Going green: The Green House Gas Emissions Balance for selected Climate Smart Agriculture Practices

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Abstract:

Even though agriculture is the backbone of Uganda's economy, its sustainability still needs to be improved. In part, climate change and its related shocks, which plague the sector, are to blame for the increasingly dwindling total factor productivity that has been dwindling for the last two decades. Thus, this study was rolled out to estimate the Green House Gas (GHG) balance for transitions in agricultural production technologies among the smallholder maize farmers in Uganda. This study relied heavily on secondary data sources, including socio-economic and production data from 218 smallholder maize farmers. We used STATA 15 to generate the descriptive statics while The EX-ACT Tool, Tier 1 –IPCC, was used to estimate the GHG emissions from selected transitions in agricultural production technologies. Overall, GHG emissions abatement was highest when smallholder farmers adopted a bundle of different improved agricultural production technologies relative to the adoption of isolated practices. The findings also showed that the burning of agricultural residues was the most significant contributor to GHG emissions generated by the smallholder maize farmers compared to the different tillage and carbon input practices. We also found that adopting irrigation technologies increases the carbon footprint among smallholder maize farmers, albeit in a small magnitude. Based on these findings, we recommend opting for improved agricultural practices as a bundle, including retaining agricultural residues in the farming plots to increase the amount of GHG sequestered in the ecosystem.

Keywords: GHG, GHG emissions, GHG emissions balance, CSA, Conventional agriculture.

1 Introduction

1.1 Current State of Agriculture in Uganda

Globally, agriculture remains the most important source of livelihood for most of the rural population, who are among people experiencing poverty. This situation is even more exacerbated in sub-Saharan Africa (SSA). About 60% of the population in SSA comprises smallholder farmers, and 58% live in rural areas (Goedde et al., 2019). Like the rest of SSA, about 68% of the population of Uganda derive their livelihood from agriculture (UBOS, 2016). Interestingly, women and youths contribute most of the labor used in the agricultural sector in Uganda. About 55% of the women contribute to Uganda's economically active population; they contribute over 75% and 90% of the labor force used on farms and in primary processing operations, respectively. Nearly half (45%) of the smallholder farming households in Uganda are headed by household heads under 40.

The agricultural sector contributes about 24% of Uganda's Gross Domestic Product (GDP) (World Bank, 2018). The sector's contribution remains significant and contributes about 33% of the total exports in Uganda. Indeed, the agricultural sector remains a critical engine in contributing to achieving Uganda's Vision 2040. Uganda's Vision 2040 will transform the Ugandan Society from a Peasant to a Modern and Prosperous Country within 30 years (National Planning Authority, 2020). The Government of Uganda (GoU) is advancing Uganda's Vision 2040 agenda through (i) increasing on-farm productivity, (ii) transforming smallholder farmers into either enterprise farmers or commercial farmers, (iii) increasing food security and food availability in all parts of the country; (iv) increase agriculture exports; and (v) increase efficiency and effectiveness of agricultural services such as research, extension, and regulatory bodies.

Unfortunately, the development of the agricultural sector in most developing economies, including Uganda, is still disappointing (Hazell & Wood, 2008). On one hand, most smallholder farms' productivity is increasingly declining. Moreover, the growth in agricultural output is different from the population growth. According to the World Bank (2018), the total factor productivity of the agricultural sector in Uganda for the last two decades is negative. Although the country's population grows at about 3.3% per annum, the agricultural output grows at a lower rate of 2% per annum. This is unfortunate because the growth in agricultural productivity in other East African countries has been higher (5%) compared to the 2% that is recorded in Uganda. This is in part explained by the subsistence and smallholder nature of agriculture in Uganda, which is characterized by limited use of purchased agricultural inputs, poor quality of labor, and limited investment in critical infrastructure such as roads by the government, among others (Bjornlunda et al., 2020). In addition, most farmers face several environmentally induced challenges, such as the increased prevalence of pest infestation, prolonged drought, and climate change-related shocks, which exacerbate the dwindling factor productivity of these farms. The low quality of agricultural inputs, poor input distribution and control systems, and inadequate quality-assurance processes also, in part, contribute to the low total factor productivity that currently exists in the country. Similarly, most of the smallholder farmers in Uganda have small land endowments with limited tenure security, hindering the commercialization and development of the agribusiness sector in Uganda. Smallholder farmers expand cropland into dwindling fragile ecosystems such as forests and wetlands to increase agricultural production.

On the other hand, the poor farming practices employed by smallholder farmers in developing economies, coupled with other anthropogenic activities in both developing and developed economies, exacerbate the intensity of climate change shocks. Like most parts of the world, Uganda is experiencing variable and less predictable weather patterns, increasing temperatures, and an increased prevalence of crop and animal pests and diseases. The average temperatures in Uganda have increased by 1.3°C since 1960 and could rise by up to 2.5° by 2050. This is unfortunate because the country contributes less to the global carbon footprint. Uganda's greenhouse gas (GHG) emissions per capita were estimated at 1.3 tCO_2e in 2019, far below the global average of about 6.4 tCO_2e.

Moreover, the rural areas, which produce most of Uganda's agricultural output, cannot adapt quickly to climate change, hindering agriculture's growth under the present climate trends. Climate change adaptation is critical for increasing smallholder farmers' resilience to climate change shocks. Unfortunately, the need for more empirical evidence about the GHG balance for transitions in agricultural production technologies among smallholder farmers partly contributes to the low adoption of practices that can help farmers adapt to climate change. Thus, it is against this background that this study was conducted.

1.2 Main objective

The main objective of this study was to estimate the GHG balance for transitions in agricultural production technologies among smallholder maize farmers in Uganda.

1.2.1 Specific objectives

Specifically, the study seeks to:

1) Characterize the smallholder maize farmers in Uganda;
2) Estimate the GHG emissions from selected transitions in agricultural production technologies and
3) Estimate the financial value of GHG emissions from selected transitions in agricultural production technologies.

2 Methodology

This study estimates the GHG balance for transitions in agricultural production technologies among the smallholder maize farmers in Uganda. We relied heavily on secondary data, including baseline data and a literature review, to address this objective. This sub-section describes the technical approach that was used to estimate the mitigation potentials and the associated economic value for selected transitions in agricultural production technologies.

2.1 Description of the data types

This study relied heavily on secondary data, including baseline data and a literature review. The baseline survey data used in this study was from 218 smallholder farmers engaged in maize production who were targeted beneficiaries for agricultural Business Initiative (aBi) supported projects. The smallholder farmers from whom the baseline surveys elicited data were Kikuube and Masindi from the South-western sub-region; Jinja, Iganga, and Bugiri from the Eastern sub-region; Nakaseke and Kayunga from the Central sub-region; and Omoro District from the Northern sub-regions of Uganda (East Africa).

The study also relied on data generated from the review of literature, including World Bank (2022), Zizinga et al. (2022), Pepo et al. (2008), and Danso et al. (2019). The data used in this study helped inform the assumptions upon which the analysis was done. First, this study assumed that adopting Climate Smart Agriculture (CSA) practices among smallholder farmers increases the yield of maize by 20% (Zizinga et al., 2022). Similarly, adopting irrigation by smallholder farmers would increase the yield for maize by 40% (Pepo et al., 2008; Danso et al. (2019). This study also used 10 US$/$tCO_2e$ as the market price of carbon and 75 US$/$tCO_2e$ as the Transformational price of carbon in 2030 (World Bank, 2022). To answer objectives 2 and 3 of this study, we used 1,000 smallholder farmer adopters to model the GHG emissions and the associated economic value at the scale of a named project.

2.2 Analytical methods

This study relied on descriptive statistics (means, frequencies, percentage) to estimate the GHG balance for transitions in agricultural production technologies among the smallholder maize farmers in Uganda. We used STATA 15 to generate the descriptive statics while The EX-ACT

Tool, Tier 1 –IPCC, was used to estimate the GHG emissions from selected transitions in agricultural production technologies (Smith et al., 2007). Computation of the economic value of GHG emissions from selected transitions in agricultural production technologies was done using Microsoft Excel.

3 Results

3.1 Socio-economic characteristics of the smallholder farmers

About 52% of the smallholder farmers engaged in maize production were males, and the rest were females (Table 1). This is consistent with (UBOS, 2016), who found that about 55% of the women are engaged in agriculture. The average age of the household head for the households that participated in the baseline studies was 48 years, while their spouses were 40. This is also consistent with (UBOS, 2016), who found that 45% of the smallholder farming households in Uganda were headed by household heads who were under the age of 40 years, and the rest were older. Almost all (96%) household heads had received formal education. Formal education is critical in increasing the adoption rate of improved agricultural production technologies such as Climate Smart Agricultural (CSA) Practices. The findings show that the households growing maize in Uganda have large family sizes. The findings show that the household size was found to be seven members. Because most smallholder farmers rely on family labor for their production needs, this large family size is critical for adopting labor-intensive technologies such as soil and water conservation. About 31% of the household members were found to be comprised of dependents. On average, the smallholder farmers were found to own about 4.3 acres and had about an acre of maize plot per season in 2022. About 52% of the smallholder farmers were found to have used inorganic fertilizer in 2022 in maize production. We also found that the average cost of production of maize was Ush 613 per kg while the average price of maize received by smallholder farmers was Ush 991 per kg. The findings show that the average maize productivity observed by the smallholder farmers was 1,319 kg per acre.

Table 1: The socio-economic characteristics of the smallholder farmers

	Overall	
	n	**Mean**
Sex of farmer (1=Male, 0=Otherwise)	218	0.52
Age of household head (Years)	218	47.72
Age of spouse (Years)	218	39.98
Household heads who attained formal education (1=Yes, 0=Otherwise)	218	0.96
Household Size	218	6.88
Dependency ratio	218	0.31
Size of land owned (acres)	218	4.34

Size of maize plot (acres)	218	0.78
Households that used inorganic fertilizer (1=Yes, 0=Otherwise)	218	0.52
Production cost of maize (Ugx / kg)	218	613.14
Maize productivity (kg/acre)	218	1,319.44
Price of maize grain (Ugx/kg)	218	991.14

3.2 Estimate the GHG emissions from selected agricultural production transitions.

Adoption of CSA has been proposed as one of the approaches to ameliorate the prevalence of GHG emissions from the agricultural sector. Thus, in this sub-section, we investigate the variation in GHG emissions from selected agricultural production technologies. Table 2 estimates GHG emissions from selected agricultural production practices under a low-carbon input regime. Generally, the findings show that under the low carbon input regime, retaining agricultural residues in the farmers' field contributes significantly to carbon sequestration compared to improving tillage practices. Adopting a combination of full-tillage, low carbon input, and burning resulted in a net GHG emission of 315 tCO_2e among 1,000 smallholder maize farmers of nature, like those who participated in the aBi baseline surveys. When smallholder farmers transition from conventional agriculture and adopt a combination of full-tillage, low carbon input, and retaining of agricultural residues, the smallholder farms were found to act as carbon sinks, sequestering about 180 tCO_2e**.**

Interestingly, the adoption of reduced tillage in combination with low carbon input and burning of agricultural residues results in a net GHG emission of 14 tCO_2e. When smallholder farmers transition from conventional agriculture and adopt a combination of reduced-tillage low-carbon input and retain the agricultural residues, these farms sequester about 166 tCO_2e. The findings further show that adopting zero tillage increases the amount of carbon sequestered in the ecosystem. This study found that adopting no-tillage combined with low carbon input and burning agricultural residues resulted in a net carbon sink of 57 tCO_2e. When smallholder farmers transition from conventional agriculture, adopt a combination of no-tillage, low carbon input, and retain agricultural residues, 237 tCO_2e is estimated to be sequestered into the ecosystem.

Table 2: Estimate the GHG emissions from selected agricultural production transitions without irrigation.

Tillage	Input of organic material	Residue management	Yield (t/ha/yr)	Start	Area (ha) Without project	With project	Emissions (tCO_2e) Without project	With project	Mitigation potential (tCO_2e)
Full tillage	low carbon input	burned	3.3	312	312	0	314.75		314.75
Full tillage	low carbon input	retained	3.3	312	0	312		134.94	-179.81
Reduced tillage	low carbon input	burned	3.3	312	0	312		329.01	14.26

Reduced tillage	low carbon input	retained	3.3	312	0	312		149.20	-165.56
No-tillage	low carbon input	burned	3.3	312	0	312		257.69	-57.06
No-tillage	low carbon input	retained	3.3	312	0	312		77.88	-236.87

Note: + source, -sink

Table 3 estimates GHG emissions from selected agricultural production technologies under a high carbon input regime. Like the low carbon input regime, the findings show that under the high carbon input regime, retaining agricultural residues in the farmers' fields still contributes significantly to the sequestering of carbon compared to adopting improved tillage practices. Adopting a combination of full-tillage, high carbon input, and burning of agricultural residues resulted in a net carbon sink of 553 tCO_2e. When smallholder farmers transition from conventional agriculture to a combination of full-tillage, high carbon input, and retaining of agricultural residues, these farms were found to sequester about 769 tCO_2e of carbon. Interestingly, the adoption of reduced tillage in combination with high carbon input and burning of agricultural residues resulted in the sinking of 533 tCO_2e of carbon. The findings also show that about 749 tCO_2e of carbon is sequestered when smallholder farmers transition from conventional agriculture to a combination of reduced tillage, high carbon input, and retaining agricultural residues. Adoption of zero tillage in combination with high carbon input and burning of the agricultural residues contribute to the sequestration of about 846 tCO_2e of carbon. Lastly, when smallholder farmers adopt a combination of zero-tillage high carbon input and retain the agricultural residues in the aggregate, these farms sequester about 858 tCO_2e of carbon.

Table 3: Estimate the GHG emissions from selected agricultural production transitions without irrigation.

Tillage	Input of organic material	Residue management	Yield (t/ha/yr)	Area (ha)			Emissions (tCO_2e)		Mitigation potential (tCO_2e)
				Start	Without project	With project	Without project	With project	
Full tillage	High carbon input, with manure	burned	3.96	312	312	0		-238.12	-552.87
Full tillage	High carbon input, with manure	retained	3.96	312	0	312		-453.88	-768.63
Reduced tillage	High carbon input, with manure	burned	3.96	312	0	312		-218.65	-533.40
Reduced tillage	High carbon input, with manure	retained	3.96	312	0	312		-434.42	-749.17
No-tillage	High carbon input, with manure	burned	3.96	312	0	312		-531.75	-846.49

No-tillage	High carbon input, with manure	retained	3.96	312	0	312		-543.72	-858.46

Note: + source, -sink

Table 4 shows an estimate of GHG emissions from selected agricultural production technologies under a high carbon input regime with irrigation. Like the high carbon input regime without irrigation, retaining agricultural residues in the field still contributes significantly to carbon sequestration compared to the improved tillage practices under the high carbon input regime with irrigation. Unfortunately, integrating irrigation with the different tillage and agricultural residue handling practices under a high carbon input regime has a lower carbon sequestration potential than adopting a combination of different tillage and agricultural residue handling practices under a high carbon input regime without irrigation. This study's findings show that adopting a combination of full-tillage, high carbon input, and burning of agricultural residues with irrigation results in a net carbon sink of 489 tCO_2e. Without irrigation, adopting a combination of full-tillage, high carbon input, and burning of agricultural residues yielded a high carbon sequestration potential of the magnitude of 553 tCO_2e. When the smallholder maize farmers transition from conventional agriculture to a combination of full-tillage, high carbon input, and retain agricultural residues with irrigation, our study found this technology mix to sequester about 738 tCO_2e.

Smallholder farmers adopting reduced tillage combined with high carbon input and burning agricultural residues with irrigation sequester 466 tCO_2e of carbon. In aggregate, a transition from conventional agriculture to practicing a combination of reduced tillage, high carbon input, and retaining of agricultural residues with irrigation, this study found that smallholder farmers would sequester about *718* tCO_2e of carbon. The findings further show that practicing zero tillage increases the amount of carbon sunk in the ecosystem. Adopting no-tillage in combination with high carbon input and burning agricultural residues with irrigation resulted in a net carbon sink of 590 tCO_2e. When smallholder farmers transition from conventional agriculture, adopt a combination of low-tillage high carbon input and retain the agricultural residues with irrigation, these farms sink about 816 tCO_2e.

Table 4: Estimate the GHG emissions from selected agricultural production transitions with irrigation.

Tillage	Input of organic material	Residue management	Yield (t/ha/yr)	Area (ha)			Emissions (tCO_2e)		Mitigation potential (tCO_2e)
				Start	Without project	With project	Without project	With project	
Full tillage	High carbon input, with manure	burned	4.62	312	312	0		-171.19	-485.94
Full tillage	High carbon input, with manure	retained	4.62	312	0	312		-422.91	-737.66
Reduced tillage	High carbon input, with manure	burned	4.62	312	0	312		-151.73	-466.47

Reduced tillage	High carbon input, with manure	retained	4.62	312	0	312	-403.45	-718.20
No-tillage	High carbon input, with manure	burned	4.62	312	0	312	-275.05	-589.80
No-tillage	High carbon input, with manure	retained	4.62	312	0	312	-500.78	-815.52

Note: + source, -sink

3.3 Estimate the financial value of GHG emissions from selected agricultural production transitions.

Carbon trade is one of the innovations being promoted to improve the market efficiency in agriculture. Table 5 estimates the financial value of GHG emissions from selected agricultural production practices under a low-carbon input regime. The findings show that smallholder farmers who retain agricultural residues within their gardens would earn more from the carbon trade. Smallholder farmers who adopt a combination of full-tillage, low carbon input, and burning should pay about US$ 3,147 for the ecosystem's 315 tCO_2e of net GHG emission. When smallholder farmers transition from conventional agriculture and adopt a combination of full-tillage, low carbon input, and retention of agricultural residues, these farmers would earn about US$ 1,798 from carbon trade because of sinking about 180 tCO_2e. The smallholder farmers should pay a total of US$ 143 for the net GHG emission of 14 tCO_2e when they adopt reduced tillage in combination with low carbon input and burning. When smallholder farmers transition from conventional agriculture and adopt a combination of reduced tillage, applying low carbon input, and retaining the agricultural residues within the fields, these farms sink about 166 tCO_2e, worth US$ 1,655. The findings further show that no-tillage increases the amount of carbon sunk in the ecosystem. About US$ 571 should be paid to smallholder farmers for the 57 tCO_2e of GHG emissions sequestered when they adopt no-tillage in combination with low carbon input and burning results into a net carbon sink. The highest revenue would be generated when smallholder farmers transition from conventional agriculture, adopt a combination of no-tillage, apply low carbon input, and retain the agricultural residues. Under this scenario, US$ 2,369 would be earned when the smallholder farmers sequester about 237 tCO_2e by adopting a combination of no-tillage, applying low-carbon input, and retaining the agricultural residues.

Table 5: Estimate the financial value of GHG emissions from selected agricultural production transitions.

Tillage	Input of organic material	Residue management	Value of carbon (US$)	Value of carbon at transformation price (US$)
Full tillage	low carbon input	burned	3,147	236,061
Full tillage	low carbon input	retained	- 1,798	- 134,858
Reduced tillage	low carbon input	burned	143	10,698
Reduced tillage	low carbon input	retained	- 1,655	- 124,160

No-tillage	low carbon input	burned	- 571	- 42,794
No-tillage	low carbon input	retained	- 2,369	- 177,652

Note: + farmer ought to pay, -Farmer ought to be paid.

Table 6 estimates the financial value of GHG emissions from selected agricultural production technologies under a high carbon input regime. A total of US$ 5,529 in carbon trade revenue would be earned by the smallholder farmers engaged in maize production when their farms sequester about 553 tCO_2e from adopting a combination of full-tillage, high-carbon input, and burning of the agricultural residues. When the smallholder farmers transition to adopt a combination of full-tillage, high carbon input, and retain agricultural residues, and when engaged in carbon trade, they earn US$ 7,686 in revenue from the sale of a total of 769 tCO_2e sequestered. The adoption of reduced tillage among the smallholder maize farmers, in combination with the utilization of high carbon input and burning of agricultural residues, would generate a total of US$ 5,334 in revenue for the smallholder farmers due to the sequestration of 533 tCO_2e by their maize plots. Similarly, when the smallholder farmers transition from conventional agriculture and adopt a combination of reduced-tillage practices, high carbon input and retain the agricultural residues on their maize plots, a total of US$ 7,492 of revenue would be generated from the trade of about 749 tCO_2e that are sequestered. This study also found that an aggregate of US$ 8,465 in carbon trade revenue would be generated because of the 846 tCO_2e sequestered due to the smallholder maize farmers adopting zero tillage practices combined with high carbon input and burning agricultural residues. We also found that when the smallholder farmers transition from conventional agriculture and adopt a combination of zero-tillage, high carbon input and retain the agricultural residues in the maize plot, a total of US$ 8,585 in revenue would be generated from trading of an aggregate of 858 tCO_2e of carbon sequestered.

Table 6: Estimate the financial value of GHG emissions from selected agricultural production transitions.

Tillage	Input of organic material	Residue management	Value of carbon (US$)	Value of carbon at transformation price (US$)
Full tillage	High carbon input, with manure	burned	- 5,529	- 414,649
Full tillage	High carbon input, with manure	retained	- 7,686	- 576,473
Reduced tillage	High carbon input, with manure	burned	- 5,334	- 400,049
Reduced tillage	High carbon input, with manure	retained	- 7,492	- 561,874
No-tillage	High carbon input, with manure	burned	- 8,465	- 634,870
No-tillage	High carbon input, with manure	retained	- 8,585	- 643,848

Note: + farmer ought to pay, -Farmer ought to be paid.

4. Recommendations

Based on the current findings, burning agricultural residues is the most significant contributor to GHG emissions among smallholder farmers compared to tillage practices. The findings also suggest that adopting irrigation among smallholder farmers increases the carbon footprint. We also conclude that adopting improved agricultural practices as a bundle increases the amount of GHG sunk in the ecosystem. Thus, based on these findings, the following recommendations were drawn:

1) Smallholder farmers need to adopt a combination of CSA practices to ameliorate the prevalence of GHG emissions. This is because the current study has found that the highest amount of GHG emissions sunk into the ecosystem and the associated revenue from carbon trade that would be generated when the smallholder farmers transition from conventional agricultural and adopt a combination of no-tillage, high carbon input and retain the agricultural residues.
2) Smallholder farmers ought to retain agricultural residues in their fields. This is because the current study found that retaining the agricultural residues in the farmer's fields had the highest amount of GHG emissions sunk into the ecosystem and the associated revenue from carbon trade compared to either adoption of no-tillage or high carbon input and
3) The Governments and their development partners need to advocate for better prices for carbon. This is because the current findings have shown that smallholder farmers would earn more income when they sell carbon at transformation prices compared to the current market prices.

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