Science | Technology | Development

Ghana Journal of Science, Technology and Development | Vol. 9, Issue 1, July 2023
e-ISSN: 2343-6727
DOI: https://doi.org/10.47881/209.967x

Received: October 8, 2020
Accepted: June 16, 2023

Prospects of Shea Trees (*Vitellaria paradoxa*) in Climate Change Mitigation - A Case Study in Cheyohi in the Kumbungu District of Ghana

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ABSTRACT

There is presently inadequate information on carbon stocks and sequestration potential of shea trees in Ghana and shea-growing areas in Africa in general. A study was therefore conducted to find out the prospects of shea trees in climate change mitigation in the Kumbungu District. A randomized complete block design (RCBD) with three replications was used to set up the experiment and analysis of variance (ANOVA) was used to analyze the gathered data. The research identified 3 cropping systems practised by farmers and these were developed into sole shea tree parkland model (SS), mixed shea trees and crops model (MS) and sole crops model (SC). Findings of the study show that there was no significant difference ($p>0.05$) between SS and MS in carbon (C) stock. SS however stored more carbon (2.49 Mg ha-1 C) than MS which recorded 2.21 Mg ha-1 C. There was also no significant difference between SS and MS ($p>0.05$) in terms of C sequestered, although SS sequestered more C (0.0246 Mg ha-1yr-1) than MS which had 0.0217 Mg ha-1yr-1 C. SS had the capacity to generate the most income from the sale of shea products (CO_2seq, shea nuts and fuelwood). This was followed by MS, with SC having the least potential. SS is therefore recommended for adoption by farmers. Alternatively, MS is also recommended as it has an almost equal potential to generate high income and sequester C and CO2. It has an added advantage of producing food crops for both domestic consumption and for sale to generate income for the upkeep of the family.

Keywords: *Climate change, Shea trees, Carbon sequestration, Economic potential, Farmers, Ghana*

INTRODUCTION

The shea tree, *Vitellaria paradoxa* (Maranz *et al.*, 2004) is a major component of the woody flora of the Sudanian regional centre of endemism (White, 1983). The tree contributes immensely to local livelihoods, amelioration of micro-climate and nutrient recycling through decay of its leaves and fine roots (Dianda *et al.*, 2009). It grows well on a varied array of soils, and these include very degraded, rocky, semi-arid and arid soils (Dogbevi, 2007). It generally grows to a height of approximately 15 m with a lot of branches and a deeply-fissured and thick waxy bark which enables it to be fire-resistant. Shea trees grow in twenty-one (21) countries across the African continent, namely; Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Cote d'Ivoire, Democratic Republic of Congo, Ethiopia, Gambia, Ghana, Guinea, Guinea Bissau, Mali, Niger, Nigeria, Senegal, Sierra Leone, South Sudan, Sudan, Togo and Uganda (FAO, 1988a).

The trees grow in nearly throughout northern Ghana, covering a land area of over 77,670 km^2 in western Dagomba, southern Mamprusi, western Gonja, Lawra, Tumu, Wa, Paga, Bole, Daboya and Nanumba with eastern Gonja having the densest stands. There is a sparse shea tree population in Brong- Ahafo, Ashanti, Eastern and Volta regions in the southern part of Ghana. In the absence of any hazards, including tree felling, the shea tree can bear fruits for 200 years (Dogbevi, 2007).

In general, shea trees are valued for their fruits and nuts. Many parts of the tree are useful to humans; the bark can be used as fuelwood or for making charcoal. Shea tree is an important source of medicine for curing diseases like diabetes, skin discoloration and minor burns (Fobil, 2007). The products are increasingly becoming popular globally, and it is foreseen that as demand increases there will be the need for sustainable management of the trees as they have an enormous economic potential for improving livelihoods of people (Teklehaimanot, 2004; Sanou *et al*., 2004). Shea trees form the main off-season farming activities for most women and children in northern Ghana (Fobil, 2007).

The sale of shea trees products has immense employment and revenue potentials for the people of northern Ghana and the national economy as a whole. The shea industry is, however, not formally structured, and this has led to disorganized production and marketing within the industry. Rural women and children who are the pickers of the fruits and nuts from farms risk losing their livelihoods because of the fact that prices of shea products, such as shea nuts and shea butter, are dictated by companies and individuals who buy such products.

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Emissions from deforestation and degradation of forests, largely from tropical countries, constitute nearly 20% of the global emissions of greenhouse gases (Bond *et al.,* 2009). Even though this estimate has been reviewed downward to 12% to reflect revised FAO data (or 15% when peat degradation is included), deforestation is still rated as the second biggest anthropogenic source of carbon dioxide to the atmosphere, after fossil fuel combustion (van der Werf *et al.,* 2009). Other results however suggest that the emission rates are between 25 and 50% of the original estimate (Harris *et al.,* 2012). Emissions from the Agriculture Forestry and Other Land Uses (AFOLU) sector of 22.9 $MtCO_2e$ produced the biggest greenhouse gases emissions in Ghana, making up 54.4% of the country's emissions of 42.2 $MtCO_2e$ (National Climate Change Report, 2020).

The estimated total global CO_2 emissions as of 2017 was 53.5 $GtCO_2e$. In view of this, it is extremely important to prevent additional loss as well as degradation of primary forests, protect and restore peatlands and protect grasslands which could cumulatively lead to the prevention of emissions by as much as 6.1 Gt CO_2eq per annum (Dooley *et al*., 2018).Restoring 25 % of degraded global natural forests (600 million ha) will lead to the restoration of primary forests and increase primary forest areas by half of the global forests as well as sequester more carbon globally by approximately 1.9 $GtCO_2e$ annually. An increase in natural forests for the restoration of 350 million ha by 2030 will sequester additional 3.9 $GtCO_2e$ per annum (Brack, 2017).

As carbon stored in organic matter represents one of the world's major carbon pools (Houghton, 1995), shea trees which constitute part of the general organic matter also play an important role in carbon storage, which according to findings of research conducted in Ghana indicate that shea trees store above-ground carbon of about 9.0 t C ha^{-1} (Shu-aib Jakpa, 2016).

In the 1990s, it was projected that climate change would bring net benefits to global agriculture and motivate farmers to manage trees, grown together with food crops on farms, to mitigate climate change (Mendelsohn *et al*., 1994). This is due to the fact that trees generally have huge prospects in climate change mitigation. Thus, incentive packages given to farmers to, for instance, manage and protect trees to sequester carbon dioxide could eventually impact positively on crop production as well as play significant roles in climate change mitigation, since trees grown together with crops on the same piece of land could also benefit from agronomic practices to enhance their growth and prospects in mitigating climate change.

Due to the fact that shea trees mostly grow and increase in numbers through natural regeneration, the trees are not properly managed (Gwali *et al.,* 2012 and Shu-aib Jakpa *et al.,* 2018). There is therefore the need to protect the trees from deforestation and bushfires since they generate significant income for the people of northern Ghana and Ghana as a whole. As woody perennials, shea trees have the potential to play a major role in climate change mitigation. And with incentive packages in the form of sale of carbon credits on the international carbon markets and direct cash payments from reduced emissions from deforestation and forest degradation (REDD+) through the Ghana Government, shea tree owners and farmers will be motivated to reduce or stop the felling of shea trees and increase existing populations of the trees in Ghana to sequester atmospheric carbon and mitigate climate change.

As there is however no documented information on carbon stocks and sequestration potential of shea trees in Ghana and limited literature in the entire shea-growing areas in Africa (Shu-aib Jakpa, 2016), this study was undertaken to assess the prospects of shea trees in climate change mitigation in Ghana, a case study in Cheyohi in the Kumbungu District of Northern Region.

The objectives of the study were to:

- *estimate the amounts of carbon stocks and carbon sequestered by shea trees in the Cheyohi Community;*
- *identify and develop models from existing cropping systems in the Cheyohi community that can be used to mitigate climate change;*

MATERIALS AND METHODS

Experimental site

The research was carried out in Cheyohi in the Kumbungu District of the Northern Region of Ghana which lies on latitude 9˚24 N and longitude 0˚98W with an altitude of 183 m above sea level (Kumbungu District Assembly Report, 2015). Mean annual rainfall at Cheyohi is 1,043 mm. Temperature usually varies between 15 ºC (minimum) in December-January and 42 ºC (maximum) within the March-April period with an average yearly temperature of 28 ºC and average relative humidity of 54 % per annum. Cheyohi community experiences one rainy season within a year, which starts from April/May to September/October with a peak level in July/August. The main soil types at Cheyohi include clay, laterite ochrosols and sand (SARI, 2004). The main farming systems are monocropping, mixed cropping, mixed farming (integrated system involving cropping and livestock rearing) and agro-pastoral system (MoFA-DADU, 2007). As typically in most of the communities in the Kumbungu District, rice, maize, cassava, sorghum, groundnuts, yam, pigeon pea, cowpea, cotton, soybeans, sheanuts and several vegetables such as tomatoes, pepper, okro, ayoyo (*Corchorus* olitorius), *Hibiscus sabdariffa*, and *Amaranthus spp* form the foremost subsistence and cash crops in Cheyohi (GSS, 2014).

Experimental procedure

Treatments used

Three (3) treatments, based on cropping / farming systems practised in the Cheyohi community, were used in the experiments. These were:

- Sole shea trees (SS)
- Sole crops (SC)
- Mixed shea trees and crops (MS)

Experimental design

The research was conducted using 3 x 3 Randomized Complete Block Design (RCBD). Each treatment was replicated three times, giving rise to a total of nine plots. Each treatment plot had a dimension (size) of 50 m x 50 m (2500 m^2).

Demarcation of plots

Each plot was demarcated by measuring out a dimension of 50 m x 50 m (2500 m^2) parcel of farmland in each treatment. Demarcation of plots was done using a measuring tape and the four corners of each plot were then pegged and lines marked between the planted pegs using hoe to indicate the boundaries of each plot. More pegs were planted along the boundaries of each demarcated plot.

Data collection

The type of data collected depended on the type of treatment used. The following were the treatments and the parameters on which data were collected:

Sole trees treatment

Parameters of the sole trees treatment on which data were gathered were:

- *Stem diameter per tree*
- *Yield of shea nuts per shea tree*
- *Yield of wood per shea tree* – this was determined by analyzing responses from farmers on cash obtained from sale of wood per shea tree or the cash equivalent of wood harvested from each shea tree and used at home or given out as gift

Sole crops treatment

Data were collected on the following parameters of the sole crops treatment:

- *Types of crops cultivated per plot*
- *Yield per crop per ha*

Mixed trees and crops treatment

Parameters of the mixed trees and crops treatment on which data were gathered were:

- *Stem diameter per tree*
- *Yield of shea nuts per shea tree*
- *Yield of wood per shea tree*
- *Types of crops cultivated per plot*
- *Yield per crop per ha*

Estimation of carbon stocks and carbon sequestration of shea trees

Carbon stock of each shea tree was estimated using an allometric equation. The sole shea trees treatment had a total of 1728 trees (with an average 36 trees ha^{-1}) and there were 997 trees on the mixed shea trees and crops treatment plots with an average of 13 shea trees ha^{-1}. The sole crops treatment however had only food crops, and therefore did not have any shea trees. As there are no specific allometric equations for shea trees in Ghana, the following allometric equation by Peltier *et al.* (2007) for *Vitellaria paradoxa* (shea) was used to calculate the above-ground biomass (AGB) of the shea parkland trees:

Above-ground biomass of tree (kg) = 0.08*(X2^(2.46))

where,

X= diameter at breast height (DBH in centimetres)

Above-ground biomass refers to "all living biomass above the soil including stem, stump, branches, bark, seeds and foliage" (IPCC, 2006).

Allometric equations are used to estimate the volume or biomass of above-ground components of trees from data on diameter at breast height (DBH) and height of the trees. Thus, the allometric equation above shows a correlation between the above-ground biomass and the diameter of the shea trees.

The equation is for *Vitellaria paradoxa* in Mafa Kilda, Cameroon, with average annual rainfall of 997 mm, which can also be applicable in tropical dry regions with similar climatic conditions including shea-growing areas of Ghana. The equation covers shea trees of DBH range of 15–53 cm, for which shea trees in the study area with diameters of 17–33 cm fell within that range. To calculate carbon in the biomass, the carbon fraction rate of 0.5, as suggested in the UNFCCC guideline (Takimoto *et. al.*, 2008; Escobedo *et al.*, 2009), was used.

Survey on types of crops, shea nuts and fuelwood and their yields

Sampling procedure used to collect data

As Cheyohi is a homogenous farming community, a simple random sampling technique was used to select a total of 19 out of a list 54 farmers in the community. By conducting personal interviews with the farmers through administration of questionnaires, information was gathered from the farmers on the types of cropping systems they practise. Other aspects covered by the administered questionnaire included the following:

- *Types and yields of crops cultivated*
- *Yields of shea nuts and fuelwood harvested per ha per year*
- *Income from crops, shea nuts and fuelwood per ha per year*

Data analysis and interpretation

The data collected were subjected to analysis of variance (ANOVA) using Genstat Discovery (7^{th} edition) and the means were separated using least significant difference (LSD). The results were interpreted in simple descriptive statistics in the form of graphs.

RESULTS AND DISCUSSION

Estimated carbon stocks and carbon sequestered by shea trees in Cheyohi

Among the 3 treatments, carbon stocks and carbon sequestered by SS and MS were estimated since they had shea trees. SC had only annual crops whose carbon stocks and carbon sequestered were negligible compared to those of the trees (Takimoto *et al.*, 2008).

Carbon stocks of shea trees in Cheyohi

Results of the study show that there was no significant difference ($p > 0.05$) between SS and MS in terms of the carbon stocks stored. SS however had more carbon stocks (2.49 Mg ha^{-1}) than MS which recorded less carbon stocks of 2.21 Mg ha^{-1} (Figure 1).

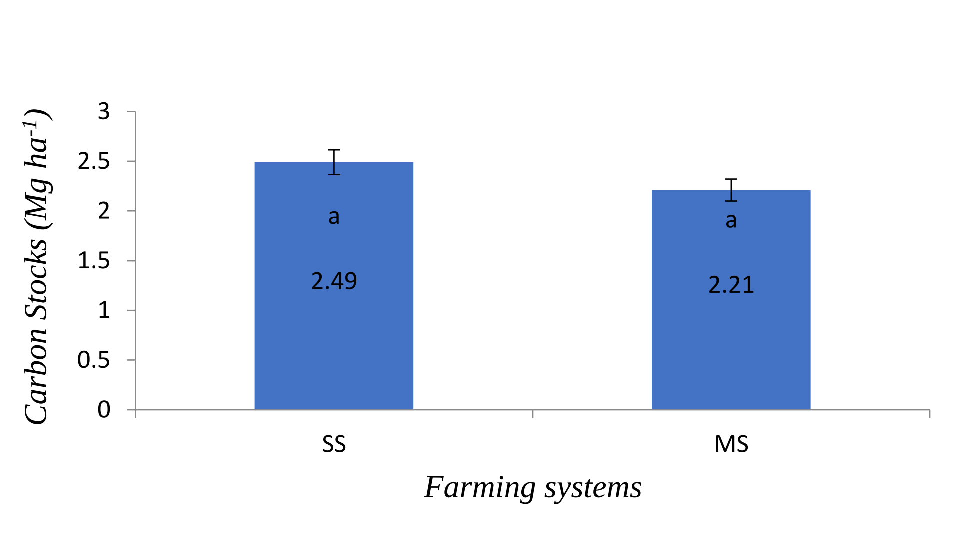

Figure 1. Estimated carbon stocks of shea trees in the SS and MS in farming systems practised by farmers in Cheyohi, Kumbungu District, Ghana. SS = Sole Shea, MS = Mixed Shea. Error Bars = ± LSD. Different letters indicate significant differences (ANOVA, $p < 0.05$).

This confirms the findings of Okiror *et al* (2012) that shea trees are reliable sinks for carbon. Kirby and Potvin (2007) in a similar study on teak (*Tectona grandis*) also found out that monoculture teak plantation made up of more teak trees stored more C than the fewer teak trees in an agroforestry system together with food crops due to the fact more C was contributed by the more densely populated teak plantation.

SS stored more C probably due to the fact that it had more shea trees (36 trees ha^{-1}) than MS which had 16 trees ha^{-1}. The farmers explained that they usually get low yields in food crops due to the adverse effects of the trees on their food crops. The farmers explained that the trees produce excessive shade which tends to reduce yields of food crops. They therefore remove some of the shea trees in the MS plots to create space for the cultivation of food crops.

Carbon sequestered

As shown in Figure 2 below, in terms of carbon sequestered there was no significant difference ($p > 0.05$) between SS and MS although SS had a slightly higher mean of 0.0246 Mg/ha/yr than MS which recorded a mean of 0.0217 Mg/ha/yr.

There was no significance difference between SS and MS ($p > 0.05$) although SS sequestered more C (0.0246 Mg ha^{-1}yr^{-1}) than MS which had 0.0217 Mg ha^{-1}yr^{-1}. This was probably due to the fact that SS had higher density of shea trees than MS, as a result of farmers cutting down the trees in MS plots to make way for the cultivation of food crops. In addition, despite the mean diameter of MS (22.77 cm) being about twice that of SS (19.37 cm), the cumulative sequestered C by SS is much higher as its mean tree density (36 trees ha^{-1}) is about thrice that of MS (13 trees ha^{-1}). This agrees with the research findings of Kirby and Potvin (2007) who postulated that monoculture teak plantation which consisted of a higher number of teak trees sequestered more C than the lower number of teak trees growing together with food crops on the same piece of land owing to the fact the higher density of the trees in monoculture plantation contributed more C.

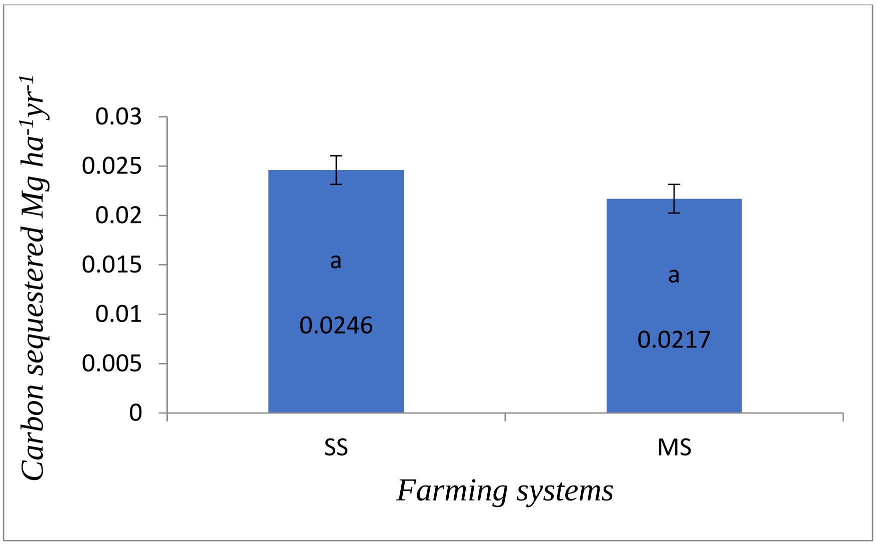

Figure 2. Carbon sequestered by shea trees in the SS and MS in farming systems practised by farmers in Cheyohi, Kumbungu District, Ghana. SS = Sole Shea, MS = Mixed Shea. Error Bars = ± LSD. Different letters indicate significant differences (ANOVA, $p < 0.05$).

Carbon dioxide sequestered

There was also no significant difference ($p > 0.05$) between the two treatments. However, SS relatively had more sequestered C of 0.09 Mg/ha/yr than MS which had 0.079 Mg/ha/year (Figure 3).

An analysis of the results of the study in Cheyohi shows that there was no significant difference between SS and MS, although SS had a higher value of 0.09 Mg $ha^{-1}yr^{-1}$ of sequestered carbon dioxide (CO_{2Seq}) while MS had 0.079 Mg $ha^{-1}yr^{-1}$ of CO_{2Seq}. This could be due to SS having a higher density of trees with each tree sequestering more CO_{2Seq} than MS with relatively low density of trees. This confirms the findings of Schuman *et al*. (2001) that the presence of high levels of CO_2 stored in the soil is due to more trees having their roots in the soil to sequester more CO_{2Seq} than MS with fewer trees.

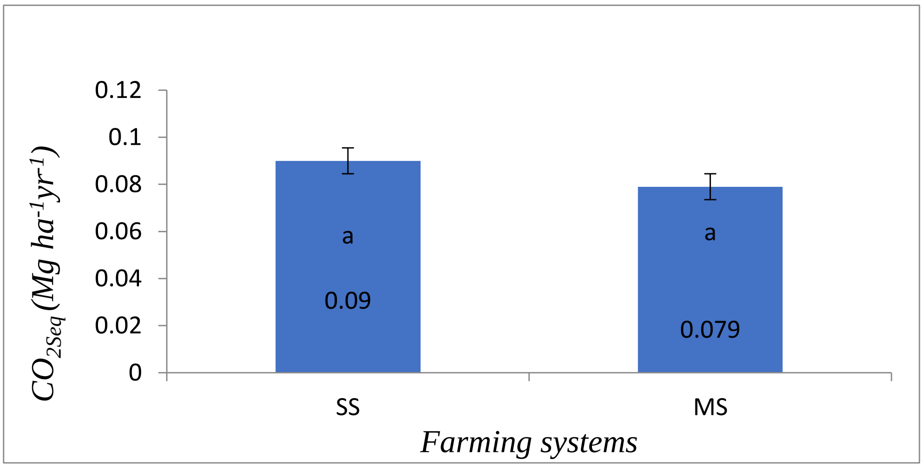

Figure 3. Carbon dioxide sequestered by shea trees in the sole shea trees and mixed shea trees and crops farming systems practised by farmers in Cheyohi, Kumbungu District, Ghana. SS = Sole Shea, MS = Mixed Shea. Error Bars = ± LSD. Different letters indicate significant differences (ANOVA, $p < 0.05$).

Cropping systems practised in the Cheyohi community

Three cropping systems were identified as being practised by farmers in the Cheyohi community. The cropping systems were:

1. Sole shea trees in a parkland
2. Sole crops
3. Mixed shea trees and crops

Sole shea trees parkland

This involves only shea trees growing on a piece of land. Such shea parklands are usually fallow lands that have either never been put to crop cultivation or were once under crop cultivation and have been allowed to lie fallow permanently or for a number of years, sometimes up to 5 to 20 years or more, for the land to replenish its lost nutrients. During this time, as a way of continuously laying claim to the land and preserving it as a clan or family property, the farmer continues to regularly visit the parkland to carry out some management practices on the land together with the trees. Such management practices include creation of fire belts at the boundaries of the land and around the trees, as well as pruning the branches of the trees. Results of the study indicate that 21% of the farmers said they manage shea trees growing on parklands, as shown in Figure 4.

Findings of the research show that a relatively smaller percentage (21%) of the farmers interviewed said they practised SS. In view of this, it is possible to develop this system as practised by farmers into a model. This will involve managing existing shea trees and seedlings in the parklands to increase their numbers and protecting them against bushfires, destruction by animals, as well as logging. Through these management practices, it is possible to increase the density of the trees from 36 trees per ha to 100-400 trees per ha, with a mean of 250 trees per ha recommended for the developed sole shea trees model or establish new shea plantations 100-400 trees per ha, with a mean of 250 trees per ha. This is due to the fact that results of earlier studies prove that it is possible to obtain an optimum density of 100-400 shea trees ha^{-1} at a spacing of 5–10 m x 5–10 m (especially under newly-established plantations), or approximately 204 shea trees ha^{-1} from an optimum spacing of 7 m x 7 m by vegetative propagation (Dakwa, 1985; Frimpong and Adomako, 1989; Tawiah, 1994; Yidana, 1994; Shu-aib Jakpa *et al.,* 2020).

Sole cropping

This is a cropping system that involves the cultivation of only food crops. The farmers usually cultivate one or more food crops on the same piece of land. Examples of food crops cultivated in the Cheyohi community are maize, cassava, yam, rice, tomato, pepper, soya beans, groundnuts, millet and okro. Of the 19 farmers interviewed in the Cheyohi community, 42% indicated that they grow only crops on their farms.

The sole crop system was identified as relatively being widely-practised by the farmers in Cheyohi, with as much as 42 % of the farmers practicing this system. There was therefore the need to repackage it as a developed model together with the necessary recommended practices for adoption by farmers. This is due to the fact that crop farming serves as the largest means of livelihoods for the people of northern Ghana, with almost 98 % of households engaged in the cultivation of various crops such as maize, rice, sorghum, soy beans, cowpea, cassava, yam, cotton and vegetables (Bawa, 2019). Farmers in Cheyohi therefore usually cultivate one or more crops on the same piece of land with the view to selling the produce to fetch income for the upkeep of their families as well as for domestic consumption.

Mixed shea trees and crops

This involves the cultivation of food crops together with shea trees growing on the same piece of land. Crops are usually cultivated in-between shea trees. As shown in Figure 4, 37 % of the farmers interviewed said they cultivate crops and shea trees on the same piece of land.

As shea products are increasingly becoming popular worldwide, it is foreseen that their growing demand will correspondingly raise the need for sustainable management of the trees as they have a huge economic potential for improving livelihoods of people (Teklehaimanot, 2004; Sanou *et al*., 2004). This will also increase the need for farmers to grow food crops in-between shea trees on the same piece of land so that both the shea trees and the food crops will benefit from such management practices. It is recommended that, as a developed model from the mixed shea trees and crops system which about 37% of the farmers in Cheyohi practise, the same planting distances of shea trees be used for higher yields as in the case of the sole shea trees model. Due to the fact that food crops will be grown in-between the trees, the recommendation is that the planting distances between the trees should be wider. This will involve creating wider spacing on the farm by retaining the shea trees and their saplings and seedlings at some recommended distances and removing the remaining ones that grow in-between them. Such wider distances such as 10 m x 10 m for the shea trees are recommended for adoption and implementation in existing farms. This will give rise to about 100 trees ha^{-1} in the MS recommended model. On the other hand, 125 trees ha^{-1}, which is 50% of the proposed stocking density (250 trees ha^{-1}) in the SS model could be adopted by farmers in the proposed SS model. Thus, with the improved density of shea trees in MSR, there will be more C storage and C sequestration by the trees.

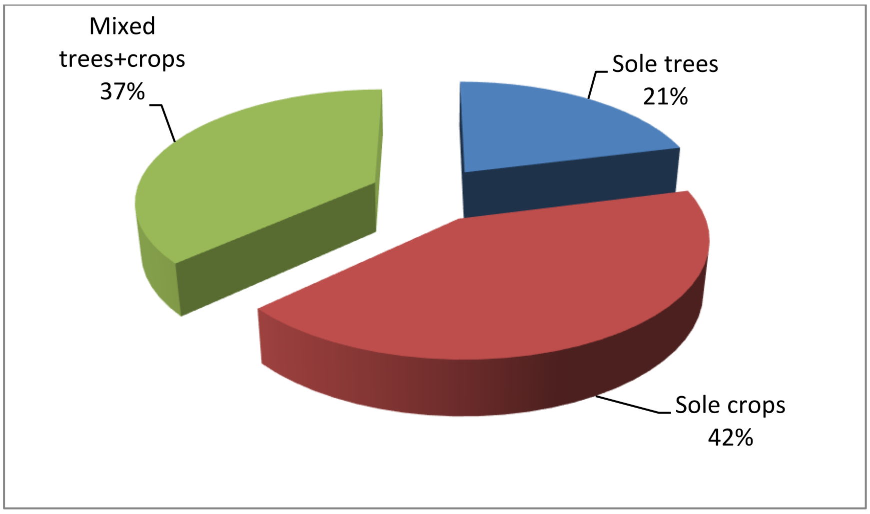

Figure 4. Cropping systems practised by farmers in Cheyohi

Models developed from existing cropping systems

Based on the 3 cropping systems identified in the Cheyohi community, 3 models were developed with recommended practices as strategies for mitigating climate change. These models are:

Sole shea trees model

In accordance with the already existing cropping system, this developed model involves growing only shea trees on a piece of land. Given that the mean density of shea trees in the shea plantations, referred to as the farmers' sole shea trees system was 36 trees ha^{-1}, a density of 100 – 400 trees ha^{-1}, with a mean of 250 trees ha^{-1}, is recommended for the developed sole shea trees model. This is because, findings of earlier studies show that it is possible to obtain an optimum density of 100 – 400 shea trees ha^{-1} at a spacing of 5–10 m x 5–10 m, or approximately 204 shea trees ha^{-1} from an optimum spacing of 7 m x 7 m by vegetative propagation (Yidana, 1994; Shu-aib Jakpa *et al.*, 2020) or 100 shea trees ha^{-1} from 10 m x 10 m (Kavaarpuo, 2010). Furthermore, Boffa (1995) reported that research stations in countries like Ghana achieved a higher optimum shea tree density of 400 shea trees ha^{-1} through natural regeneration. As such, similar tree densities could be considered, adopted and implemented in Ghana when establishing shea plantations.

Sole crops model

As widely practised by the farmers in Cheyohi, this system involves the cultivation of only food crops. Usually, the farmers cultivate one or more crops on the same piece of land, without any pattern in terms of planting distances. As such, the various planting distances on the farmers' fields were estimated and the averages were computed, although most of them fell within wide ranges and therefore varied widely from the computed averages. It is therefore proposed that the sole crops model, as an improved cropping system, should involve the adoption of the recommended planting distances of crops (as indicated in Table 1 below) for higher crop yields.

Table 1. Planting distances and yields of crops from farmers' fields and recommended planting distances and expected yields of some selected crops

Crop	*Farmers' planting distance*	*Farmers' yield (t/ha)*	*Recommended Planting distance*	*Expected yield (t/ha)*
Groundnuts	30 cm x 30 cm	0.88	50 cm x 20 cm	0.7 – 1.8
Maize	50 cm x 55 cm	0.43	40 cm x 75 cm	6.0
Soya beans	55 cm x 5 cm	0.34	75 cm x 5 cm	1.5 – 2.2
Rice	10 cm x 10 cm	1.71	20 cm x 20 cm	2.5 - 2.8
Chili pepper	50 cm x 50 cm	0.38	70 cm x 30 cm	3.99 – 7.53
Tomato	40 cm x 50 cm	2.09	20 cm x 60 cm	3.0 – 12.0

[1]Recommended planting distances of crops: Groundnuts (Gaikpa *et al.*, 2015), maize (Lihiang & Lumingkewas, 2017), soyabeans (Haruna *et al.*, 2017), rice (Ansah *et al.*, 2017), chili pepper (Markos and Mekonen, 2017) and tomato (Amare and Gebremedhin, 2020).

Mixed shea trees and crops model

In view of the fact that this involves the cultivation of food crops together with shea trees growing on the same piece of land, as a developed model, the recommended planting distances in Table 1 be used for the crops in this mixed shea trees model for optimum yields. As the food crops will be grown in-between the trees, the planting distances between the trees should however be wider. Thus, wider distances such as 10 m x 10 m should be used for the trees, which will give approximately 100 trees ha^{-1}. As a result, more carbon will be stored and sequestered by trees since the density of trees will increase compared with the farmers' practice of having 13 trees ha^{-1}.

Recommended models of shea cropping systems that will yield optimum economic and global environmental benefits

Economic analysis of the three systems practised by the farmers

An economic analysis showed that there was a significant difference ($p < 0.05$) among the farming systems practised by the farmers, in terms of the total income obtained by farmers from the sale of their harvested produce (Figure 5). Results of the study show that the farmers obtained an average of about twelve thousand two hundred and twenty-seven cedis (GH¢ 12227.06) per household per year from their mixed trees and crops farms (MS) as income from sale of shea tree products (shea nuts, shea butter, fuelwood, etc) and food crops. Also, farmers obtained an average of about five thousand two hundred and ninety-five cedis (GH¢5294.55) from the sale of their harvested sole crops (SC), while an average of about eighteen thousand seven two hundred and eighty-four cedis (GH¢ 18784.01) was obtained by each household as income per year from the sale of harvested sole shea tree (SS) products such as shea nuts, fuel wood and sequestered carbon (assuming the carbon credits were sold).

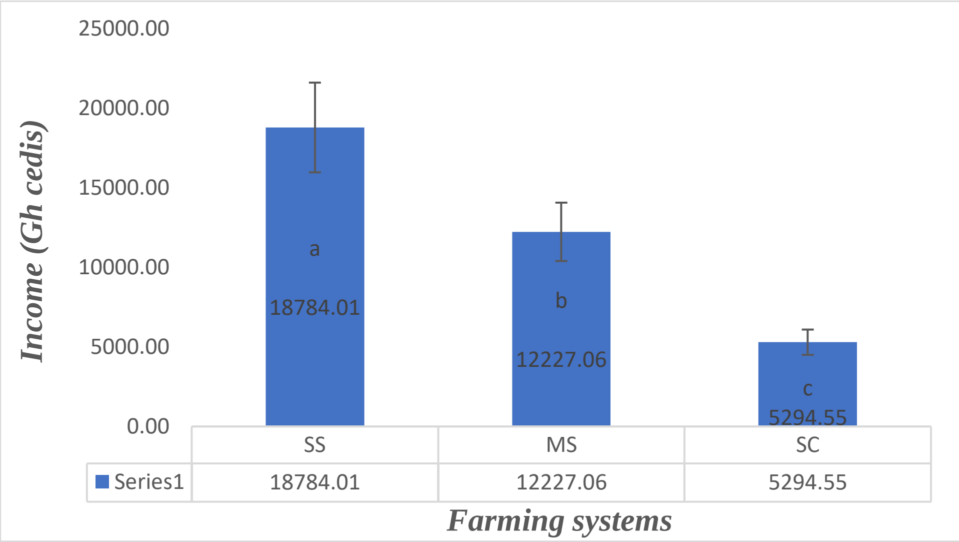

Figure 5. Average income (in GH¢) per household obtained in three farming systems practised by farmers in Cheyohi, Kumbungu District, Ghana. SS = Sole Shea, MS = Mixed Shea, SC = Sole cropping. Error Bars = ± LSD. Different letters indicate significant differences (ANOVA, $p < 0.05$).

Economic analysis of the recommended models

A hypothetical economic analysis (based on the recommended planting distances) of the 3 recommended models, show that there were significant differences (p = 0.00067) among them in terms of the total income obtained by farmers from the sale of their harvested food crops and shea tree products (Figure 6). However, there was no difference between recommended sole shea farm (SSR) and recommended mixed shea trees and crops farm (MSR). SSR registered the highest income of sixty-six thousand cedis (Gh¢66,0670.00) by each household as income per year from the sale of harvested crops. This was followed by MSR which had about sixty-five thousand cedis per household per year. Recommended sole crops farm (SCR) recorded the lowest income of about thirty-one thousand cedis per household per year.

Based on the findings of the research, an economic analysis of the 3 recommended models indicate that there were significant differences (p = 0.00067) among them, with regards to the total income obtained by farmers from the sales of their harvested crops (Figure 5). SS and MS however did not show any significant difference between them. Comparatively, SS had the highest income of about sixty-six thousand cedis (Gh¢66,0670.00) from sales of food crops, and this was followed by MS which recorded a value of approximately sixty-five thousand cedis (Gh¢ 65,000.00) from the sale of shea products and food crops. SC produced the lowest amount of about thirty-one thousand cedis (Gh¢31,000.00) per household per year from the sale of their crops. Therefore, from the economic point of view, SS recorded the highest income, thus SS is recommended for adoption. Since farmers however need food crops for both domestic consumption and for sale to generate income for the upkeep of their families, MS is also recommended for adoption, particularly as SS and MS were not significantly different. This buttresses the point made by Song *et al.* (2018) that trees are of economic and environmental importance. Furthermore, according to Ospina (2017), the practice of crop cultivation as well as conservation of trees on the same piece of land is a vital climate-smart panacea with numerous profits, including provision of food and environmental benefits.

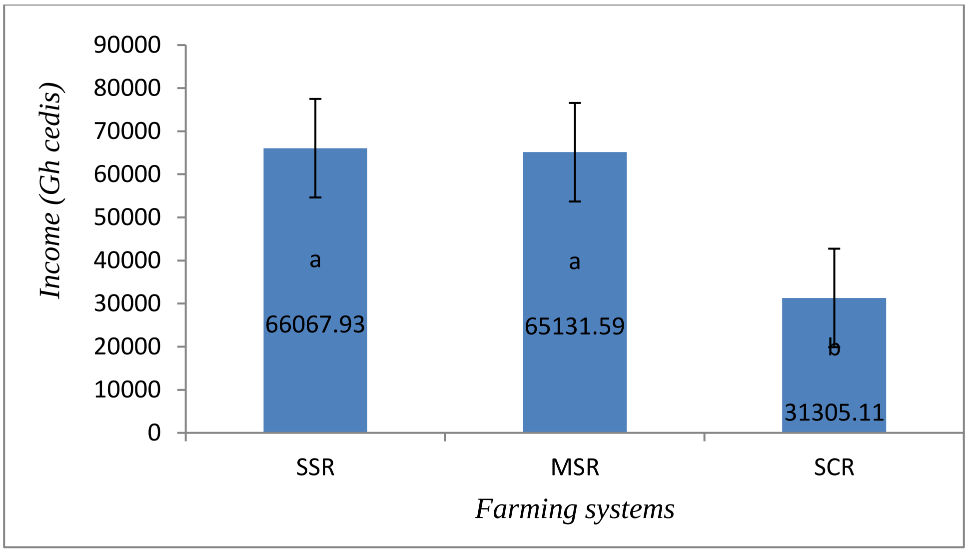

Figure 6. Incomes obtained from the three recommended models of three farming systems practised by farmers in Cheyohi, Kumbungu District, Ghana. SS = Sole Shea, MS = Mixed Shea, SC = Sole cropping. Error Bars = ± LSD. Different letters indicate significant differences (ANOVA, $p < 0.05$).

Comparisons between farmers' practices and recommended practices

There was a significant difference ($p < 0.05$) between the farmers' sole shea system (SSF) and the recommended sole shea system (SSR) in terms of the income generated from the sale of shea tree products (Figure 7). On the average, the farmers said they got an average of approximately eighteen thousand seven hundred and eighty-four cedis (Gh¢18784.01) as total income per household per year from the sale of their harvested shea products. The farmers explained that each household in Cheyohi has an average of 20 ha of shea parklands. Based on this, the recommended model of the sole shea parkland system could generate a total of approximately sixty-six thousand cedis (Gh¢66,0670.00) cedis per household per year from the sale of sequestered carbon, shea nuts and fuelwood, if the recommended silvicultural and other management practices (such as recommended planting distances, pruning, protection of trees from bushfires, control of pests and diseases are adopted and implemented.

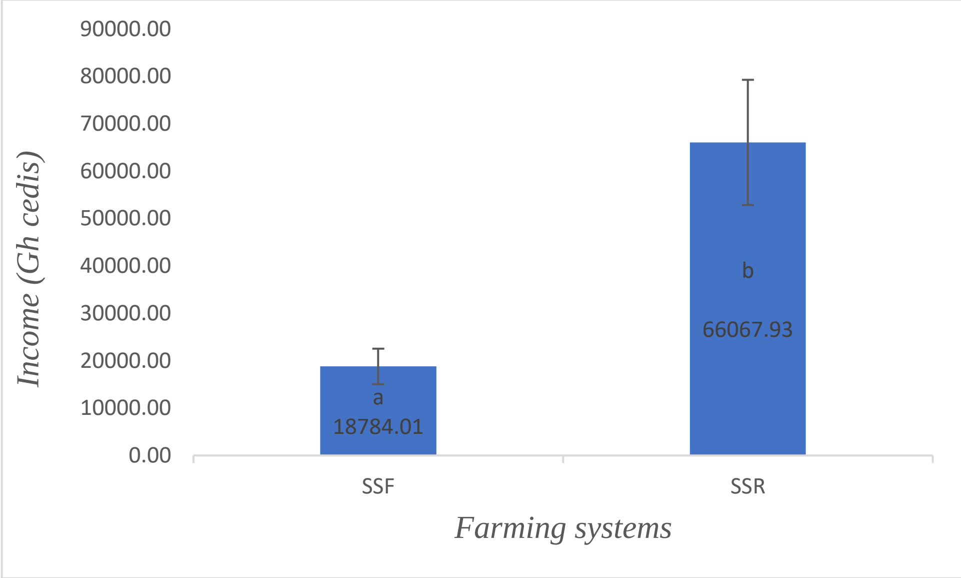

Figure 7. Comparison between incomes from farmers' sole shea system (SSF) and the recommended sole shea model (SSR) in Cheyohi, Kumbungu District, Ghana. SS = Sole Shea, MS = Mixed Shea, SC = Sole cropping. Error Bars = ± LSD. Different letters indicate significant differences (ANOVA, $p < 0.05$).

An economic analysis of the mixed shea trees and crops systems practised by the farmers (MSF) and that of the recommended model (MSR) show that there was a significant difference ($p < 0.05$) between the farmers' practice and the recommended model, in terms of the total income obtained by farmers from the sale of their harvested shea tree products and crops (Figure 9). Results of the study show that MSF obtained about twelve thousand two hundred and twenty-seven cedis (GH¢12227.06) per household per year while MSR recorded about sixty-five thousand cedis (Gh¢65,000.00), if the recommended model (MSR) is adopted by farmers.

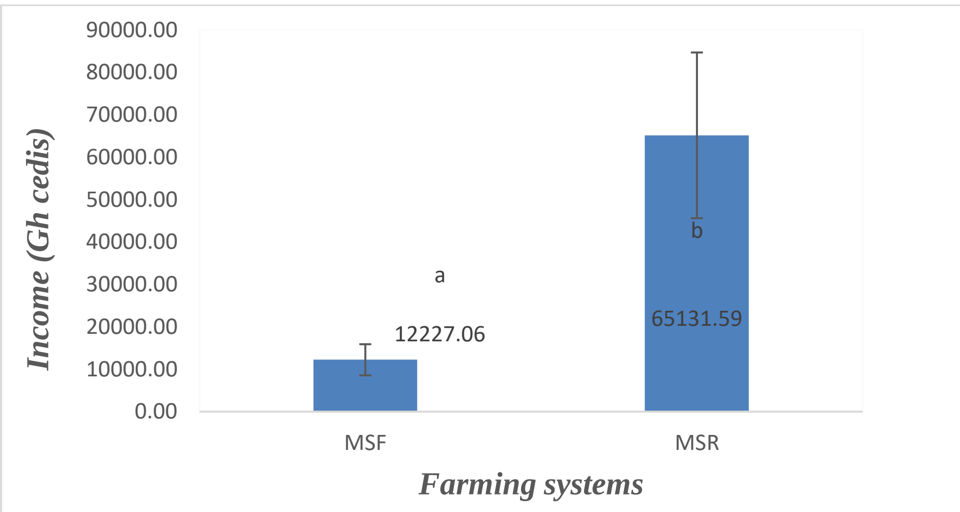

Figure 8. Comparison of incomes from mixed shea trees and crops systems practised by farmers (MSF) and the recommended model (MSR) in Cheyohi, Kumbungu District, Ghana. SS = Sole Shea, MS = Mixed Shea, SC = Sole cropping. Error Bars = ± LSD. Different letters indicate significant differences (ANOVA, $p < 0.05$).

An economic analysis of the sole cropping system showed that there was a significant difference ($p < 0.05$) between the farmers' practice (SCF) and the recommended model (SCR), in terms of the total income obtained by farmers from the sale of their harvested crops (Figure 8). Results of the study show that the farmers obtained an average of about five thousand two hundred and ninety-five cedis (GH¢5294.55) per household per year from the sale of their crops. From the proposed recommended model, however, an average of about thirty-one thousand cedis (Gh¢31,000.00) can be obtained by each household as income per year from the sale of harvested crops if the recommended cropping practices (such as weeding, fertilizer application, control of pests and diseases, harvesting), appropriate planting distances are adopted and implemented.

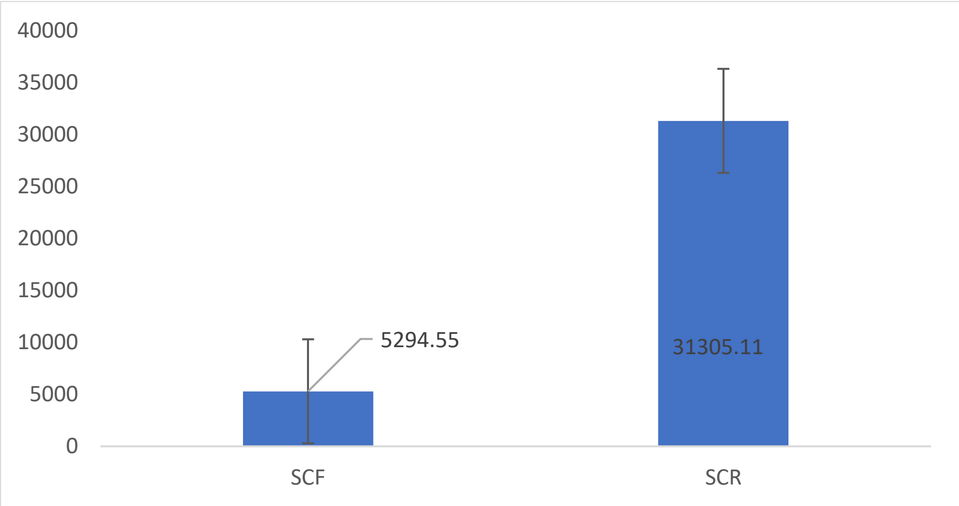

Figure 9. Comparison between incomes from farmers' sole crop system (SCF) and the recommended sole crop system (SCR) in Cheyohi, Kumbungu District, Ghana.
SS = Sole Shea, MS = Mixed Shea, SC = Sole cropping. Error Bars = ± LSD.
Different letters indicate significant differences (ANOVA, $p < 0.05$).

Global environmental analysis of the 3 models

As illustrated in Figures 2 and 3 and Table 2, findings of the research show that SS registered the largest amounts of sequestered carbon (Cseq) and sequestered carbon dioxide (CO_{2seq}) of 0.024 Mg ha^{-1} and 0.090 Mg $ha^{-1}yr^{-1}$ respectively. This was followed by MS which sequestered C_{seq} of 0.022 Mg ha^{-1} and CO_{2seq} of 0.079 Mg $ha^{-1}yr^{-1}$. As shown in Table 2 below, for the recommended SS model, a density of 250 trees ha^{-1} can produce 0.15 Mg ha^{-1} Cseq and 0.56 Mg $ha^{-1}yr^{-1}$ $CO_{2\ seq}$ while a density of 125 trees ha^{-1} for the proposed MS model can produce 0.16 Mg ha^{-1} C_{seq} and 0.58 Mg $ha^{-1}yr^{-1}$ CO_{2seq}. The amount of C_{seq} and CO_{2seq} by sole crops (SC) is however negligible since they are annual crops. SS had more C_{seq} and CO_{2seq} than MS due to the fact that SS had more trees than MS.

Table 2. Sequestered C and CO_2 by SS, MS and SC farming systems practised by farmers and the proposed models in Cheyohi

	Recorded data from farmers' fields				*Proposed for the developed model*			
Type of Shea product	***No. of shea trees (no. of trees ha^{-1})***	***Carbon stock per ha (Mg ha^{-1})***	***Carbon sequestered per ha/yr (Mg ha^{-1} yr^{-1})***	***CO_2 sequestered (Mg/ha^{-1} yr^{-1})***	***No. of shea trees (no. of trees ha^{-1})***	***Carbon stock per ha (Mg ha^{-1})***	***Carbon sequestered per ha/yr (Mg ha^{-1} yr^{-1})***	***CO_2 sequestered (Mg/ha^{-1} yr^{-1})***
Sole shea farm/plantation	36	2.49	0.024	0.09	250	15.49	0.15	0.56
Mixed trees and crops	13	2.21	0.022	0.08	125	16.01	0.16	0.58
Sole food crops farm	0	-	-	-	0	-	-	-

With regards to the global environmental analysis of the 3 treatments, in terms of their capacity to sequester C and CO_2, SS recorded the highest amounts of Cseq and CO_{2seq} with respective values as 0.024 Mg ha^{-1} and 0.090 Mg ha^{-1}yr^{-1} due to the fact that SS had more trees than MS. This was followed by MS which had 0.022 Mg ha^{-1} Cseq and 0.079 Mg ha^{-1}yr^{-1} CO_{2seq}. Since SC consisted of only annual food crops, it had negligible Cseq and CO_{2seq}. In view of these, in terms of global environmental benefits, SS is recommended for adoption by farmers since it has the greatest potential to sequester the most carbon and carbon dioxide to mitigate climate change. In absolute terms, in view of SS and MS not being significantly different, with reference to their potential to sequester C and CO_2, MS is also recommended as it provides additional benefits in the form of food crops, which can be consumed domestically as well as sold to generate income for the upkeep of the family.

CONCLUSION

The study identified 3 cropping systems practised by farmers in Cheyohi. These systems were developed into models (SSR, MSR and SCR) with their accompanying recommended practices proposed for farmers to adopt and implement for higher yields in crops and shea products. There was no significant difference in carbon stock between the two models of shea trees (SS and MS) farming systems practised by the farmers although SS stored more carbon (2.49 Mg ha^{-1} C) than MS which recorded 2.21 Mg ha^{-1} C. There was also no significance difference between SS and MS. SS however sequestered more C (0.0246 Mgha^{-1}yr^{-1}) than MS which had 0.0217 Mg ha^{-1}yr^{-1} C. The research also identified SS as the model that has the highest capacity to generate the most income from the sale of shea products (CO_{2seq}, shea nuts and fuelwood) and therefore recommended for adoption. This was followed by MS, with SC having the least potential. As an alternative to SS, MS has an added advantage of producing food crops for both domestic consumption and for sale to generate income for the upkeep of the family. Therefore, the general conclusion that can be drawn, based on the results of the study involving the three farming systems in the Cheyohi community, is that the farming or land use systems with shea trees (SS & MS) are significantly better, in terms of prospects of climate change mitigation and economic benefits, than the other system (SC) without shea trees. As a result, SS and MS are recommended for farmers in Cheyohi to adopt in order to profit from those benefits, although MS has an added advantage of integrating food crop cultivation into shea tree conservation.

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