sustainability

Review

Carbon farming practices and application amongst crop cooperatives in Uganda

Ashiraf Migadde [1], and Jerke de Vries[2]

[1] Agynet Agribusiness Limited Uganda; ashirafsiraj5@gmail.com
[2] Van Hall Larenstein University of Applied Sciences Netherlands; jerke.devries@hvhl.nl

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Abstract: Climate change is undermining the importance and sustainability of cooperatives as important organizations in small holder agriculture in developing countries. To adapt, cooperatives could apply carbon farming practices to reduce greenhouse gas emissions and enhance their business by increasing yields, economic returns and enhancing ecosystem services. This study aimed to identify carbon farming practices from literature and investigate the rate of application within cooperatives in Uganda. We reviewed scholarly literature and assed them based on their economic and ecological effects and trade-offs. Field research was done by through an online survey with smallholder farmers in 28 cooperatives across 19 districts in Uganda. We identified 11 and categorized them under three farming systems: organic farming, conservation farming and integrated farming. From the field survey we found that compost is the most applied CFP (54%), crop rotations (32%) and intercropping (50%) across the three categorizations. Dilemmas about right organic amendment quantities, consistent supplies and competing claims of residues for e.g. biochar production, types of inter crops need to be solved in order to further advance the application of CFPs amongst crop cooperatives in Uganda.

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Keywords: Carbon farming; Developing countries; Cooperatives, Smallholder; Ecosystem services; Trade-offs;

1. Introduction

Cooperatives play an important role in agricultural production and commercialization [1] in most developing countries. In Uganda, around 80% of the populations' livelihoods are directly reliant on the agricultural sector, yet it is the most vulnerable to current changes of the ecosystems and the services they provide and the changes in climate through emission of greenhouse gases (GHGs) such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) [2]. Under these current circumstances, smallholder farmer groups must remain competitive and sustainable.

Greenhouse gases (GHGs) are released by all sectors including the Agriculture, Forestry and Other Land Use (AFOLU). Worldwide the AFOLU sector contributes 24% of these GHGs [3]. GHGs in agriculture are mostly a result of farming operations such as; decomposing crop residues, the production and use of (in)organic fertilizers, land tillage, production and application spraying of pesticides and, planting and harvesting crops [4]. Agriculture may also contribute to GHG emission reductions by e.g. sequestering carbon (C) through a process called C sequestration [5]. Farming practices that include some sort of C sequestration are called C farming practices (CFPs). CFPs are also practices that are known to improve the rate at which CO_2 is removed from the atmosphere and converted to plant material and soil organic matter [6].

CFPs have been existing for a long time. However, current conditions aim to revitalize such practices within cooperatives in order to sequester more C in light of increasing temperatures, but also to benefit the crop cooperatives. However, these practices have not been adopted widely among small holder farmers and where such practices are implemented, there are failures due to poor implementation [7]. This review explores different CFPs based on their carbon sequestration potential and examines their economic effects in terms of yield, inputs, profitability, income and what the ecological effects are in terms of ecosystem services while contrasting their economic and ecological trade-offs. These findings are then compared and contrasted within CFP application amongst smallholder farmers in cooperatives as a basis for both the community of practice and policy interventions towards low carbon agriculture in Uganda.

The objective of the study was to identify CFPs and their economic and ecological effects and trade-offs and to provide insight into how and to what extent are they applied amongst crop cooperatives in Uganda

2. Materials and Methods

The first part of the objective was to identify CFPs. Scholarly literature was reviewed, and the identified CFPs were addressed within three farming systems; Organic farming (OF) [8], Conservation farming (CF) [3] and Integrated farming (IF) [9]. This categorization is based on the notion that these CFPs encompass most of what different literature sources attest to in relation to carbon sequestration. To assess the economic and ecological effects, the following indicators: 1. Yield (t/ ha), 2. input use (unit), 3. Income (per ha) and 4. Profit (percent) [10] and six ecosystem variables; 1. carbon sequestration, 2. soil quality, 3. water holding capacity, 4. pollination, 5. biodiversity, and 6. pest and disease control [11] were considered.

The second part of the objective was the assess how and to what extent the CFPs were applied amongst crop cooperatives in Uganda. To do so we administered an online survey amongst representatives from 28 cooperatives and online interviews with 6 key informants. The economic and ecological effects reviewed in literature were also used as a guide during the survey for ease of analysis. Descriptive statistics were used to analyze quantitative data from the online survey while qualitative data was analyzed by use MS Excel and MS Word.

3. Results

3.1. Literature

The literature review of CFPs resulted in an overview presented in Table 1. Scholarly categorization of CFPs included but not limited to; improved agronomic practices, nutrient management, water management, agroforestry, land cover (use) change, management of organic soils and restoration of degraded lands [12], Agroforestry, Farmer Management Natural Regeneration (FMNR) and Sustainable Agricultural Land Management (SALM) [13], diversification practices and soil management practices [14], forestry practices, land based agriculture, livestock and integrated systems [15], soil nutrient management practices, improved agronomic practices, improved livestock management practices, sustainable energy technologies, restoration of degraded lands soil and water conservation measures [46], conservation agriculture, integrated soil fertility management, irrigation, agroforestry, crop diversification, improved livestock and feeding practices [16] and single and diversified practices [10].

Table 1. CFPs identified in literature and categorized per farming system

Farming system	Carbon farming practice	Carbon Sequestration potential
Organic Farming (OF)	Compost application [17, 18, 19, 20]	2.14Gt – 3.1Gt between 2020 – 2050 [3]
	Manure application [21, 22 ,23]	0.16g kg^{-1} yr^{-1} increase per year [21]
	Biochar application [24 ,25, 26]	0.60–0.97 Mg.ha^{-} yr^{-1} for 3–23 years [25]
Conservation Farming (CF)	No Till / Reduced Till [3, 22, 27]	C redistribution along the soil profile [22]
	Residue Management [28, 29, 30]	C increase from 4.38% to 4.44% [29]
	Cover crops [31, 32]	C increase from 0.37 – 3.24 tCO2e ha^{-1} yr^{-1} [32]
	Crop rotations [28, 22, 33]	C stability due legume crops with carbon compounds [28]
Integrated Farming (IF)	Intercropping [34, 35, 36]	C emmission reductions by 7% [35]
	Agroforestry [3, 37]	C increase from 0.84 – 4.23 tCO2e ha^{-1} yr^{-1} [32]
	Agropastoral [38]	
	Agrosilvopastoral [39, 40]	

CFPs under OF are often Business as Usual (BAU) in the context of developing countries where often low-income farmers have neither access to agricultural input commodities like mineral fertilizers or pesticides [41]. While CFPs under CF were not initially considered as soil carbon sequestration practices, they are now widely considered as a potential technology to mitigate GHG emissions and reduce fossil fuel consumption [43] during tillage practices. CFPs under IF are useful in reducing the carbon footprint due to the land sharing concept which is fundamental in ecosystems services enhancement, such as carbon storage, pest control, pollination and climatic change adaptation [44]. Non-intensive agricultural, biodiversity-friendly, and ecosystem-preserving IF agricultural systems play a profound balance of conservation with environmentally and socially sound agriculture [45]. The economic and ecological effects are presented in Table 2.

Table 2. Literature overview of CFP economic and ecological effects under different farming systems

	Economic effects	Ecological effects
Organic Farming **Compost, Manure and Biochar**	Improved farm productivity [13]	Enhancement of soil ecological health functions [22]
	Diversified incomes [13]	Biodiversity protection [50]
	Reduced chemical fertiliser and pesticide use [47]	Increased water holding capacity [13]
	Premium price markets for organic produce [41]	Crop drought and flood tolerance [15]
	21.4% increase in fruit productivity, 22.4% fruit weight and 7.8% increase in fruit diameter for compost [48]	Lower GHG emissions & reduced global warming potential [24]
		Capacity to control plant diseases [51]
		Soil organic carbon build up [48]
		Reduced nutrient leaching [52]
		Source of renewable energy [53]

			Balanced ecosystem services provisioning [54]
Conservation Farming	**No Till, Cover crops, Crop residues and Crop rotations**	Enhancing farmers' income [55]	Conserving natural resources [55]
		Low costs of production [55]	SOM increase [8]
		Increased yield [27]	Reduce atmospheric CO_2 emissions [8]
		Low productivity [56]	Soil erosion control [60]
		Reduced pesticides use [31]	Weed control [61]
		Lower input costs [10]	Reduce the rainfall intensity [31]
		Improved pollination services [31]	Pest control [31]
Integrated Farming	**Intercropping, Agroforestry, Agropastoral, Agrosilvopastoral**	Improved productivity [57]	Disease and pest suppression [57]
		Input-reduction [57]	Improve soil fertility [58]
		Yield improvement [58]	Lowering carbon emissions [35]
		Diversified income sources [43]	Weed suppression [58]
		Increased production [59]	biodiversity conservation [32]
		Soil erosion and flooding control [3]	
		Improved water holding capacity [11]	
		Enhance pest, disease control [11]	
		Organic matter content [40]	

The main goal of CFP adoption lies in reducing GHG emissions which involves change of practices that may collide with crop production goals in both positive and negative forms [62] which results in trade-offs. Trade-offs occur when a CFP is adopted by farmers at the expense of economic benefits or vice versa. A critical dilemma is often faced when farmers need to switch to that completely transform their farm business operations [63]. On the other side, CFPs seem expensive [50], they may not be such productive [11] and farmers are likely to only voluntarily adopt such practices if economically profitable [5]. Another trade-off may be the change in land use such as farm expansion into forest land which is one of the most potent global threats to biodiversity conservation [64]. Other trade-offs include , more skills, knowledge , yields compromises, farming system incompatibilities, farm business uncertainty alongside land tenure rights [65]. Hence, win-win situations may be possible by combining an awareness of what may produce a trade-off with an understanding of why and what trade-offs result to create the synergies sought for better outcomes [66]. The economic and ecological trade-offs are presented in Table 3.

Table 3: Overview of CFP economic and ecological trade-offs under the different farming systems

Farming Systems CFPs		**Trade-offs**
Organic Farming Systems Compost, Manure and Biochar	Ecological	Inadequate to control pests and diseases [70]
		Provide insufficient pollination [70]
		GHG pollution swapping [71]
		Increase risk of accelerated erosion [26]
	Economic	Lead to reduced crop yields [67]
		Competing uses for crop residues [26]
Conservation Farming Systems	Ecological	High decomposition rates hence short-lived benefits [26]
		Minimum pest, weed and disease control [72]

No Till, Cover crops, Crop residues and Crop rotation**s**	Economic	Enhanced herbicide application on crop lands [10] Crop residue competing uses [68]
	Ecological	Reduced in pollination services [10]
Integrated Farming Systems Intercropping, Agroforestry, Agropastoral, Agrosilvopastoral	Economic	High technical knowledge, implementation maintenance labour and input costs [40, 10, 69] Farm profit reduction [5] Loss in productivity [12]

3.2. Field

Responses from the online survey were collected from amongst from 28 cooperative respondents (Figure 1) in 19 districts and 6 key informants online interviews. The economic and ecological effects were reviewed in literature and reported in tables and were also used as a guide during the survey for ease of analysis.

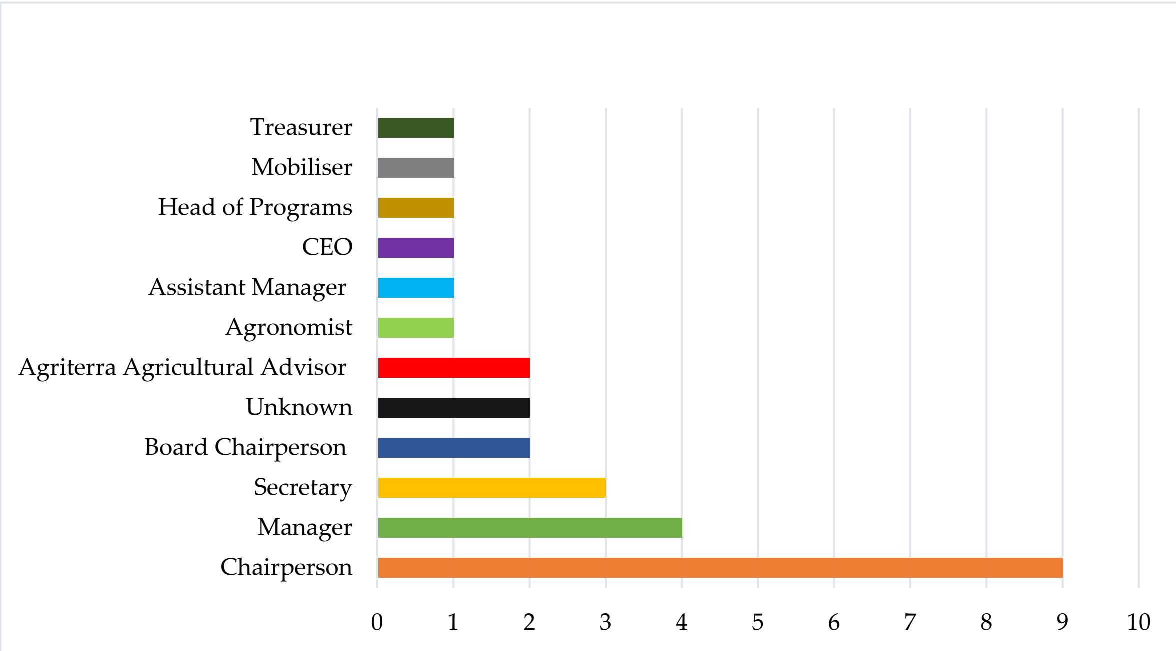

Figure 1. Online survey cooperative respondent portfolios

CFP application amongst cooperatives under OF systems

Amongst the CFPs examined in this farming system, the combination of compost and manure had the most respondents (54%) while the single most reported CFP under OF practiced by respondents was compost (Figure 2). The most reported beneficial effects of CFPs on the ecology where improved soil quality (Table 4) in terms of fertility, improved water holding capacity, enhanced microbial activity by natural organisms, pest, disease and weed control. However, biodiversity, pollination services and carbon sequestration were not mentioned by any respondent in this category. When considering economics, improved yield was the most reported effect of the CFPs followed by increased profitability as a result of improved incomes.

Within the OF system the combination of compost and manure was applied the most (54%) while the single most reported CFP was compost application (Figure 2). The most reported beneficial effects of CFP's on the ecology where improved soil quality (Table 4) in terms through increased fertility, improved water holding capacity, enhanced microbial activity, pest, disease and weed control. Biodiversity, pollination services and carbon sequestration were not mentioned as beneficial effects by any of the respondents. When considering economics, improved yield was the most reported effect of the CFP's followed by increased profitability as a result of improved incomes.

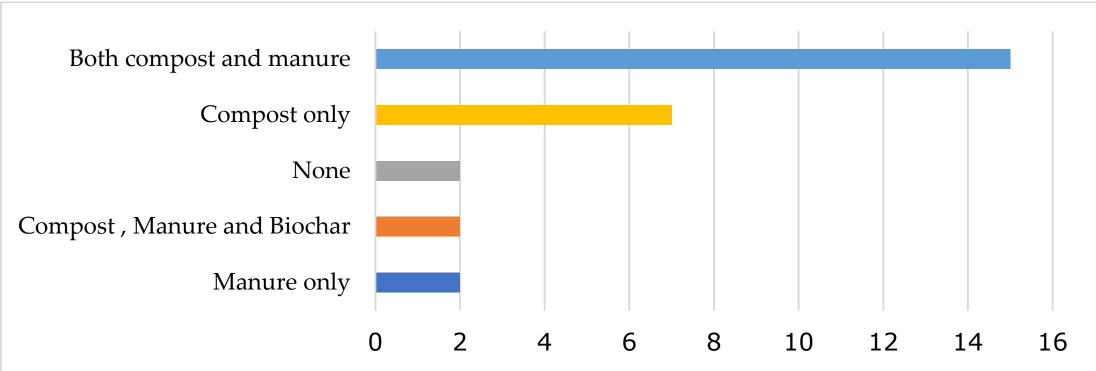

Figure 2. CFP application among cooperatives under Organic Farming systems in Uganda.

Table 4: Reported ecological and economic trade-offs of CFP's under Organic Farming systems

(n = Frequency of effect among all respondents)

Effects				**Trade-offs**			
Ecological	*n*	*Economic*	*n*	*Ecological*	*n*	*Economic*	*n*
Improved soil quality	16	Improved yield	17	Knowledge and adequacy of right amounts and mixtures	9	Access, purchase cost, transportation &, hectic, bulk of amendments	18
Enhanced water-holding capacity	5	Increased profits	6	Long decomposition time	7		
Increased natural organisms	3	Improved incomes	5	Harbor pests	2		
Better pests, weeds, disease control	3	Reduced input use	2				
Total	**27**		**30**		**18**		**18**

CFP application amongst cooperatives under CF systems

Amongst the CFPs, examined in this system; majority of the respondents (32%) were applying all the four CFPs. The single most applied CFP was crop rotation, (Figure 3). Ecologically, improved soil quality was the most reported effect of CFP among the ecosystem services followed by improved water holding capacity and better pest, disease and weed control. Under this category, biodiversity, pollination services and carbon sequestration services were not mentioned by any respondent. Economically, yield improvement was the highest reported effect of followed by reduced usage of other inputs while profitability and improved incomes were the least mentioned effects of the application of the CFPs respectively. This is the only CFP category in which low yield was reported compared to OF and IF systems. The ecological effects outweighed economic effects while economic trade-offs outweighed ecological trade-offs (Table 5).

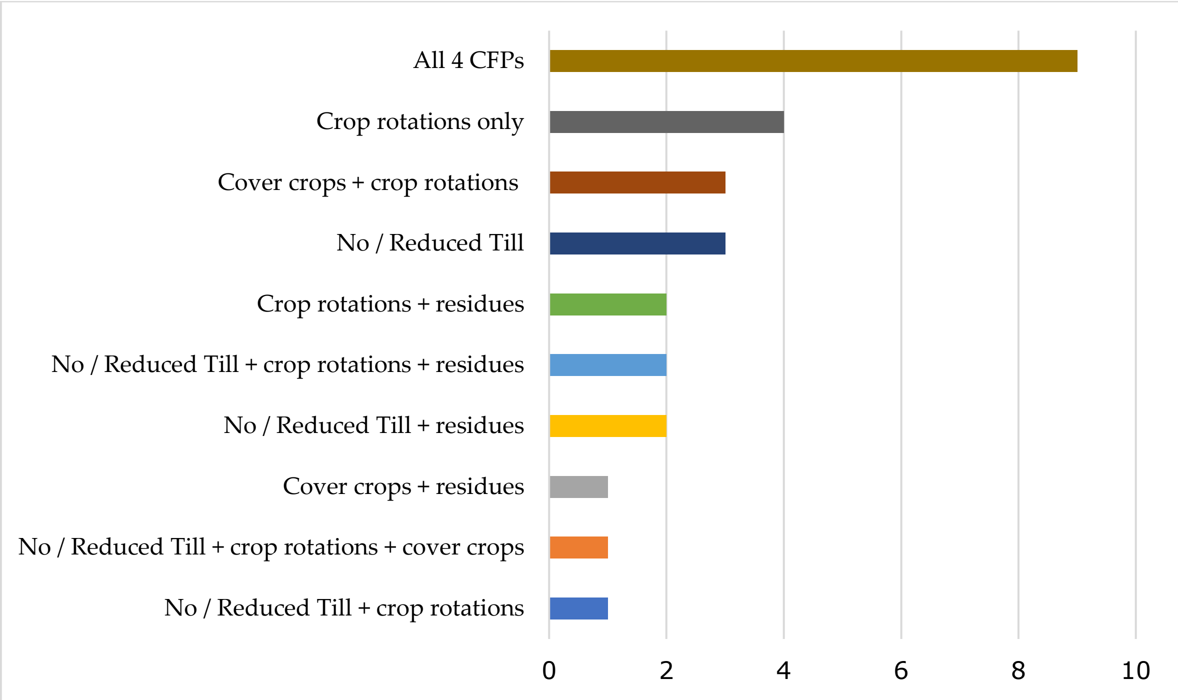

Figure 3. CFP application among cooperatives under Conservation Farming systems in Uganda.

Table 4: Reported ecological and economic trade-offs of CFP's under Conservation Farming systems

n. = Frequency of effect among all respondents

Effects				Trade-offs			
Ecological	*n*	*Economic*	*n*	*Ecological*	*n*	*Economic*	*n*
Improved soil quality	12	Improved yield	12	Land availability / shortage	7	Capital, costs & availability of materials & Knowledge and skills	8
Enhanced water-holding capacity	6	Reduced input use	4	Right crop rotations varieties, pathogens, harbour pests,	3	Time consuming, labour intensity, shortage, and costs	4
Better pest, weed and disease control	5	Increased profits	2			Low yield	3
		Improved incomes	2				
Total	**23**		**20**		**10**		**15**

CFP application amongst cooperatives under IF systems

Intercropping was the most reported CFP (50%) in IF systems while agroforestry was the least reported CFP (Figure 5). Improved soil quality was the most reported effect followed by enhanced water holding capacity and better pests, weeds, disease control. Other ecosystem services such carbon sequestration, pollination services, and biodiversity were not mentioned by any respondent. Economically, improved yield as a result of diversification under CFPs under this category recorded the highest number of respondents while reduced inputs due to interdependence of the farming system activities were mentioned second, followed by improved incomes and increased profitability (Table 5) .

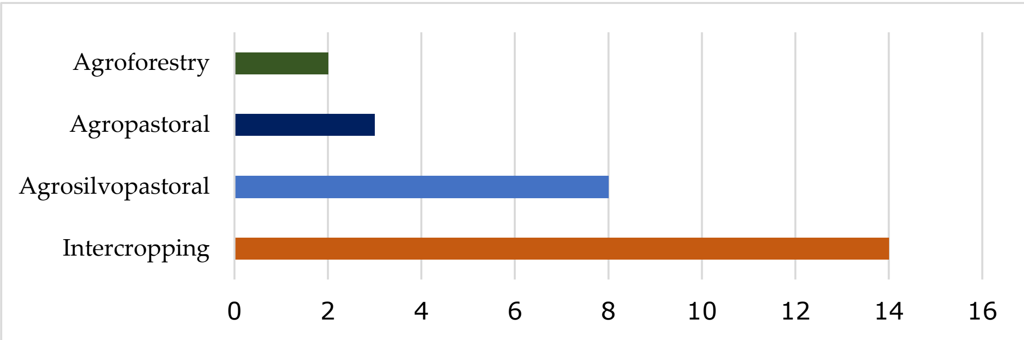

Figure 5; Respondents CFP application under Integrated Farming

Table 5. Reported ecological and economic trade-offs of CFP's under Integrated Farming systems

n. = Frequency of effect among all respondents

Effects				**Trade-offs**			
Ecological	*n*	*Economic*	*n*	*Ecological*	*n*	*Economic*	*n*
Improved soil quality	3	Improved yield	13	Soil rest, fertility loss, nutrient competition,	5	Management, time consuming, costly, high labour, land, capital	10
Enhanced water-holding capacity	1	Reduced input use	6	Pests, animal eat up crops	4	Low yield	2
Better pests, weeds, disease control	1	Improved incomes	4			Knowledge, skills, Not common system	3
		Increased profits	2				
Total	**5**		**23**		**9**		**15**

4. Discussion

Of the CFP's studied here, application of compost was the single most applied CFP under OF in small holder cooperatives in Uganda. This corresponds to a study [17] which discovered that smallholder farmers' perceptions and their understanding of the benefits of compost can increase its adoption rate. This is also because compost application by a large majority of respondents could also be due to local availability of cheap organic amendments [75]. More so, the high compost and manure combination rate by farmers also resonates with [73] who asserted that most composts are made of plant residues and manure as well as [74] who suggested organic amendments combinations for benefit maximization. Biochar has been widely documented including in studies from within Uganda such as [25] although implementation is still limited as shown in the results of this study. This is probably due to limited awareness, yet it can be easily produced locally [26] from the burnt on-field crop residues which is a common practice among small-holder farmers. Results showed that respondents are more aware about the soil fertility effect, also mentioned by [60], improved water holding capacity, mentioned by [43], enhanced microbial activity by natural organisms, enhanced pest, disease and weed control as argued by [52]. Although, the non-recognition of services like biodiversity and carbon sequestration calls for attention since they are of great significance in carbon farming and for reducing the GWP potential. This non-recognition could arise from the invisibility and intangibility of biodiversity and carbon sequestration as relevant parameters for production and climate mitigation and resilience. Unawareness hereof may potentially increase the risk of cropland expansion into forests which highly further threatens biodiversity [64]. Improved yield [76], increased profitability [41] as a result of improved incomes and reduced use of other inputs [77] as reported effects appeared more appealing and attractive to the respondents. Some studies that suggest that organic amendments lead to reduced yield [70] and are quite expensive to implement. More to this are the increments in economic resources surrounding organic amendments' access, costs, transportation, bulky nature and labor intensity which are serious trade-offs that should be considered.

A large percentage of the respondents implemented multiple CFPs under CF. This provides opportunities for enhancing ecosystem services [33]. This study shows that crop rotations was the most implemented CFP which contradicts the norm across most farms in the country where monocultures are grown on the same piece of land for long periods of time. The low use of crop residues by respondents is justified in residue burning while preparing farmland which is also a very common practice amongst smallholder farmers especially prior to the rainy season. Our study also confirms that CFPs enhance ecosystem services [27] through soil fertility increase [10], water holding capacity [8], weed pest and disease control [61] as validated by small holder farmers. These three most mentioned ecosystem services are directly tangible and related to output which results into economic viability inform through yield increase [27], increased profitability [55] and reduced use of inputs [31]. However, yield increment is claimed to be in form of small percentages that could compromise food security in the long run [79]. Chances of yield and income maximization are higher when CFPs are jointly applied [78] as most respondents in this study revealed. Consequently, other ecosystem services such as, carbon sequestration, biodiversity and pollination roles need to be a norm at farm level amongst smallholder farmers.

The study revealed that most respondents were involved in mixed farming systems under IF and mostly practice the intercropping combination, agroforestry was the least applied. According to several experts, the big difference is probably due to the perceived non profitability of agroforestry systems by farmers on arable lands coupled with small pieces of owned land. In as much as [43] argued improved incomes for agroforestry systems, this is not evidently appealing to most respondents. A study by [38] suggested that agropastoral combinations are a default system among small holder settings. This assertion stands to resonate with common practice where smallholders rear among others: poultry, cows, goats, rabbits, pigs, fish on their farms. These livestock units are mostly not for commercial purposes. The economic effects of CFPs under IF clearly outweighed the ecological effects in this study in form of yield improvement [4], reduced input [58] and diversified incomes [43]. Yield increases up to 150% were reached compared to conventional agricultural systems [35]. The reduced use of input is arguably due to the interdependency of the farming systems and shareable inputs as suggested by some agropastoral respondents and [80].

In contrast to OF and CF systems, the IF results show the improvements in soil fertility are an outcome of intercropping with leguminous crops [43] and agrosilvopastoral combinations [40]. Although little responses in terms of water holding capacity and pest, disease and weed control were reported in the IF category [11], other ecosystem services were still not reported. Perceived ecological trade-offs like nutrient loss were reported by most respondents due to nutrient competition on the same piece of land compared to respondents in support of soil fertility improvement. This could imply that CFP application under IF still lacks localized proof and scientific evidence for implementation in favor of ecological benefits [59]. The most economic trade-offs involved CFP application were in form of management complexities and high resources which connects with [40, 10]. More to this are the knowledge requirements reported which are in relation to a recent study conducted in Uganda [81].

Irrigation, nutrients, pest, disease and weed management during CFP implementation require proper attention before implementation across various farming systems because these are the ultimate determinants of sustainable farming systems. This study suggests that increased ecological benefits under combined CFPs although this requires increased economic investment which is not readily available for small holder farmers in cooperatives whose core focus is to earn a livelihood. Our study provides a basis for CFP application in cooperatives and on grounds of presented positive effects. As far as trade-offs portrayed herein are concerned, attention of great significance in specific contexts of implementation is needed. Since CFP application is quite labor intensive, this could promote more gender inequalities since women are the most involved in farm work compared to men [79]. This requires careful consideration for the community of practice and smallholder farmers. Our study focused on crop land management as a major production factor of the farming system and the interaction of the system components (Figure 6). Other GHG production factors such as; water use, energy use, labor, capital and other inputs of the farming system small holder households need consideration.

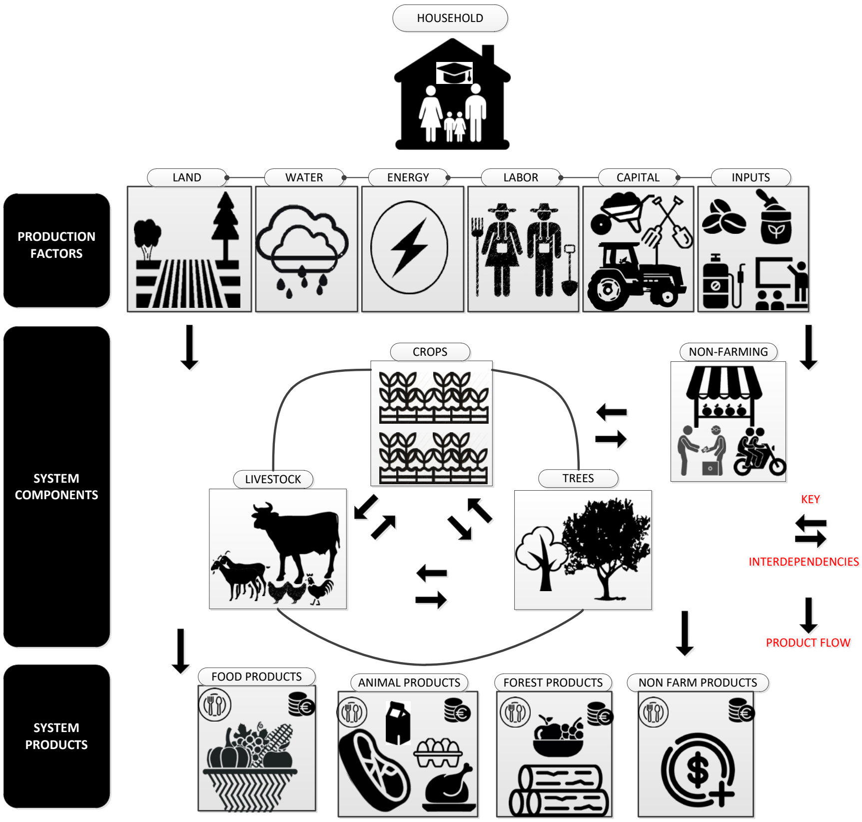

Figure 6: Illustration of how CFPs can contribute to a climate smart an agricultural farming system

5. Conclusions

In this study, the following CFPs were identified and categorized under three farming systems; compost, manure and biochar under organic, no/reduced till, crop residues, cover crops and crop rotations under conservation and intercropping, agroforestry, agropastoral and agrosilvopastoral under integrated farming systems. The main positive CFP ecological effects were carbon sequestration with varying sequestration potential. The main economic effect was increased yield which also varies per CFP, crop grown and farming system. The main trade-offs were increases in high investment requirements required for CFP application amongst small holder farmers cooperatives.

From the field survey we found that compost and manure were the most applied CFPs (54%) under organic farming, multiple CFPs under conservation farming were applied most and simultaneously (32%) while intercropping was the most applied CFP (50%) under integrated farming. Dilemmas about right and consistent organic amendments quantities and supplies need to be solved in order to further advance the application of CFPs amongst crop cooperatives in Uganda.

Supplementary Materials: None

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