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Towards low carbon agriculture: Systematic-narratives of climate-smart agriculture mitigation potential in Africa

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ABSTRACT

The agricultural sector is the second major source of climate change globally, contributing to anthropogenic Greenhouse Gas (GHG) emissions. In low-to-middle income countries, estimations indicate future increases in agricultural emissions. Climate-Smart Agriculture (CSA) has an express opportunity to transform agriculture across the globe. In Africa, CSA targets focused on resilience building and food security with less emphasis on the GHG mitigation potential. Nevertheless, to make CSA conclusive as an express low emission development strategy in Africa, understanding the mitigation potential in this context is paramount. Through a systematic-narrative review approach conducted on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), the study aimed to identify opportunities to mitigate GHG emissions in Africa. We observed that the distribution of studies that quantitatively assessed the GHG emissions of CSA practices was disproportionate across Africa. For instance, out of twenty studies evaluated, nine were conducted in Southern Africa; three in East Africa, and the rest distributed among Central, Western, and North Africa. Observed in the studies, advanced livestock breeding and feeding, organic nitrogen input, improved pastures and switching land-use practices, all contributed to GHG emission reduction. As limited experimental evidence exist on the GHG mitigation potential for some of the CSA alternatives including agroforestry, rotational farming, improved livestock breed and intensification of ruminants' diet, we recommend further experimental studies into these alternatives in more locations/contexts in Africa. Also, progress on the mitigation pillar is still limited in Africa due to lack of the necessary analytical infrastructure to conduct the needed measurements. We call for urgent investments into laboratory facilities and skills training to improve data collection and quality.

Contents

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1. Introduction

Greenhouse gases (GHG) concentrations in the atmosphere including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have increased rapidly within the 20th Century (Sparrevik and Utstøl, 2020; Nayeb et al., 2019; Zheng et al., 2019). The contribution of agricultural GHG emissions is estimated at 60% for Africa and Latin America, 30% for Asia, and approximately 10% for Europe and North America (FAO, 2020). In these regions, agricultural GHG emissions are expected to increase (Smith et al., 2014a, 2014b; Herrero et al., 2013). Moreover, smallholder farmers that are dominant in these regions (Africa, Latin America and Asia) have low absolute GHG emissions per hectare, but high emission intensities, i.e., emissions per unit of food produced (Wollenberg et al., 2016; Seebauer, 2014). For instance, in most African countries, the recent increase in GHG emissions from the sector has been highly recognized (Tongwane and Moeletsi, 2018; Bonilla-Findji et al., 2017; Smith et al., 2014a, 2014b). The last three decades experienced increases in agricultural output in the continent mainly from the extension of rain-fed crop cultivation, especially food crops, resulting in the degradation of marginal soils and reducing traditional fallow periods (Tongwane and Moeletsi, 2018). Influenced by rapid human population growth, unsustainable agriculture practices including increased use of inorganic fertilizer, insecticides, and pesticides have been recorded in different African countries (FAO, 2020). The fast-rising wealth of urban populations and changes in dietary needs for livestock products has also motivated more livestock production (WHO, 2018; FAO, 2013, 2014).

Due to low mechanization in Africa's agriculture, the non-CO_2 gases dominate the total GHG emission budget. Non-CO_2 GHGs including CH_4 and N_2O contribute substantially to overall warming. These gases continue to define the emissions trajectory of Africa's agriculture. For instance, as of 2017, 42%/75% of total CH_4/ N_2O emissions originated from agriculture (FAO, 2020). The main sources of these emissions (CH_4 and N_2O) are from enteric fermentation, manure management, manure deposits on pastures and soil management/fertilization (Wiedemann et al., 2015; Valentini et al., 2013). Global GHG analysis shows that Sub-Saharan Africa (SSA) has the highest absolute GHG emissions per unit of livestock 4580 kg CO_2-eq. GJ^{-1}, where enteric fermentation and manure contribute 2877 kg CO_2-eq. and fodder production 1689 kg CO_2-eq. (Bennetzen et al., 2016; Herrero et al., 2016; Gerber et al., 2011). It has been estimated that livestock accounts for 7.1 Gt CO_2eq/year, of which 3.1 Gt CO_2eq/year is in the form of CH_4, 1.92 Gt CO_2eq/year as CO_2, and 2.06 Gt CO_2 eq/year as N_2O (Gerber et al., 2013).

Distribution of GHG emissions within the African continent reveals that Eastern and Southern Africa contribute substantially to total GHG emissions. Southern Africa contributes 27%, whereas Eastern Africa accounts for 21% (FAO, 2020). Within Southern Africa, agricultural GHG emissions projection indicates about 37.7% increase by 2050 (Stevens et al., 2016). Out of the ten (10) countries included in the East Africa Regional mission, eight (8) countries have available GHG emissions data with two (Somalia and South Sudan) currently without data. The Democratic Republic of Congo (DRC) is noted to have the highest total GHG emissions in the region, followed by Tanzania, Ethiopia, Kenya, Central African Republic (CAR), Burundi, Rwanda and Djibouti (WRI, CIAT, 2015). Agriculture emissions from West Africa, Central and North Africa are quite lower compared to Eastern and Southern Africa. West Africa however is experiencing a significant growth in agriculture GHG emissions accounting for 20% of agriculture emissions in the continent (Tongwane and Moeletsi, 2018).

To slow down the rapid increases in agricultural GHG emissions, the concept of Climate Smart Agriculture has been developed (FAO, 2010; Lipper et al., 2014). Climate-Smart Agriculture (CSA) focuses on three major pillars, (1) sustainably increase productivity to support the development, and equitable increase in farm incomes and food security, (2) increase resilience, and (3) reduce or eliminate GHG emissions (mitigation) wherever possible (Saj et al., 2017; de Nijs et al., 2014; FAO, 2010; Lipper et al., 2014). Under this concept, several agricultural practices including agroforestry, integrated nutrient management, advanced seeds, conservation tillage, water resource management and improved livestock breeds have been proposed (FAO, 2020; Aggarwal et al., 2019). Current literature (Dunnett et al., 2018; Andrieu et al., 2017; Sain et al., 2017; Brévault and Bouyer, 2014) on the efficacy and potential of CSA in agriculture systems transformation in Africa have mostly focused on two pillars (Pillar 1: adaptation and, Pillar 2: food security). Prioritizing research on the third pillar (Pillar 3: mitigation) is salient to bridge the science-policy knowledge gap and provide substantial information that can inform regional, national and international public and private sector investment (Aggarwal et al., 2019; Olorunfemi et al., 2019; Das et al., 2014). Appropriate CSA mitigation strategies can also be developed based on available technical options and their cost of implementation (Richards et al., 2019a, 2019b; Hammond et al., 2017). Employing a systematic-narrative approach, our paper collected evidence from existing case studies on the GHG mitigation potential (Pillar 3) of CSA in Africa.

2. Materials and methods

The paper adopts a mixed review approach based on systematic and narrative reviews. The systematic review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach. With extensive adherence to the PRISMA protocols, a systematic review of articles and documents on CSA practices in Africa was undertaken (Liberati et al., 2009; Moher et al., 2009). PRISMA protocols (Liberati et al., 2009; Moher et al., 2009) represent a more robust adjunct to documentary analysis techniques. However, as the investigation did not examine "studies" as the PRISMA statement (Moher et al., 2009) was designed to investigate, not all components of the statement were relevant. The systematic-narrative approach was employed to present an overview of the GHG mitigation potential of CSA in Africa and provide a sense of direction for policy and future studies. The systematic-narrative approach also helped to identify research gaps and improve upon current understanding of the topic, highlighted relevant methodological concerns and provided clarification on context-specific CSA options promoted in Africa. A narrative in this paper is understood as a storyline about the past, present, and future based scenarios and assumptions about GHG mitigation trajectories of one or more context components (soil organic carbon, carbon stock changes, livestock enteric fermentation, livestock manure management, and fertilization) (Table 1). The narratives were compiled from summarized speeches on CSA, media discussions and general policy statements commonly used in the CSA literature. The narratives provided the bases for comparing conventional agriculture and CSA thereby guided the selection of the included articles.

2.1. Search strategy/terms

A detailed literature search was conducted on numerous database platforms including SCOPUS, Science Direct, Google Scholar, Springer Link, and Emerald. Further, an in-depth hand search to identify additional literature including project evaluation reports was conducted. The same key terms were used in the searches on the various databases including CSA/SALM mitigation, carbon sequestration, livestock enteric fermentation,

Table 1
Common narratives/storylines of CSA.

Mitigation narratives	Conventional agriculture	CSA
Soil Organic Carbon (SOC)	- Leads to erosion of soil organic carbon (C) stocks through the burning of crop residues, and the use of fossil-fuel intensive inputs like mechanised ploughs. Higher use of chemical fertilizers. →	+ Prevents soil erosion and maintains cover crops especially when practiced with trees, increases C sequestration and storage. + Promotes recycling of waste and organic residues thereby limiting the use of external inputs like inorganic fertilizer.
Agroforestry (Carbon Stock Changes)	- Forests are cleared or degraded for new agricultural lands and farm expansions. →	+ Increases tree cover that contributes to promoting biomass above and below ground including soil carbon. +Reduces forest degradation through improved practices and higher productivity.
Livestock Enteric Emissions (LEM)	-fewer cattle produced in intensive systems. Poor management systems including inappropriate diet quantity and poor diet quality increases CH_4. →	+ Mitigation strategies are often related to the intensification of cattle production. Approaches including fertilizing pastures to increase the pasture productivity, reducing grazing period and adding more concentrated (less fibrous) feed to the diet reduces emissions.
Livestock Manure Management (LMM)	-A Low percentage of manure managed; illegal disposal, no surface crust, liquid manure flushed into the environment, manure not collected at one place and high anaerobic conditions. →	+ Composting, improve manure handling and storage, (e.g. covering manure heaps) application techniques (e.g. rapid incorporation). Alternative uses of manure like the biogas, can reduce GHG emissions.
Fertilization	-Increase soil fertility through synthetic fertilizers; affects water quality, reduces soil fertility over time, weaken soil texture and predispose soil to erosion. → -Higher fertilization of soils with nitrogen increase releases of N_2O.	+ Increase soil fertility through organic fertilizers. Organic fertilizers improve and maintain productive soils and stimulate plant growth without environmental degradation.

Source: Compiled by Authors, 2020

livestock manure management, carbon stock change, GHG emission reduction, nutrients management, improved agronomic practices, sustainable intensification, low emission strategies and low carbon development, including agriculture and Africa as either prefixes or suffixes. The specific key word search included the search strings “agroforestry” and “mitigation”, “improved livestock breed” and “emission reduction”, “no-till” and “mitigation”, “water conservation” and “soil organic carbon” as well as “nutrient management” and “low emissions”. Articles that only made assumptions on the GHG mitigation potential of CSA without actual quantitative measurements were not considered. The searches were performed between January 1 and February 20, 2020.

2.2. Inclusion and exclusion criteria

Articles published in the English language with the main focus on CSA mitigation and Sustainable Land Management (SALM) conducted on the African continent were considered. Most importantly, those published in languages other than English were excluded. The paper considered a decade of CSA implementation. This implies that articles published on CSA and mitigation for the years 2010–2020 were qualified for the review. In 2010, CSA became a buzz word after the World Bank and FAO took comprehensive measures to transform agriculture systems in the face of climate change (World Bank, 2010; FAO, 2010). The motivation was to present information on the contribution of CSA to GHG mitigation in Africa. Moreover, to capture possible relevant articles, those without CSA or GHG mitigation directly mentioned but addressed one or more of the CSA/mitigation options mentioned by the proponents of the concept were included (FAO, 2013). For instance, articles addressing issues on: soil organic carbon, carbon stock changes, livestock enteric fermentation, livestock manure management and fertilization were included. Also, articles that addressed both adaptation and mitigation synergies were considered. However, these articles must have stated clearly and empirically the GHG mitigation potential of any of the CSA practices contextualized. Articles with the main focus outside CSA/SALM mitigation potential; conducted outside Africa, including reviewed studies, commentaries, letters, and editorials, duplicated articles published before 2010 were excluded.

2.3. Search results

A total of 222 electronic articles were retrieved from the databases (SCOPUS = 59, Science Direct = 55, Google Scholar = 60, Springer Link = 31, and Emerald = 17). The hand search yielded 6 additional relevant articles on the topic under investigation resulting in a total of 228 retrieved research articles. Out of the 228 retrieved articles, 8 were duplicates and 200 were excluded based on their titles and/or abstracts, as they did not fulfill the inclusion criteria (Fig. 1). Most of the excluded studies also provided qualitative representation of the GHG mitigation potential of CSA rather than quantitative evidence. The final review included 20 articles. A few of these studies were global studies but provided a central focus to Africa with empirical evidence of one or multiple CSA practices. The selected studies were categorized into different themes, thus, geographical distribution, type of CSA mitigation option addressed, the study methods/designs used, and the outcomes/findings.

3. Results

3.1. Geographical distribution of studies

Out of the 20 studies, nine were conducted in Southern Africa; Zimbabwe (studies 5, 10, 11, 15, 16 and 17), Malawi (studies 2, 14 and 19), Zambia (studies 1, 12) and Mozambique (studies 1 and 13) (Shown in Table 2). Three were from Eastern Africa (studies 1 to 3) and one a comparative study for Eastern and Western African countries (study 12). The rest of the studies were collaborative, analysing issues from the global perspective with empirical evidence from Africa (4 and 18) perspective. Others included sectional studies; tropics (study 6), arid regions (study 20), Sub-Saharan Africa (studies 5 and 8).

3.2. Agriculture categorization

For the specific agriculture categorization investigated; five studies solely focused on cropland (studies 2, 3, 5, 13 and 18), two were on livestock (studies 6 and 9), and one combined both cropland and livestock (study 1). Studies 3, 4, 7 and 8 captured issues on Soil Organic Carbon (SOC), soil quality management was captured by Studies 5, 10, 11, 12, 17 and 20 and Conservation Agriculture (CA) (3, 14, 15 and 19) as shown in Table 3.

3.3. Outcome of studies

The outcome of the studies was influenced by time and scale, geographical and weather conditions, as well as methodological approaches. The livestock sector was observed to have some intensification practices that were sustainable to the environment. Study 1 established that improved livestock feeding resulted in a small increase in GHG emissions thereby decreasing emission intensity per produced energy.

Studies 1, 6 and 9 found that improved forage quality (FoCo) by supplementing larger quantities of Napier grass (*Pennisetum purpureum* Schumach.) with concentrates (FoCo) reduced GHG emission intensity from 2.4 ± 0.1 to 1.6 ± 0.1 kg CO_2eq per kg milk. Contrary, in-calf cross-bred heifers' (*Girinka*) distribution in Rwanda increased GHG emissions by 1174 kg CO_2eha^{-1} yr^{-1} hence it is not a promising option to reach CSA triple win goal (Study 1).

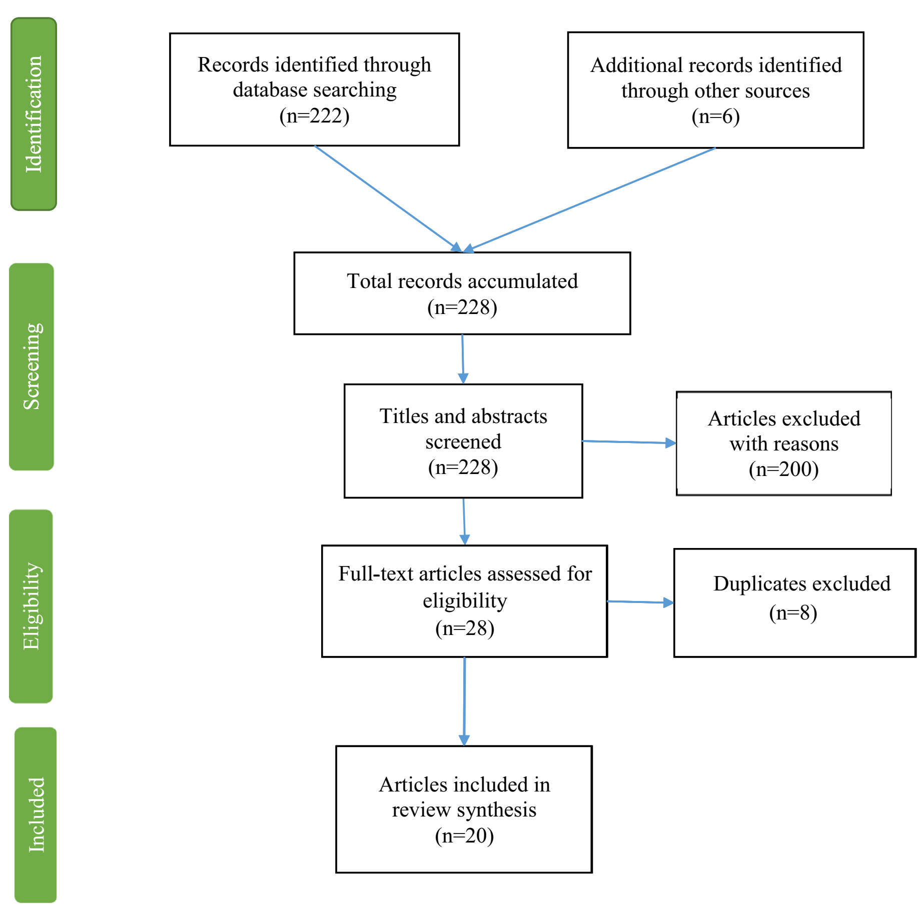

Fig. 1. Flow-diagram of search process.

Table 2
Summary results from selected studies.

Reference Author (s) Year, Country/region	Agriculture categorization	CSA alternative evaluated	Methods, design	Key findings
1 Paul et al. (2018) Rwanda	Cropland and livestock	Improved livestock breed and feeding. Soil and crop management	Ex-ante impact analyses across different agro-ecologies	Improved livestock feeding resulted in a relatively small increase in GHG emissions (50 kg CO_2e hh^{-1} yr^{-1}) thereby decreasing emission intensity per produced energy. In-calf crossbred heifers' (*Girinka*) distribution increased GHG by 1174 kg CO_2ehh^{-1} yr^{-1} hence not a promising option to reach CSA triple win.
2 Bellarby et al. (2014) Kenya and Ethiopia	Soil and cropland	Organic Nitrogen (N) input	Cool Farm Tool (CFT) estimation of GHG emissions from best practices	Found residue addition to contribute significant amounts of N to the soil, lowering emissions than when N is supplied as synthetic fertilizer only. Farmyard manure resulted in lower GHG emissions compared to equal amounts of fertilizer in synthetic form.
3 Ambaw et al. (2019) Eastern Africa (Tanzania, Kanye & Uganda)	Cropland (Soil Organic Carbon)	Agroforestry, farm yard manure, soil and water conservation	SOC analyzed using flash combustion	Integration of CSA practices into land uses increased SOC stocks by 42–196% at the depth of 0–15 cm, and 19–110% at cumulative one-meter depth soil profile compared to BAU. At the depth of 0–15 cm, improved agroforestry practices increased SOC by 42% (Nyando), 119% (Hoima) and 185% (Lushoto) compared with the corresponding BAU.
4 Powlson et al. (2014) Global	Soil Organic Carbon (SOC)	No-till practice	Standardized annual C accumulation rate (0.3 Mg C ha^{-1} yr^{-1}) applied to global regions	Found an annual global rate of SOC accumulation of 0.17 Gt C, equal to 0.6 Gt CO_2e for no-till practice for global cereal area of 559 Mha, and 0.4 Gt CO_2e yr^{-1} for areas under wheat, maize, and rice (where no-till can be most easily practised).
5 Powlson et al. (2016) IGP and SSA	Agro-ecosystems	Conservation Agriculture	Meta-analysis of Indo-Gangetic Plains (IGP) and Sub-Saharan Africa (SSA)	Predicted annual rates of increase of SOC stock by 0.37 $\pm$ 0.045 Mg C ha $^{-1}$ yr. $^{-1}$ compared to conventional practice. Individual rates of increase for reduce tillage (0.49 Mg C ha $^{-1}$ yr. $^{-1}$), residue retention (0.16 Mg C ha $^{-1}$ yr.$^{-1}$) and crop diversification (0.47 Mg C ha^{-1} yr.$^{-1}$). In SSA increases were between 0.28 and 0.96 Mg C ha $^{-1}$ yr.$^{-1}$.
6 Thornton and Herrero (2010) Tropics	Livestock and pasture management	Improved pastures, intensifying ruminants diets, changes in land-use practices and changing breeds of large ruminants	Dynamic system modelling (RUMINANT)	The sum of mitigation potentials of various livestock intensification practices (improved pastures, intensifying ruminants diets, changes in land-use practices and changing breeds of large ruminants) amounted to 417 Mt. CO_2-eq corresponding to approximately 12% of the global livestock-related CH_4 and CO_2 emissions that are associated mainly with extensive livestock systems.
7 Brown et al. (2012) East and West Africa	Soil Carbon Sequestration	Switching land use practices (degraded-improve, reduced tillage-native ecosystems etc.)	IPCC framework/carbon tool, NASA MODIS and ESA MERIS	Change in practices (switching from severely degraded grazing lands to those with improved management; switching from rain fed cultivation with full tillage to reduced tillage and with different level of nutrient inputs; switching from reduced tillage rain fed cultivation to native ecosystems, and converting combined mosaic vegetation (assumed to be shifting cultivation cycle) to native ecosystems) resulted in carbon sequestration rates in the top 30 cm of soil of about 0.4 to 5 t CO_2e ha^{-1} yr^{-1} and for changes that included in the soil and vegetation of about 6 to 22 t CO_2e ha^{-1} yr.
8 Roobroeck et al. (2015) Sub-Sahara África	Soil Organic Carbon (SOC)	Integrated soil fertility management	long-term multi-locational trials	The content of organic C in the top 5 cm of soil at the end of many years for trials of different input showed a change of C content from 12.2 g C soil kg^{-1} to 13.3 g C soil kg^{-1} when fertilizers and organic inputs are combined as compared to exclusively fertilizers or organic materials.
9 Brandt et al. (2019) Kenya	Livestock	Improvements in forage quality (Fo), feed conservation (Fe) and concentrate supplementation (Co)	The Livestock Simulation Model (LivSim)	Improved forage quality (FoCo) by supplementing larger quantities of Napier grass (*Pennisetum purpureum* Schumach.) with concentrates (FoCo) reduced GHG emission intensity from 2.4 $\pm$ 0.1 to 1.6 $\pm$ 0.1 kg CO_2eq per kg milk; (b) using feed conservation (FeCo) by producing maize silage and feeding concentrates, closing the yield gap of fodder maize reduced it to 2.2 $\pm$ 0.1; and a combination of Napier grass, maize silage and concentrates (Fo FeCo) increased it to 2.7 $\pm$ 0.2 kg CO2eq per kg milk because of land-use change emissions.
10 Thierfelder and Wall (2012) Zimbabwe	Soil quality	Conservation Agriculture (CA)	Long-term on-farm and on-station trial	Increased in SOC was observed by 46% in the first 20 cm on the sandy soils in rip line-seeded (RS) and by 104% in direct-seeded CA treatments in four cropping seasons, whereas it stayed at low levels on the conventionally tilled control treatment.
11 Thierfelder et al. (2012) Zimbabwe	Soil quality	CA	Long-term on-farm and on-station trial	Soil carbon was greater in intercropped treatment in the first 0–30 cm, suggesting additional carbon input from the intercropped legumes. Bulk density was however lower in the top soil and in deeper soil horizons.
12 Thierfelder et al. (2013) Zambia	Soil quality	CA	Long-term on-farm and on-station trial	Greater SOC recorded under CA compared with conventional agriculture in the top 30 cm soil depths. After five years' of CA treatment, using direct seeding with a maize cotton rotation SOC was 46% (9.7 Mg ha^{-1}) greater compared with a conventional plough treatment with sole maize.

(continued on next page)

Table 2 (*continued*)

Reference Author (s) Year, Country/region	Agriculture categorization	CSA alternative evaluated	Methods, design	Key findings
13 Rusinamhodzi et al. (2012) Mozambique	Cropland	Intercropping	Additive and substitutive design	Intercropped maize with pigeon pea (*Cajanus cajan* (L.) Millsp.) For up to five years and showed huge increases in SOC, which became larger the longer the intercropping lasted.
14 Ngwira et al. (2012) Malawi	Cropland	Intercropping	linear mixed effects model (REML procedure)	Observed a 76% increase in SOC when maize was intercropped with legumes.
15 Nyamangara et al. (2014) Zimbabwe	Cropland	Tillage systems	Paired plots analysis	Observed that, after CA treatment for 5 years, there was about a 70% increase in SOC in sandy soils and a 40% increase in finer textured soils compared with conventional agriculture.
16 Mujuru et al. (2013) Zimbabwe	Land use	Rotational farming	Farmer managed experiments	Carbon increased in a maize-soybean rotation.
17 O'Dell et al. (2015) Zimbabwe	Soil management	Cover cropping	Micrometeorological methods: Four Bowen ratio energy balance (BREB)	Winter wheat cover crop produced a net accumulation of 257 g CO_2-C m^{-2} under no-tillage, while tilled plot with no cover crop produced a net emission of 197 g CO_2-C m − 2 and the untilled plot with no cover emitted even higher rates of 235 g CO_2-C m^{-2}.
18 van Kessel et al. (2013) Global	Cropland	Reduced-tillage	Nonparametric weighting function	There were no differences between conventional tillage and reduced tillage systems on N_2O emissions. However, when disaggregated by climate, in experiments carried out over 10 years, N_2O emissions were 27% lower under reduced tillage than conventional tillage in drier climates.
19 Ngwira et al. (2013) Malawi	Cropland	Mulch, reduced-tillage, rotation etc.	linear mixed effects model (Restricted Maximum Likelihood)	Observed no differences between CA and conventional practices after six years of experimentation for SOC measured at 0–10, 10–20, 20–30 and 0–20 cm.
20 Abdalla et al. (2016) Arid regions	Soil management	No-tillage	Comparative evaluation	Observed that conventionally tilled soils emitted 21% more CO_2 than untilled soils, with greater emissions occurring in sandy soils and arid climates.

The combination of livestock practices (including improved pastures, intensifying ruminants' diets, changes in land-use practices and changing breeds of large ruminants) contributed in an estimated mitigation potential of 417Mt CO_2-eq corresponding to approximately 12% of the global livestock-related CH_4 and CO_2 emissions associated mainly with extensive livestock systems (studies 6 and 9).

For Soil Organic Carbon (SOC), integration of improved agroforestry increased SOC stocks by 42–196% at the depth of 0–15 cm, and 19–110% at cumulative one-meter depth soil profile compared to Business-As-Usual (BAU) while no-till practice increased annual global rate of SOC accumulation by 0.17 Gt C (3, 4).

Similarly, Study 7 found that changes in practices including; switching from severely degraded grazing lands to those with improved management, switching from rain-fed cultivation with full tillage to reduced tillage and with different level of nutrient inputs, switching from reduced tillage rain-fed cultivation to native ecosystems and converting combined mosaic vegetation (assumed to be shifting cultivation cycle) to native ecosystems resulted in carbon sequestration rates in the top 30 cm of the soil of about 0.4 to 5 t CO2e ha^{-1} yr^{-1}, and for changes that included in soil and vegetation of about 6 to 22 t CO2e ha^{-1}yr.

Further, soil carbon was observed to be greater in intercropped treatment in the first 0–30 cm, suggesting additional carbon input from the intercropped legumes but bulk density was however lower in the topsoil and deeper soil horizons (study 11).

The implementation of multiple practices (minimum tillage, crop diversification and soil cover) at the same time could increase the GHG mitigation potential for some of the practices. For instance, five years of Conservation Agriculture (CA) treatment using direct seeding with a maize cotton rotation, SOC was 46% (9.7 Mg ha^{-1}) greater compared with a conventional plough treatment with sole maize (studies 12 and 15). Five years of CA treatment also increased SOC by 70% in sandy soils and 40% increase in finer texture soils compared to conventional agriculture (studies 12 and 15).

In a similar finding, results from the study 17 shows that Winter wheat cover crop produced a net accumulation of 257 g CO_2-C m^{-2} under no-tillage whereas tilled plot with no cover crop produced a net emission of 197 g CO_2-C m^{-2} and the untilled plot with no cover emitted even higher rates of 235 g CO_2-C m^{-2}. However, in an initial evaluation, study 18 found no significant differences between conventional tillage and reduced tillage systems on N_2O emissions. Reiterating the dilemma, study 19 found no differences between CA and conventional practices after six years of experimentation for SOC measured at 0–10, 10–20, 20–30 and 0–20 cm in Malawi.

4. Discussion

CSA is a low carbon agriculture strategy that has the potential to transform agricultural agriculture systems (Frank et al., 2019; Allen et al., 2018; Feliciano et al., 2013). The data (presented in Table 2) indicates that CSA mitigation potential is of interest to African countries. Nonetheless, a huge gap exists in the actual quantification of the GHG mitigation potential of CSA practices. As observed, few studies have taken into consideration the rigorous quantification of the GHG mitigation balance of CSA practices. A disproportionate number of studies were found across Africa. For instance, Southern and Eastern Africa had the most studies conducted on CSA mitigation. Southern and Eastern Africa are considered the hub of CSA in Africa due to the numerous CSA projects implemented (Ambaw et al., 2019; Bellarby et al., 2014). Therefore, extensive trials and experiments to ascertain the GHG mitigation potential of CSA in those areas are explored. Many countries in Central, Western and North Africa are progressively integrating

CSA into their agriculture value chain (FAO, 2020). The steady growth in the number of projects requires in-depth scientific evaluations into the GHG mitigation potential of climate-smart agriculture in those areas.

Greenhouse gas emissions from cropland management dominated the studies. Cropland constitutes a significant source of GHG emissions. Nevertheless, cropland management presents several opportunities for GHG emissions reduction (Mutenje et al., 2019; Paul et al., 2018). Most of the studies concentrated on SOC, soil quality, land-use and soil fertility management with less emphasis on livestock management. Nevertheless, while in several African countries livestock production represents a significant GHG emitter, many of the CSA practices targeted cropland management. Cropland cultivation is a primary practice for almost every farmer, whereas livestock is considered a luxury in some communities and is conducted by specific ones (Olorunfemi et al., 2019; Das et al., 2014). The complexities of livestock management in Africa contribute substantially to its low prioritization for climate change mitigation actions in some countries. For instance, pastoralism in Central, Western and some parts of Eastern Africa complicate CSA targets for the livestock sector. Constant movements and unreliable sources of feed impede long-term intensification measures, as well as monitoring and evaluation systems.

The specific CSA practices analyzed in the studies show that agroforestry, organic manure application and switching from degraded lands to improved lands have a vast potential of reducing GHG emissions. Agroforestry increases tree cover and contributes to increased biomass above and below ground including SOC (Ambaw et al., 2019). Tree litter enhances soil microclimatic conditions, produces green manure and improves fallowing practices. As observed in study number 3, the implementation of improved agroforestry practices increased SOC in experimental areas across the continent. Even though agroforestry presented a substantial GHG mitigation potential, we found only one detailed assessment on this CSA option. Degraded lands are lands with low carbon stocks (usually less than 35 t of carbon per hectare) (WRI CAIT, 2015). Degraded lands have less tree cover and peat, thereby unable to contain or sequester much carbon. Land switching provides ample opportunities for land restoration and mitigation benefits. Results from some of the studies (7, 16) affirm that switching from severely degraded lands to those with improved management practices resulted in substantial carbon sequestration and land restoration.

Integrated nutrient management, intercropping and reduced/no-tillage were also effective in reducing GHG emissions. Even though analytical approaches varied across different countries, results were similar for these practices (integrated nutrient management, intercropping and reduced/no-tillage). For instance, study number 8 concluded that C content increased when fertilizers and organic inputs are combined compared to the exclusive application of fertilizers or organic materials. Intercropping with nitrogenous plants increased soil GHG sequestration potency, which became larger the more extended the intercropping (13, 14). Management practices such as improved pastures, intensification of ruminants' diets and changing breeds of large ruminants have been proposed as practices with climate change mitigation benefits (Gerber et al., 2013). Improved pastures provide sufficient nutrition to animals compared to native savanna pastures (Paul et al., 2018; Thornton and Herrero, 2010). In the context of a cut and carry system, improved pastures reduce CH_4 emissions from livestock enteric fermentation and promote spot collection of manure. Sustainable intensification of ruminants' diets, including feed additives, increases digestibility, lowers CH_4 emissions from enteric fermentation and manure storage. For example, improved forage quality by supplementing *Pennisetum purpureum Schumach* with concentrates reduced GHG emissions intensity in Kenya (9).

Methodological limitations were reported in several of the studies. For instance, even though progressive interest was established on the contribution of CSA to GHG mitigation, methodological weaknesses resulted in less robust analysis. Many of the studies relied on the IPCC Tier 1 hierarchical model for GHG quantification. The Tier 1 approach is important in describing GHG situations, especially in developing countries where GHG mitigation experts and quantification materials are lacking (Hanle et al., 2019; Briner and Moarif, 2017). Nevertheless, the approach is not robust enough to present accurate picture and future scenarios. The few studies that employed Tier 2 and "limited Tier 3" showed significantly different estimations as compared to the Tier 1 studies. A more specific methodological gap observed in the studies was the absence of specific emission factors used in the evaluations. The inability to employ area-specific emission factors affected the establishment of key categories for some specific areas.

An area-specific analysis is expected to generate reliable information that feeds into national circumstances. Key category analysis provides the opportunity to identify the major sources and sinks of GHG emissions. Identification of key categories in the Agriculture Forestry and other Land use (AFOLU) sector helps to channel resources and technical expertise to achieve GHG targets efficiently. Localization of GHG emission estimations also helps to reduce uncertainties in national circumstances (Hanle et al., 2019; Briner and Moarif, 2017). As CSA remains prominent in Africa, progress is expected to advance towards specific emission factors for key emission categories. The use of region-specific emission factors will lead to reliable quantification and will inform appropriate mitigation actions. However, the general lack of technical and financial capacity to conduct the needed measurements and modelling hinders the ability of African countries to budget their GHG emissions accurately.

5. Conclusion and policy implications

CSA is a relevant mechanism to support food system transformation in Africa. Its' role in GHG mitigation is as recognizable as food security and climate change adaptation. The systematic-narratives reveal that analysis and interpretation of the GHG mitigation potential of CSA have become relevant among the scientific community in Africa. A detailed search of resources has outlined some important scientific studies on the topic. However, there was a disproportionate distribution of the studies across the continent, calling for more research in the lagging areas. Most of the studies employed the IPCC lower-tier methodology (Tier 1), which is not robust enough for accurate results. We thus, call for more robust methodological approaches in CSA mitigation estimation. As limited experimental evidence exist on the GHG mitigation potential for some of the CSA alternatives including agroforestry, rotational farming, improved livestock breed and intensification of ruminants' diet, we recommend further experimental studies into these alternatives in more locations/contexts in Africa. The limited studies may be insufficient for generalization indicating a need for more studies that focus on the mitigation pillar. Progress on this pillar is generally limited by a lack of the necessary analytical infrastructure to conduct the needed measurements. Hence, there is an urgent need to invest in laboratory facilities and skills training to improve data collection and quality. In policy context, we recommend development of stronger collaborations among scientists in developed and developing countries for efficient transfer of knowledge and technology for GHG estimation. Financial investments into CSA emission targets are relevant to advance interest in mainstreaming CSA into national development plans and Nationally Determined Contributions (NDCs). Simultaneously, appropriate Measurement, Reporting, and Verification (MRV) systems should be developed.

Availability of data and materials

Data that support findings of this study are available upon request through the corresponding author.

Consent for publication

Not applicable.

Ethics approval and consent to participate

Not applicable.

Declaration of Competing Interest

The authors declare that they have no competing interests.

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