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# Climate Change and Carbon Sequestration among Smallholder Farmers in Uganda: An Introduction and Review of Literature

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## Abstract

In Uganda, sorghum constitutes the second most widely grown cereal according to the latest statistics from the country's statistics body, the Uganda Bureau of Statistics. This notwithstanding, there has been, in the context of Uganda, very little research and published literature on its potential to sequester carbon. There is no sufficient data on the exact levels of carbon sequestered by this sorghum/legume intercropping system, which is widespread as a technology within Uganda's smallholder sorghum farmers, most especially in the two agro-ecological zones considered for this study: Eastern Highlands: specifically, Serere district and Northern farming system; specifically, Lira district. The purpose of the present article is to introduce a broader research agenda through which I aim to intervene on this subject. The article also engages key recent research on Carbon Sequestration (CS), focusing on studies that engage the question of CS and smallholder farmers.

## Subject Areas

Agro-Ecology, Biodiversity, Climate Smart Agriculture, Ecology, Agronomy, Environmental Science, Soil Science

## Keywords

Climate Change, Agro-Ecological Zones, Carbon Sequestration Specifically Comparing Fragile Agro-Ecological Zones of Uganda, Sorghum/Legume Intercropping System, Smallholder Farmers

## 1. General Introduction

Recent years, more specifically since the end of the 20th century, have seen a growing interest in the subject of Carbon Sequestration (CS). This growing interest has corresponded with global developments within the framework of the United Nations on the broad theme of climate change. In particular, the last quarter of the 20$^{th}$ century *inter alia* saw the formation of the United Nations Framework Convention on Climate Change (UNFCCC [1]), and the Inter-Governmental Panel on Climate Change (IPCC) [1]. These developments were themselves triggered by earlier observations on the deteriorating environment, first introduced to the global public as an intractable problem during the 1972 Stockholm UN Conference on the Human Environment (Sachs 2010: 25 [2]). With the publication of the report of the World Commission on the Environment and Development in the late 1980s (the 1987 Brundtland Commission Report, *Our Common Future*), which now houses the classic definition of what has come to be discussed as "Sustainable Development", the question of CS gained more ground and credence in the scientific study of carbon-related processes in the natural world, and how these processes and developments affect life in the human social world. Over the years in the course of this century, the subject of CS has continued to attract attention from various sections of the scientific scholarly community, and this paper endeavors to conduct a critical review of this literature. More broadly, however, this paper introduces the research conducted by the author on the subject of CS among smallholder farmers in Uganda, these occupy different agro-ecological zones in Serere and Lira districts, located in Eastern and Northern Uganda respectively. This article critically reviews recent research on CS and outlines the broader research agenda on CS and smallholder farmers from which numerous other articles will follow.

### 1.1. Background

This study seeks to make a contribution to research that has put primacy on smallholder farmers and how their age-old agricultural practices contribute to CS. The contextual setting of the study in Uganda, considering two agro-ecological zones: Serere district in the Eastern Highlands and Lira district in the Northern farming system. These two agro-ecological contexts are elaborated shortly below. With the ongoing conversation on the rising GHG gas concentrations in the atmosphere and the warming planet, recently expounded upon by the Inter-Governmental Panel on Climate Change (see IPCC 2022 [2]), this study maintains that the hope for the ideal future of keeping the global temperatures at the IPCC recommended level of below 1.5˚C lies mainly in exploring the numerous carbon-off-setting practices by smallholder farmers of the world, and building upon these efforts, including strengthening them through the application of contemporary agricultural scientific practices.

If the environmental catastrophes that have been linked to human engagement with the natural world have been primarily due to human advancement in the science of exploiting the natural world, including through agricultural technological advancement, this study maintains that this is the time to learn from the experience of those who have least benefited from the much-celebrated agricultural technological boom, and thus least contributed to the escalation of GHG concentrations in the atmosphere that are now threatening the very continuity of life on Earth. While numerous studies on CS in Uganda's agricultural sector have convincingly dealt with the sequestration potential more generally, more work is still needed that gives primacy to smallholder farmers. To these efforts, this research seeks to make a contribution. The study is based on two localities, one in Eastern Uganda, the Eastern Highlands (NASAARI, Serere district), and another one in Northern Uganda, the Northern farming system (Ngetta, Lira district). These occupy two different agro-ecological zones, both well-known for their predominant small-scale sorghum farming. The Uganda Bureau of Statistics (see UBOS 2019 [3]) estimates that these two districts put together are the leading producers of sorghum in Uganda.

Sorghum is the second most widely grown cereal in Uganda (see UBOS 2019 [3]). Yet, despite this fact, there has been, in the context of Uganda, very little research and minimal published literature on its potential to sequester carbon (for exceptions, see e.g. Roobroeck *et al.* 2019 [4]; Ekepu *et al.* 2016 [5]; Jindal *et al.* 2006 [6]). There is no sufficient data on the exact levels of carbon sequestered by this sorghum/legume intercropping system, which is a widespread technology within Uganda's smallholder sorghum farmers in Serere and Lira districts. This study seeks to intervene in this gap by not only evaluating the CS capacity of sorghum/legume intercropping in these areas, but by also suggesting ways through which this capacity can be enhanced. As such, besides being an intervention in an existing scholarly gap, this study also hopes to aid efforts geared towards conversion of smallholder carbon off-setting agricultural techniques into carbon credits, and thus into financial value to smallholder farmers in these areas. For many, this research will provide a baseline for further research on the subject in other areas, while the results may be critical in future theoretical work on the subject of CS among smallholder farmers. Moreover, the data from this study can also be used to calibrate and validate other crop models. As numerous researchers have pointed out, soil is a major carbon sink. Some estimates suggest that soil stores up to 1500 Gt of carbon, which is about two times the atmospheric carbon and three times the amount in the terrestrial biomass. As such, any alterations in land use and management can bring about changes in soil carbon stocks.

### 1.2. Literature on Carbon Sequestration: A Critical Exploration

Studies whose main object is CS in different geographical and temporal contexts have made interventions at different levels. The most noticeable and widespread focus within these studies has been more exploratory, the core objective being to explore the potential of CS in different contexts (see e.g. Musekiwa *et al.* 2022 [7]; Corbeels 2020 [8]; Namirembe *et al.* 2020 [9]; Ambaw *et al.* 2020 [10]; Gonzalez-Sanchez *et al.* 2019 [11]; Roobroeck *et al.* 2019 [4]; Kamusingize *et al.* 2017

[12]; Kiyingi *et al.* 2016 [13]; Chambers 2016 [14]; Lal *et al.* 2015 [15]; Mandal *et al.* 2015 [16]; Smith *et al.* 2014 [17]; Abdalla *et al.* 2013 [18]; Corsi *et al.* 2012 [19]; Conant 2010 [20]; Blanco-Canqui *et al.* 2009 [21]; Govaerts *et al.* 2009 [22]; Jindal *et al.* 2008 [23]; Henry *et al.* 2008 [24]; Lal 2008 [25]; Jindal 2006 [6]; Vågen & Singh 2005 [26]; Smith 2004 [27]; Cacho *et al.* 2003 [28]; Bruce *et al.* 1999 [29]; Schlesinger 1999 [30]). There are, however, significant differences in how different researchers have approached the question of the potential of CS in different contexts. While some of these studies have been concerned with exploring, in an abstract sense, the broader subject of CS (e.g. Lal *et al.* 2015 [15]; Bruce at al. 1999 [29]), others have focused on Conservational Agriculture (CA), the main objective being one of exploring its modalities and potential to sequester carbon (see e.g. Corbeels *et al.* 2020 [8]; Okeyo *et al.* 2014 [31]; Abdalla *et al.* 2013 [18]; Govaerts *et al.* 2009 [22]; Blanco-Canqui *et al.* 2009 [21]; Mandal *et al.* 2015 [32]). Other studies, on the other hand, have focused on both CA and Traditional Agriculture (TA), and have in turn explored the CS potential that underly both mechanisms in different contexts (e.g. Lal 2008 [25]; Schlesinger 1999 [30]). There has also been a growing interest in the potential of above-the-ground CS through biomass, with the accent on biodiversity (see e.g. Justine *et al.* 2019 [33]; Henry *et al.* 2008 [24]).

A number of observations have been made by these studies. On CS more broadly, some scholars have noted that numerous anthropogenic activities such as plowing, biomass burning, wetland drainage, poor grazing practices and so on (see Lal *et al.* 2015 [15]) degrade the soil, and thus reduce its capacity to sequester carbon. They thus argue that it is important for interventions aiming at increasing the CS potential of soils to focus on proven strategies, such as tillage reduction, intercropping, yield-promoting practices, as well as resorting, wherever possible, to "permanent perennial vegetation" (p. 384). From the perspective of most researchers focusing on CA, the most sustainable modality through which to increase the Soil Organic Carbon (SOC) is through practices that embody limited or no-till when it comes to agriculture (see esp. Corbeels *et al.* 2020 [8]; Gonzalez-Sanchez *et al.* 2019 [11]; Mandal *et al.* 2015 [16]; Abdalla *et al.* 2013 [18]; Blanco-Canqui *et al.* 2009 [21]; Govaerts *et al.* 2009 [22]). According to Mandal *et al.* (2015 [16]), for example, "there are enormous potential to sequester soil organic carbon through greater adoption of best conservation agricultural systems" (p. 2). Within studies whose core focus is CA, it is strongly believed that the ambition to reduce atmospheric carbon concentrations through agricultural operations rests predominantly on strategies to reduce tillage operations on the soil (see esp. Govaerts *et al.* 2009 [22]).

Yet, even if, at a general level, there is a broad consensus on the vitality of CA in enhancing both the above-the-ground and under-the-ground CS potential, a heated debate lies in the details regarding these processes. Thus, when, in 2019, Gonzalez-Sanchez *et al.* (2019 [11]) concluded, in their study titled "Meta-analysis on carbon sequestration through Conservation Agriculture in Africa", that "the potential estimate of annual carbon sequestration in African agricultural soils through CA amounts to 143 Tg of C [carbon] per year, that is 524 Tg of $CO_2$ per year" (p. 22), Corbeels *et al.* (2020 [8]) branded these results as "exceedingly optimistic". They write that Gonzalez-Sanchez *et al.* (2019 [11]) "grossly estimated the total SOC sequestration potential through the practice of CA in Africa", insisting that such potential cannot exceed 10.8Tg C [carbon]$\cdot yr^{-1}$ assuming an average per area of 0.45 Mg C$\cdot ha^{-1}\cdot yr^{-1}$ and 20% of the current soil C-depleted (annual) croplands (estimated at 120 Mha) are cultivated with CA" (see Corbeels *et al.* 2020 [8]). This debate, obviously, simply points to the complexity involved in any attempt to estimate the carbon off-set potential of CA practices in the global South, later on to convert it into monetary terms.

There is also a body of studies that embody a combined exploration of the CS potential of both CA and TA. In an earlier text, Schlesinger (1999 [30]) writes that "conversion of large areas of cropland to conservation tillage including no-till practices, during the next 30 years could sequester all the $CO_2$ emitted from agricultural activities and up to 1% of today's fossil fuel emissions in the United States" (p. 1). Other studies on this are more exploratory in nature. Lal (2008 [25]), for example, looks at both biotic and abiotic mechanisms of CS, weighing the potential in both. Focusing on the vitality of biodiversity in increasing the potential of above-the-ground CS, Henry (2008 [24]) writes that in the case of smallholder farmers in western Kenya, "higher financial compensation for CS projects that encourage biodiversity would allow cleaner win-win scenarios", and that "in tropical forests, carbon storage depends largely on species composition", with the implication that "there may be a close relationship between carbon stocks and biodiversity" (p. 239 see Minase *et al.* 2016 [34]).

Besides research focusing on the different dimensions to the potential of CS, there has also been a noticeable interest on understanding the relationship between CS and climate change (Lal 2009 [35], 2005 [36], 2004 [37]), agriculture-based carbon trading mechanisms (Purdon 2018 [38]; Fisher *et al.* 2018 [39]; Öborn *et al.* 2017 [40]; Tumwebaze & Byakagaba 2016 [41]; Lipper *et al.* 2011 [42]; German *et al.* 2010 [43]; Nakakaawa *et al.* 2010 [44]; Jackson *et al.* 2005 [45]). In other instances, indigenous agricultural strategies have been identified as critical resources to be grasped and worked with in devising sustainable modalities for CS (see e.g. Altieri & Koohafkan 2008 [46]). The conversation on carbon trading mechanisms is an especially critical one, given its deployment of market-based strategies to incentivize the intensification of global efforts to reduce greenhouse gas (GHG) concentrations in the atmosphere. Within localities of the global South, especially in the context of smallholder farmers in different agro-ecological localities, the debate has mainly focused on agreeable modalities of measurement and payment for carbon off-set practices in the agricultural sector (see esp. Purdon 2018 [38]; Minase *et al.* 2016 [34]; Rapsomanikis 2015 [47]; Lipper at al. 2011 [42]; Conant 2010 [20]; Altieri & Koohafkan 2008 [46]; Jackson *et al.* 2005 [45]).

The image that emerges from the above exploration of literature suggests a broad interest, in the existing studies on CS, in exploring the CS potential in different contexts, such as in TA and CA. The intervention this study seeks to make takes smallholder farmers as the vantage point from which to make sense of the question of CS. More specifically, the study seeks to examine, in the Northern and Eastern Uganda agro-ecological contexts, the CS potential of a leading crop in the areas, sorghum, and how to enhance its observed potential to sequester carbon. In the context of Uganda, research on the CS potential of smallholder farmers has not sufficiently dealt with the centrality of sorghum in the agricultural life of communities especially in Northern and Eastern Uganda. This study builds on this gap in a broader research agenda that seeks to explore smallholder farmers' CS practices, and more specifically CS practices around sorghum, a major crop grown in Eastern and Northern Uganda.

## 2. Research Objectives

Given the predominancy of small-scale sorghum farming in both Serere and Lira district of Uganda, the main objective of this study is to evaluate the effect of existing legume/Sorghum intercrops in enhancing Carbon Sequestration with a view of informing policy making on this question in Uganda. To do this, the study is based on three specific objectives:

1) To assess the existing practices on carbon sequestration amongst small holder farmers in two selected agro-ecological zones of Uganda.

2) To determine the quantity of Carbon sequestered by Sorghum under selected sorghum legume intercrops in different agro-ecological zones.

3) To determine the most efficient sorghum/legume intercrop practice for the two agro-ecological zones.

The significance of this study is four-fold. First, the study is a fresh intervention into the Ugandan, and indeed global, conversation on the dynamics of CS among smallholder farmers, drawing new insights from the time-tested agricultural practices of small-scale sorghum farmers in Northern and Eastern Uganda. Secondly, the study aims to be of benefit to the people in the two research sites, by underscoring the best sorghum/legume intercrop for best enhancement of carbon sequestration and its benefits; high productivity, sustainable food security and environmental conservation. Thirdly, study will also immensely benefit a wide range of other stakeholders including policymakers, research organizations, development organizations, government among others who are interested in agriculture adaptation and mitigation to climate change, especially those working in the local context amongst small holder farmers using cereal legume intercrop as a climate smart practice. It is hoped that with the findings of this study, the government will ably advocate for the use of sorghum/legume intercrop that sequesters carbon amongst small holder farmers, doing so from an informed point of view. Finally, this research will aid future researchers, specifically by building upon the findings of this study for further research on climate smart technologies that sequester carbon amongst small holder farmers.

## 3. Context and Justification

The study entails evaluation of existing carbon sequestration practices amongst small holder farmers and the effect of legume intercrops in enhancing the CS capacity of Sorghum. Evaluation of existing CS practices is done by randomly selecting households for surveys. Determining CS and productivity is by an experiment laid out in a split plot design with a Randomized Complete Block Design (RCBD) at main plot level for specific objectives (ii) and (iii). Two agro-ecological sites have been considered for this study: the Eastern highlands (Serere district) and Northern farming system (Lira district). According to UBOS (2019a), the total population of Serere is 345,900 and that of Lira is 465,900.

## 4. Theory, Method, and Techniques

The study draws theoretical inspiration from two sources. First, it seeks to draw from Everett M. Rogers' Diffusion of Innovations theory (see Rogers 2003 [48]. see Lamorte 2018 [49]). It also seeks to draw from the complexity theory (see McMillan 2008 [50]). Lamorte (2018 [49]) argues that the diffusion of innovations (DOI) theory explains adoption of an idea or product through a population or system over time. This is the point that Rogers (2003 [48]) himself emphasized regarding diffusion of innovations and social change. He argued that it is possible to "understand social change processes more accurately if the spread of a new idea is followed overtime as it courses through the structure of a social system" (2003: 104). For this reason, Rogers (2003 [48]) saw the focus of diffusion research being "on tracing the spread of innovation through a system over time and/ or across space…" (*ibid* [48]). DOI theory stipulates that adoption means a person doing something different from how they had previously done it; the idea being perceived as new and innovative is key. Adoption of an innovation is used, in the context of this study, to refer to the adoption of farming methods that sequester carbon, especially in the context of smallholder farmers.

Studies have shown that people who adopt an innovation early have different characteristics from those who adopt late. It is therefore important to understand the characteristics of a target group before promoting an innovation. The five adopter categories according to the DOI theory include: innovators, early adopters, late adopters, late majority and laggards. These are influenced by factors such as: compatibility, relative advantage, complexity, observability, and triability. Yet despite its numerous uses, DOI theory does not take into consideration an individual's resources to adopt the new innovation. These adoption categories are further elaborated upon later on in Appendix 3.

There is a commonplace tendency, however, to think the notion of "innovation" in terms of a technological import, most especially an import from outside the context in which such an innovation is to be applied. This creates a fictitious binary of sites of innovation (in most cases, the "developed world") and sites of application (the "third world"). By drawing on the DOI theory in the study of CS practices among smallholder sorghum intercrop farmers in Northern and Eastern Uganda, my goal is to challenge the idea that innovations can only be imported from without. The study is largely quantitative but it also employs some qualitative elements of inquiry. Specifically, the study uses a cross sectional survey for specific objective 1), and an experiment laid out in a split plot design with a RCBD at sub plot level for objectives 2) and 3) (see e.g. Oehlert 2010 [51]).

## 4.1. Sampling Methods and Techniques

The study makes use of purposive sampling technique in the selection of agro-ecological study zones. This makes it possible for questionnaires to be administered in order to assess the level of adoption of existing practices on carbon sequestration amongst small holder farmers.

### 4.1.1. Sample Size Determination

In this study, the sample size was determined using Bhattacharyya *et al.* (2007 [52]. The probability that the respondents will give a Yes/No answer was set at 50%. Without prior knowledge, P and Q assume the probability of Yes and No. This is the same as Fischer's formula (1991 [53]). The P value is 0.5 because there had been no study done to establish the prevalence. So in statistics, the assumption is usually 0.5 because the chance of it happening and not happening is half, half.

$$n = PQ\left[\frac{Z_{\frac{\alpha}{2}}}{d}\right]^2$$

$$n = \frac{1}{2} \times \frac{1}{2} \times \left[\frac{1.96}{0.05}\right]^2 = 384 \text{ Households}$$

where:

$n$ = desired sample size; $Z$ = standard numerical deviation responding to 95% confidence interval (1.96); $\sigma$ = Error (0.05); $P$ = Probability of Yes/No response = 50%; $Q = 1 - p\,(0.5)$.

### 4.1.2. Calculating Sample Size per District

To calculate sample size per district, the study used proportion. Lira has a population of 465,900 while Serere has 345,900. Total is 465,900 +345,900 = 811,800.

1) Number of questionnaires to be used in Lira is: $\frac{465,900}{811,800} \times 384 = 220$ Questionnaires.

2) Number of questionnaires for Serere is: $\frac{345,900}{811,800} \times 384 = 164$ questionnaires.

## 4.2. Quality Control Methods

### 4.2.1. Pretesting Questionnaires

These constitute 10% of all questionnaires in the sample size. The pretest is planned to take place in a different community not included in the study area but with a similar setup to the selected study areas. Pretesting of the questionnaire allows for the modification of questions to elicit the required information. Furthermore, it helps in the identification of mistakes made during the construction of the data collection instrument (on this, see e.g. Blair and Srinath 2008 [54]).

#### 4.2.2. Data Collection Procedures

Questionnaires as data collection tools are administered for this study. The questions that constitute it most crucially seek to gather information on socio-demographic characteristics, types of carbon sequestration technologies, and their levels of adoption.

#### 4.2.3. Data Management and Processing

The data is collected through a survey, using a purposive sampling technique, and employing questionnaires as a tool. In using this, the following assumptions are considered. First, it is assumed that all respondents are above 18 years of age. Secondly, it is assumed that all respondents are independent-minded and not coerced or influenced. Finally, triangulation is employed as a control to ensure the answers given are correct.

The collected data is analyzed using SPSS. Results are presented in tables, bar graphs, and pie charts. Regression models are used to determine the association between socio-demographic characteristics like education levels, land size, household size, and levels of adoption of carbon sequestration practices. Cross tabulation is done to profile the carbon sequestration practices across the different agro-ecological zones. ANOVA is used find to out if there is any significant difference in the levels of adoption of carbon sequestration technologies across the selected agro-ecological zones in Eastern and Northern Uganda.

### 4.3. Data Analysis

The survey data is coded and entered into SPSS Version 22 (2017) for analysis. Data on socio-economic characteristics and the different carbon sequestration practices are analyzed and presented in descriptive statistics such as mean (e.g. number of acres under sorghum and legumes), and percentage (e.g. of carbon sequestration practices). Linear regression is used to estimate the relationship between socio-economic characteristics and the level of adoption of carbon sequestration practices within the farms. The independent variable is used to indicate the affecting or exposure variable and the dependent variable is used to indicate the affected or outcome variable. For example, the level of education and the farm size are the independent variables and the level of adoption of carbon sequestration practices is the dependent variable. Both are unadjusted and presented in models with the independent and the dependent variables. The adjusted models include other variables that could be confounding the relationship between the dependent and the independent variable. Once the potential confounders are found, they are added to the model one by one to assess if they affect the regression coefficients for the independent variable of interest. A p-value of <0.05 is considered significant.

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## Conflicts of Interest

The author declares no conflicts of interest.

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