Journal of Agriculture and Ecology Research International

22(5): 52-62, 2021; Article no.JAERI.74982
ISSN: 2394-1073

Adoption of Conservation Agriculture in Eastern Kenya: Identified and Measured Indicators of the Sustainability of the C.A Practices

Sharon Chepkemboi Waswa[1*] and Lenah Mutindi Mulyungi[2]

[1]Scuola di Agraria, Universita degli Studi di Firenze, UniFl / School of Agriculture, University of Florence, UniFl, Italy.
[2]School of Environmental Studies, Kenyatta University, Nairobi, Kenya.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAERI/2021/v22i530202
Editor(s):
(1) Dr. Chandra Shekhar Kapoor, Mohanlal Sukhadia University, India.
Reviewers:
(1) Sitti Nurani Sirajuddin, Hasanuddin University, Indonesia.
(2) Maybelle Saad Gaballah, National Research Centre, Egypt.
Complete Peer review History: https://www.sdiarticle4.com/review-history/74982

Original Research Article

Received 05 August 2021
Accepted 10 October 2021
Published 15 October 2021

ABSTRACT

Conservation agriculture (CA) is fronted as the solution to sub Saharan Africa food insecurity problems in light of climate change. Sustainability of agricultural landscapes has become a primary issue for policy-makers and land managers at different hierarchical levels including farmers, advisors, policy-makers, and scientists as reflected in many of the Sustainable Development Goals (SDGs). The SDGs focus on ending poverty, protecting the planet, and ensuring prosperity for all, as part of the new sustainable development agenda initiated in 2015 to precede the Millennium development goals. With the recognition that Sustainability assessment needs to move from global and regional scale to local scales to enable people measure their progress towards sustainability, a conceptual model guides the sustainability assessment approach adopted for this study. The AESIS framework is adopted for indicator selection and representation. This study sought to evaluate the agro-environmental and socio economic sustainability of Conservation Agriculture as practiced in Kenya. Results show that 8 out of 24 indicators performances are rated as best, 5 indicators performances are rated as good, 4 indicators performances are rated as moderate while 7 indicators performances are rated as either unacceptable or limited forming a basis for the points of improvement in agro-ecosystems under conservation agriculture.

**Corresponding author: E-mail: chepkemboiwaswasharon@gmail.com;*

Keywords: Sustainability assessment; indicator; SAFA; AESIS; conservation agriculture; sustainable agriculture.

1. INTRODUCTION

1.1 Background

Conservation agriculture (CA) is fronted as the solution to sub Saharan Africa food insecurity problems in light of climate change. The basis for these assumptions is on success stories in Brazil. However, studies that have been conducted since inception of CA in Africa and particularly in Kenya have pointed towards low adoption over the years mainly due to inadequate mulch cover due to insufficient organic resources and competing uses for the existing resources especially in mixed farming smallholder systems in Southern and Eastern Kenya. The unavailability of specialized tools for CA has also contributed to low adoption of the minimum tillage principle of CA while sociocultural aspects such as the 'maize syndrome' (a great dependence on maize only for food and limited preferential food options) in Kenya coupled with small farm sizes have continuously frustrated crop rotation efforts. Studies also show that lack of streamlined markets for purchase of inputs and sale of produce – a key prerequisite condition for adoption of new technologies were lacking. The case studies recommend the need to target end users and adapt CA systems to the local circumstances of the farmers, considering in particular the farmer's investment capacity in the practice of CA and the compatibility of CA with his/her production objectives and existing farming activities [1]. This study aims to determine why the same barriers to adoption still manifest in spite of years of increased conservation agriculture advocacy and project implementation in Kenya over the years. What are the prospects for adoption of CA in Kenya and what are the stakeholders' views on the actual socio-economic and environmental aspects of Conservation Agriculture as they practise it?

1.2 Agro-ecosystem Properties

Agro-ecosystem properties are classified into structural and functional properties as described in Fig. 1 below. The structural properties of diversity, coherence, and connectedness express the composition of an agro-ecosystem in terms of components and processes and their interrelations or the relations with the environment outside the boundaries of the system under analysis. These properties are relevant to understand the mechanisms that govern agro-ecosystem performance. [2] and to identify possible changes in the system to improve its sustainability. Diversity is related to the number of different components and processes present and their relative abundance, whereas coherence provides measures of the numbers and strengths of the connections among components and processes within the system. Connectedness is similar to coherence, but concerns the connections with entities outside the system.

Coherence and connectedness can typically be quantified using network and flow analyses. Monitoring of the flows within the system and thus coherence through time in relation to disturbances can be used to determine the capability of the system for adaptation, self-organization and for maintaining its integrity [3].

1.3 Conservation Agriculture: Principles & Practice

Baker *et al.* [5] Defines Conservation Tillage as: "the collective umbrella term is commonly given to no-tillage, direct-drilling, minimum-tillage and/or ridge-tillage, to denote that the specific practice has a conservation goal of some nature. Usually, the retention of 30% surface cover by residues characterizes the lower limit of classification for conservation tillage, but other conservation objectives for the practice include conservation of time, fuel, earthworms, soil water, soil structure and nutrients. Thus residue levels alone do not adequately describe all conservation tillage practices." Conservation agriculture (CA) aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. It contributes to environmental conservation as well as to enhanced and sustained agricultural production. It can also be referred to as resource efficient or resource effective agriculture as defined by FAO, [6-7]. Three CA main principles and advantages are drawn from success stories in Lesotho are outlined as follows [3-7]:

1. Minimum tillage & reduced soil disturbance: Conservation Agriculture

advocates for direct planting with minimal soil disturbance. This can be achieved manually or using mechanized equipment. The advantages of minimum tillage are: protection of soil against wind and water erosion, long term cost savings on fuel, labour and time, improved soil infiltration and moisture conservation, improves soil organic matter and yield per hectare hence reducing the dependence on external inputs i.e. fertilizer use.

2. Permanent soil covers i.e. cover crops or mulches: cover crops are intercropped with other crops to provide cover. Mulch insulates and enriches the soil increasing the soil organic matter content. Permanent soil cover protects the soil from erosive agents, enriches the soil through promoting nutrient recycling, conserves soil moisture and suppresses weed growth.
3. Crop rotation and intercropping: CA advocates for alternating crops (preferably cereals and legumes) in the same field. Intercropping is growing more than one type of crop in alternating rows (preferably cereals and legumes). These practices increase water use efficiency, reduced incidences of crop-specific pests and diseases and aid in soil fertility through nitrogen fixation.

1.4 Brief History of CA in Kenya

Results of study conducted by FAO to establish a basis for up scaling of Conservation Agriculture in Kenya in order to improve adoption levels of CA, showed that Conservation Agriculture has been in practice in some countries in Africa as a traditional soil and water conservation strategy by specific communities or at pilot project scale. In Kenya, Conservation Agriculture projects are currently being implemented at large scale by various agencies including the FAO in collaboration with the Ministry of Agriculture at the national level and the county department of Agriculture. Regardless of the difficulties and low adoption rates in the first years of implementation, the benefits from this practice have shown great potential in boosting agricultural production and diversifying livelihood incomes especially in the Arid and Semi-Arid Lands where the uncertainties of climate change continue to pose a threat to the country's food security. This is especially so in regions where water stress and degraded soils limit the ability of the land to fully maximize it's potential in food security. According to experiences from elsewhere in Africa, CA's main advantages are evident where Conservation Agriculture has been shown to:

- Improve African Yields: The African population continues to increase while crop yields and consequently food production in many areas are falling. In many parts of the continent, grain yields are at no more than 1 ton/ha which is much less than what is needed to achieve the SDG 2. The major cause is attributed to soil infertility often caused by extractive and exploitative farming methods. The intensive annual tilling of the soil destroys soil structure, produces a hard pan in the soil, restricting root growth and stunting plant growth. Moreover, the impact of raindrops on bare soil causes sheet and rill erosion. The resulting soil erosion and land degradation are quite severe in Africa and lead to an annual decrease of 3 percent agricultural production. Conservation Agriculture where it has been implemented has shown a high potential to reverse this trend [8].
- Reduce production costs: Conventional agricultural practices such as tilling are expensive especially within the context of rising fuel and labour costs. Experiences in Ghana and Kenya have shown a decrease of labour costs by 40 percent input by using no tillage methods [8].
- Work where there is a shortage of labour and farm power: A number of factors including rural-urban migration, HIV/AIDS and cash constraints among others are contributing to shortage of labour and farm power. Conservation Agriculture takes less work, thus enabling efforts to be channelled to other development activities [8].
- Reverse Environmental degradation: Sustainable Land Management (SLM) is now an emerging top agenda in Africa in the context of TerrAfrica Initiative. Conservation Agriculture protects the land and feeds the soil. It has the potential to halt and reverse land degradation and could be a major part of the package for SLM [8] Even though Conservation Agriculture has been backed by studies as well as empirical evidence as the solution to food insecurity in Sub-Saharan Africa, low levels of adoption prevail with the total

area of coverage estimated to be less than one percent of the continent's land [8].

1.5 Current Reality of CA Implementation in Kenya by FAO

CA is under implementation under a project of the Food and Agriculture Organization of the United Nations whose outcome targets to increase graduation of small-scale farmers in semi-arid areas to commercially orientated climate – resilient agricultural practices through improvements in productivity, post-harvest production practices and market linkages for targeted value chains i.e. pulses, sorghum and sunflower value chains. The project is established in eight counties: Kitui, Makueni, Machakos, Tharaka Nithi, Meru, Laikipia, Kwale and Kilifi counties.

A total of 51,832 farmers (36,152 females and 15,680 male) in 1,828 farmer groups have been trained through an elaborate training program in the project areas. The farmers have attended 15 training sessions on Conservation Agriculture, Good Agricultural Practices and agribusiness related topics over a 3 months' period. A total of 16,272 farmers ,68% of which are female and (32%) male, have been reached through field days organized around 1,526 demonstration plots established as learning sites across the first four counties (Tharaka-Nithi, Kitui, Makueni and Machakos). On farm connectedness Market linkages have been established for pulses, Sorghum and oil seed production.

2. MATERIALS AND METHODS

A Stakeholder focussed group discussion was conducted in each of the four counties to determine trade-offs, actions to minimize them, Agro-ecological and socioeconomic challenges to CA implementation and adoption.

A detailed description of a conceptual framework to identify and systematise indicator sets for sustainability evaluation of land use options is described in the introduction section of this dissertation.

A methodological approach employing the use of the AESIS tool, a support tool for the evaluation of the sustainability of agro-ecosystems was adopted for sustainability evaluation as applied by (Pacini, *et al*., [9].In this approach a three phase procedure was put in place as modified from [10] and applied by (Pacini, *et al*., [9].

Phase 1. Definition of indicator based agricultural sustainability in the study set up

a) Issues related to agricultural sustainability globally, regionally in Sub-Saharan Africa as well as in Kenya as a country were identified.
b) Critical points were identified in current agricultural production systems and their linkages to the environment determined.
c) Indicators of sustainability were chosen

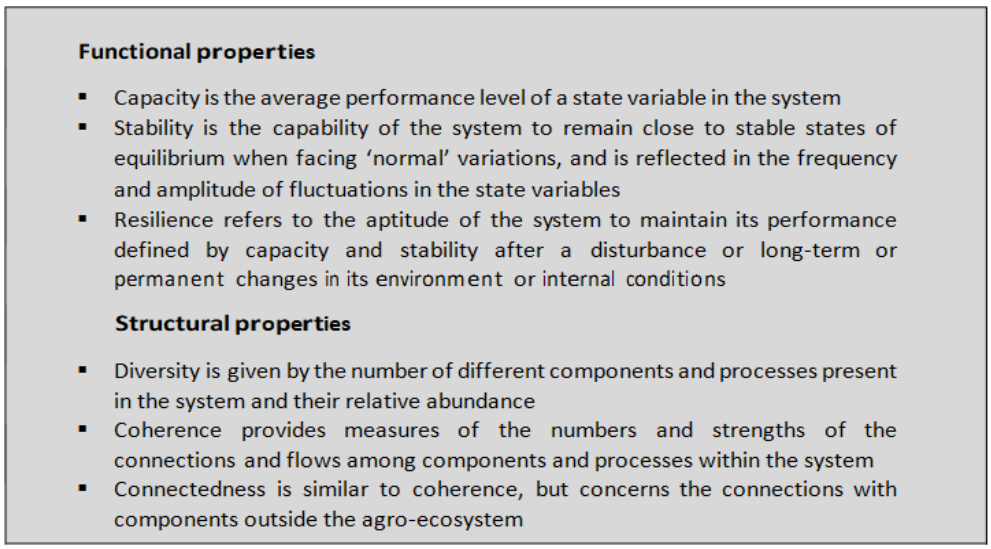

Fig. 1. Agroecosystem properties of the conceptual framework for sustainability assessment of agricultural systems adapted from [4]

Phase 2. A Methodological approach to measuring agricultural sustainability

a) A comparison layout was formulated incorporating a detailed analysis of farm performances based on sustainability thresholds in four counties of Kenya.
b) The researcher identified indicator thresholds i.e. critical limits and sustainability targets for the country (Kenya) and region (Sub Saharan Africa) against which the measured indicators were compared based on the Sustainability assessment of Food and agriculture systems and other supporting literature. In some cases, comparisons with conventional system were drawn to aid in user defined indicator measurement [6-7]. A brief description of Conservation Agriculture as applied in Kenya and its history based on literature review is provided in the introduction section of the paper. A summary of the applied CA compared to the 'ideal' Conservation Agriculture methods worldwide is also summarised in the introduction section.

Phase 3. Sustainability Analysis of Conservation Agriculture

a) Calculation methods of indicators were selected to quantitatively evaluate the sustainability of Conservation Agriculture as applied in Kenya based on the Sustainability assessment of Food and agriculture system guidelines [6-7].
b) Indicators were measured and assigned a SAFA score.
c) Results from the study were aggregated for sub-theme, theme and overall level(s), results presented, conclusions drawn and recommendations for further studies proposed in the latter chapters of this dissertation.

2.1 Study Area

The study compares and draws lessons from a Conservation Agriculture (CA) implementation project in four counties of Kenya by the Food and Agriculture Organization of the United Nations. CA is being implemented as the flagship farm management system for increased productivity and profitability of small holder farmers through promotion and up-scaling of Good Agricultural Practices & Conservation Agriculture in the productive Semi-Arid areas of Kenya. The counties include: Tharaka-Nithi, Kitui, Makueni and Machakos counties.

Kitui and makueni counties are categorized as 85-100% ASAL in the Categorisation of counties based on percentage of ASAL coverage while Tharaka Nithi and Machakos counties fall in the 50-85% ASAL category. The total percentage of the counties region occupied by ASAL area is 25% for the latter and 8% for the former [11]. Kenya is divided into seven agroclimatic zones based on a moisture index [12]. Zones I-III are considered to have high potential for cropping, given favourable moisture availability, whereas Zones IV-VII comprise semi-humid to arid regions, covering 88% of Kenya's land mass. The study area lies within the 88% of Kenya's land mass comprised of zones IV-VII.

Kenya's ASALs host 35% of the country's human population, which translates to 14 million people. ASAL population growth has been relatively high compared with other parts of the country, as a result of immigration and higher fertility rates according to the Republic of Kenya, [13]. Migration from high-rainfall areas puts extra pressure on existing limited resources. As a result of the increasing population, there is an increased unplanned human settlement and cultivation in ecologically fragile areas and areas of relatively high agricultural potential [14]. The ASAL ecosystems are therefore unable to cope with both the natural and the human-induced pressures that may undermine the sustainability of land resources.

Productivity in semi-arid areas could be improved through efficient water harvesting, storage and utilisation; use of appropriate technologies; integration of young skilled labour along the various value chains; and the empowerment of ASAL communities to access and utilise appropriate technology. [15]. In General, ASALs have some of the highest poverty levels and lowest levels of human development in Kenya, with over 60% of the population living below the poverty line [16].

2.2 Indicator Selection

Sustainability issues in Kenya and Sub-Saharan Africa were defined in accordance with existing literature and in accordance with the Sustainability Assessment of food and agriculture systems guidelines [6-7]. A 2012 stock taking in the run up to Rio+20 on Sustainable development in Kenya acknowledges that the relationship between agriculture and the environment is complex. The agricultural sector has been greatly affected by

environmental degradation and associated climatic variation and change. Agriculture on its part has also contributed significantly to environmental crises currently facing the country through an increased water demand for production and value addition processes as well as an increased use of agrochemicals that has escalated water pollution and sedimentation through improper land management practices. (UNDP, 2012).

The Economic Recovery Strategy noted that within the past two decades, the agricultural sector, with the exception of horticulture, experienced low and declining productivity regarding export earnings, employment creation, food security and household farm incomes. Since agriculture is the backbone of Kenya's economy, this scenario in agriculture portrays a critical challenge to the country's economic recovery especially now and specifically the quality of life for Kenyans. Among the six main reasons identified for the decline in the sector, inappropriate and unresponsive technology was a factor. Five years after the compilation of this study and measures put in place sustainability issues still persist as characterized by low adoption of appropriate technologies, food insecurity, low household farm incomes and high unemployment, this study sought to evaluate sustainability in farms under Conservation Agriculture in four counties of Kenya (Makueni, Machakos, Kitui and Thraka Nithi counties).

As illustrated in the AESIS general framework presented in [3] critical points were selected from the complete AESIS list coherent with the identified sustainability issue. In order to maintain a holistic view of the farming systems considered for the study, all agro-ecosystem aspects i.e. environmental aspect (Water, soil, biodiversity, air), production aspect as well as the social aspect at the household level in the study context were considered in the indicator identification and analysis process. In accordance with the proportionality principle, and taking into consideration the scale of family-run, ordinary farms, two indicators per environmental system was chosen. A total of 24 indicators were selected. An activity to Identify issues related to sustainability in the region as well as critical points and connect them to farm environmental and production systems was done leading to identification of sustainability indicators.

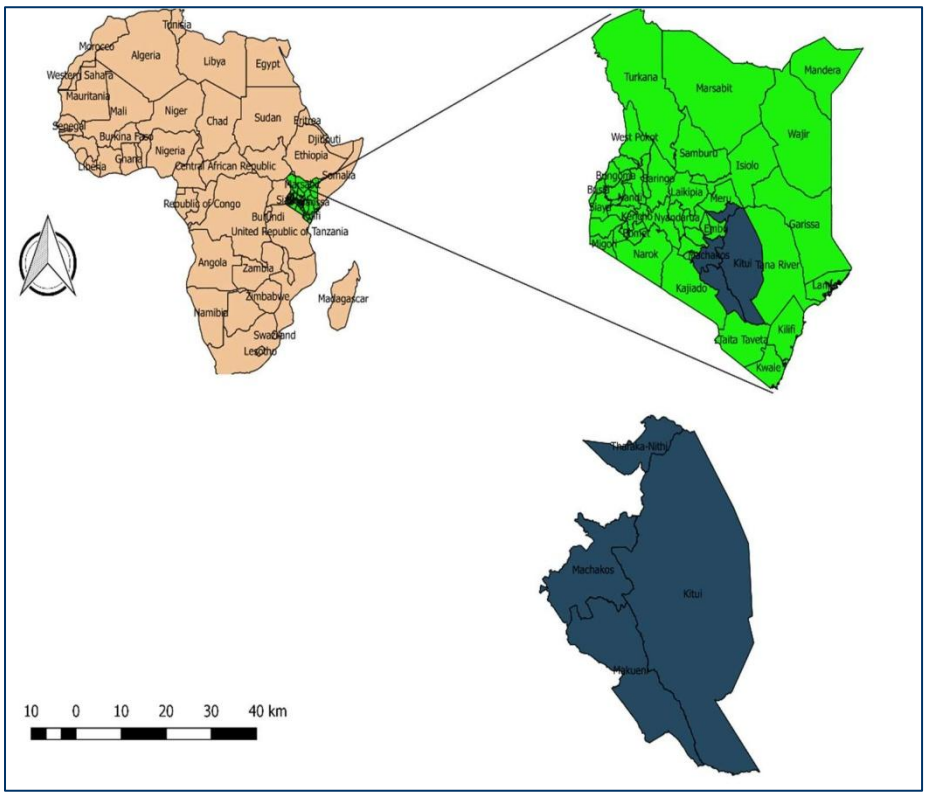

Fig. 2. Research Study Area (Source: Author, 2021)

Table 1. Indicator identification an analysis

Sustainability Analysis of CA agro-ecosystems, Kenya	Environmental Dimension	Productive Dimension	Social Dimension
Diversity	-Habitat diversity/ associated biodiversity: percentage of farmland -Green manure potential: Availability of seeds for green manure in locality	-Planned Biodiversity: Crop diversification -Rotation blocks : Farmer reported no of rotations per year	-Gender Equity:% project participants or technology users who are women -Farmer equity: Uptake and benefits among better off and poorer farmers
Coherence	-Reduced Soil fertility due to erosion: % farmers reporting erosion -Carbon stock exchanges: Percentage of area under advanced management practices i.e. CA	-Forage supply: Proportion of plant biomass allocated to fodder -Mulch supply: Proportion of plant biomass allocated to mulch	-Time % devoted to other activities: Replacement of labour by technology -Farmer knowledge: % farmers reporting reporting better positioned to solve problems
Connectedness	-Dependence on external inputs: % chemical fertilizer replaced -Perceived Impact on soil health of increased use of chemicals: CIP score* of pesticides in use in CA systems	-Increased initial cost of CA investment: Capital Investment -Proximity to markets: Mean distance to market (KM)	-Farmer organization: membership in groups , Collective Marketing organizations, Saccos and Societies -Access to support systems: Farmer reported access to extension and other sources
Functional Properties (Productivity, Stability, resilience and adequity)	-Soil Health: Soil cover Index -Water use efficiency: Potential Evapotranspiration with and without CA	-Crop Yield: percentage increase under CA and non CA systems -Total income: % of farmers	-Food sufficiency: Number of days with food deficiency per annum in CA practicing households
Adaptability Equity)			

2.3 Definition of Indicator Based Agricultural Sustainability in the Study Set-up

The study began with collecting and reviewing existent data and literature on issues relating to sustainability in the developing countries concept and particularly in Kenya.

Land use critical points corresponding to issues of sustainability were identified and formed the basis for establishing sustainability indicators of functional properties of the agro ecosystem as defined in the Millennium Ecosystem Assessment, [17]. These are shown in Table 1 above.

3. DISCUSSION OF THE RESULTS AND FINDINGS

3.1 Indicator Specific Calculation Procedures

Results obtained through a questionnaire administered to respondents, Focussed group discussions, field observations, modelling and GIS techniques are reported in the sections below:

3.2 Farmer Equity

This is a measure of social sustainability. This takes into account the needs of poor and better off farmers and is a measure of the applicability of this technology across the wealth divide. Farmer equity is measured through a wealth ranking exercise to categorize respondents into discrete wealth groups based on a criterion. In this study the same criteria (land size) was correlated with percentage allocated to conservation agriculture as a measure of adoption. A survey was also done among individual respondents to determine their opinion on disparities in technology uptake between wealthier and poorer farmers.

3.3 Wealth Ranking Exercise

This exercise was conducted in reference to a wealth ranking study conducted by (Lekshmi, et al. [18] in India:

Table 2. Wealth ranking results of respondents based on land size

W1-Wealth category	Criteria (size of land)	% of farmers
1. Rich > 10 acres of land	6-10 acres	9.1
2. Medium 2-5 acres of land	2-5 acres	29.5
3. Poor < 2 acres of land	0.25-1 acre	61.4

Table 3. Portion of land allocated to Conservation Agriculture

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0-25%	30	22.6	22.7	22.7
	25-50%	90	67.7	68.2	90.9
	50-75%	9	6.8	6.8	97.7
	75-100%	3	2.3	2.3	100.0
	Total	132	99.2	100.0	
Missing	System	1	.8		
Total		133	100.0		

Table 4. Is there a disparity in the adoption of Conservation Agriculture between wealth and poor farmers in your group?

				Valid	Cumulative
				Percent	Percent
Valid	No	104	78.2	81.3	81.3
	Yes	24	18.1	18.7	100.0
	Total	128	96.3	100.0	
Missing	System	5	3.7		
Total	133		100.0		

Step 1: The list of farmers in a representative group was obtained from the County Programmes Officer. Numbers were assigned for each farmer and their household
Step 2: Small pieces of paper were arranged. The number of each farmer and name as written on each piece of paper separately.

Step 3: The Master trainers (key Informants) sorted out the pieces of paper into as many wealth categories as he/she think are presented in the group.

Step 4: A table was prepared on a paper and the responses of the key informants were recorded.

Step 5: The key informants revealed their criteria for categorization as land size owned by farmers.

Step 6: Each Key informant had full freedom to use as many numbers of categories as possible.

Step 7: For each farmer a score of the portion of land allocated to CA was determined

A correlation between farm size and the portion of land allocated to Conservation agriculture i.e. adoption extent was computed. A Pearson's correlation coefficient of -0.148 was obtained. The correlation hence is negative but not significant. Hence the conclusion that adoption cuts across all wealth classes identified. A survey conducted among farmer respondents further confirmed this with 81% of respondents being of the opinion that individual farmer wealth status had no influence on the level of CA adoption in their fields.

4. CONCLUSION

In line with the second phase of AESIS as illustrated in the Methodology section, potential solutions to factors undermining CA adoption. A comparison layout between two representative farming systems run with conventional agriculture and conservation agriculture, respectively was selected based on key critical points relevant to production, environmental and social aspects of an agro-ecosystem and the following indicator summary was achieved from the study.

In conclusion, conservation agriculture as applied in Kenya has some points for improvement in its journey towards sustainability. A place based process approach to sustainability both in the long term and short term is privileged over other approaches. In the context of the Agro environmental information systems framework the following dimensions as illustrated in table above, need to be urgently considered for improvement and further action to ensure the sustainability of agricultural systems in Eastern Kenya. The functional properties in the Environmental dimension, in particular water use efficiency must be addressed. In the social dimension, food sufficiency should be improved through reducing the number of days households go without food. Promoting a market based agricultural system as well as sealing loopholes such as water use in Conservation agriculture is key to realizing the potential of these regions in food production [21-22].

Indicator	**Sustainability threshold/target**	**Type**	**Sustainability range**	**Source**
Habitat/associated diversity	5%-50%	Min	3-5	Vereijken, [19] FAO, [6-7]
Green manure potential	4	Range	3-5	(FAO, [6-]
Planned biodiversity	5	Range	3-5	(FAO, [6-7]
Rotation blocks	>4	Min	3-5	Vereijken,[19] FAO, [6-7]
Gender equity	5	Range	3-5	(FAO, [6-7]
Farmer equity	5	Range	3-5	(FAO, [6-7]
Soil fertility	5	Range	3-5	(FAO, [6-7]
Carbon stock exchanges	3	Range	3-5	(FAO, [6-7]
Forage supply	2	Range	3-5	(FAO, [6-7]
Vertical Integration	3; 30%	Range; Min	3-5	(FAO, [6-7] (Baker, *et al*., [5]
Time devoted to other activities	3	Range	3-5	(FAO, [6-7]
Farmer knowledge	3	Range	3-5	(FAO, [6-7]
Dependence on external inputs	3	Range	3-5	(FAO, [6-7]
Pesticide impact	4	Max	1-3;3-5	(Alessandro, [20]

Pesticides and active ingredients used in conservation agriculture risk reversing the performance of the practice on soil as determined by the soil cover index, erosion control and carbon exchanges score through impacting on overall soil health. The 12 most commonly used herbicides and pesticides all had active ingredients that possess a maximum potential impact on at least two aspects of the agro-ecosystem (water, ecosystem and human health). This falls in the environment dimension of the connectedness property of the AESIS tool. Hence for CA to be sustainable, it should not be disconnected from the impacts of the replacement of tilling by herbicide and pesticide use for crop operations on water, ecosystem and human health. It is therefore paramount that an Integrated Pest Management system is developed and implemented together with conservation agriculture to optimize the sustainability of these agricultural systems.

CONSENT

As per the international standards or university standard, respondents' written consent has been collected and preserved by the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist

REFERENCES

1. Corbeels M, de Graaff J, Ndah TH, Penot E, Baudron F, Naudin K, Adolwa IS. Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. Evaluating Conservation Agriculture for Small-Scale Farmers in Sub-Saharan Africa and South Asia. 2017;187:155–170.
   Available:https://doi.org/10.1016/j.agee.2013.10.011
2. Ives AR, Carpenter SR. Stability and diversity of Ecosystems. Science. 2007;317.
3. Pacini GC, Groot JCJ. Sustainability of Agricultural Management Options Under a Systems Perspective. In Encyclopedia of Sustainable Technologies. 2017;191–200. Elsevier.
   Available:https://doi.org/10.1016/B978-0-12-409548-9.10057-0
4. El-Hage Scialabba N, Pacini C, Moller S. Smallholder Ecologies. FAO, Rome: Italy; 2014.
5. Baker CJ, Saxton KE, Ritchie WR. No-tillage seeding: science and practice, 2nd edn. Oxford, UK: CAB International; 2002.
6. FAO. The 3 principles of Conservation Agricuture. Conservation Agriculture: Food security in Lesotho for a changing climate; 2014.
   Retrieved from http://www.fao.org/ag/ca/
7. FAO. SAFA: Sustainability Assessment of Food and Agriculture Systems Guidelines. FAO, Rome: Italy; 2014.
8. FAO. Case studies on Conservation Agriculture (CA); 2009.
   Retrieved January 30, 2017,
   Available:http://www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/scpi-home/managing-ecosystems/conservation- agriculture/ca-cases/en/
9. Pacini GC, Lazzerini G, Vazzana C. AESIS: a support tool for the evaluation of sustainability of agroecosystems. Example of applications to organic and integrated farming systems in Tuscany, Italy. Italian Journal of Agronomy. 2011 (1):3.
   Available:https://doi.org/10.4081/ija.2011.e3
10. Weersink A, Jeffrey S, Pannell D. Farm-Level Modeling for Bigger Issues. Applied Economic Perspectives and Policy. 2002;24(1):123–140.
    Available:https://doi.org/10.1111/1058-7195.00009
11. Weersink A, Jeffrey S, Pannell D. Farm-Level Modeling for Bigger Issues. Applied Economic Perspectives and Policy. 2002;24(1):123–140.
    Available:https://doi.org/10.1111/1058-7195.00009
12. Sombroek WC, Braun HMH, Van der Pouw BJA. Explanatory Soil Map and Agro-Climatic Zone Map of Kenya'. Report E1. Nairobi: National Agricultural Laboratories, Soil Survey Unit; 1982.
13. Republic of Kenya. Post-Disaster Needs Assessment: 2008-2011 Drought. Nairobi: Republic of Kenya; 2012.
14. Republic of Kenya. Marsabit County Integrated Development Plan 2013-2017'. Nairobi: Republic of Kenya; 2014.
15. Njoka JT, Yanda P, Maganga F, Liwenga E, Kateka A, Henku A, Bavo C. Kenya: Country situation assessment. Pathways to Resilience in Semi-arid Economies (PRISE); 2016.

16. Mati BM, Muchiri JM, Njenga K, de Vries FP, Merrey DJ. Assessing Water Availability under Pastoral Livestock Systems in Drought-prone Isiolo District, Kenya. Working Paper 106. Colombo. IWMI; 2006.
17. Millennium Ecosystem Assessment. Ecosystems and human well-being: Synthesis. Island Press: Washington DC; 2005.
18. Lekshmi PS, Venugopalan R, Padmini K. Livelihood Analysis using Wealth Ranking Tool of PRA. Indian Res. J. Ext. Edu; 2008.
19. Vereijken P. Manual for prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms. AB-DLO, Wageningen the Netherlands; 1999.
20. Alessandro Franchi. Fitofarmaci: Classe di impatto potenziale - CIP.Un indicatore per guidare nelle scelte di sostenibilità. ARPAT: Firenze; 2017.
21. Boyer R, Peterson N, Arora P, Caldwell K. Five Approaches to Social Sustainability and an Integrated Way Forward. Sustainability. 2016;8(9):878. Available:https://doi.org/10.3390/su8090878
22. Pacini GC, Lazzerini G, Migliorini P, Vazzana C. An indicator based framework to evaluate sustainability of farming systems: review of applications in Tuscany. Italian Journal of Agronomy. 2016;(4):23–40.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle4.com/review-history/74982