservation. Of this SOM, about 55-60% is SOC (FAO 2017). Most of the SOC comes from plants as biomass. When they die, organic C compounds are left in the ground. Microbes use these compounds for energy and building blocks while the C is transferred into the new compounds in their own biomass, some is released back into the ground and the rest released into the atmosphere as CO_2 and CH_4 (Kane 2015; FAO 2017). SOM has an effect on the physical, biological and chemical soil properties and has a big impact on how the soil functions. The organic matter consists of soil fauna and microbes. Soil fauna in East-Africa includes earthworms, termites, spiders, ants, beetles, mites, springtails and potworms (Ayuke 2019). Microbes includes fungi and bacteria, decaying matter from plants and animals, their faecal matters and the decomposed matter from them (Ontl 2012). Soil biodiversity including both soil fauna and microbes has an important role in production of food and in the resilience of the soil to climate change, and soil fauna moves SOC to deeper depth in soils for greater storage time (FAO 2017). SOM, which is a mixture of highly C enriched matter is directly connected to the soil organic levels. The SOC pool is a result of several processes, key processes being photosynthesis, respiration and decomposition. The input of SOC in usually measured using root biomass, but also includes the matter coming from the plant parts above the ground. The SOC is directly a result of the growth and deaths of the roots of plants but also indirectly a result of the symbiotic associations between plant roots and soil-microbes. When soil microbes decompose the biomass, it results in microbial respiration which causes C loss while a small part of the C stays in the soil as humus, a long-term storage for SOC, giving the soil its dark colour. (Ontl 2012).

How long the C is stored in the soil depends on respiration and the soil structure. If the SOC is well protected from microbes through soil aggregation, then there is less respiration due to less activity by microbes using the C as their own energy source and releasing C. Microbe activity is enhanced by higher temperature, high moisture, nutrient availability and oxygen concentrations. C can be fixed to clay by chemical reactions or re-synthesized to complex molecule structures, which also protects C from microbes. The time C remains in the soil can be divided into three categories. The fast SOC pool usually holds the C from a few days to a few years before the C is again released into the atmosphere. The fast SOC pool consists of fresh plant residues and similar. The slow SOC pool usually holds the C from years to decades and consists of plant residues that are more processed and C molecules that are protected from microbes by soil characteristics. The stable pool consists of humus and is slow to change and has a holding time from centuries to millennia. (Kane 2015; FAO 2017).

Soil aggregation mediated by fungus which protects the SOC together with the effectiveness of fungal microorganism process in the earth increases C sequestration (Six 2006). By increasing soil fertility and by keeping the fungus/bacterial ratio high it is possible to lower the amount of SOC lost through soil respiration. Fungus in the soil is increased by the addition of plant litter to the soil while the bacterial ratio is largely similar. This contributes to the fungal dominance which increases SOC sequestration. (Malik 2016).

3.3 Photosynthesis

In the photosynthesis, which is a part of the C cycle, the plant takes CO_2 from the atmosphere. This is a part of the process of producing oxygen (O_2), water (H_2O) and carbohydrates ($C_6H_{12}O_6$) which will be used by the plant as an energy source.

In the photosynthesis process electrons, transferred by light energy, produce carbohydrate from water (H_2O) and C dioxide (CO_2). During this process the water loses electrons and the C dioxide receives electrons. (Vidyasagar 2018).

$$6CO_2 + 12H_2O + \text{Light Energy} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

In this case six molecules of C dioxide (CO_2) reacts with twelve molecules of water (H_2O) with the input of light energy. The end products are six molecules each of water and oxygen together with a single carbohydrate molecule ($C_6H_{12}O_6$, or glucose). (Vidyasagar 2018)

3.4 Plant respiration

C is cycled back from the plant to the atmosphere through the release of energy from the carbohydrates created in the photosynthesis. This process in the plants is a chain of chemical reactions and is called cellular respiration. The plant respiration occurs in the stem, the leaves and in the roots of the plants. The main objective for the respiration is to produce energy for the plant and its cells for growth or to stay alive. The respiration includes oxidation of the carbohydrates, or the glucose. In this process it combines the carbohydrates with oxygen and releases C dioxide, water and energy. (Royal Society of Chemistry n.d.).

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$$

In this case the single carbohydrate molecule is broken down together with six molecules of oxygen. The end products are six molecules each of CO_2 combined with six molecules of water and about 3000kJ mol^{-1} of energy. (Royal Society of Chemistry n.d.). In the respiration process the C dioxide removed by photosynthesis is returned to the atmosphere as a waste product.

3.5 Decomposition and soil respiration

Soil respiration is the combination of the decomposition of soil organic material, the respiration of soil fauna and of root respiration.

When decaying plant parts are added to the surface of the soil it gives its contribution to biological activities and the process for soil C cycling. In this process the organic material is broken down in the soil and also includes the growth and decomposing of plant roots. Plants and microorganisms are a part of C cycling which is an ongoing movement of organic and inorganic C compounds. (Kane 2015).

In the process of decomposition there are different things that are released: CO_2, methane (CH_4), nutrients, water, energy and organic C compounds that have been rebuilt. Humus is created by a process called humification as a result of successive decomposition and modified organic matter. In the decomposition process humus is an important organic matter as it improves soil properties, increases the capacity of water storage and also it sequesters atmospheric C. In the mineralization process microorganisms in the soil use SOM as food and as organic matter is broken down excess nutrients are realised into the soil. (FAO 2005). When organic matters decompose under oxygen-poor conditions, mainly in waterlogged soils, CH_4 is released from the soil (FAO 2017). In this case temperature and nitrogen determines how much C is sequestered because methane emission is regulated by them (Kane 2015).

Humus resulting from the decomposition of organic matter is a longer-term SOC storage pool as it is not easily further decomposed because of its characteristics and consists of approximately 60% carbon (Encyclopaedia Britannica n.d.).

3.6 Soil carbon sequestration

Depending on management systems and land use, the soil can work either as a sink of C or as an emitter of atmospheric CO_2, as is shown in table 1. Management systems that add organic matter to the soil and use no-tillage methods tend to fix more C into the soil. The management systems that fix C into the soil work with certain methods: reduction of erosion, diverse cropping systems, reduced tillage, healthy use of fertilizers etc. (FAO 2005).

Table 1 Characteristics determing whether soil fix or loose atmospheric CO2. Cited from (FAO 2005).

Soil as a source of CO_2	Soil as a sink of CO_2
Soil properties: coarse textured soil, excessive drainage, high susceptibility to erosion	Soil properties: clayey soil, poorly drained ecosystems, depositional sites, including foot slopes
Land use: seasonal crops, simple ecosystem, shallow roots and low root-shoot ratio	Land use: perennial crops, diverse ecosystem, deep roots and high root-shoot ratio
Soil management: intensive tillage based on plough, negative nutrient balance, residue removal and/or burning, continuous cropping, loss of soil and water by runoff and erosion	Soil management: no tillage, positive nutrient balance, mulch farming cover crops in rotation, cycle, soil and water conservation

SOC sequestration is a process where C is harvested from the atmosphere by photosynthesis and keeping it in into the soil by hindering the microbes from releasing it into the atmosphere again by respiration. The rates of C sequestration depend on local conditions of land management, land use and landscape combined with C inputs. Ecosystem processes such as soil erosion, rainwater infiltration, soil temperature and deposition of sediments also affects C sequestration in the soil. (Ontl 2012). The exploitation of the soil decreases the amount of soil SOC and decreases the amount of C sequestered in the soil, opening up an opportunity to sequester more C from the atmosphere.

CO_2 is on an average absorbed by a living plant usually within a few years after its released into atmosphere and on the average released back into the atmosphere within a few years after that. The only long-term storage pool are the deep oceans where C can be stored for a long time, but it takes centuries or decades for the released C to reach that status. (Baird 2008). C sequestration in the soil is a relatively quicker way and has additional benefits of increasing the soil organic material for improved soil and increased yields.

Most of the C found in the terrestrial ecosystems is found in the soil. The total of C in the terrestrial ecosystems is about 3150 gigatons (GT) and of this is approximately 2500GT (80%) found in the soil. Comparatively the atmospheric pool is approximately 800GT and the oceanic pool is approximately 38 000GT. (Ontl 2012). As the amount of C emitted to the atmosphere annually is around 9 GT/year and the amount found in the atmosphere at any given time is 3,8GT/year the rest, 4,9 GT/year, must be sequestered by terrestrial systems giving the terrestrial system (including soil) a great potential for sequestering C. (Abdullahi 2018)

As the focus is on the C stocks in the 0-30 cm depth range it is important to also put more emphasize on the deeper soils as it can also contributes significantly to the SOC stock. Ideally the research should include the whole C soil profile and include the depth range of 0-100cm. (Börjesson 2018). To include also subsoil C stocks and to be able to take samples using hand-tools it is recommended to increase the depth range to 0-50cm (Simo 2019). Going even deeper than 100cm can bring more long-term C stocks as the turnover time increases with depth (Lorentz 2005).

The soil has reached a C saturation limit when the processes in the soil cannot protect more C from microbes. At this point the soil either starts to be a source of CO_2 or it stabilizes and consequently only stores as much CO_2 as it emits on a yearly basis. The soil type has great influence on the saturation limit and despite the soil having a saturation limit, most of the soils are far from being saturated. (Kane 2015).

The changes to management practices must also be done with long-term perspective as the shortest time suggested for large scale observations when reaching a point of saturation where soil C gains and losses are in balance is 20 years or more. For comparing different options land management on site specific locations shorter periods like 10 years, might be usable. Also, if there is a lack of management data shorter times can be acceptable. (Goglio 2015)

Brito et al. study (2005) (as cited in FAO 2005) stated that soil temperature has great impact on CO_2 emissions as soil respiration is accelerated by high temperatures. For this reason, not only for reasons mentioned before, it is important to cover the soil with for example GMCC. This will keep soil temperatures down reducing CO_2 emissions.

3.7 Green manure cover crops

According to (Bunch 2019), a green manure cover crop is:

"Any species of plant, usually a legume, whether it be a tree, a bush, a vine, a crawling or a water-borne plant, that farmers use (among other reasons) to maintain or improve their soil fertility or control weeds"

Traditionally green manure is grown by itself and when the growth and the plant is still green, it is ploughed into the soil. This is done before the main crops are planted. Small holders in the tropics do it in another way. First of all, because of lack of land they do not have the possibility not to grow food, the green manure must be grown at the same time as the main crops or during the dry season. Usually GMCC is grown intercropped with the main crops and only sometimes during the dry season. GMCC can also be grown below other crops, such as trees, or over the crops as trees to give shade. Secondly small holder farmers do not cut the GMCC during flowering stage but let them stand until they have produced seeds. These seeds are used for food, fodder and/or for income. Thirdly, small holder farmers almost always leave the residue on the ground, saving money and labour by not ploughing it into the ground. Fourthly, small holder farmers want to have other benefits from GMCC other than soil fertility such as using it as food, fodder or to sell. And last but not least, for small holder farmers, fertilizing the soil is not as important as controlling weed. (Bunch 2019).

GMCC can be planted among the main crops, bringing increases in the yield during the next years after the first year. An alternative is to intercrop the GMCC, planting them in the middle or in the end of the main crop growing season, in this case the GMCC would continue growing during the dry season. (Echo Community 1985). In the tropics there are over 150 different GMCC cropping systems including over 100 different GMCC species, giving a waste array of different possibilities for different biological and geographical conditions. Choosing the right cropping system includes some 20 different factors to consider, including the local and international market conditions, local food habits, locally dominant weeds and crops, environmental conditions, farmer preferences and local economic needs. (Bunch 2019). There is also a significant contradiction when poor/starving farmers must choose between applying space and labour requiring GMCC cropping systems that should be left on the soil to decompose and the needs of the farmers for food and fodder.

3.8 Advantages and disadvantages of GMCC

There are many advantages using GMCC, and also disadvantages, table 2. Despite all benefits of GMCC it is important to understand to disadvantages to successfully implement it, otherwise there is a big risk of failure. (Bunch 2019).

Table 2 Advantages and disadvantages of using GMCC (Bunch 2019; Echo Community 1985)

Advantages of using GMCC	Disadvantages of using GMCC
Carbon sequestration and increased SOM. Some GMCC can produce up to 1kg/m^2 of dry biomass building up the topsoil by about 2 cm/year. It also improves the soils structure and capacity to hold water, nutrient content, texture of the soils and friability.	Space for planting. The farmers will refuse GMCC especially if they are non-food-producing.
GMCC can provide protein rich fodder for the livestock especially in the end of the dry season. Some GMCC provide food for humans. Long-term yield increase.	Slow result. Results do not normally show before half-way into the second cropping cycle.
Nitrogen fixation. GMCC fix nitrogen together with micro-organisms called rhizobia. In the process nitrogen is taken from the air and increase the nitrogen in the soil making it available for the growth of the crops, usually between 80to 400 kg/ha N. This will reduce the need of synthetic fertilizers.	Dry season problem. GMCC can be destroyed during the dry season by animals, sun or fires.

Resilience to drought. GMCC improve the soils ability to infiltrate rainwater. Some GMCC that grow in harsh conditions can be used to recover wastelands.	Difficult growing conditions. Farmers must fight drought, free grazing animals, poor soils, flooding, sun or a combination of these.
Financial benefits. Low costs especially when compared to synthetic fertilizers (e.g. transport). GMCC do not need any financial input after the start as the farmers themselves will grow new seed and there is no need for chemicals. Increases income (selling firewood, food, fodder and seed).	Timing. It's important that that nutrients are available to plants when they need them.
Weed control and reduces pests. Some GMCC reduce the labour and the costs of weeding.	
Soil cover and erosion prevention. GMCC provide soil cover which prevents erosion and protects from wind. GMCC can also in the case of higher plants work as shades for the plants below, preserving moisture and organic matter.	
Zero tillage. GMCC reduces the tillage costs while reducing the loss for farmers during the low production period while reducing the need for machinery.	

When comparing GMCC to synthetic fertilizers and animal manure, there are differences. For most species synthetic fertilizers are not in the price range of small holder farmers and animal manure is not available for most small holder farmers in the extent needed. Compared to compost, composts require more work, only decomposes material already available without adding more and does not add new nitrogen to the soil. (Bunch 2019; Echo Community 1985).

The advantage with using GMCC compared to other management methods for increasing SOC is that GMCC increase the yields and it does not add C losses like using organic manure (Poeplau 2014).

For GMCC systems to be successful there are some things that need to be considered (Bunch 2019):

1. The land where GMCC are planted must not have any other income or food generating function.
2. The GMCC that do not produce any food or income must be very cheap or free.
3. GMCC must not increase labour much, especially if they are not generating food or income.
4. GMCC that do not generate food or income must fit well into the existing management system.
5. The GMCC should at least add one benefit to the farmer except soil improvement.

3.9 Green manure cover crop threats

Despite GMCC having many benefits, they are also threatened by different things. Some are caused by the nature and some are caused by humans. Some of the threats has already been covered above

There must be bylaws regulating the use of lands as traditions and cultural land use might give room for free grazing of livestock. In the local Tanzanian culture, it is common that you let the livestock free on agricultural lands after harvest. Unfortunately, bylaws are not always followed, and this causes frictions within the local communities. There is also a risk that corruption makes it possible for richer and more powerful farmers occupy the lands of the poorer farmers letting their livestock graze on their lands. Affordability and poverty are also a threat to use of GMCC. Poor farmers cannot afford to buy the seeds needed for planting or when GMCC are supposed to be let on the ground they let their own livestock graze on the fields, or they feed their own starving families. There is also a lack of knowledge and skills regarding GMCC among the majority of the small holder farmers. One threat is cultural believes, which might be seen as a very big threat. As many farmers worship their ancestors, they avoid upsetting their ancestors by disturbing the peace and order, which would cause problems to their village according to their believes. This hinders change from happening as farmers are reluctant to try out new things as if there is some kind of catastrophe hitting the village, the villagers will accuse the people trying out new things for disturbing the order and bringing the wrath of the ancestors over the whole village.

3.10 Green manure cover crop species

GMCC species can be divided into annuals and perennials. As annuals have to grow a new root system every year, the perennials have a root system at place from earlier years. When there is a drought this full-grown root system with access to water helps the plants to survive. Normal annuals also fail to improve the soil if they are grown in dry areas because they die early, and the residues suffer from heat and volatilization making them useless as GMCC. Short-term and long-term annuals can be used as GMCC as the can fertilize the crops they are grown with or have a life span that makes them survive until the next rain season. Where there is rain or shade, or in areas above 1500m, annuals can well be used as GMCC as they improve the soil as well as perennials and they produce food more quickly. (Bunch 2019).

Even though GMCC species are best introduced one by one, the more successful GMCC systems can include from three to ten species of GMCC. These systems improve not only soil-fertility, drought resistance, food production and biodiversity, but they also improve the overall health of the biological community of plants and animals. Although these systems are usually used by bigger farmers, most small-holder farmers would benefit from growing several GMCC in a management system. (Bunch 2019).

According to interviewed experts, Rowe-Miller, Kinsley and Laizer, the most common and good GMCC species in Tanzania includes cowpea (*Vigna unguiculata)* and lablab (*Lablab purpureus)*, whereas mucuna (M*ucuna pruriens)* and jackbean (*Canavalia ensiformis)* are good in areas where there is a problem with free grazing animals and they also fix greater amounts of N in the soil (personal communication, 2019). These species have different characteristics and are suitable in different management systems and geographical areas. Below, these four species are presented shortly.

Lablab beans (*Lablab purpureus)*

The lablab (*Dolichos lablab or Lablab purpureus*), shown in figure 2, fertilize the soil very well, produce 50t/ha/ biomass, control weed, and is easily intercropped with maize (*Zea mays)*. Lablab *(Lablab purpureus)* is popular among cattle as food as well as among humans. Although lablab *(Lablab purpureus)* in not well suited for degraded soils, it withstands drought well after it has grown to 4 months old. Lablab *(Lablab purpureus)* suffer from pests and often need some sort of pest control. The lablab *(Lablab purpureus)* resists drought very well, fits well in shady areas and requires soils that are well-drained. The lablab *(Lablab purpureus)* grows fast and need pruning if grown together with for example corn, it can also be intercropped at the end of the planting season. (Bunch 2019; Echo Community 1985).

Figure 2 Lablab (*Lablab purpureus*) intercropped with maize *(Zea mays*). (Source: https://www.echocommunity.org/resources/cbd44000-eb1b-42fd-999b-12a1cb3a04bd)

Cowpeas (*Vigna unguiculate*)

The cowpeas (*Vigna unguiculate*), shown in figure 3, fix N well and are tolerant to drought and acid soils. Unfortunately, they have little biomass and in lowlands they quickly lose all N before the next season. Cowpeas (*Vigna unguiculate*) are consumed by humans and can be also be found as the crawling cowpea (*Vigna unguiculate*), the 60-day cowpea (*Vigna unguiculate*) and as the “Lojy Be” (Cow pea (*Vigna unguiculate*). (Bunch 2019).

Figure 3 Maize (*Zea mays*) with a cowpea (*Vigna unguiculata*). (Source: https://www.echocommunity.org/resources/42b85f00-312c-414f-b905-7cf675acb675

Jackbean (*Canavalia ensiformis)*

The jack bean (*Canavalia ensiformis*), shown in figure 4, are very drought resistant and very resistant to poor soils. Almost no pests affect them, they fix a lot of N (240kg/ha/y) and produce more then 40t/ha biomass. They fit well in recovery of wastelands and is quick to improve the fertility of degraded land. It does not fit well into lands with much water but lives for months shading the soil during the dry season. The jack bean (*Canavalia ensiformis)* is preferably not edible by humans and not liked by animals and thereby fit well into areas where there are free grazing cattle. There are two versions of the jack bean (*Canavalia ensiformis)*, one version that climbs and also covers soil on the ground, and one version that is more like a bush and not climbing. The versions that do not climb are well fitted for controlling weed and for fixing nitrogen under for example fruit trees. (Bunch 2019; Echo Community 1985)

Figure 4 Banana trees with jack-bean (*Canavalia ensiformis*). (Source: https://assets.echocommunity.org/images/0375bd06-84b8-4c63-bc29-df336b09a028/banana-planting-with-jack-bean-as-a-cover-crop_sm.jpg)

Mucuna *(Mucuna pruriens)*

The mucuna or velvet bean (*Stizolobium pruriens or mucuna pruriens*), shown in figure 5 and 6, is considered the most important of GMCC. The mucuna (M*ucuna pruriens)* is not easy to eat but is very good at controlling weed. Mucuna (M*ucuna pruriens)* fixes N 140 kg/ha/y and produced biomass up to 60 t/ha/y. Mucuna (M*ucuna pruriens)* grows very aggressively and is not easy to grow with other species, dying after setting seed. It first covers the soil where planted and then starts to climb, over 6 meters high. The mucuna (M*ucuna pruriens)* is best used in areas with sandy soils and heavy rains, but not in waterlogged areas. It restores soil fertility quickly and survives drought well, but not as well as jack-bean (*Canavalia ensiformis)*. Using mucuna (M*ucuna pruriens)* as human food is safe if properly treated but is not well suited for some animals or not very much liked by some animals and thereby fits into areas with free grazing. (Bunch 2019; Echo Community 1985).

Figure 5 Mucuna (*Mucuna pruriens*) with maize (*Zea mays*). (Source: https://s3.amazonaws.com/docs.echocommunity.org/linked_images/ETN_Green-Manure-Crops_Page_4_Image_01.jpg)

Figure 6 Mucuna (*Mucuna pruriens*) with maize (*Zea mays*). (Source: https://s3.amazonaws.com/docs.echocommunity.org/linked_images/ETN_Green-Manure-Crops_Page_4_Image_01.jpg)

3.11 Green manure cover crops carbon sequestration

As we have seen before, soil is storing C, and has a big role in managing the level of CO_2 in the atmosphere. The removal happens naturally in the photosynthesis and the decomposing of plants, where it is sequestered. Where the plants produce a large amount of biomass and where there is a large amount of residues left on after harvesting and where there is not tillage of the soil, there is an especially big potential or the soil to sequester C.

It is of interest to notice how much the soil organic carbon content is dependent on which type of GMCC is used. From table 3, we can observe the examples from a study done in Brazil, here for example mucuna (M*ucuna pruriens)* adds 7,5 t/ha/yr. of biomass and of this biomass 52% is C. (FAO 2011). What is not included in this table biomass is the influence of the root system and other species in possible management systems. If included theses would purposely increase the biomass and possibly change the percentage.

Table 3 The amount of biomass produced, and the amount of C sequestered annually by the above ground parts of some GMCC species in Brazil. (FAO 2011)

GMCC	**Biomass (dry matter) t/ha/yr.**	**Organic C (% of biomass)**	**Organic C (t/ha)**
Pigeon Pea (*Cajanus cajan)*	9,2	56,3	5,2
Mucuna (M*ucuna pruriens)*	7,5	52	3,9
Jack Bean (*Canavalia ensiformis)*	7,7	50,15	3,9

Even though the amount varies a lot, GMCC of good quality produces from 10-20 ton/ha of biomass (dry weight). The amount in this biomass that reaches long term stability is not clear, but for poor soils it is approximately 20% and in rich soils it is 70%. (Bunch 2019).

3.12 Analysis of earlier studies

According to the study done by Poeplau and Don (2014) GMCC is an important option for increasing soil organic C. They did a study that included most of the cover crops studies in the world. Their meta-analysis concluded that the mean annual SOC sequestration of GMCC was **0,32 ± 0,88 t/ha/yr**. The study concluded that the sequestered C could last more than 100 years and around 50% of the SOC increase would happen during the frist 20 years. The study included results from 54 years and during this time no saturation was observed. Unfortunately there were no African countries included inte the study.

Experiments done by Barthes (2007) in Benin showed that there was an **1,3 t/ha/yr.** change in C stock in the 0-40 cm depth over a period of 12 years using GMCC relay-cropped with maize (*Zea mays)*. The GMCC was mucuna (M*ucuna pruriens)*, and it added 10 ton/ha/yr. of biomass with 83% of the biomass above ground. The total biomass of the mucuna (M*ucuna pruriens)* and maize (*Zea mays)* was 20 ton/ha/yr. Compared with a management system using fertilized maize (*Zea mays)* cropping the result was 0,2-ton C ha/yr. in the same depth range including 13 ton/ha/yr. of biomass. (Barthes 2007).

According to an email correspondence with Ph.D. David Johnson from New Mexico State University the C sequestration of GMCC in a 4,5-year trial was on average **10.7-ton** C/ha/year in 30 cm depth. I did not get any information where and how this number emerged, but as Johnson is active in the southern part of the United States, he can be assumed to have knowledge in tropical farming context.

In experiments made in Brazil (T. B. Amado 2001) it was concluded that the soil under a natural field did not change and remained stable. In the beginning of the experiment the field was prepared and for four following years the soil organic C content of the soil decreased. During the fourth to eight year of the eight-year experiment soil organic C additions occurred in all management systems. The biggest increase happened in the system using maize (*Zea mays)* and GMCC. The maize (*Zea mays)* itself did not have a substantial impact on the result but as GMCC increased the yields, also the maize (*Zea mays)* increased the level of C addition. The GMCC added (maize (*Zea mays)*-jackbean (*Canavalia ensiformis)*) on an average up to 2,2 t/ha/yr. of C to the soil where the maize (*Zea mays)* added 2,4 t/ha/yr., resulting in a total of 4,7 t/ha/yr. When using a traditional system (maize (*Zea mays)*-fallow) the addition of C was 0,2 t/ha/yr. for the maize (*Zea mays)* and 0,7 t/ha/yr. for the cover crops. Totally, under the 8-year period, then traditional system released 4,32 ton/hr of CO_2

when the maize (*Zea mays)*/mucuna (M*ucuna pruriens)* system during the same time period fixed approximately 16 ton/hr of CO_2. As we can see in figure 7, comparing to the other management systems the maize (*Zea mays)*/mucuna (M*ucuna pruriens)* sequesters approximately 20 tons more CO_2 t/ha, or approximately 5,4 t/ha C, than the traditional system. We can also observe that in this experiment most other systems than the maize (*Zea mays)*/mucuna (M*ucuna pruriens)* released more CO_2 than the natural field.

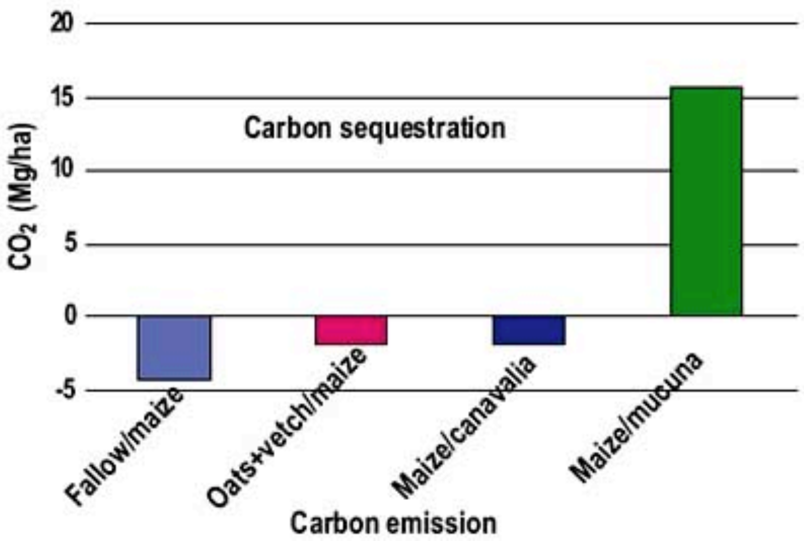


Figure 7 Estimation of release and fixing of CO_2 under different management systems compared with natural growth in southern Brazil (total during 8 years). Zero level is the filed under natural condition. Figure from (FAO 2005) adapted from (T. B. Amado 2001).

As there were no specific research available for East-Africa or specifically Tanzania it is not easy to make any clear specific conclusions. Looking at the results describes above, and in table 4, none of them specifically fits into the Tanzanian context. The research done by Popleau and Don (2014) was done in temperate regions. The research done by Barthes, et al. (2007) was done in Benin in West-Africa where the soils are acidic and generally low-fertility. There are many different soil types in Tanzania including the fertile soil of the volcanic areas and the river basin areas, and less fertile and dry areas of the plateus (Encyclopaedia Britannica n.d.). The results from Brazil by Amado are of course not directly comparable to an Tanzanian context, but there are some similar characteristics. For example, it is possible to intercrop because of more sunlight and heat, the direction of the sunligt and hand-farmed fields without mechanisation. There is also no winter and in addition to that there are a wast selection of GMCC species to mix together for the best result.

According to approximated calculations made by Bunch (2019), a moderate management system growing maize (*Zea mays)* intercropped with pigeon pea (*Cajanus cajan)* and "Lojy Be" (Cow pea (*Vigna unguiculate*) produced after the 10th year in total 17,5 t/ha biomass (dry mass). This biomass corresponds according to Bunch to **5,8 t/ha/yr.** sequestered long term C. These moderate calculations are made based on farming system based in tropical countries where growth is faster. According to email correspondence with Mr Bunch, the calculations on sequestration were not based on maximum values but on what could be widely be possible in Africa, and if they would be based on maximum values the value would be closer to those of Mr Johnson. Compared to afforestation/reforestation, which of course is very dependent of many factors, a typical annual sequestration rate for tropical forests is in the 3,2-10 ton/ha/yr. range (FAO 2001). Would it then be correct to assume that GMCC are good at sequestering C when using the best possible management system compared to traditional management systems.

Table 4 Comparison between sources (Poeplau 2014; Amado 2005; Bunch 2019; Barthes 2007; personal communication with David Johnson 2020; FAO 2001)

Source	Poeplau 2014	Amado 2005 Maize*-Jackbean**	Amado 2005 Maize*-fallow	Bunch 2019	Barthes 2007 Maize*-Mucuna***	Barthes 2007 Fertilized Maize*	Johnson 2020	Typical tropical forest (FAO 2001)
Location	Multiple countries	Brazil	Brazil	Afrika	Benin	Benin	n/a	n/a
C sequestration (t/ha/yr.)	0,32	4,7	0,9	5,8	1,3	0,2	10,7	3,2-10

*(*Zea mays),* **(*Canavalia ensiformis*), ***(M*ucuna pruriens*)

4 Results of the survey

The result of the survey is presented according to the themes in the questionnaire and in the same order as they were asked in the interview situation. The survey was done in 4 different locations and included 44 respondents. The locations were the villages of Losikito, Ekenywa, Oldonyowas and Olasiti in Arusha region, shown in figure 8. The relation between gender and age can be seen in figures 9 and 10. Answers to the questions on knowledge on GMCC, soil health and yields can be found in figures 11 and 12. Farmers were also asked about the reasons for stopping using GMCC and the answers can be found in figure 13. In figure 14 we can observe the farmers answers on which species they have tried on their lands. In figure 15 and 16 there is an assortment of pictures taken during the survey. The questionnaire can be found as an appendix to this thesis.

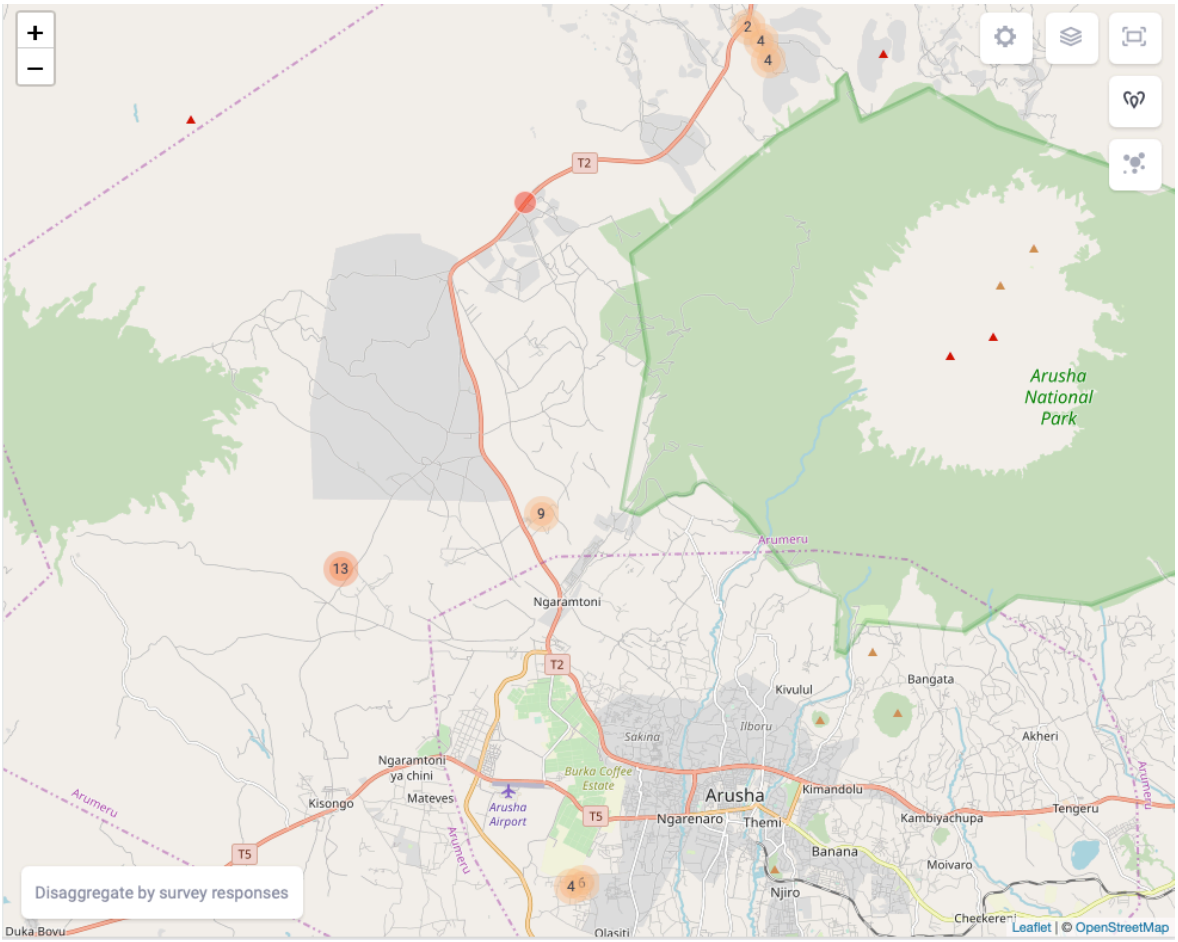
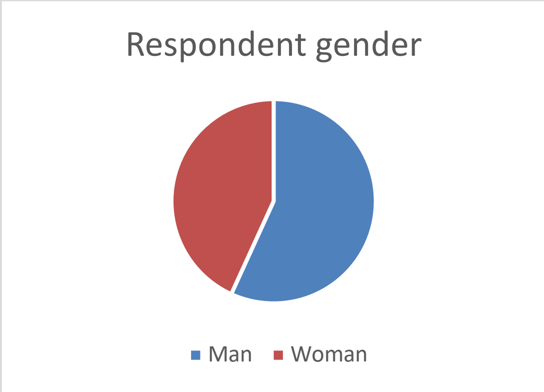


Figure 8 Positions of interviews in Arusha region (Source: KoboToolBox/OpenStreetMap)



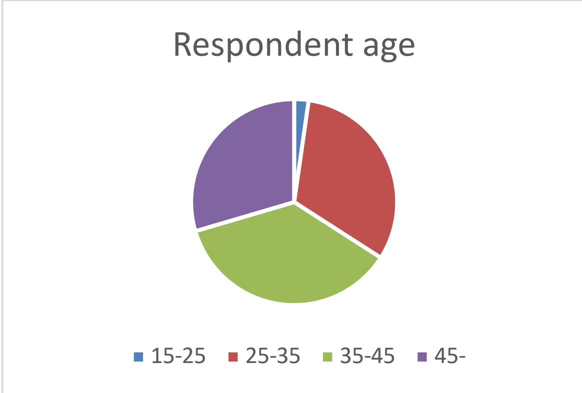


Figure 9 Respondent gender

Figure 10 Respondent age

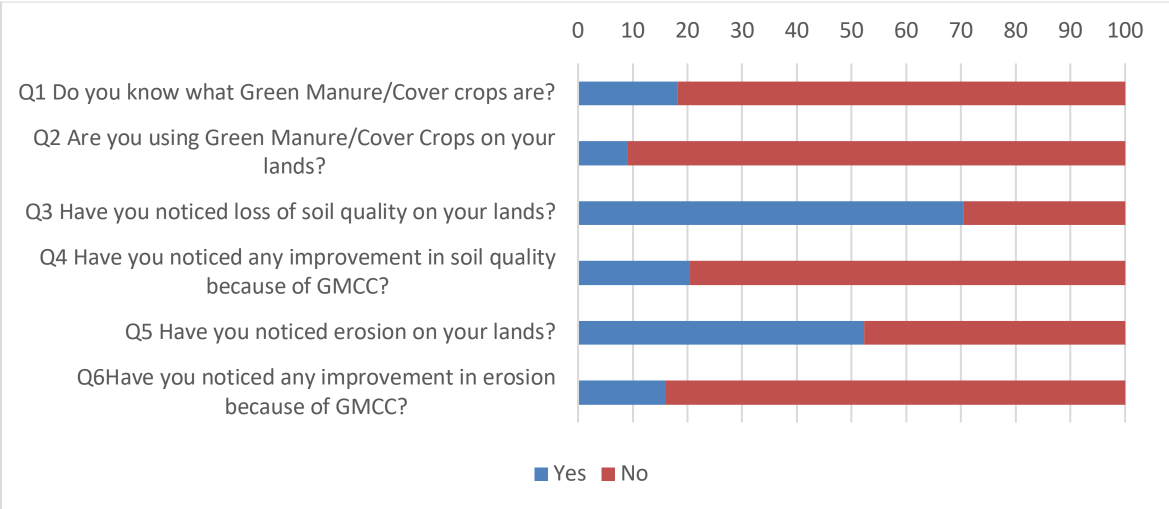


Figure 11 Survey questions 1-6 (Scale is percentage of the answers)

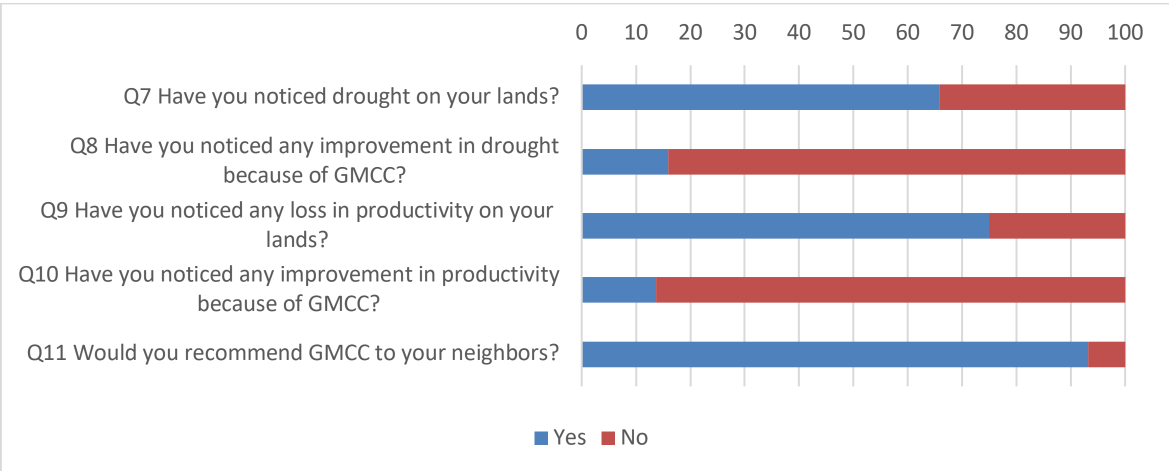


Figure 12 Survey questions 7-11 (Scale is percentage of the answers)

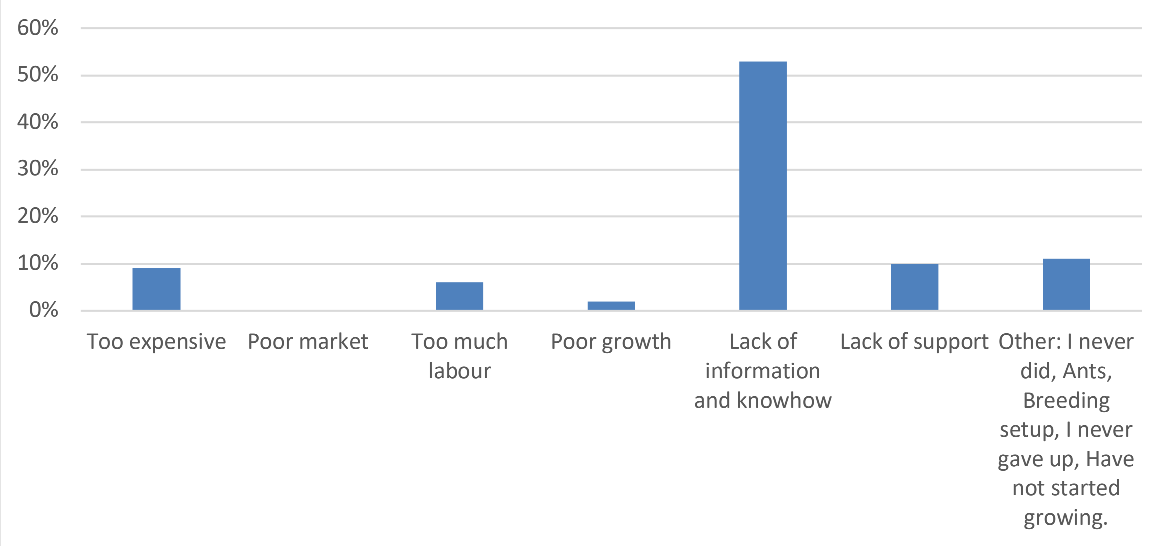


Figure 13 Survey question 12 “If you have used GMCC on your lands and stopped doing so, why have you stopped?”

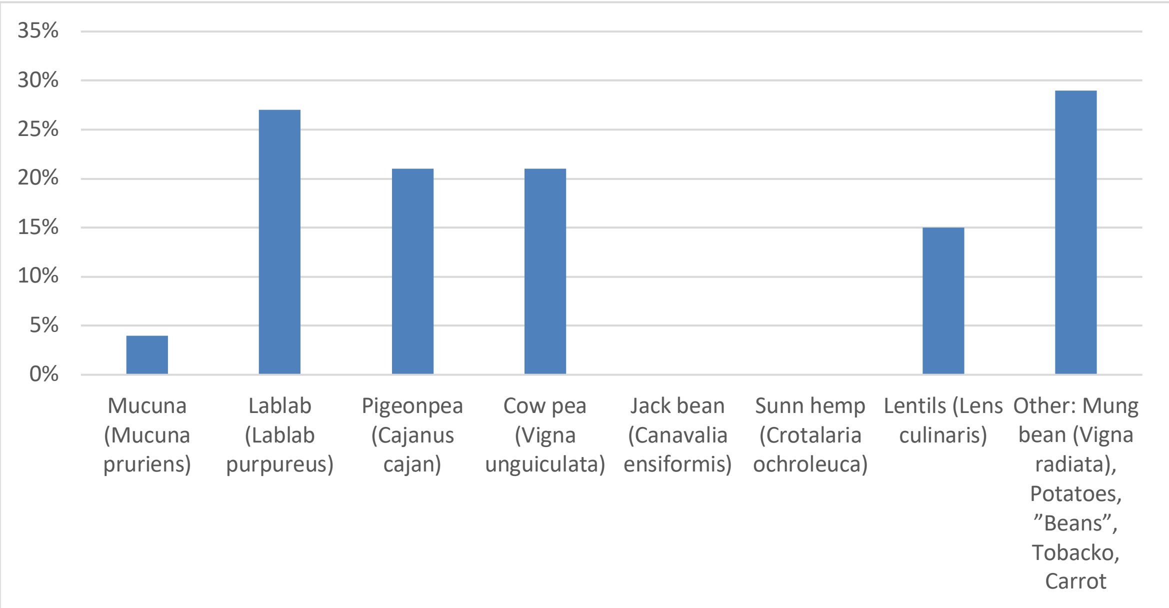


Figure 14 Survey question 13 "What species have you tried on your lands?"

Figure 15 Lablab (Lablab purpureus) and maize (Zea mays) (Elijah Kitadu 2019)

Figure 16 Lablab (Lablab purpureus) and maize (Zea mays) (Elijah Kitadu 2019)

5 Discussion

The main question asked in this thesis was if GMCC is an effective method for soil improvement and C sequestration? The analysis confirms that there is a potential for GMCC to act as both a means of improving the soil and yields, but also as a means of sequestering carbon in the soil and fight climate change. By using GMCC farming systems the amount of C sequestered is comparable to a typical tropical forest, compared to traditional farming systems the amount of C sequestered is multiple (T. L. Amado 2005; FAO 2001). The effects are great, increasing the amount of SOM and consequently SOC in the soil improves the livelihood of Tanzanian small holder farmers by increasing the yields combined with improved soil health, biodiversity, clean water and increased resilience to climate change (FAO 2017). Unfortunately, in the scope of this thesis and the research done within, it was not possible to find research to determine the actual amount of C sequestered in the soil by implementing GMCC management systems in a Tanzanian context. Secondly, even though the benefits of using GMCC as a means of improving the soil and yields, there is still a long way to go before a significant part of the farming community in Tanzania has implemented the method.

As mentioned before, the result of the literature study was weak as it was not possible to make any conclusions on the amount of C sequestered in small holder agriculture in Tanzania based on the available documentation, but it gave an insight in global C sequestration and adaptation. The different aspects of biological and geographical differences between different regions and species have a great influence on the outcome and must be taken into account when choosing GMCC species or combinations (Bunch 2019). In Tanzania there are eight different agro-climatic zones, five different agro-ecological zones and six different main soil types, all making it very complex to make any general conclusions (Sarwatt and Mollel 2006; Arndt 2012). But as experiments and research in other countries and continents has shown, by using appropriate GMCC farming systems for area and soil type in question, we can achieve the expected outcome (Bunch 2019; Poeplau 2014; T. L. Amado 2005; Barthes 2007). One aspect that came up during this study was the conflict between the traditional synthetic fertilizer driven farming system and the GMCC management system. Can this conflict decrease the introduction of alternative farming methods, which in itself hinders the research and adaptation of them? This is outside the scope of this thesis, but it is still an aspect to consider when trying to implement alternative farming methods such as GMCC.

The survey shows that the farmers experience the challenges that would be expected, for example soil degradation and erosion. The results indicated strongly that there is a lack of knowledge and information concerning GMCC. But at the same time most of the farmers were using some kind of legumes, which might simplify the adoption process. Also, most of the farmers that indicated that they knew GMCC (9%) answered that they had not experienced any improvement of drought, erosion or productivity. Still, around 10% used GMCC on their lands and 15-20% of the respondents had noticed an improvement on their lands thanks to GMCC, which would presumably make these farmers potential lead-farmers with demonstration farms. Presumably these farmers are already education their peers and sharing knowledge and best practices. If not, these farmers could potentially be approached for increased farmer to farmer learning, increasing awareness and know-how. The most common GMCC species, 27%, was lablab *(Lablab purpureus)* with 27% of respondents answered that they had used it on their lands, lablab *(Lablab purpureus)* was also mentioned in the interviews as one of the common and good species in Tanzania. It is also one of the most common species globally coming second to the pigeonpea (*Cajanus cajan)*, which came on a shared second place, 21%, in the survey with shared with the cow pea *(Vigna unquiculata)* (Bunch 2019). From a biological point of view, it is good that lablab *(Lablab purpureus)* is widely used as it produces biomass well, especially compared to cow pea *(Vigna unquiculata),* though it is probably mostly grown for food and fodder. Mucuna (*Mucuna pruriens)* and jack bean (*Canavalia ensiformis)* that were also mentioned as good and common species in the interviews did get very low response, presumably because these species are not easily edible for humans and cattle. There is a lot of inconsistency in the answers which probably says a lot about the difficulty of, not only making good surveys, but also of introducing new management systems. The way things are communicated are critical and things must be done in ways that are compatible with local customs and traditions. What is positive though, is that most of the farmers state that they would tell about GMCC to their neighbour. This could be seen as a sustainable foundation for wider adaptation.

Despite the benefits of using GMCC there are some challenges in adaption. Adaption is a crucial question when considering GMCC. The Tanzania agriculture does not only cover many different growing conditions and practical implications, but also different cultural challenges. Practically, the challenge of free grazing of livestock creates a lot of frustration if not supported by bylaws, which in itself is not a guarantee of success if not followed. Cultural traditions like the worshipping of change reluctant ancestors create conflicts where initiative farmers are willing to try out new methods. Mitigating cultural challenges is complicated but could presumably be successfully done through lead-farmer led development processes within the communities. Adaption requires a big change in how people think and act, of mind sets and of attitudes. Interviews done in Tanzania with Kinsley, Rowe-Miller and Lazier agree on that GMCC must bring benefits that are big enough to motivate the farmers to change the way they are farming, and the benefits must cover the cost of the needed change (personal communication, 2019). An effective way of introducing GMCC could be to use demo farms with lead farmers (Shetto 2007). These lead farmers can educate and involve other farmers, maintaining cultural sensitivity including indigenous knowledge (Shetto 2007). The lead farmers can be identified by observing farmers in a community, finding those who are innovative and active (personal communication, 2019). For sustainability it is important that these lead-farmers multiplicate where new farmers get inspired by the results and themselves become advocates for GMCC (Francis and Weston 2015). From the perspective of the westerner adaption might seem simple, we just tell our friends in the developing country how to do it and then the problem would be solved. In practice the task is multifaceted and must be approach holistically. It is important to remember that GMCC is a holistic, flexible system and not a system of strict procedures and methods. Combining a flexible system to a mindset where farmers have the possibility to express their concerns and include indigenous knowledge, will bring mutual learning, sharing of knowledge and best practices for GMCC in the specific context (Shetto 2007).

As such, for the small holder farmers to experience an improvement in life quality, there must be a mindset change not only on farmer level, but also on community and governmental level, where farmers are given opportunities to try out new methods without being exposed to prejudices and poor legislation. There are good alternatives of adaption methodologies that can be introduced, but for a successful outcome the farmers must be able to influence and feel ownership of the process. This cannot be achieved by pouring money or forcing new unconventional methods into a context which is not prepared to receive it, on the contrary that will leave a trail of failure in the Tanzania agricultural landscape. If it fails, the soil depletion will continue, the yields will continue to decrease and for the Tanzanians this is a question of life or death.

This thesis includes a literature study, interviews done with professionals locally and a survey done among local small holder farmers. As a whole, the combination of these elements covered the topic quite well. The literature study quite clearly showed that there is still a lot of systematic and documented research lacking in the field of using GMCC in a Tanzania context, especially regarding C sequestration. The result of this lack of systematic and documented research was that the conclusions were not made based on precise data but on a generalization based on the available information. The best way of getting the information regarding C sequestration by using GMCC would be to do practical experiments in Tanzania covering a wide array of species and locations. Unfortunately, this was not possible during the scope of this process, but hopefully somebody will implement this process in the near future. The process started in Finland in late September 2019, when the agreement was signed by the employer FIDA International me and Novia. The idea for the subject came from FIDA as a need has emerged from the field to study the subject of GMCC adaption and C sequestration. The research started in Finland during October and then I moved to Tanzania for three months to do my internship together with FIDA. This transfer to Tanzania gave the research the substance it needed because it thereby got down to a very practical level when doing research among Tanzanian small holder farmers, their practices and culture. To get the right overall picture of the possibilities and challenges it was very important to stay in locally Tanzania and observe. As we might imagine there were also some challenges. Most of them were predictable as language and culture. Fortunately, I have visited and lived in Tanzania before, so I was prepared for most of them.

The Arusha region is located in the north of Tanzania at an altitude of 1400m above sea-level and has because of this a very pleasant climate. Because of this many non-governmental organisations (NGO) has their base in the Arusha region together with many diplomatic offices. Because of the large number of NGOs in the region there is already a lot of activities in the agricultural sector. Many organisations work with improving the livelihood of local farmers introducing different techniques. Many organisations introduce conservation agriculture (CA) as a way of sustainable agriculture and some also introduce GMCCs as a complement to CA. In working with this thesis, I have been in contact with some of them as mentioned in paragraph 5.3. Using GMCC together with other management systems and other actors in the region is as such not a big challenge, but as everybody focuses on their own strategies it is necessarily not a high priority. As such there is a great need of soil improvement techniques that are affordable and not labour-intensive. Because of this, the topic of this thesis is highly relevant and the challenges regarding the adaptation of GMCC are commonly known and accepted.

Challenges involved in the survey were heavy rains that made it impossible to reach certain areas, farmers that were reserved and first believed that the interviewer wanted to sell them something, some farmers wanted to get paid to participate, language problems and some farmers did not want to give out information because they were suspicious. The interviews created a lot of discussions and a lot of questions about the aim of the survey. From the positive side, the cooperation with the farmers was good, also there was time to tell farmers about the benefits of GMCC, and also some of the farmers were really happy to learn more about GMCC.

The main challenge overall was communication, not so much the use of language, but the use of terminology. For example, how to make a survey in English, which then is translated into Swahili, and then partly presented to farmers mainly using Masai-language. Even though a name of for example a plant is correct in English, and maybe in Swahili and Maasai, the farmers do not necessarily use this specific name but something local and they know of no other name. Another limitation is that the survey could have had a wider geographical spread, now it covered only the Arusha region.

For myself I would want to continue this process of researching C sequestration and soil improvement through the adaption of GMCC techniques. As soil fertility is decreasing globally this method is as relevant in Tanzania as some other country. Thereby I will not restrict myself to work in some specific context, but again, East-Africa is close to my heart.

6 Recommendations and conclusions

The thesis aimed to find out if GMCC are an effective method for soil improvement and C sequestration. Based on the qualitative content analysis, interviews and the survey, it can be concluded that GMCC are an effective way to fight climate change and soil degradation in small holder agriculture in Tanzania. The result indicates that even though GMCC are an effective way, adaptation is still low due to lack of knowledge and cultural restrictions, this must be addressed through involvement of local farmers and awareness raising. Future research is needed to know the specific amount of C sequestered in the different farming systems and regions in Tanzania as it is of greatest importance to understand and exactly estimate the possible gains and losses of using GMCC in mitigating crop yield decline and climate change. Based on these conclusions, long-term research in GMCC should continue in a national Tanzanian context where the most important climate zones and soil types are included with the most important species and their combinations. There is also a need of wider awareness raising among local small holder farmers and stakeholders for wider adaptation of GMCC, this can be done through farmer to farmer knowledge sharing. For us westerners it is important to stay openminded when approaching the task in hand, while applying holistic and inclusive methods for empowerment of the local farmer. But as such GMCC is a sustainable way of improving yields and fighting climate change. By implementing simple and non-labour-intensive methods for increasing soil health and sequestering atmospheric CO_2 in the soil one can make a change for coming generations of small holder farmers, their families in Tanzania and the whole global family.

7 References

Abdullahi, A. Siwar, C. Shaharudin, M. & Anizan, I. 2018. *Carbon sequestration in the Soils:The Opportunities and the Challenges.* [Online] http://dx.doi.org/10.5772/intechopen.79347 [Accessed 06.02.2020]

Amado, T. Bayer, C. Eltz, F. & Brum, A. 2001. *Potencial de culturas de cobertura em acumular carbono e nitrogenio no solo platio dereto e a melhoria da qualidade ambiental.* [Online] http://www.scielo.br/pdf/rbcs/v25n1/20.pdf [Accessed 21.02.2020]

Amado, T. Lovato, T. Conceição, P. Spagnollo, E. de Campos, B. & Costa, C. 2005. *O potencial de sequestro de carbono em sistemas de produção de grãos sob plantio direito na região sul do Brasil.* [Online] https://www.researchgate.net/publication/284658053 [Accessed 17.02.2020]

Arndt, C. Farmer, W. Strzepek, K. & Thurlow, J. 2012. *Climate Change, Agriculture and Food security in Tanzania.* [Online] https://openknowledge.worldbank.org/handle/10986/12045 [Accessed 04.02.2020]

Ayuke, F. Kihara, J. Ayaga, G. & Micheni, A. 2019. *Conservation Agriculture Enhances Soil Fauna Richness and Abundance in Low Input Systems: Examples From Kenya.* [Online] https://doi.org/10.3389/fenvs.2019.00097 [Accessed 20.04.2020]

Baird, C. & Cann, M. 2008. *Environmental chemistry.* W.H Freeman and Company.

Barthes, B. Azontonde, A. Blanchart, E. Girardin, C. Villenave, C. Oliver, R. & Feller, C. 2007. *Effect of a legume cover crop on carbon storage and erosion in an utilsol under maize cultivation in southern Benin.* [Online] https://hal-bioemco.ccsd.cnrs.fr/bioemco-00175371 [Accessed 12.02.2020]

Börjesson, G. Bolinder, M. Kirchmann, H. & Kätterer, T. 2018. *Organic carbon stocks in topsoil and subsoil in long-term ley and cereal monoculture rotations.* [Online] https://link.springer.com/content/pdf/10.1007%2Fs00374-018-1281-x.pdf [Accessed 20.01.2020]

Botkin, D. & Keller, E. 2005. *Environmental science: eart as a living planet.* John Wiley & Sons

Bunch, R. 2019. *Restoring the Soil: How to use Green Manure/Cover Crops to Fertilize the Soil and Overcome Drouhgts.* ECHO. Inc.

Echo Community. 1985. *Green Manure Crops.* [Online] www.echocommunity.org [Accessed 06.02.2020]

Encyclopaedia Britannica. n.d. *Humus.* [Online] https://www.britannica.com/science/humus-soil-component [Accessed 17.01.2020]

FAO. 2001. "Food and agriculture organization of the United Nations." *State of the world's forests.* [Online] http://www.fao.org/3/Y0900E/y0900e00.htm [Accessed 24.02.2020]

FAO. 2005. “Food and agriculture organization of the United Nations.” *The importance of soil organic matter.* [Online] http://www.fao.org/3/a0100e/a0100e00.htm#Contents [Accessed 07.01.2020]

FAO. 2011. “Food and agriculture organization of the United Nations.” *Green manure/cover crops and crop rotation in conservation agriculture of small farms.* [Online] http://www.fao.org/3/i2190e/i2190e00.pdf [Accessed 24.02.2020]

FAO. 2017. “Food and agriculture organization of the United Nations.” *Soil organic carbon, the hidden potential.* [Online] www.fao.org/3/a-i6937e.pdf [Accessed 03.04.2020]

Francis, R, and P Weston. 2015. *The social, environmental and economic benefits of Farmer Managed Natural Regeneration.* [Online] http://fmnrhub.com.au/wp-content/uploads/2015/04/Francis-Weston-Birch-2015-FMNR-Study.pdf [Accessed 22.04.2020]

Gifford, R. 2003. "Plant respiration in productivity models: Conseptualizing representation and issues for global terrestial carbon-cykle reserach." *Functional Plant Biology* 30: 171-186

Goglio, P. Smith, W. Grant, B. Desjardins, R. McConkey, B. Campbell. & C. Nemecek, T. 2015. *Accounting for soil carbon changes in agricultural life cycle assessment (LCA): a review.* [Online] https://doi.org/10.1016/j.jclepro.2015.05.040 [Accessed 20.01.2020]

Hamisi, S. & Mbogoni, J. n.d. *Status, needs and priorities for sustainable management of soil resources in Tanzania soil resources in Tanzania.* [Online] http://www.fao.org/fileadmin/user_upload/GSP/docs/South_east_partnership/Tanzania.pdf [Accessed 20.04.2020]

Houghton, J. 2009. *Global warming.* Edinburgh: Cambridge university press

Kane, D. 2015. *Carbon Sequestration Potential on Agricultural Lands: A review of Current Science and Available Pratices.* [Online] Accessed 01 27, 2020. sustainableagriculture.net/publications

Kimaru, G. & Gachene, C. 2003. *World Soil fertility and land productivity A guide for extension workers in the eastern Africa region.* [Online] http://apps.worldagroforestry.org/downloads/Publications/PDFS/B13197.pdf [Accessed 20.04.2020]

Lorentz, K. & Rattan, L. 2005. *The Depth Distribution of Soil Organic Carbon in Relation to Land Use and Management and the Potential of Carbon Sequestration in Subsoil Horizons.* [Online] https://doi.org/10.1016/S0065-2113(05)88002-2 [Accessed 20.01.2020]

Malik, A. Chowdhury, S. Schlager, V. Oliver, A. Puissant, J. Vazques, P. Jehmlich, N. von Bergen, M. Griffiths, R. & Gleixner, G. 2016. *Soil Fungal: Baterial Ratios Are Linked to Altered Carbon Cycling.* [Online] https://dx.doi.org/10.3389%2Ffmicb.2016.01247 [Accessed 02.04.2020]

Mureithi, J. Gachene, C. & Ojiem, J. 2003. *The role of green manure legumes in smallholder farming systems in Kenya: The legume Research Network Project.* [Online] https://www.redalyc.org/pdf/939/93911288003.pdf [Accessed 24.02.2020]

Olsson, L. Barbosa, H. Bhadwal, S. Cowie, A. Delusca, K. Flore-Renteria, D. Hermans, K. Jobbagy, E. Kurz, W. Li, D. Sonwa, D. & Stringer, L. 2019. *Land Degradation. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.* [Online] https://www.ipcc.ch/site/assets/uploads/sites/4/2019/11/07_Chapter-4.pdf [Accessed 20.02.2020]

Ontl, T. & Shulte, L. 2012. *Soil Carbon Storage*. [Online] www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790/# [Accessed 06.02.2020]

Poeplau, C. & Don, A. 2014. *Carbon sequestration in agricultural soil via cultivation of cover crops - A meta analysis.* [Online] http//:dx.doi.org/10.1016/j.agee.2014.10.02 [Accessed 06.02.2020]

Royal Society of Chemistry. n.d. *Respiration.* [Online] https://www.rsb.org.uk/images/14_Respiration.pdf [Accessed 14.01.2020]

Sarwatt, S, and E Mollel. 2006. *Country Pasture/Forage Resource Profiles UNITED REPUBLIC OF TANZANIA.* [Online] http://www.fao.org/ag/AGP/AGPC/doc/Counprof/PDF%20files/Tanzania_English.pdf [Accessed 22.04.2020]

Shetto, R. & Owenya, M. 2007. *Conservation agriculture as practiced in Tanzana: three case studies.* [Online] https://www.semanticscholar.org/paper/Conservation-agriculture-as-practised-in-Tanzania-%3A-Shetto-Owenya/c14a88321ade737968dbea30ea46f96cbce1c6d7 [Accessed 20.04.2020]

Simo, I. Schulte, R. O'Sullivan, L. & Creamer, R. 2019. *Organic carbon stocks in topsoil and subsoil in long-term ley and cereal monoculture rotations.* [Online] https://doi.org/10.1007/s00374-018-1281-x [Accessed 20.01.2020]

Singh, M, H Upadhyaya, and S Ishwari. 2013. *Genetic and Genomic Resources of Grain Legume Improvement.* [Online] https://doi.org/10.1016/C2012-0-00217-7 [Accessed 22.04.2020]

Six, J. Frey, S. Thiet, R. & Batten, K. 2006. *Bacterial and Fungal Contributions to Carbon Sequestration in Agroecosystems.* [Online] https://pdfs.semanticscholar.org/65a5/f3923273bab7658b7b4a0775163c767595d4.pdf [Accessed 04.02.2020]

Vidyasagar, A. 2018. *What is photosynthesis.* [Online] https://www.livescience.com/51720-photosynthesis.html [Accessed 07.01.2020]

Zomer, R. Bossio, D. Sommer, R. & Verchot, L. 2017. *Global Sequestration Potential of Increased Organic Carbon in Cropland Soils.* [Online] https://www.nature.com/articles/s41598-017-15794-8 [Accessed 20.04.2020]

8 Appendixes

Green Manure/Cover crops in Tanzania small-holder agriculture

FIDA International is dedicated to improving environmental sustainability and coping to the climate change. Through this brief survey, your answers will be helpful in enhancing our activities and in making an impact. Thank you very much for your time and suggestions.

Directions: Please indicate your agreement or disagreement with each of these statements regarding your farm. Place an "X" mark in the box of your answer.

		Yes	No
Q1	Do you know what Green Manure/Cover crops are?		
Q2	Are you using Green Manure/Cover Crops on your lands?		
Q3	Have you noticed loss of soil quality on your lands?		
Q4	Have you noticed any improvement in soil quality because of GMCC?		
Q5	Have you noticed erosion on your lands?		
Q6	Have you noticed any improvement in erosion because of GMCC?		
Q7	Have you noticed drought on your lands?		
Q8	Have you noticed any improvement in drought because of GMCC?		
Q9	Have you noticed any loss in productivity on your lands?		
Q10	Have you noticed any improvement in productivity because of GMCC?		
Q11	Would you recommend GMCC to your neighbours?		

If you have used GMCC on your lands and stopped doing so, why have you stopped?

- ☐ **Too expensive**
- ☐ **Poor market**
- ☐ **Too much labour**
- ☐ **Poor growth**
- ☐ **Lack of information and knowhow**
- ☐ **Lack of support**
- ☐ **Other: ________________________**

What species have you tried on your lands:

- ☐ **Mucuma**
- ☐ **Lablab**
- ☐ **Pigeonpea**
- ☐ **Cow pea**
- ☐ **Jack bean**
- ☐ **Sunn hemp**
- ☐ **Lentils**
- ☐ **Other: ________________________**

What is your gender:

- ☐ **Woman**
- ☐ **Man**

What is your age:

- ☐ **15-25**
- ☐ **25-35**
- ☐ **35-45**
- ☐ **45-**

IV. Thank you for sharing your thoughts with us.