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Carbon sequestration potential of East African Highland Banana cultivars (*Musa* spp. AAA-EAHB) cv. *Kibuzi, Nakitembe, Enyeru* and *Nakinyika* in Uganda

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Despite the global interest to increase the world's carbon stocks, most carbon sequestration strategies have largely depended on woody ecosystems whose production is threatened by the continuous shortage of land, hence the need to explore viable alternatives. The potential of bananas to sequester carbon has been reported but there is limited knowledge on the performance of various cultivars as specific carbon stocks are often lost in global assessments. Therefore, this study aimed at exploring the potential of and variability in carbon stocks of selected East African Highland Banana (EAHB) cultivars. Plant and soil data were collected using destructive and non-destructive techniques in 30×30m^2 sampling plots for 4 cultivars *Kibuzi*, *Nakitembe*, *Enyeru* and *Nakinyika* growing in two agro-ecological zones of Uganda being the L.Victoria Crescent and the South-western region. Total carbon and Soil Organic Carbon (SOC) stocks did not differ considerably across cultivars (P>0.05). However, there was significant variation (P<0.05) in plant carbon stock being lowest in two cultivars: *Nakinyika* at 0.37±0.19 Mgha^{-1} and *Nakitembe* at 0.40±0.19Mgha^{-1}; and highest in *Enyeru* at 1.64±0.18 Mgha^{-1}. The SOC stock variation difference across depth was 2.9-8.5 Mgha^{-1} being higher in top soil than sub-soil. Despite the small plant carbon stock amounts, the system enables much more carbon to be stored in the soil considering the proportion of what is contained in the plant to that in the soil across all cultivars (0.4-2%). The study therefore recommends revision of existing carbon frameworks to incorporate the contribution of non-woody perennials like bananas in the carbon cycle so that the poor small scale farmers who cannot afford large acreages to establish tree plantations can also benefit from such initiatives.

Key words: Agro-ecological zone, growth stage, carbon stock, cultivars, SOC

INTRODUCTION

Developing adaptation and mitigation strategies for addressing global climate change has become an increasingly important issue influencing management of ecosystems around the world. Among other management approaches being proposed to mitigate climate change, the need to enhance carbon stores in the biosphere (Nair et al., 2009; Anthony et al., 2011) through carbon sequestration has gained momentum in recent years especially in agro-ecosystems (Lal, 2011).

Despite the global interest to increase the world's carbon stocks, most carbon sequestration strategies have largely depended on woody ecosystems given their quickest means of increasing above ground carbon stocks (Henry et al., 2009; Nair et al., 2009). However, studies have shown that land available for production of such systems is continuously becoming limited (Henry et al., 2009); perhaps due to the increasing demand for agricultural production to meet food requirements of the ever increasing population. Hence, the increasing limitation of land calls for a need to explore viable alternatives such as the use of appropriate crops as well as good land management strategies that lead to increased carbon retention (FAO, 2002). Given the perennial and morphological nature of a crop like banana, it is worthwhile exploring its contribution to the carbon cycle. Moreover, its production ensures proper environmental management in addition to contributing to poverty eradication and food security (AATF, 2009; Rodel et al., 2000).

Other globally recognized mitigation options include: improved agricultural land management and agronomic practices, restoration of organic soils and rehabilitation of degraded land (Aertsens et al., 2013). In order to meet the ultimate objective of United Nations Framework Convention on Climate Chang - UNFCCC (Hairiah et al., 2010), it calls for trade-offs between increasing carbon stocks and livelihood needs so as to create a win-win situation; like a high net benefit obtained from crop production and sequestration (Palmer and Silber, 2012). This is in line with the World Bank report (2012) that calls for the need to ensure that new climate change adaptation and or mitigation strategies proposed are compatible with emerging economic challenges. This, therefore, puts agricultural research and development efforts geared towards identifying and evolving strategies against climate change at the fore front.

Uganda is one of the largest national producers and consumers of bananas in the world ranking second and first respectively after India. It is also recognized as a secondary center of diversity with different observed cultivars on individual farms with over 75% being East African Highland Bananas (Suzanne and Emile, 1999; Edmeades et al., 2005; FAO, 2009, Karamura, 1998; Nantale et al., 2008). Banana farming system dominates Uganda's cropping system (Bagamba et al., 1999; Kamanyire, 2000). The perennial banana crop is an important food security crop cultivated in a wide range of agro-ecological zones and readily fruits throughout the year (NARO, 2001; Eledu et al., 2004; Wairegi, 2010). The crop has viable economic benefit as a source of income for smallholder farmers in many parts of the country (AATF, 2009). The banana crop occupies the greatest acreage of land utilized for agricultural production covering about 38 % of the total arable land with most of the production on small subsistence farms of less than 0.5% ha (Gold et al., 1998; Svetlana et al., 2006). The crop is mostly grown as a mono-crop and or commonly intercropped with perennial or annual crops (Svetlana et al., 2007).

The potential of banana to sequester carbon has been reported with a carbon storage capacity of 114.72 mgha^{-1} (Rodel et al., 2000; Christina, 2004; Oliver, 2009). However, there is limited knowledge on how much carbon the different cultivars sequester considering the high morphological and physiological differences among cultivars within the *Musacea* family.

Despite their importance in climate change mitigation, the potential of non-woody plants to sequester carbon in agro-ecosystems has generally received little attention (Mesele et al., 2013). This could perhaps be attributed to the fact that agricultural ecosystems have been known for the depletion of important terrestrial carbon pools such as Soil Organic Carbon (SOC), thereby creating a large carbon debt (Lal, 2011). On the contrary, the banana crop has a high potential to restore such lost carbon pools because its agronomic management practices do not involve disastrous processes like burning biomass and removal of plant residues (Joris et al., 2013). This study, therefore, sought to explore the variability in plant and soil carbon stocks of selected EAHB cultivars grown in Uganda.

MATERIALS AND METHODS

Study area

Plant and soil carbon data were obtained in 2013 from two distinct agro-ecological zones, that is, the Lake Victoria Crescent and South-western Grass Farmlands in Lwengo and Mbarara districts, respectively. The zones were selected because they were classified as potential banana production areas by Eledu et al., (2004). Data was specifically obtained from Kisekka and Nyakayojo sub-counties for Lwengo and Mbarara districts, respectively (Figure 1). The districts were based on consultation with local agricultural authorities who identified them as important banana growing areas, while the sub-counties were based on a reconnaissance study conducted in these districts in December 2012 that identified them

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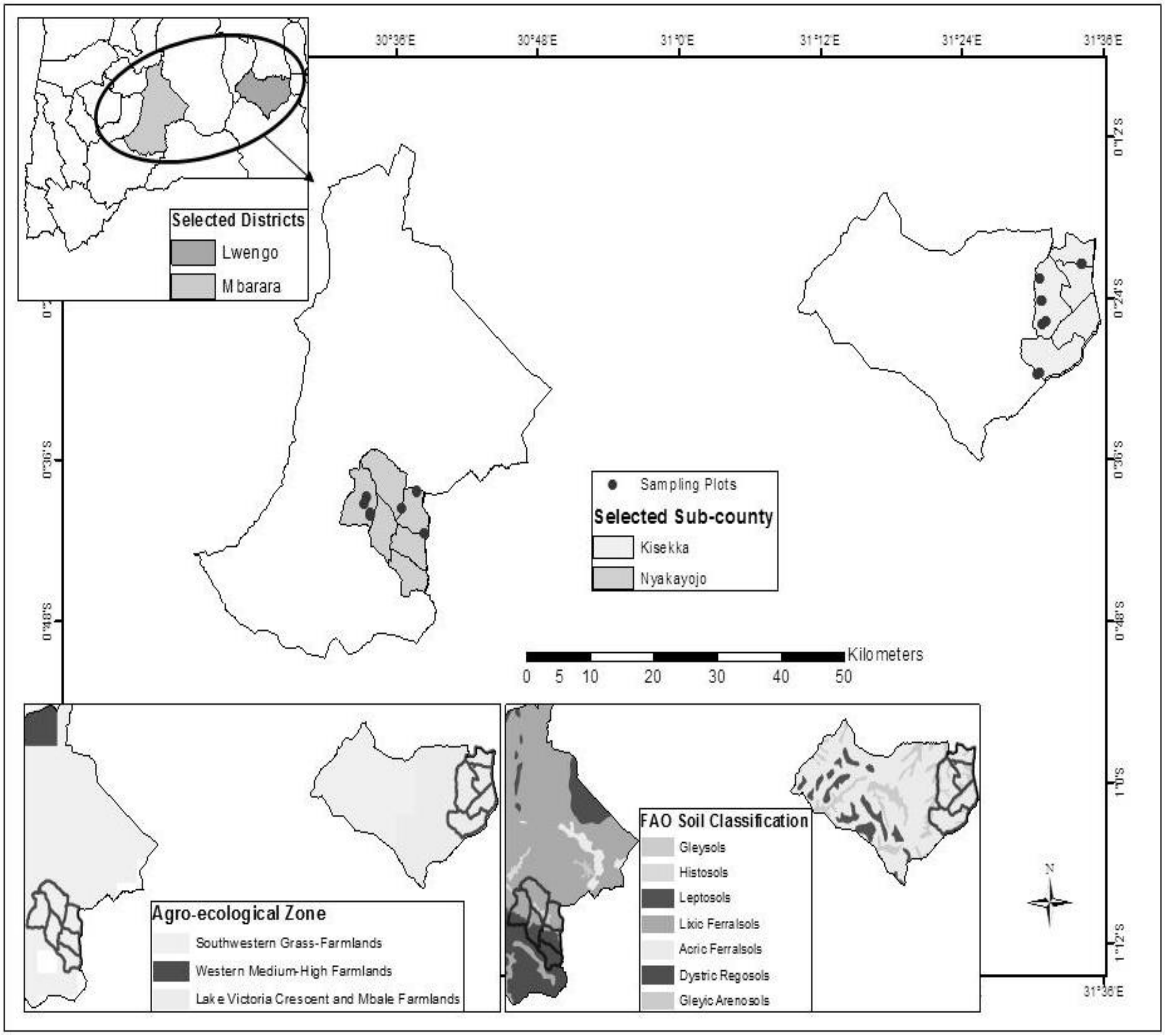

Figure 1. Detailed map of the study area showing sampling plots.

as the highest banana producing areas in the respective districts. Mbarara district lies at a high altitude of about 1400 m above sea level (0°20.5'S 30°31'E) and Lwengo at a low altitude range of 1080-1330 m above sea level (00°24'S 31°25'E) (NEMA, 1997; Nantale et al., 2008; Kemigabo and Adamek, 2010). Both areas experience a bimodal mean annual rainfall range of about 1000-1500 mm (Lwengo) and 1000-1200 mm (Mbarara). Their mean annual temperature range lies between 20-25ºC. According to the 1998 FAO soil classification (FAO, 1998), the soil types are acric ferralsols, and dystric regosols; and lixic ferralsols for Kisekka and Nyakayojo, respectively (Figure 1). However, to minimize variability across regions, all farms selected were comprised of the ferralsol soils given that they are deep in nature and cover about 60% of the potential banana production area for Uganda (Eledu et al., 2004).

Farm site selection

Prior to data collection, a reconnaissance survey was carried out in the proposed study areas in December 2012 to obtain a clear understanding of what cultivars are grown by the farmers as well as some physical and historical characteristics of the plantations; such as soils, altitude and plantation age. Based on the preliminary findings of the survey and with the aim of minimizing the effect of potential confounding factors, participating farmers were purposively selected following a set of criteria: a) The farm had all the cultivars of interest; b) The plantation was mature (20 to over 50 years); c) All farms in a given region existed in a similar soil type classification and relatively same altitude range; and d) The farmer was willing to participate fully in the study. (b) and (d) were also considered for the same reason in other studies (e.g. Nantale et al., 2008; Wairegi et al., 2009). Therefore, out of 58 visited farms, a total of 14 farmer plantations (7 in each area) were considered since they were the only ones meeting the above criteria.

Sampling plots

Considering the differences in plantation sizes ranging from 0.4 ha to about 3 ha, 2 squared sampling plots of 30×30 m were established randomly on each farm using a measuring tape and plot demarcation stakes. This was also done because banana plantations have low variability in terms of species composition in a single stand (Timothy et al., 2005; Hairiah et al., 2010). Sample plot center coordinates were also geo-referenced and mapped in the field using a GarminGpx60 GPS instrument (±3 Accuracy). A total of 28 sampling plots were established, 14 per site.

Biomass estimation

In reference to the findings of the reconnaissance survey, only 4 cultivars were chosen for the study; that is, *Kibuzi* and *Nakitembe* existing in both sites, and *Enyeru* and *Nakinyika* being unique to Mbarara and Lwengo sites, respectively. These were selected because they had a higher population density than others cultivars identified, similar to observations of Wairegi et al. (2009). In each sampling plot, all individuals belonging to the cultivars of interest were inventoried *in-situ* (ICRAF, 2011). Using a diameter tape, Diameter at Breast Height (DBH) measurements were recorded for the estimation of total plant biomass using cultivar specific allometric equations developed by Kamusingize (2014).

Soil organic carbon sampling

Banana plants invest carbon in the soil through nodal roots that arise from the corm (Turner, 2003). Therefore, composite soil samples were collected from underneath cultivars of interest for SOC determination. Composite samples were obtained from 4 points around one mat per cultivar, randomly selected in each sampling plot, drawn using a soil auger at 2 depth levels of 0-15 cm and 15-30 cm following sampling procedures by Hairiah et al. (2010) in the plant's rhizosphere, 30 cm from the mat. Using a fabricated core of 15 cm height and 4.3 cm diameter, two samples were also systematically drawn at 2 points from each selected mat at the same depth levels for average bulk density analysis. In total, 296 bulk density samples were obtained (148 per site) and 148 composite samples (74 per site). Samples were analyzed at the National Agricultural Research Laboratories Soil Science Department using procedures laid out in Okalebo et al. (2002); that is, SOC concentration by the wet acid oxidation method and bulk density by the core method. Prior to analysis, all samples were oven dried at 40°C. Samples for SOC analysis were ground to powder and passed through a 1 mm sieve after removing all identifiable roots, stones and any crop materials.

Estimation of carbon stocks

Total carbon stock per cultivar was obtained from both plant and soil carbon stocks. Plant carbon stock was estimated using the equation described by Christina (2004) with modification whereby;

$$Plant\ Carbon\ Stock\left(Mgha^{-1}\right) = Total\ Plant\ Biomass\left(Mgha^{-1}\right) \times C_B\% ......\text{Eqn 1}$$

Where C_B was equal to 47.6% (before flowering – H1) and or 48.8% (at maturity – H2), mean carbon content value of EAHB cultivars at different growth stages as determined in a study by Kamusingize (2014). SOC was estimated using the equation obtained from Anderson and Ingram (1993) and Hairah et al. (2010) as:

$$C\ Storage\ in\ Soil = \%C\ Concentration \times Bulk\ Density \times Soil\ Depth .....\text{Eqn 2}$$

$$C\ Storage\ in\ Soil\ per\ hectare\left(Mgha^{-1}\right) = \frac{Result\ Eqn2}{Area\ of\ Subplot} \times 10000\ ......\text{Eqn 3}$$

Therefore, total carbon stock per cultivar was then estimated based on an equation adopted from Woomer and Palm (1998) as:

$$Total\ Carbon\ Stock\ (Mgha^{-1}) = \sum Eqn1 + Eqn3 ......\text{Eqn 4}$$

Data analysis

All data were statistically analyzed using GenStat software (v.13.3.5165) to ascertain the variability of carbon stocks across cultivars. One Way ANOVA was performed to test for any significant differences, if any, in plant carbon stock, SOC stock and total carbon stock across cultivars at a 95% confidence interval. Mean values of the various carbon stocks per cultivar per site were also determined. The proportion of plant to SOC stock was also determined for all cultivars to establish how much carbon stock iscontained in the banana plant compared to that in the soil.

RESULTS

The observed variation in cultivar specific carbon stocks from the 2 sites under study are presented in Tables 1, 2 and 3. There were significant differences ($P<0.05$) in plant carbon stocks across cultivars (Tables 1 and 3). However, SOC stock and total carbon stocks were not significantly different ($P>0.05$) across cultivars (Tables 2 and 3). The highest total carbon and SOC stocks were observed in site specific cultivars *Enyeru* and *Nakinyika* (Table 3). On the contrary, cultivar *Nakinyika* (at 0.37 ± 0.19 $Mgha^{-1}$) and *Nakitembe* (at 0.40 ± 0.19 $Mgha^{-1}$) had the lowest total plant carbon stock in Lwengo and Mbarara, respectively. Results for the 2 cultivars common to both sites -*Kibuzi* and *Nakitembe* showed higher total plant carbon stock in Lwengo than that obtained in Mbarara (Table 3). Furthermore, the mean variation observed in plant carbon stock before flowering and at maturity stages was very small and in some cultivars zero (Table 1).

The total SOC stocks underneath all cultivars studied was high with over 81 $Mgha^{-1}$ (Table 3). However, there were SOC stock differences across soil depth with more carbon stored in the top soil (0-15 cm) than in the sub-soil (15-30 cm). In terms of studied cultivars, the least SOC stocks were obtained in site common cultivars compared to site specific cultivars (Table 2). In addition, the % contribution of plant carbon stock to total carbon stock in all cultivars was very small (0.4-2.0%) compared to that obtained from the soil (Table 3).

Table 1. Variation of plant carbon stock at two growth stages across cultivars.

Site	Cultivar	Mean Carbon Stock before flowering±95%CI(Mgha^{-1})	Mean Carbon Stock at maturity±95%CI (Mgha^{-1})	Mean Plant Stock Difference±95%CI (Mgha^{-1})
Lwengo	*Kibuzi*	0.06±0.01	0.04±0.01	0.02
	Nakitembe	0.03±0.01	0.02±0.01	0.01
	Nakinyika	0.03±0.01	0.01±0.00	0.02
Mbarara	*Kibuzi*	0.04±0.01	0.04±0.01	-
	Nakitembe	0.02±0.01	0.02±0.00	-
	Enyeru	0.09±0.01	0.06±0.01	0.04

Table 2. Variation of SOC stock with soil depth across cultivars.

Site	Cultivar	Mean SOC Stock±95%CI 0-15 cm (Mgha^{-1})	Mean SOC Stock±95%CI 15-30 cm (Mgha^{-1})	Mean SOC Stock Difference±95%CI (Mgha^{-1})
Lwengo	*Kibuzi*	43.95±4.23	37.48±3.19	6.5
	Nakitembe	46.34±2.59	42.34±4.07	4
	Nakinyika	50.20±3.25	42.27±3.26	7.9
Mbarara	*Kibuzi*	42.72±2.94	39.32±3.26	3.4
	Nakitembe	44.11±3.66	41.22±4.45	2.9
	Enyeru	49.51±3.17	41.01±2.68	8.5

Table 3. Means of total carbon stocks across cultivars.

Site	Cultivar	Total Plant Carbon Stock±95%CI (Mgha^{-1})	Total SOC Stock±95%CI 0-30 cm (Mgha^{-1})	Total Carbon Stock±95%CI (Mgha^{-1})	Proportion of Banana/Soil (%)
Lwengo	*Kibuzi*	1.03±0.19	81.4±5.06	82.5±5.05	1.3
	Nakitembe	0.54±0.21	88.7±5.77	89.2±5.76	0.6
	Nakinyika	0.37±0.19	92.5±5.27	92.8±5.26	0.4
Mbarara	*Kibuzi*	0.85±0.21	82.0±5.77	82.9±5.76	1.1
	Nakitembe	0.40±0.19	85.3±5.06	85.7±5.05	0.5
	Enyeru	1.64±0.18	90.5±4.88	92.2±4.87	2

DISCUSSION

Although there are no significant differences in total carbon stock across the studied banana cultivars (Table 3), the values were considerably higher (82.5 ± 5.05 - 92.8 ± 5.26 Mgha^{-1}) than those reported for Eucalyptus dominated woodlots (63.8 Mgha^{-1}) and perennial crops of *Allophylus africanus* (49.6 Mgha^{-1}) in Eastern Uganda, Sirike (2012). However, the total plant carbon stock across cultivars was small (0.37-1.64 Mgha^{-1}) compared to that reported in some perennial crops such as cocoa at 9 Mgha^{-1} in Above Ground Biomass stock (Eduardo et al., 2013) and banana (*Musa sp.*) at 3.0-3.1 Mgha^{-1} which dominate home gardens in Western Kenya (Henry et al., 2009). This could perhaps be attributed to the high cultivar diversity on a given banana plantation (Karamura, 1998) affecting the overall number of individuals assessed per cultivar per farm which in turn result in relatively small biomass amounts as shown in Figure 2; e.g. *Nakitembe* and *Nakinyika* in Mbarara and Lwengo, respectively. This also explains the small variation difference in plant carbon stocks across growth stages given that the number of mature plants (H2) assessed in the field were on average lower than that of plants at pre-

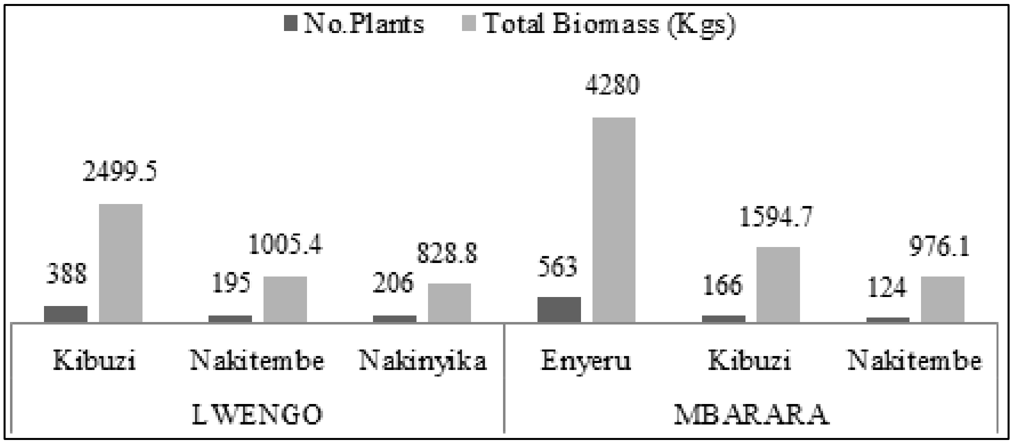

Figure 2. Number of plants and biomass assessed per cultivar.

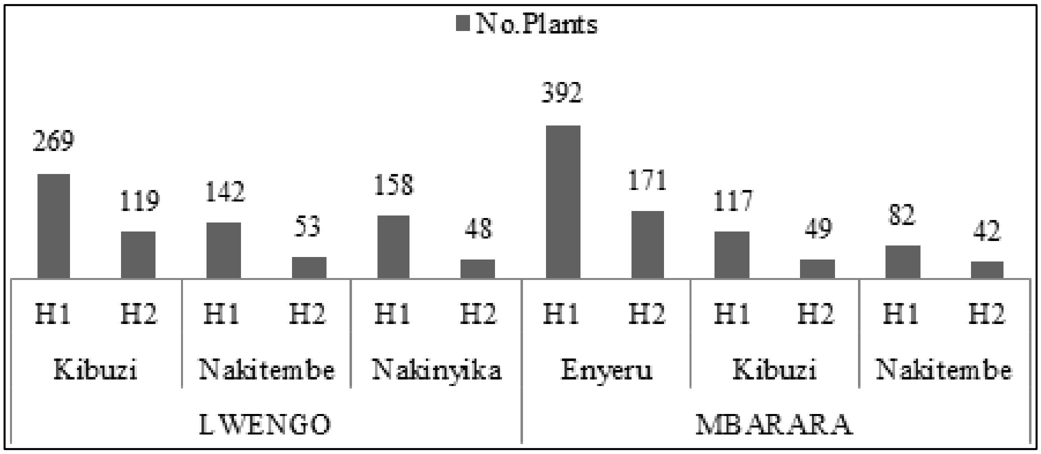

Figure 3. Number of plants assessed per cultivar across growth stage.

flowering stage (H1) (Figure 3). This could also perhaps explain the significantly different result of plant carbon stock ($P<0.05$) across all cultivars. But also, more importantly to the fact that banana as a crop contains a high moisture content (Jing et al., 2010) resulting in small amounts of plant dry biomass which in turn give small plant carbon stocks.

Though not significantly different ($P>0.05$), the total SOC stock beneath all cultivars was considerably high ranging from 81-92 Mgha^{-1}. This is in agreement with previous reports showing that banana plants not only invest carbon into the soil through nodal roots that arise from the corm but also over time during photosynthesis as carbon moves from the vegetative canopy into the soil (Turner, 2003; Hairiah et al., 2010). Results from this study show that EAHB are capable of sequestering higher carbon stocks in the soil compared to the stocks estimated in Eucalyptus dominated woodlots in Eastern Uganda at 55.4 Mgha^{-1} (Sirike, 2012), tea plantations at 69 ± 10.0Mgha^{-1} and the natural forest at 68.6 ± 14 Mgha^{-1} in South Western Uganda (Twongyirwe, 2010; Twongyirwe et al., 2013). However, soil carbon stocks estimated from EAHB plantations were similar to that obtained in *Patula* pine plantations of Columbia at 87.2 Mgha^{-1} (Juan et al., 2010). Results obtained from this study therefore place banana cultivars close to woody species in the SOC stock spectrum.

The banana cropping system enables much more carbon to be stored in the soil despite the fact that banana cultivars contain small average amounts of plant carbon stocks. In this study, the proportion of carbon contained in the plant to that in the soil across all cultivars was in the range of 0.4-2%. Large soil carbon stocks in banana cropping systems under study could perhaps be attributed to the sustainable agricultural land management practices employed by farmers such as mulching, the use of trenches to minimize erosion, minimal or no tillage and the return of crop residues - leaves, stem cuttings and banana peelings (Lal, 2011; Paswel et al., 2012; Joris et al., 2013).

Investing in proper management of banana plantations is invaluable towards contributing to SOC as a major carbon pool in agro-ecosystems. Considering that EAHB cultivars cover 75% of the total area under banana production in Uganda (Gold et al*.,* 1998; Nantale et al., 2008), banana cropping systems therefore need to be revised to incorporate species as EAHB whose significant contribution towards a major carbon pool has for years gone unnoticed. In addition, climate change mitigation and adaptation efforts like the Clean Development Mechanism (CDM) framework should be considered to improve investments in smart agricultural practices like proper management of banana plantations. This is because the CDM framework tends to be economically benefitial to activities under afforestation/re-afforestation through say carbon trade (UNFCCC, 2004), while under estimating the sequestration potential of non-woody but important perennials like banana cultivars.

Existing reports from a study conducted in Sub Saharan Africa show that it is cheaper and better for small scale farmers to adopt environmentally beneficial agricultural practices that also enhance productivity under a carbon payment system rather than subsidies on agricultural inputs (Paswel et al., 2012). Therefore, given that bananas contribute substantially to food security and poverty reduction in Uganda (Eledu et al., 2004), large scale production of banana cultivars that lock more carbon into the soil could be proposed and promoted as an accommodative adaptation and mitigation strategy to climate change as well as rural development.

CONCLUSIONS

Key findings from this study showed a significant difference in total plant carbon stock ($P<0.05$) across different cultivars and sites. Plant carbon stock was also found to be very small ranging between 0.37-1.64 Mgha^{-1}, yet SOC was considerably high 81.4-92.5 Mgha^{-1}. In all banana cultivars evaluated, the proportion of carbon contained in the plant to that in the soil was only 0.4-2%. Nevertheless, despite the small amounts of plant carbon, the banana cropping system was found to enable much more carbon to be sequestered into the soil to amounts comparable to tree plantations.

RECOMMENDATIONS

Emphasis should be put on proper management of existing and or establishment of more banana plantations constituting more EAHB cultivars to enhance SOC stocks. Due to high sequestration into the soil, banana cropping systems have potential to benefit small scale farmers in terms of carbon initiatives that have presently gained momentum for woody species. In addition, enhancing carbon stocks will have a significant contribution towards global efforts to mitigate climate change without compromising food production and economic development. Finally, future studies on carbon sequestration in banana cropping systems could consider exploring factors like slope, management practice, landscape positioning and cropping systems to ascertain their effect on SOC variability.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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