

Article

Conservation Agriculture for Environmental Sustainability in A Semiarid Agroecological Zone under Climate Change Scenarios

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Abstract: Using the Mann–Kendall Test to analyze data from a survey of 400 farmers, this study compared the rate of adoption of conservation agriculture (CA) in two contrasting villages of Mnyakongo and Ugogoni locating in the Kongwa District, a semi-arid zone in central Tanzania. Results exhibited that the level of CA adoption was <10% of the total households. The trend of CA adoption was determined at the coefficient of $R^2 = 0.95, 0.90, 0.68$ and 0.57 for mulching, crop rotation, agroforestry and little tillage, respectively. Despite little tillage and crop rotation having high acreage under CA, the rate of mulching adoption was significantly higher than that of others. Furthermore, there were significant correlations between the CA adoption and crop yields or environmental sustainability ($p < 0.05$). Maize, sorghum and millet yields were significantly greater under CA (1.7 t ha^{-1}) than no-CA (0.7 t ha^{-1}). Particularly, maize yields were increased from 1.3 to 2.3 t ha^{-1} from 2000 to 2015 under CA when it was intercropped with legumes. The majority farmers (>70%) asserted that CA had optimized their yields for both food and economic incentives. Thus, this study recommends the adoption of CA in the semi-arid agro-ecological zones.

Keywords: climate change; crop yields; environmental services; intercropping; legumes; Mann–Kendall test; vulnerability; Tanzania

1. Introduction

The significance of soil or environmental conservation to limit soil degradation has been advocated since 1903 [1]. The current situation of a rapid population increase and global climate change has necessitated the practicability of such soil conservation [2]. For example, the USA government has invested millions of dollars yearly to support conservation related projects [3,4]. To increase fruit production and environmental conservation in organic Australian vineyards, both mulching and composite are used as conservation agricultural practices [5]. This practice increases crop yields and environmental conservation in various areas of the country.

The increasing extreme of weather changes especially for temperature and precipitation has significantly impacted the nutrient cycling and soil moisture in most of Sub-Saharan Africa [6,7]. These weather changes could intensify in the future as various climate models have been predicting further climate alterations. As a result, a crop production system and its productivity are to worsen with possibly high outbreak of diseases, pests and pathogens.

To intervene with these authentic and potential consequences, we need to develop resilient agricultural systems through rational and affordable strategies that maintain the ecosystem functions

and protect livelihoods [8–10]. Studies have recommended different conservation agriculture (CA) practices to mitigate, and adapt to, climate impacts [11]. CA features in various forms such as organic soil management, agroforestry, crop rotation, etc. Bennett et al. [12] and Malviya et al. [13] in their models found that N₂-fixing legumes have potential for both crop yields optimization and environmental services. Moreover, Zhu et al. [14] realized that organic matter from dead debris and litter decomposition are important for improving soil fertility in various ecosystems. Organic soil management is an important aspect of CA.

Since smallholder farmers are vulnerable to extreme change of rainfall pattern, CA can be their best proposition to elevate their resilience [15,16]. This is particularly important because it is expected that, by 2030, Africa will have 120–150 million smallholder farmers and most of them will rely on rain-fed agriculture for their subsistence [17]. While the dependence on rainfed-agriculture is expected to increase, the projections from an assessment of 12 CMIP3 (CMIP3 - Coupled Model Intercomparison Project Three) (AR4-4th Assessment Report) GCMs (Global Climate Models) over Africa suggest an extreme variation in rainfall by the end of the 21st Century [18]. In that respect, the susceptibility of the farmers will further increase due to such increased challenging condition [19,20].

Specifically, the farmers' vulnerability with less rainfall is expected to be worst in arid and semi-arid areas due to increased drought effects in these already stressed areas [18–21]. Such effects in these areas cannot be underestimated because the global dry land areas cover about 41% of Earth's surface and sustain the livelihoods of about two billion people [21,22]. In these areas, drought is greatly exacerbated by the global increase in temperature and decrease in rainfall [23]. For instance, studies have revealed the average increase of global surface temperature as 0.8 °C during the past century or the last three decades [24], leading to the deterioration of agricultural systems. Subsequently, this deterioration has exerted more pressure on already stressed environmental resources through overutilization, thus adding more complexity to sustainable agriculture management [22–25].

The frequently excessive droughts in most dryland areas have led to significant degradation of soil fertility [26]. Such soil fertility degradation is further accrued by poor agronomic practices and excessive chemical fertilization [27–29], and studies have shown that different forms and principles of CA, such as terraces or ridges, minimum tillage cropping, cover cropping, large pits and intercropping especially legume intercropping of sweet beans and lablab, have the potential to improve soil fertility and mitigate climate change impacts.

Similarly, soil fertility, crop production and carbon sequestration have increased in most areas where CA has been effectively applied [20]. Under CA, soil microbial communities become more functional than without CA and can influence a wide range of soil functions and ecological services such as organic matter turnover and nutrient cycling (nitrogen, phosphorus and carbon), among others [30,31]. Thus, CA has been recently proposed as Climate-Smart Agriculture (CSA) in most African countries because it is economically viable and environmentally friendly [20,30–32]. According to FAO [33], the CA practice could elevate food security, resilience and/or adaptive capacity to climate variability impacts by sequestering carbon in both plant biomass and soils.

Similarly, Lal [34] promoted that reduced tillage is a powerful tool for retaining soil carbon and improving soil fertility for healthy crop growth and biochemical transformation of biomass carbon into soil organic matter or humus. It was evidenced that conventional tillage loses soil nutrients and water through infiltration [35]. Even minor soil disturbance has significant ecological effects on soil fertility in eastern and northern Tanzania [36,37].

However, despite this significance, there has been high inconsistency of CA adoption in most of Sub-Saharan Africa where about 70% of agriculture industry is under smallholder farmers who are most vulnerable to global climate changes. Their vulnerability is accrued by the high dependence on rain fed agriculture [38]. Thus, Sub-Saharan African countries have recently adopted the CA practice, although the adoption rate has not been sufficient in most of Sub-Sahara Africa (Figure 1).

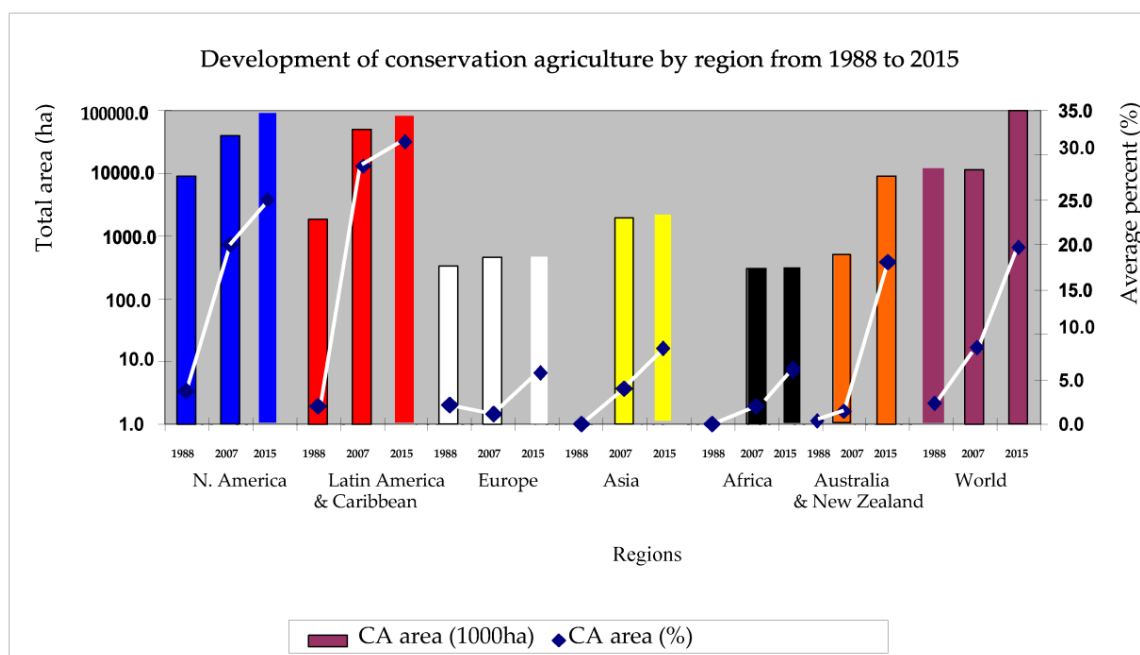


Figure 1. Development of conservation agriculture over the last 20 years by world region in total area (ha) and as an average percentage across the adopting countries of the respective region. African countries seem to adopt conservation agriculture slowly. It needs more emphasis for a good take off. Afterwards, the continent will increase crop yields in terms of quantity and quality as well as conserving the ecosystems (Source: Adopted from FAO [17]).

Most Sub-Saharan countries recently started the adoption of CA. For example, Malawi, Zambia and Zimbabwe intensified their CA adoption in the 1990s [6,7,37]. Having been informed on the significance of CA, there is an immediate need to emphasize the optimal adoption and utilization of CA in the region (Sub-Sahara Africa) where most farmers are destitute and marginalized.

An Overview of Conservation Agriculture in Tanzania

Most Tanzanian communities adopted indigenous agricultural conservation practices, e.g., the Matengo pits (terraces) in Ruvuma, Chagga garden (agroforestry) in Kilimanjaro and Ngiriti (enclosed pasture) in Shinyanga regions to intervene the challenges associated with environmental stress. These practices have shown promise for optimizing crop yields, increasing fodder, controlling soil erosion and conserving moisture and fertility [27,39]. However, CA has only been operated in few regions including Dodoma, Manyara, Arusha and Southern highlands of Tanzania [40]. Few CAs have been practiced in the aforementioned regions that involve agroforestry, crop cover and crop rotation and are mostly influenced by private or government organizations [41–53]. Thus, reliable policy could greatly affect the CA adoption in the country. At present, CA receives little attention from the Tanzania Agricultural Policy [54] as the existing policy advocates the green revolution that emphasizes more on conventional tillage and chemical fertilization.

At the household level, the adoption of CA or any other agricultural technology is reached after the adopter is satisfied with the decision. In most cases, the household adopts new agricultural technology (i.e., CA) whose net benefits are significantly greater than those of an existing technology. In this approach, prospective new technology adopters observe the utility gained by the early adopters before adopting that technology. This can be described in various models as follows.

For example, the Heckman model [43] specified the decision and extent of technology adoption as follows:

$$C_i = Z_i\phi + \epsilon_i \text{ (CA adoption)} \quad (1)$$

$$Y_i = X_i\beta + \mu_i \text{ (extent of CA adoption)} \quad (2)$$

where C_i is a dummy variable for CA adoption; Z_i is a vector of determinants of CA adoption; Y_i is the extent of CA adoption (proportion of land area under CA); X_i is a vector of determinants of CA extent of adoption; θ and β are vectors of parameters to be estimated; and ϵ_i and μ_i are error terms.

Based on the Heckman model [43], for the estimated parameters of Equation (b) to be efficient, there should be no correlations between the two error terms (ϵ_i and μ_i). Nevertheless, the sample selection bias has resulted in a non-zero correlation between the two errors. To correct for this selection bias, the Heckman model firstly estimates Equation (a) to obtain a sample selection indicator, i.e., the Inverse Mills Ratio (IMR). This is suitable for measuring the covariance between the two errors.

The study by Rogers [9] had agreement with Heckman model, as it informed that “the innovation-decision process can lead to either adoption, a decision to make full use of an innovation as the best course of action available, or rejection, a decision not to adopt an innovation”. A few CA studies have been conducted to evaluate the extent of CA in Tanzania including on maize yields in the Uluguru Mountains (Eastern Arc Mountains) [26].

The present study focused on the semi-arid agroecological zone in Tanzania, where maize, sorghum and millet are the major crops, because this semi-arid area is the most vulnerable to climate change impacts and environmental degradation. In these areas, CA is the most reliable way of limiting these two major challenges. The dominant farming systems in the most semi-arid regions include: cropping, pastoralism and agro-pastoralism (integration of crops with livestock). Such integrations increase the biomass inputs of perennial plants and the optimization of nutrient amendments in the soil [30,39]. These systems can also increase the mutual interactions between plants roots and mycorrhizae fungi, and eventually nutrients uptake and resistant to pathogens by plants.

Although the science of CA and its significance at the global level is progressing rapidly, various knowledge gaps still exist, particularly in developing countries. This present study was geared to assess the rate of CA adoption and its ecological significance in the semi-arid areas of central Tanzania. Although several FAO-CA projects have been conducted in several Tanzanian regions, their impacts have remained trivial [41,42]. This study was hypothesized as follows:

H₁. *The rate of CA adoption is influenced by the desire of farmers to have optimal yields, preservation of soil moisture and fertility, control of soil erosion, and reduction of labor work.*

H₂. *The rate of CA adoption is not influenced by the desire of farmers to have optimal yields, preservation of soil moisture and fertility, control of soils erosion, and reduction of labor work.*

The above-mentioned items in the hypotheses were widely known to the respondents, thus it was possible to differentiate and/or synthesize one another during data collection and interpretation.

Here, we investigated the level of CA adoption in the semi-arid agroecological zone of central Tanzania. It was quite important to conduct such a study because most semi-arid areas experience frequent food-shortage associated with environmental degradation and extreme climate change impacts. Thus, the present study explored the rate of CA adoption and its socio-ecological significance to the community and environment. To achieve this objective, the rate of CA adoption was hypothesized against the factors for its adoption. The findings of such a study are expected to have significant contribution to the establishment of CA promotion policies in Tanzania with an earmark to the vulnerable communities and ecosystems. The policy advocacy on CA is a significant move toward sustainable adoption of CA in all countries' agroecological zones.

At present, the adoption of CA is determined by personal characteristics (i.e., knowledge and experience), physical factor (land availability), and social and financial factors. Despite the insignificant willingness in the CA adoption, the practice has numerous fruitful results, as it improves biological functions of the soil through mycorrhizae fungi, ants and worms that can enhance nutrients uptake by plants. The basis of the study's findings was fieldwork with a constructed conceptual framework (Figure 2) enlisting the significant aspects of the CA.

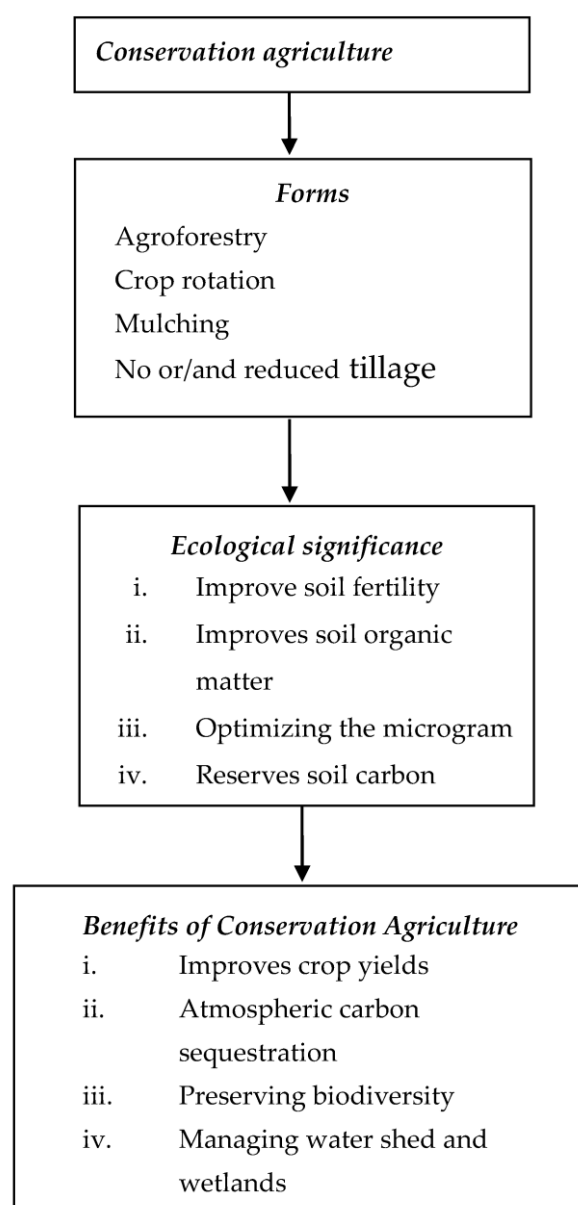


Figure 2. Conceptual framework for conservation agriculture (Source: Adopted from Mkonda and He [44]).

The framework portrays the major roles of CA as a tool firstly for increasing crop yields and secondly for environmental conservation to improve soil fertility through no- or reduced-tillage, mulching, agroforestry and crop rotation [50–61]. It also increases crop yields in terms of quality and quantity. By so doing, it curbs food insecurity and abject poverty. It further preserves biodiversity and mitigates the emission of greenhouse gases (GHGs), e.g. CO₂, CH₄ and N₂O.

2. Materials and Methods

2.1. Profile of the Study Site

This study was carried out in the Kongwa District, a semiarid zone of Central Tanzania between June and September 2016 (Figure 3). This district is located on the leeward side of Ukaguru Mountains with an area of ~4041 km² and a varying elevation between 900 and 1000 m a.s.l. (6°19'660" Latitude (S) and 36°15'36" Longitude (E)). The typical vegetation in the Central Tanzania is bush or thicket.

The mean annual precipitation is 400–600 mm (most between December and April) and the mean annual temperature is 26 °C. The soil is classified as Chromic Luvisols (the FAO Soil Taxonomic System) with a sandy loam texture. The silt contents of the soils at different farms were not significantly different ($p > 0.05$) and ranged 170–255 g kg⁻¹ soil with a bulk density of 1.25–1.65 Mg m⁻³ [37,44–48].

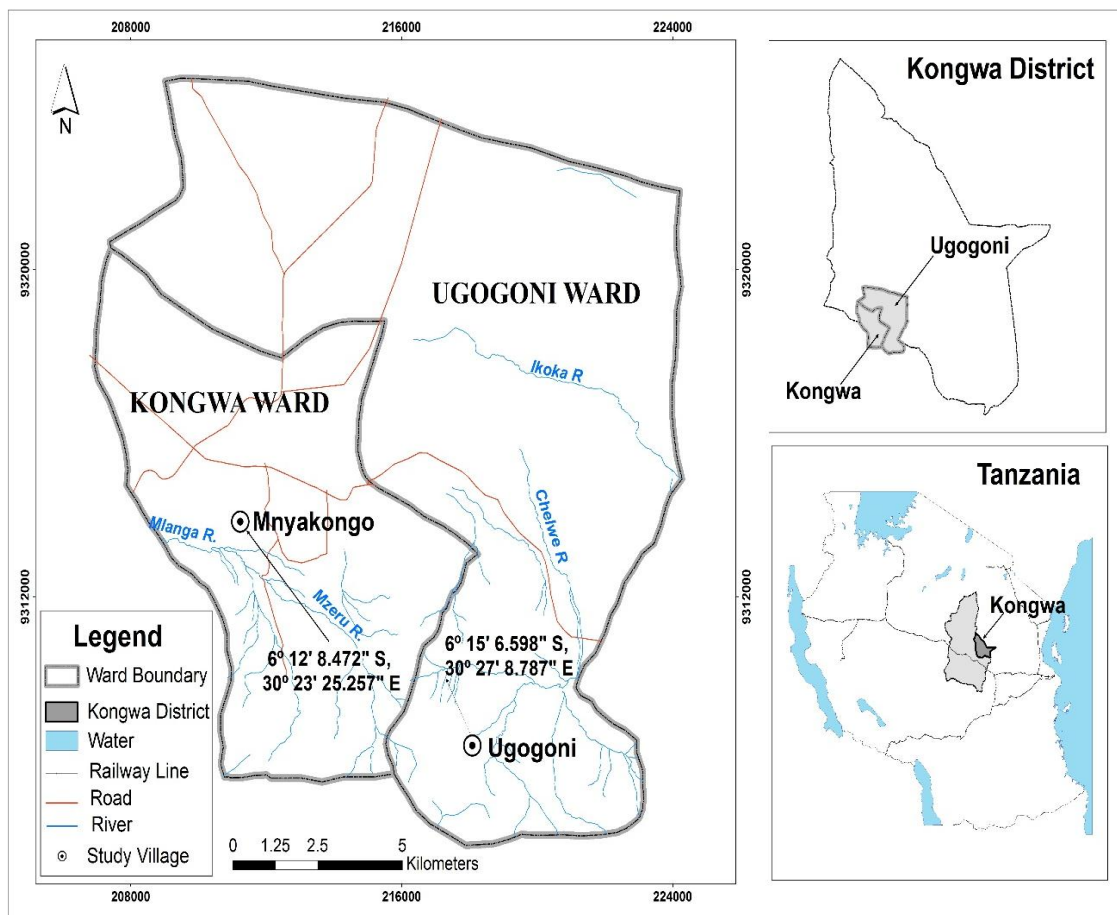


Figure 3. Location and sampling positions of the selected villages in the Kongwa District. The study sites are also denoted with latitude and longitude degrees (Source: IRA GIS Lab, UDSM: 2016).

2.2. Agricultural Systems in the Area

With 3637 km² of arable land, the study area is dominated by cropping systems, pastoral systems and mixed farming. About 80% of the cropping systems are under smallholder farmers (~2.5 hectares per household) who use a hand hoe as the main farming tool. Medium scale farmer (about 17%) use power tillers while large scale farmers (about 3%) use tractors. The dominant food and cash crops include maize, sorghum, millet, common beans, cassava, sweet potatoes, chick peas, sesame, cashews, sunflower and groundnuts. The dominant animals are cattle, sheep, pigs, donkey and goats. In addition, one ranch (~250 km²) and one pasture (~150 km²) are owned by the National Ranching Company and Livestock Research Center, respectively.

2.3. Methodology

2.3.1. Data Collection and Sampling Design

A simple random sampling was employed in selecting the study area. We picked one the Kongwa district among numerous districts of the semi-arid zone of Tanzania that are severely impacted by climate change and frequent food shortage. Purposive sampling was employed in selecting two

representative villages, i.e., Mnyakongo and Ugogoni. Priority was given to villages that have been practicing CA. A reconnaissance survey was done in April 2016, two months before the actual data collection. During this phase, data collection tools were tested to determine their effectiveness. We also used this phase to process the required research permits and determined some key informants. All discrepancies raised during this phase were fixed before the actual process of data collection.

Data collection including household surveys, group discussions, informative interviews and physical observation was conducted from June to September 2016. These activities were simple and suitable because they optimally involved relevant stockholders. A simple random sampling was applied when selecting households while a systematic sampling was used to form groups for discussions. In addition, purposive sampling was employed in selecting the interviewees.

We also conducted intensive interviews with agricultural experts, extension officers and few elders. Data on CA (i.e., acreage under CA) and crops yields were gathered from the Kongwa District Agricultural and Livestock Development Officer (DALDO) and the Ministry of Agriculture, Livestock and Fishery, Tanzania.

The acreage data about areas under irrigation were gathered from the Dodoma Region Zonal Irrigation Office (in which Kongwa is affiliated). A total of 400 questionnaires were collected from household heads of smallholders (farmer/livestock households), as shown in Table 1. The questionnaires involved both closed and open questions. The selection of households was done by dividing the total number of households in each village by the required sample size (about 10%). The household lists were obtained from the village's government leaders in the study area.

Table 1. Summary of questionnaires administration and PRAs tools in the sampled villages.

| | Mnyakongo | Ugogoni |
|---|------------------|-----------------|
| Questionnaires (<i>n</i> = 400) | Total HH (2050) | Total HH (2080) |
| Number of households interviewed | 200 | 200 |
| Crop farmers (%) | 70 | 80 |
| Livestock farmers (%) | 10 | 10 |
| Both crop and livestock farmers (%) | 20 | 10 |
| Focus group discussion (<i>n</i> = 30) | | |
| Crop farmers | 12 | 10 |
| Livestock farmers | 0 | 2 |
| Both crop and livestock farmers | 3 | 3 |
| Interview (<i>n</i> = 20) | | |
| Crop farmers | 8 | 9 |
| Livestock farmers | 0 | 0 |
| Both crop and livestock farmers | 2 | 1 |

* PRAs = Participatory Rural Appraisal; * HH = Household heads; * *n* = Number of observations. Source: Field Survey Data, 2016.

Interviews and household surveys were used to collect socio-ecological data at a society level. We collected both quantitative and qualitative data at the field and farm household level. About 258,219 ha (71%) of the total arable land (363,690 ha) in the district was cultivated by 45,271 households. The two representative villages had 4500 farming households with about 16,000 ha. Since we aimed to explore the rate of CA adoption, we selected 400 households (farmers) from the two villages on a random basis. In total, these 400 households had 1600 ha (an average of 2.0–4.0 ha per household) under crop production. We determined the overall farmers' perception on CA, and its types and benefits. In the process, we also determined the availability of extension services. Finally, information on soil characteristics was mainly obtained from the Kongwa District Land Use and Planning office and literature review.

The Participatory Rural Appraisal method (PRA) was also employed to collect socio-economic data at the field level. These PRAs include informative interviews, group discussions, physical observation, etc. The application of the PRA method has been used to explore perceptions of rural communities on environmental issues that affect their lives [49–51]. One group discussion with 15 people was convened in each village, and interviews were conducted with 20 agricultural experts, farmers, livestock keepers and village government leaders.

2.3.2. Data and Statistical Analyses

We analyzed the quantitative data using the Mann–Kendall Test (at 95% level of confidence), and Microsoft excel (window 13) software. In this regard, the p -values less than 0.05 were supposed to be statistically significant ($p < 0.05$). The qualitative data from the household surveys were analyzed using theme content methods, whereas qualitative information was summarized and inserted in the text during discussions.

3. Results

3.1. Recent Adoption of Conservation Agriculture

Results showed that, despite the recently increased rate of CA adoption (Figures 4–6), <10% of households had adopted it. For instance, in the two representative villages, 400 households cultivated an area of about 1600 ha for crop production, while 200 ha of CA were practiced by 10% of these households. At the district level, there were 45,271 farming households who had cultivated 258,219 ha (Table 2), but only 4300 households had adopted the CA for an area of 20,000 ha.

CA practices had been more adopted in Ugogoni than in Mnyakongo. The former had a higher averaged land size and total cultivated lands (Table 2). This brought significant differences in terms of socio-ecological benefits to both the community livelihoods and the environment.

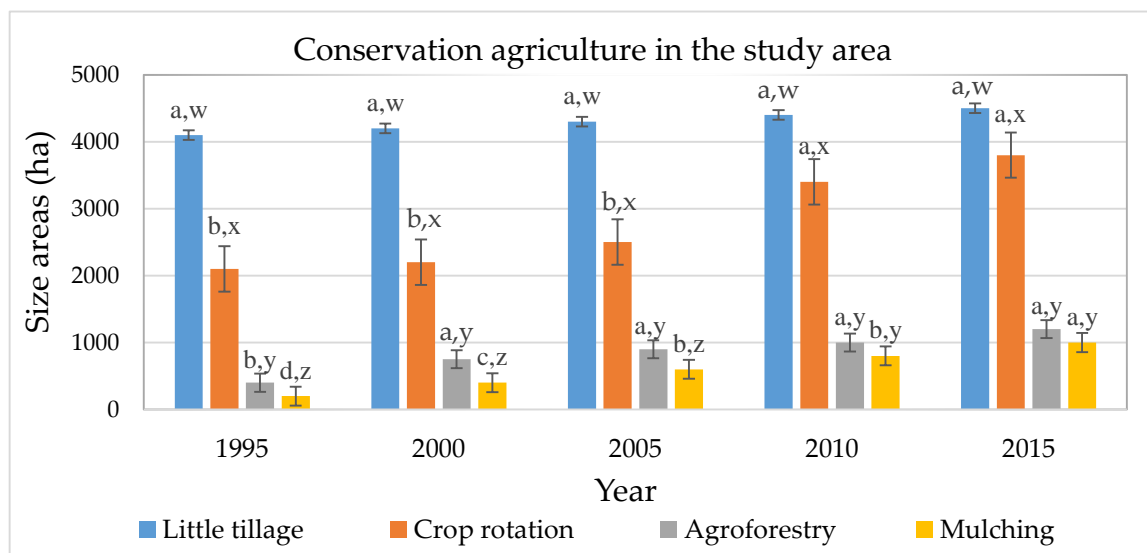


Figure 4. Variation in land use or farming systems from 1995 to 2015 (five-year averaged data) in Mnyakongo and Ugogoni villages of the Kongwa District, a semi-arid zone in central Tanzania. Data (means \pm SD, $n = 5$) with different letters denote significant differences between averaged years for the same CA practice (a, b, c, d, e) and between different CA practices for the same averaged year (w, x, y, z) at $p < 0.05$. Note: Little tillage involves shallow cultivation (minimum tillage) of the farm (i.e., non-conventional). Source: Field Survey Data, 2016.

In addition, the major types of the CA in the study area were agroforestry, mulching, crop rotation and minimum tillage. The lands allocated to CA were corrected by the total lands under farming ($p < 0.05$). Hence, predictions and extrapolations could be done based on such dimension.

Figure 4 indicates the temporal trend of CA adoption with special focus on little tillage, crop rotation, agroforestry and mulching. There was a slight increase in almost all CA practices, while reduced tillage and crop rotation were more adopted compared to others.

Figure 5 shows the adoption disparities between crop rotation and reduced tillage. More lands with CA practices were under reduced tillage (5000 ha) than under crop rotation (4500 ha). Meanwhile, crop rotation was significantly more adopted ($R^2 = 0.90$) than reduced tillage ($R^2 = 0.57$). Under such premises, it was evident that reduced tillage had less new adopters than crop rotation did, probably because it had already been adopted by the laggards (late adopters). These results agree with reduced tillage being the leading CA in Tanzania, although it is integrated with mulch, crop cover and legumes [26].

In addition, mulching and agroforestry (Figure 6) had smaller lands (1000 ha) with a high rate of CA adoption. Of these two, mulching appeared to have higher adoption rate ($R^2 = 0.95$) than agroforestry did ($R^2 = 0.68$) while the former received more new adopters. This was because most of the adoption was done within the past 20 years (1995–2015).

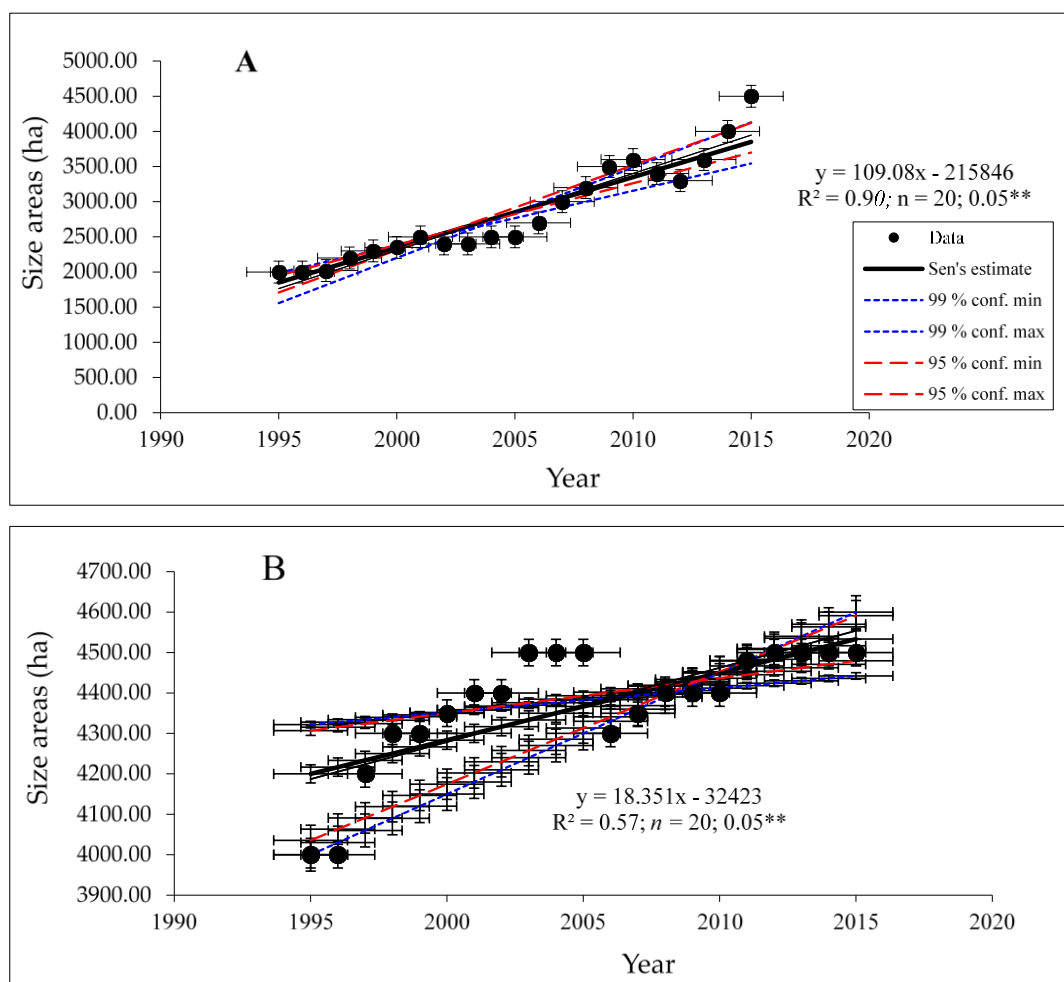


Figure 5. Adoption rate of crop rotation (A) and little tillage (B) as CA practices in the Mnyakongo and Ugogoni villages of the Kongwa District, a semi-arid zone in central Tanzania. Source: Field Survey Data, 2016.

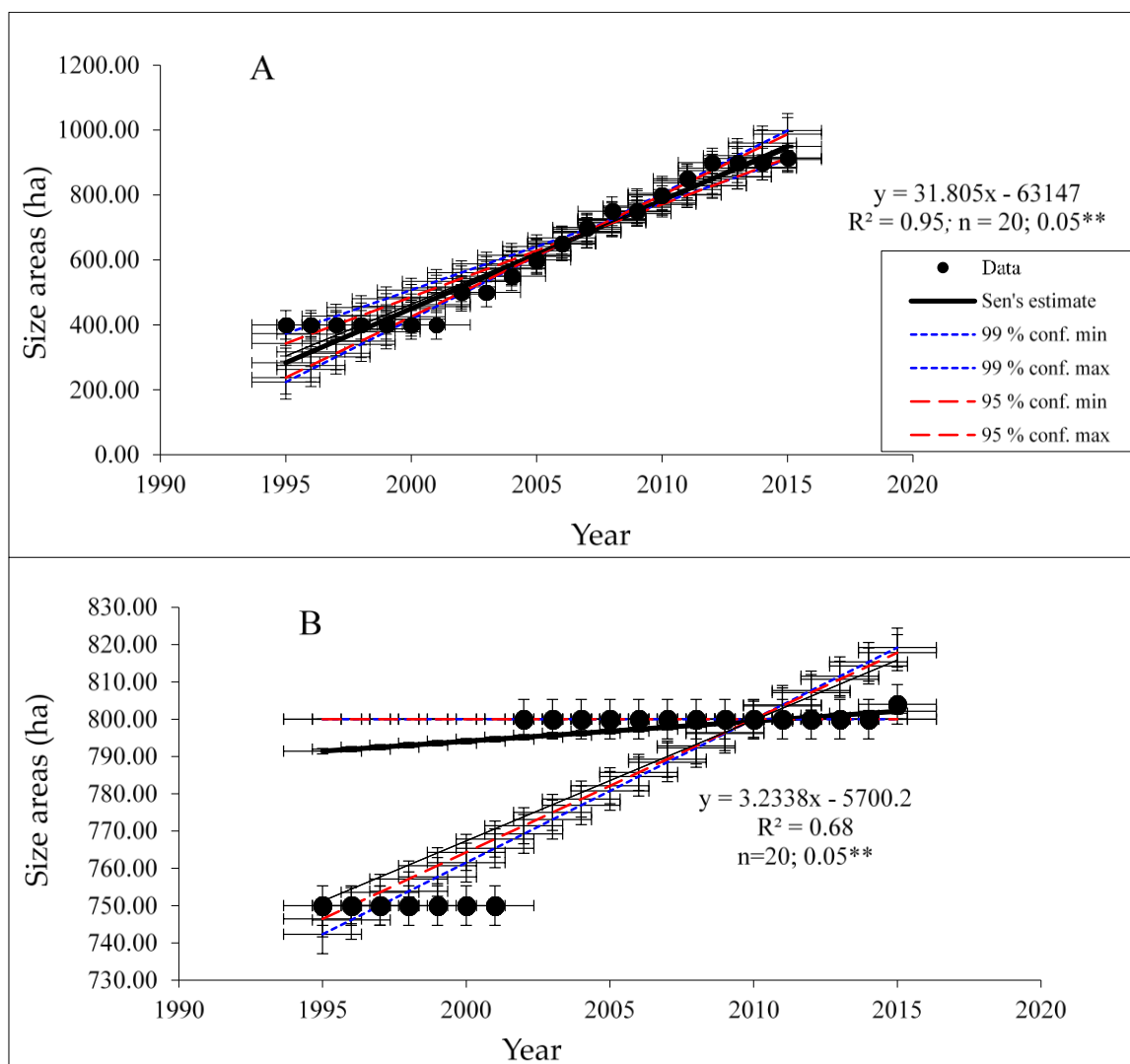


Figure 6. Adoption rate of mulching (A) and agroforestry (B) as CA practices in the study area. Source: Field Survey Data, 2016.

Table 2. Current and estimated land under conservation agriculture in the sampled villages.

| Village | Total Cultivated Land (ha) | Average-Landholding Size (ha) | Average Land under CA (ha) | Adoption Rate (%) | Estimated Land under CA (ha) |
|-----------|----------------------------|-------------------------------|----------------------------|-------------------|------------------------------|
| Mnyakongo | 8600 | 3.5 | 0.34 | 8.7 | 90 |
| Ugogoni | 9200 | 4.1 | 0.38 | 11.4 | 105 |

* The adoption rate was from the agricultural officers and others from local farmers in a 2016 field survey. Source: Field Survey Data, 2016.

In fact, there is an immediate need to establish compelling efforts to make CA understandable and sustainable to farmers (Table 3). An intensive adoption of CA would therefore optimize sustainable livelihoods, especially for vulnerable and deprived smallholder farmers.

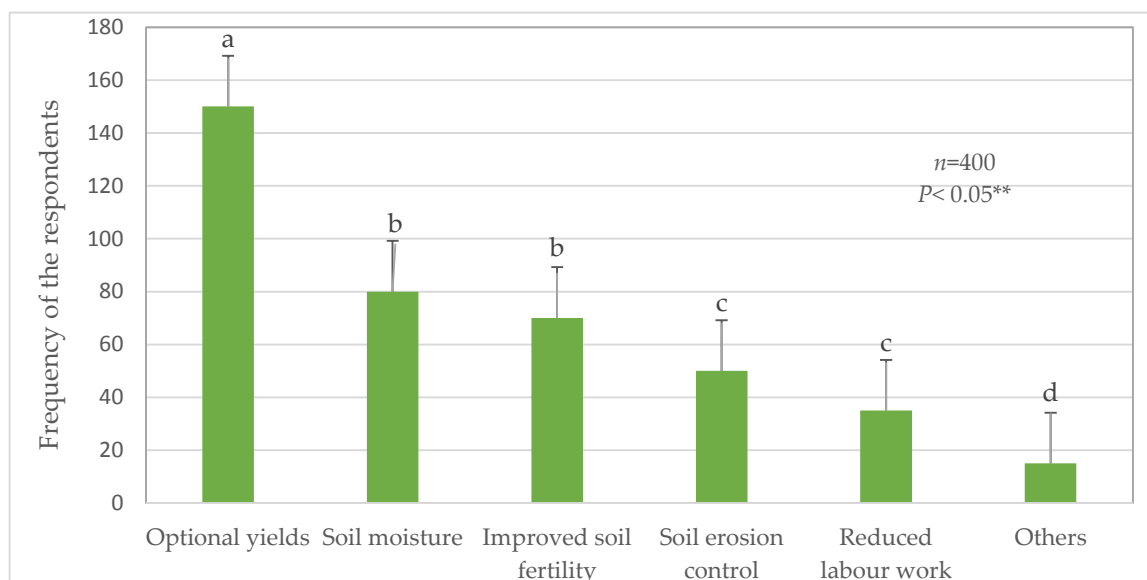
Results in Table 3 indicate that most farmers (50%–70%) asserted that the effectiveness of CA had been either very high or moderate. Most farmers (71%) asserted that crop rotation (e.g., maize, sorghum, millet, groundnuts, etc.) has been very effective, while 7% of them were not sure if the practice was effective. Likewise, most farmers (76%) asserted that the effectiveness of agroforestry has been moderate, while 6% did not think it was effective.

Table 3. Responses (%) of effectiveness to the conservation agriculture practices by local farmers in the sampled villages ($n = 200$ in each village) during a 2016 field survey.

| Conservation Methods | Very Effective | | Moderate Effective | | Not Sure | | Not Effective | |
|----------------------|----------------|----|--------------------|----|----------|----|---------------|----|
| | Mn | Ug | Mn | Ug | Mn | Ug | Mn | Ug |
| Agroforestry | 18 | 19 | 76 | 77 | 0 | 0 | 6 | 4 |
| Crop rotation | 71 | 73 | 22 | 25 | 7 | 2 | 0 | 0 |
| Little tillage | 15 | 16 | 67 | 71 | 13 | 10 | 5 | 3 |
| Mulching | 27 | 29 | 62 | 64 | 9 | 5 | 3 | 2 |

Abbreviations: Mn, Mnyakongo, and Ug, Ugogoni; Source: Field Survey Data, 2016.

Figure 7 and Table 4 indicate that most farmers essentially adopted a CA practice to optimize yields. This notion was also observed in various studies and models [9,10,43]. The improvement of agro-ecosystems such as soil moisture and fertility retention, and control of soil erosion were other substantial reasons for adopting the CA in the area.

**Figure 7.** Reasons for adopting CA in the Mnyakongo and Ugogoni villages of the Kongwa District, a semi-arid zone in central Tanzania. Different letters (a, b, c, d) denote significant differences between different reasons for the CA adoption. Source: Field Survey Data, 2016.**Table 4.** Established hypotheses as expressed in percent (from participatory research appraisals).

| Village | Optional Yields | Soil Moisture | Soil Fertility | Erosion Control | Reduced Labor | Others | Total |
|-----------|-----------------|---------------|----------------|-----------------|---------------|--------|-------|
| Mnyakongo | 21 | 7 | 8 | 8 | 5 | 2 | 49 |
| Ugogoni | 19 | 8 | 8 | 7 | 5 | 2 | 51 |
| | 40 | 15 | 16 | 15 | 10 | 4 | 100 |

Source: Data are from a 2016 field survey in the Mnyakongo and Ugogoni villages of the Kongwa District, a semi-arid zone in central Tanzania.

Figure 7 presents the farmers assertion based on questionnaires survey while Table 4 shows the findings from PRAs (i.e., mostly from discussion and interviews), although the results from these two sources correlate with each other.

3.2. Crop Yields

CA has proven to significantly contribute to crop yields. In the present study, there were significant differences ($p < 0.05$) between the yields from farms with and without CA (Figure 8). We calculated the yields in tons per hectare from different farmers with and without CA. These results agree with those of the FAO [33].

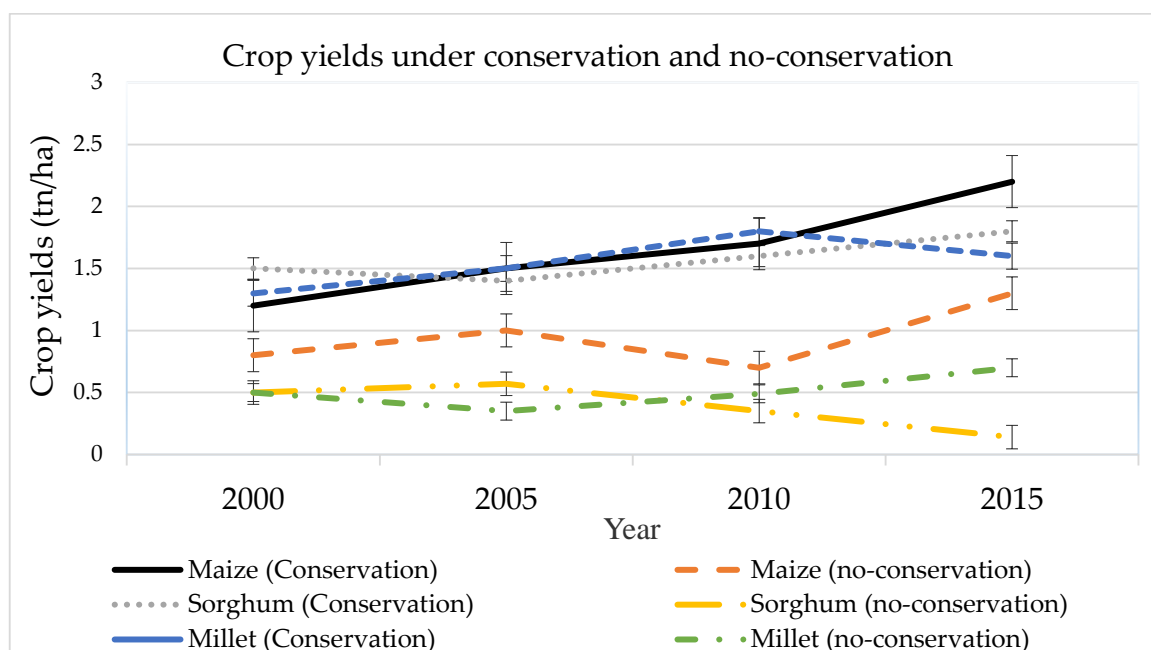


Figure 8. Variation in crop yields under conservation and no-conservation from 2000 to 2015 (five-year averaged data) in the Mnyakongo and Ugogoni villages of the Kongwa District, a semi-arid zone in central Tanzania. Vertical bars indicate the standard error of the means ($n = 4$). Source: Field Survey Data, 2016.

The findings of the present study revealed that maize, sorghum and millet yields were significantly greater (1.7 t ha^{-1}) under CA than (0.7 t ha^{-1}) without CA (Figure 8). The yields of maize, a preferred food crop in Tanzania, increased from 1.3 t in 2000 to 2.3 t ha^{-1} in 2015. Further, its yields were even more when intercropped with leguminous crops. In farms without CA, maize yields trailed by 0.8 t ha^{-1} in 2000 and more than 1 t ha^{-1} in 2015. Thus, there are significant differences ($p < 0.05$) between the two scenarios in terms of yields.

4. Discussion

4.1. Conservation Agriculture

The results from analyses revealed that, despite the significance of CA to both crop yields and environmental conservation, its adoption at both local and national level was very low (Figures 4–6 and Table 2). This reflects the African trend where CA is less adopted and predominantly under small scale (Figure 1). Crop rotation and reduced tillage were more optimally adopted than other forms in terms of land hectares (Figure 5).

However, the rate of adoption was significantly greater for mulching (Figure 6), with $R^2 = 0.95$, followed by crop rotation, agroforestry and little tillage at 0.90, 0.68 and 0.57, respectively (Figures 5 and 6). The CA with high land hectares (Figure 5) had been in practice for a couple of years while mulching and agroforestry (Figure 6) appeared to be new to the farmers, although the latter received high attention. Thus, time factor had significant influence in the CA adoption.

The findings indicate that households always adopt new agricultural technology when the benefit of a new technique is significantly greater than that of the existing technology. This utility-based adoption approach was also observed by Rogers [9], Mwaseba et al. [10] and Heckman [43]. In the study area, 150 respondents specifically adopted CA because they wanted higher yields, while 65 and 60 did so to conserve soil fertility and soil moisture and control erosion, respectively. In addition, 45 and 20 farmers adopted CA to reduce frequent labor work and related activities, respectively (Figure 7 and Table 4).

Most households adopted CA after a careful decision based on the trade-off. These results agree with Thierfelder et al. [6], Ngwira et al. [7] and Kimaro et al. [26] who had similar observations in other Sub-Sahara countries. Since the rate of CA was mainly hypothesized against the desire for higher yields, preservation of soil moisture and fertility, control of soils erosion, and reduction of labor work, this study has confirmed that the majority farmers adopted CA for higher yields.

Despite not being an extremely labor demanding practice, it was noted that labor shortages hampered CA adoption to some extent. This was critically caused by the rural–urban migration amongst the working class in search of employment and wage labor. As a result, agricultural practices in most rural areas remain under the dependent class (children and old people) who are less energetic. To some extent, agroforestry was less affected by this migration compared to other CA forms as it mostly involved perennial crops that would not demand frequent labor.

Through interviews and discussions, most agricultural officers acknowledged proposing several CA practices, however, the financial constraint has been a major limiting factor to regularly visit farms, especially in remote areas. Despite the financial constraints, this study realized that the adoption of CA practices may solely depend on skills, interest, awareness and priorities of the adopters (i.e., early, moderate and laggards). However, to enhance CA adoption in the study area and the country at large, agricultural and extension officers should pay adequate visit to advise farmers on different agronomic practices that can optimize yields and elevate environmental services.

This is important because, at a farm level, some farmers blamed agricultural experts for not giving substantial extension services. This means, despite the farmers' willingness to adopt the CA, if there will be no extension support, obviously, the adoption rate will slow down. This is because their indigenous knowledge may not be enough to cope with climate change. During the series of discussions, an anonymous farmer claimed that agriculture is meant for the poor. He further justified that most of the officers/experts had not engaged in it, instead they preferred other clerical jobs. His claims were associated with numerous government reports that indicated that 70% of agricultural industry in the country was under smallholder farmers who were mostly economically deprived.

Based on such premise, this study suggests that agricultural and extension officers should instill a sense of awareness and confidence among farmers that agriculture is a respectable industry and, thus, anyone can do it, regardless his/her economic status. This can contempt the long standing local joke "*mkulima*", a Swahili word that means "poor" as associated to agriculture. Here, they mean that agriculture is for the lowest class and jobless people. The government is always asking and requesting jobless people, especially in towns, to join agriculture industry for their survival and development.

4.2. Crop Yields

The influence of CA on crop production has been substantially revealed. From 2000 to 2015, the yields of sorghum and millet were significant greater under CA (1.5–1.8 t ha⁻¹ and 1.3–1.6 t ha⁻¹, respectively) than under no-CA (0.2–0.5 t ha⁻¹ and 0.5–0.7 t ha⁻¹, respectively) (Figure 8). Of the two crops, sorghum yields had significant variation between the farms with (1.8 t ha⁻¹) and without CA (0.2 t ha⁻¹) compared to millet, i.e. 1.6 t ha⁻¹ with CA and 0.5 t ha⁻¹ without CA (Figure 8).

Thus, for optimal yields, the CA practices need to be more integrated with sorghum than with millet production. These results agree with and Kimaro et al. [26], Glaser et al. [37] and Dixon et al. [52]. The yields increase has been significant in limiting the level of hunger in the area. Moreover, CA gave

optimal yields when integrated with irrigation and organic fertilization. Thus, the incorporation of these aspects in CA is worthwhile to increase crop yields in the study area.

On the other hand, the increasing demand of organic food at the global market may increase the adoption of CA (organic farming) in various countries [33]. While other parts of the globe have considerably adopted CA, Africa has not yet done well in that aspect (see Figure 1). Thus, compelling measures and emphasis are required in the continent to increase this adaption [44,45]. This will enhance the adaptive capacities among the smallholder farmers and limit the level of vulnerability from the global and local environmental change [15,16,45]. Thus, while proposing the increased CA adoption at a local level and in various agroecological zones, we also advocate its adoption at national, regional, continental and global levels because mitigation measures can have both global and local impacts [52–61].

4.3. Irrigation

With respect to the semi-arid areas, CA observed to work properly through irrigation. It mainly safeguards soil fertility and moisture, thus improving agroecosystems tenable for crop production and environmental conservation. Even though irrigation was limited to small area (about 5814 ha, i.e., <5% of the total area) located near the Mseta, Mzeru, Mlanga, Ikoka and Chelwe Rivers (Figure 3), it had significant contribution to yields and conservation.

However, Water User Association (UWA) and Irrigators Organization (IO), which control irrigation operation in the area, have encountered multiple challenges: water use conflicts, destruction of irrigation infrastructures and financial constraints. All these challenges posed some consequences.

The small area under irrigation denies the exploitation of a wide range potentials associated with irrigation. This problem is also acute at a national level where less than 4% of the total irrigable land potential has been harnessed [53,54]. According to the zonal irrigation engineers, the area has abundant ground water that could be the best option, but this potential has not yet made into use.

It was further clarified that various geophysical surveys have indicated that most ground water is located at less than 60 m depth. This is contrary to countries such as China where this depth can exceed 200 m [52]. As a way forward, the substantial investment in technology is very important for exploitation of both ground and rain water.

During rains, some farmers collect running water from seasonal rivers for spate irrigation. This water is intended to be reserved and used during water stress. However, due to weak infrastructure, the loss of this water is critically high. Thus, suitable mechanisms are required to boost their local innovations.

4.4. Fertilization

Fertilization has significant contribution to CA as it increases crop yields. CA gives optimal advantages when integrated with fertilizations [26,61]. The present study found that the majority (62%) of farmers did not use any fertilization on their farms; 80% of those (38%) applied organic fertilizers while few (20%) used chemical fertilizers.

It was realized that most organic fertilizers come from straw and animal manure. Most animal manure comes from goats, sheep, cattle, pig and donkeys. In terms of amounts, most farmers were assertive that, for optimal crops yields, they required at least 5000–10,000 kg ha⁻¹ of organic fertilizers whose fertility could remain in the farm for five years. However, organic fertilization was insignificantly applied in the study area.

On the other hand, chemical fertilization such as DAP (Diammonium Phosphate), NPK (Nitrogen Phosphorus Potassium), SA (Ammonium Sulphate), TSP (Triple Super Phosphate) and UREA were applied in few areas especially under irrigation schemes. This is because the Ministry of Agriculture, Livestock and Fishery (MALF) recommends chemical fertilizers under irrigation schemes, as it does better under constant soil moisture than in mere drought areas (i.e., where evaporation is high).

The MALF has been providing inadequate share of chemical fertilizers to Dodoma Region, i.e., 1×10^4 . This meant that only 4000 ha could be fertilized in the whole region. In that share, Kongwa District received <2000 vouchers that fertilized very few hectares. However, it increased crop yields to 7.2 t ha^{-1} (from less than 3 t ha^{-1} under no-CA).

Overall, this study realized that, for a successful CA, there is an immediate need to attach irrigation and fertilization for sustainable conservation of soil moisture and fertility. It was also realizable that CA offered economic and socio-ecological advantages to the farmers depending on the biophysical environment. Areas under irrigation schemes that received chemical fertilization provided favorable conditions for crops production.

4.5. Environmental Sustainability

The study by FAO [46] has showed that chromic luvisols with a sandy loam texture is the dominant soil type in the area. Soil types are among the most important factors that control several biological processes in a particular locality. It was observed that silt contents in different farms were not significantly different ($p > 0.05$) and ranged between 170 and 255 g kg^{-1} soil while bulk density was 1.11 and 1.35 Mg m^{-3} with and without CA, respectively [47]. Soil carbon ranged from 1 to 1.22 Mg C ha^{-1} (0–20 cm deep) under CA and declined in farms under no-CA, while calcium, magnesium and sodium ranged from 0.5 to 4 Mg ha^{-1} under CA [37].

In most areas, the soils had neutral pH values ranging 5.40–6.10 on the top soils [46–48]. In addition, it had moderate high cation exchange capacity and high base saturation [48–54]. The CA practices appeared to optimize important soil nutrients, i.e., soil quality in the area. Accordingly, soil nutrients were significantly greater ($p < 0.05$) under farms with CA than under no-CA due to such soil amendments. The former was better in the optimization of environmental sustainability than the latter.

Many studies conducted in similar agroecosystems, i.e., climate and soil types, have also endorsed the positive roles of soil fertility and moisture (under CA) in elevating the biological functions of microorganisms in balancing the ecosystems [29,46–48]. Mycorrhiza fungi also operate well under proper soil organic managements where they then increase the capacity of nutrients uptake and resistance to pathogens by plants [48]. This situation improves the interaction between roots and microorganisms

Moreover, a study by Haoa et al. [29] further indicated that no-tillage, crops rotation, mulching and agroforestry were the sinks of the top three greenhouse gases, i.e., carbon dioxide (CO_2), methane (NH_4) and nitrous oxide (N_2O), and, thus, confer adaptation and mitigation. It is thus obvious that the CA practices have multiple benefits to environmental sustainability [30,55–59]. Hence, CA practices have significant contributions to sustainable environmental conservation focusing on lithosphere, hydrosphere, biosphere and atmosphere.

As a result, it is advisable to build the capacity of the smallholder farmers (who form 70% of Tanzanian agriculture) so that they can effectively integrate AC in their farming. If this integration reached at least 20% of the total farm size of every household, it would definitely increase crop yields and environmental services [33,55–61]. This would have a long-term positive impact in serving the present needs of the people and environment without compromising the needs of future generations [55–61].

5. Conclusions

This study sought to explore the adoption rate of CA in the Kongwa District, a semi-arid agroecological zone in the central Tanzania. It accepted alternative hypothesis H_1 because CA adoption was greatly influenced by the farmers' desire to achieve higher yields. Besides, the retention of soil moisture, conservation of soil fertility, and control of soil erosion were among the contributing factors that attracted farmers to adopt CA. In both villages, it was realized that there was correlation ($p < 0.05$) between the size of land under CA and the total land under farming (Table 2).

Time factor was another determinant factor for the adoption trend as there has been an increase in hectares under CA over time. However, the present study showed that CA is insignificantly practiced in study area, as <10% of households were involved. Among the CA practices, mulching appeared to receive high attention to adopters as its adoption was determined at the coefficient of $R^2 = 0.95$. Little tillage appeared to dominate others in total hectares (about 6000 ha). In addition, CA practices appeared to be more beneficial when supported with organic fertilizations and irrigation.

Animal manure and straw were the main source of organic fertilization. Further, this study found the significance difference between the areas with and without CA. Crops yields and environmental sustainability were better with CA than without it (Figure 8). Therefore, despite of being understandable that CA could improve the agricultural systems, it is recommendable to quantify such environmental potentials. The present study proposes the adoption of CA practices in various agroecological zones in Tanzania to manage agricultural soils, and attain socio-economic and ecological advantages. This is because CA confers adaptation and mitigation advantages. Likewise, effective livestock keeping should be integrated into various CA practices for mutual benefits.

Subsequently, planners, policy makers, agricultural experts and other agricultural stakeholders and practitioners should consider these findings as a baseline for their future endeavors. Lastly, we call for more proactive interventions and efforts from different stakeholders to join in this agenda. These efforts should mostly target areas with extreme weather stresses.

There are several research priorities for further investigations to tackle: (1) characterization of people who are involved in CA (small scale or large scale) and the policy implications; (2) the drivers that can influence CA adoption in small-scale farming; (3) how climate variability influences positively or negatively the adoption of CA (especially during the extreme wet period as compared to the extreme dry period); and (4) how crops yield harvested from CA contribute to food security and economic welfare.

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