Info Note

Soil organic carbon sequestration for climate change mitigation in East African Climate-Smart Villages

Results from climate-smart agriculture interventions within Climate-Smart Villages in Kenya, Tanzania and Uganda

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Key messages

- Effective integration of CSA practices into different crop-based land use typologies increased soil organic carbon (SOC) stocks compared to business-as-usual (BAU).
- Improved grassland management through rotational grazing, area enclosure and cut-and-carry in integrated crop-livestock systems increased SOC stocks and contributed to achieving climate-smart landscapes in East Africa.
- Use of a portfolio of appropriate CSA practices across landscapes reduces GHG emissions; helping countries to achieve outcomes stated in their nationally determined contributions (NDCs) and National Adaptation Plans (NAPs).

Introduction

Agricultural systems in Eastern Africa are mainly rainfed and highly vulnerable to climate change and variability. Climate-related risks include variable rainfall patterns, prolonged dry spells, and extreme events such as droughts and floods, and have become more frequent and severe, negatively affecting the regions' food security. These challenges are compounded by high population growth and poverty rates, declining land sizes, and nutrient mining of soils. To address these challenges and stimulate actions that enable communities and households to respond to climate extremes and change, the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) developed the Climate-Smart Villages (CSVs) research for development approach (Aggarwal et al. 2018). Using participatory methods, communities in CSVs participate in agricultural research for development by robustly evaluating and adopting an integrated portfolio of climate-smart agriculture (CSA) practices that respond to their climate related risks, including exploring potential mitigation co-benefits. In Eastern Africa, CCAFS has been implementing the CSVs approach since 2011.

Most landscapes in Eastern Africa have gone through a transition from natural rainforest to agricultural fields, pasture lands, and agroforestry (Winowiecki et al. 2015), due to increased demand for food and fuel. Consequently, natural rainforests are found only in small patches. Approximately 195 million ha of tropical forest are cut down at the rate of 5.5 – 9.5 million ha/year $^{-1}$ (Keenan et al. 2015). This degradation contributes to 70% of the total carbon loss (Baccini et al. 2017). Globally, deforestation contributes to 20% of annual greenhouse gas (GHG) emissions (Asner 2006).

Soils rich in organic matter are able to withstand climate stresses better. In fact, through rebuilding soil organic matter capital – it is possible to strengthen adaptation and resilience of smallholder agricultural systems in regions prone to the impacts of climate variability and change. SOC is a critical component of organic matter. SOC sequestration and building SOC stock across landscapes is an important CSA strategy with significant food security and climate change mitigation benefits (Frank et al. 2017) in Eastern Africa. CSA practices with potential mitigation co-benefits that have been evaluated in the CSVs across Eastern Africa include; improved crop and grazing land management, manure management, afforestation, forest management, reduced deforestation etc. (Table 1).

While the impact of CSA practices on food security, income and asset accumulation has been done (Radeny et al. 2018), the effects of integrating CSA practices into soil carbon stocks and the role that they can play in supporting the climate change mitigation objectives of regional countries are not very well understood. SOC is an important component of the soil ecosystem and an indicator of soil health (Winowiecki et al. 2015). In agroecosystems, the SOC balance is influenced by management practices such as organic matter additions, tillage intensity, fertilization, irrigation and crop rotation. This study quantified the effect of CSA interventions on SOC stocks across CSVs in Eastern Africa and explored whether this could support adaptation and mitigation objectives of the regional countries.

Methods

The study was conducted across three CSVs of Eastern Africa: Lushoto in Northeastern Tanzania, Nyando in Western Kenya, and Hoima in Western Uganda. Soil samples were collected from different land use types (cropland, agroforestry, grassland and protected secondary forest) where CSA practices were implemented and BAU (where no CSA practices were implemented) at three depths of 0-15 cm, 15-45 cm, and 45-100 cm (Fig. 1) with six replications. Cropland CSA practices included crop rotation and intercropping of maize and beans with integrated physical and biological soil and water conservation measures across the landscape. The multi-strata agroforestry practices include leguminous trees such as Grevillea integrated with various fruit trees (e.g. mango and avocado trees) and cereals such as maize and legumes (e.g. beans) with soil and water conservation structures involving both physical and biological measures. The grassland had natural pasture under improved rotational grazing management practices.

Table 1. *Summary of CSA practices implemented in different land uses across the three CSVs*

Land uses	CSA practices implemented		
	Hoima (Uganda)	Nyando (Kenya)	Lushoto (Tanzania)
Agroforestry	Use of farmyard manure, ash and household waste; integration of leguminous trees, fruit trees, crops and vegetables	Integrated physical and biological SWC measures; use of farmyard manure, ash and household waste; integration of leguminous trees, fruit trees, crops and vegetables; water harvesting	Integrated physical and biological SWC measures; integration of leguminous trees with crops
Cropland	Integrated physical and biological SWC measures; crop rotation, improved varieties, intercropping	Integrated physical and biological SWC measures, crop rotation, improved varieties, intercropping	Integrated physical and biological SWC measures; crop rotation; improved varieties; intercropping
Grassland	Area enclosure, cut-and-carry system	Rotational grazing, area enclosure	Not sampled
Forest	Area enclosure	Area enclosure	Area enclosure

Total carbon was analyzed using the flash combustion method. The soil carbon stock was calculated using the formula:

Soil organic carbon stock (Mg ha^{-1}) = soil carbon (%) x bulk density (g/cm^3) x (1 – CF) x actual depth (cm)

where, CF is the fraction of coarse fragments >2 mm (%). Subsequently, the organic carbon stock of each soil depth was summed up to quantify the total amount of carbon sequestered up to 100 cm depth.

Figure 1. *Selected soil profiles showing land under BAU (1a) and corresponding project scenario; cropland (1b), agroforestry (1c), grassland (1d) and forest (1e) from Hoima (Uganda) CSVs. Photo: G. Ambaw (CCAFS)*

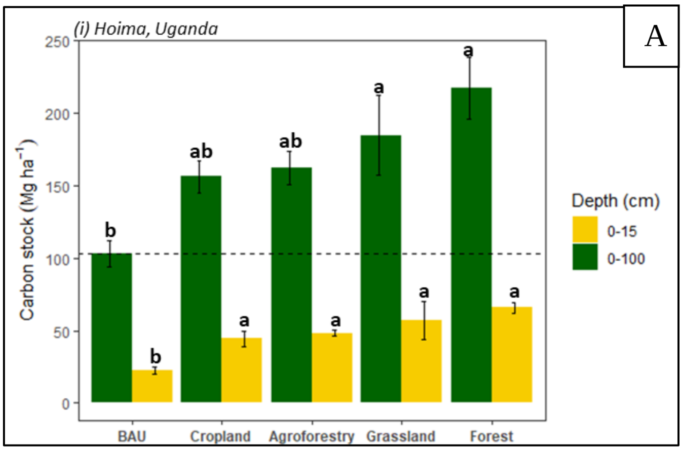
Effect of CSA on soil organic carbon stocks

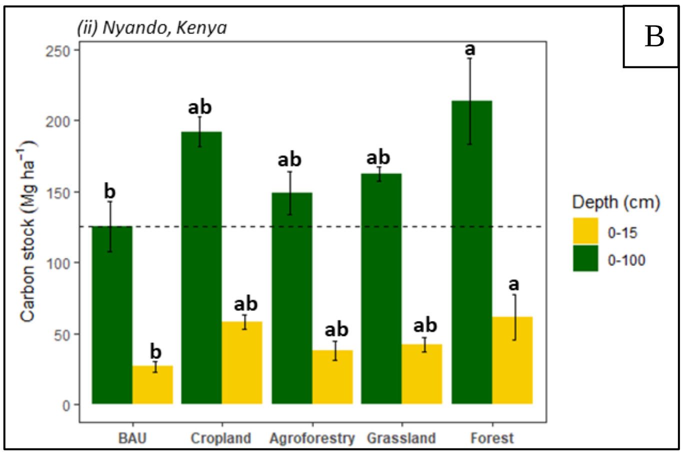
The land uses that integrated CSA practices resulted in higher SOC stocks both in the surface and entire one-meter soil profile (Fig. 2) compared with BAU in all the three CSVs. The SOC stocks in the surface soil (0-15 cm) did not differ significantly between land use types where CSA practices were integrated in each CSV, except in Lushoto (Tanzania) where SOC stock of cropland (42 Mg ha^{-1} ~ 154.1 Mg CO_2 eq. ha^{-1}) was significantly lower ($P<0.001$) than forest land (52 Mg ha-1 ~ 190.8 Mg CO_2 eq. ha^{-1}) (Fig. 2c). Similarly, the cumulative SOC stocks contained within one-meter soil profile did not significantly vary between different CSA land use interventions (Fig. 2).

Compared with BAU, where no CSA interventions were implemented across landscapes, integration of CSA practices in cropland increased surface (0-15 cm) SOC stocks by 117% in Nyando (Kenya), 95% in Hoima (Uganda) and 136% in Lushoto (Tanzania) (Fig. 2).

The CSA interventions involving agroforestry included use of farmyard manure, ash and household waste (especially in Hoima and Nyando CSVs), soil and water conservation, and integration of fruit and leguminous tree species such as mangoes and Acacia species. Thus, at the depth of 0-15 cm, improved agroforestry practices increased SOC by 42% (Nyando), 119% (Hoima) and 185% (Lushoto) compared with the corresponding BAU.

In general, integration of CSA practices into land uses across landscapes in Eastern Africa CSVs increased SOC stocks by 42–196% at the depth of 0-15 cm, and 19–110% at cumulative one-meter depth soil profile compared to BAU.





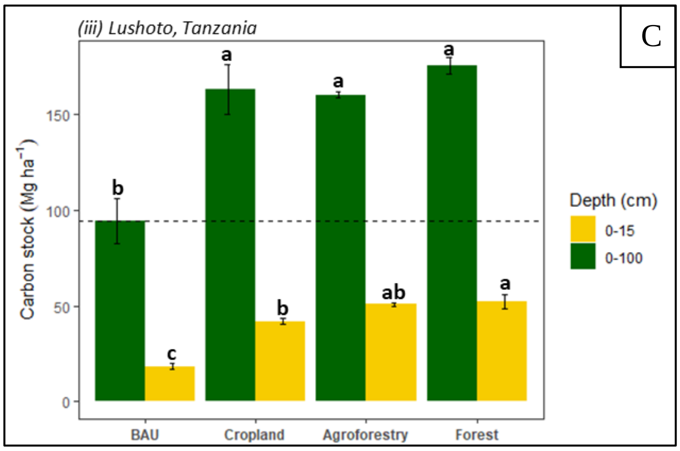


Figure 2. *Carbon stocks at the soil surface (0-15cm) (yellow) and throughout soil profile (0-100cm) (green). BAU = business-as-usual; improved land uses with CSA include cropland, agroforestry, grassland and forest. (a) Hoima (Uganda), (b) Nyando (Kenya), and (c) Lushoto (Tanzania). Error bars show standard error of the mean. Different letters across the sampling depths indicate significant differences between the means of carbon stock at p<0.05.*

Conclusions

Integrating CSA practices across different land uses improved soil organic carbon stocks in all CSVs. Use of soil and water conservation structures with specific practices like growing Napier grass, crop rotation, addition of manure, and introduction of multipurpose trees such as *Acacia* species in cropland contributed to increased carbon stock compared to BAU.

As a carbon sink, soils play a crucial role in mitigating climate change and ecological restoration. Therefore, the use of a portfolio of suitable CSA practices across different agroecological zones at scale can contribute to the reduction of GHG emissions. The Paris Agreement requests each country to outline and communicate their post-2020 climate actions — NDCs. Scaling these CSA interventions will contribute to achieving a balance between anthropogenic emissions by sources and removals by sinks of GHGs in the second half of this century.

Further Reading

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The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) brings together some of the world's best researchers in agricultural science, development research, climate science and Earth system science, to identify and address the most important interactions, synergies and tradeoffs between climate change, agriculture and food security. Visit us online at **https://ccafs.cgiar.org**.

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