EFFECTS OF LAND-USE CHANGES ON SOIL CHEMICAL PARAMETERS IN KAKAMEGA-NANDI FOREST COMPLEX †

[EFECTOS DE LOS CAMBIOS DE USO DE LA TIERRA EN LOS PARÁMETROS QUÍMICOS DEL SUELO EN EL COMPLEJO FORESTAL KAKAMEGA-NANDI]

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SUMMARY

Background. Carbon lost in form of carbon dioxide contributes to climate change corresponding to altered soil chemical properties and plant growth. Land-uses that minimize carbon loses are highly encouraged. Unfortunately, in the Kakamega-Nandi Forest Complex, the Kenyan government continues to promote shamba systems (now Plantation Establishment for Livelihood Improvement Scheme) where the forest adjacent communities are allocated bush land plots to provide land for small-scale agriculture, cash crop farming and planting of tree seedlings for a specified period of time inside the forest. **Objective.** This study analyzed six land-uses and their effect on the dynamics of soil chemical parameters using landsat images and recent soil geochemical surveys. **Methodology.** Land cover and vegetation changes were determined using a series of multispectral Landsat images. A total of seven sets of image datasets were downloaded from the Glovis web portal (http://glovis.usgs.gov/) for the years 1985 to 2015 with the cloud cover ranging from 1 to 10% taken in the dry season. The land-use/cover classification scheme adopted was based on expertise knowledge and literature of land-use/cover activities. **Results.** The results show that (i) small-small agriculture has increased while bush-land has decreased between 1985 and 2015; (ii) smallholder farming of maize, pasture and sugarcane depleted soil organic carbon whereas perennial tree plantations (regenerated forests) increased soil carbon stocks; (iii) nitrogen decreased in all tested land-uses except in maize plantations; (iv) phosphorus remained unchanged in all land-uses, potassium significantly decreased in tea plantations while sugarcane and regenerated forests land-uses had decreased soil calcium stocks. **Implications.** The study provides evidence for the review of the shamba system. **Conclusion.** The study has shown that land-use changes through the application of the shamba system alter the dynamics of soil chemical parameters key among them are soil organic carbon, nitrogen and calcium. Cultivation of annual crops decreases soil carbon stocks which may lead to an influx of carbon dioxide in the atmosphere and increased vulnerability to climate change.
Keywords: Agroforestry; Carbon Sequestration; Soil Carbon; Land-uses

RESUMEN

Antecedentes. El carbono perdido en forma de dióxido de carbono contribuye al cambio climático que corresponde a las propiedades químicas alteradas del suelo y al crecimiento de las plantas. Los usos de la tierra que minimizan las pérdidas de carbono son altamente recomendables. Desafortunadamente, en el Complejo Forestal Kakamega-Nandi, el gobierno de Kenia continúa promoviendo los sistemas de shamba (ahora establecimiento de plantaciones para el esquema de mejora de los medios de vida) donde las comunidades adyacentes al bosque reciben parcelas de arbustos para proporcionar tierras para la agricultura a pequeña escala, la agricultura comercial y plantación de plántulas de árboles por un período específico de tiempo dentro del bosque. **Objetivo.** Este estudio analizó seis usos de la tierra y su efecto sobre la dinámica de los parámetros químicos del suelo utilizando imágenes del suelo y estudios geoquímicos recientes del suelo. **Metodología.** La cobertura del suelo y los cambios en la vegetación se determinaron utilizando una serie de imágenes multiespectrales de Landsat. Se descargaron un total de siete conjuntos de conjuntos de datos de imágenes del portal web de Glovis (http://glovis.usgs.gov/) durante los años 1985 a 2015, con una cobertura de nubes del 1 al 10% en la estación seca. El esquema de clasificación de uso de la tierra /

† *Submitted October 25, 2019 – Accepted July 1, 2020.*
ISSN: 1870-0462.

cobertura adoptado se basó en el conocimiento especializado y la literatura de las actividades de uso de la tierra / cobertura. **Resultados.** Los resultados muestran que (i) la agricultura pequeña-pequeña ha aumentado, mientras que la superficie forestal disminuyó entre 1985 y 2015; (ii) la agricultura a pequeña escala de maíz, pastos y caña de azúcar redujo el carbono orgánico del suelo, mientras que las plantaciones de árboles perennes (bosques regenerados) aumentaron las reservas de carbono del suelo; (iii) el nitrógeno disminuyó en todos los usos del suelo probados, excepto en las plantaciones de maíz; (iv) el fósforo se mantuvo sin cambios en todos los usos de la tierra, el potasio disminuyó significativamente en las plantaciones de té, mientras que la caña de azúcar y los bosques regenerados los usos de la tierra disminuyeron las reservas de calcio en el suelo. **Implicaciones.** El estudio proporciona evidencia para la revisión del sistema de shamba. **Conclusión.** El estudio ha demostrado que los cambios en el uso del suelo a través de la aplicación del sistema de shamba alteran la dinámica de los parámetros químicos del suelo, entre los que se encuentran el carbono orgánico del suelo, el nitrógeno y el calcio. El cultivo de cultivos anuales disminuye las reservas de carbono en el suelo, lo que puede provocar una afluencia de dióxido de carbono en la atmósfera y una mayor vulnerabilidad al cambio climático.

Palabras clave: Agroforestería; secuestro de carbono; carbono del suelo; usos del suelo.

INTRODUCTION

An estimated 1.6±0.8 petagrams (Pg) of soil organic carbon (SOC) is lost per year in the tropics through cultivation and conversion of land-uses (Smith, 2008). Carbon lost as carbon dioxide (CO_2) contributes to climate change corresponding to altered soil chemical properties and plant growth. Land-uses that minimize carbon loses are highly encouraged. Unfortunately, in the Kakamega-Nandi Forest Complex (KNFC), the Kenyan government has licensed farming in state forest land as a means of establishing exotic forest plantations. The participants of the system, popularly known as shamba system or PELIS (Plantation Establishment for Livelihood Improvement Scheme), are serving and retired forest workers, landless peasant farmers and those living within the immediate vicinity of the forests (Oduol, 1986). These “farmers” are contracted to work for 9 months each year to clear indigenous bush land to prepare the land (shamba) for cultivation of perennial trees and subsistence crops such as maize, potatoes and cabbages. Up to 4 shambas averaging 0.5 to 0.6 ha are allocated to each participant for a period of 2 to 3 years or until the trees are large enough to suppress crop growth. About 160,000 ha of exotic forest plantations have been established in Kenya through this system (Oduol, 1986).

Land-uses without meaningful forest cover such as bare-land, subsistence agriculture, bush-land and grassland are highly vulnerable to climate change, while forest land-uses have the lowest climate change vulnerability index (CCVI) indicating that land-use and land cover contribute to CCVI (Wabusya *et al*. unpubl.). Further, land-uses with scanty vegetation such as bare-land and those without forest cover like farmlands have the highest vulnerability levels compared to those either under natural forest plantations or natural regeneration.

Forests are important carbon sinks. Plant biomass contains between 35 to 65% of organic carbon. Studies have shown that up to 19% of earth`s biosphere carbon is stored in plants and 81% in the soil. In forest land-use, 31% of carbon is stored in plant biomass while 69% is in soil. In tropical forest 50% of organic carbon is stored in biomass while 50% is stored in the soil (IPCC, 2000). Managed and stable full-grown forests sequester carbon at rates of up to 6-ton/ha (Valentini *et al.*, 2000). However, forest become carbon source for atmospheric carbon dioxide when plant remains (organic matter) are oxidized to release carbon dioxide to the atmosphere. It remains unknown if frequent disturbances such as bush clearing in shamba systems triggers massive influx of carbon dioxide into the atmosphere. Sequestration of carbon in the soils has been found to mitigate the effects of climate change.

This study sought to analyze the effects of land-use changes on the dynamics of soil chemical parameters. The central hypothesis is that cultivation of annual crops in shamba system depletes soil nutrients leading to massive influx of carbon dioxide in the atmosphere which contribute to climate change.

MATERIAL AND METHODS

Description of the sampling sites

The study was conducted in six land-uses in the Kakamega-Nandi forest complex (KNFC): natural forests (control), tea, maize, grassland, sugarcane and regenerated forests. These land-uses are found at altitudes of between 1500 to 2000 masl, covering a total area of about 54,750 ha. The annual temperature ranges between 17 to 20°C while rainfall of between 1600 to 2215 mm is received per year (Kokwaro, 1988; Mitchell *et al.*, 2006). Table 1 summaries the characteristic features of the different land-use types.

Table 1. Land use practices in the study areas.

Land use	**Descriptions**	Reference
Small-scale agriculture	These are agricultural practices that produce crops and livestock on a small piece of land without using advanced and expensive technology. Its characterised by less use of agrochemicals and labour intensive. Good example of these type of agriculture include growing of maize, sugar cane, bananas, beans and potatoes.	Kutya, 2012
Natural forest (control)	Refers to multi-layered vegetation also referred to primary forest. Natural forests spontaneously develop themself in the area through natural immigration of tree species. It is characterised by evergreen vegetation, high species diversity, dense canopy and less ground-cover.	Shackleton, 1999
Regenerated forest	This is a planted forest. It is established through afforestation of regions that initially had a natural forest and through disturbance such as logging and fires it lost most of the trees. Trees of certain species are therefore chosen and planted in the area.	Brown, 2000
Bush-land	This type of land cover is characterized by patchy vegetation of trees, shrubs and grass. Bush lands are always prone to bush fires and have greater canopy cover than wooded grassland which is defined by percentage of woody plants. The common species of trees in the bush-land is *Psidium guajava* due to its nature of colonization and dispersal (animal dispersed for examples by monkeys).	White, 1983
Grassland	This is a land cover dominated by grasses rather than large shrubs or trees. They are usually formed when there is regular logging in the forest for the purposes of cultivation and then later the land is abandoned. Grasses colonize the area to form grassland that can be recolonised by trees to create a bush-land then a forest after sometime They are characterized by annual fires. Kakamega forest has about 25 grasslands, ranging in size between 10-200 acres. These grasslands occur on the northern and southern part of the forest, and they represent over 35% of the total forest area.	Tsingalia and Kassily, 2009
Tea plantations	These are large scale of tea plantation introduced to act as buffers to reduce interference with forest. There are referred to as Nyayo tea zone. However, we still have some farmers practicing tea farming on small-scale. These plantations appear like a huge forest made of small trees that rarely reach above 1.5 m in height.	Matiru, 1999

Quantification of Land-Use/Cover Changes

Land cover and vegetation changes were determined using a series of multispectral Landsat images. A total of seven sets of image datasets were downloaded from the Glovis web portal (http://glovis.usgs.gov/) for years 1985 to 2015 with the cloud cover ranging from 1 to 10% taken in the dry season. The downloaded images were pan-sharpened and then collectively re-sampled to the 2015 imagery to harmonize the pixel resolution and atmospherically corrected using the Dark Object Subtraction (DOS) method to represent the landscape as realistic as possible. The images were geometrically rectified for distortions to facilitate change detection assessment and computation of area of classified land use/cover activities on the ground with the help of ground control points.

The image sets were geometrically corrected and referenced to the projection UTM zone 36N and datum WGS84 using an Authority Code of 32636. The transformation process posted a root mean square error of 0.5 pixel which falls within an acceptable range. The acquired images were filtered using spatial filtering method to weed out random errors and enhance the visibility of elements of land use/cover activities under interpretation. The preliminary classified images were further refined by assigning classes to their location-specific names based on the developed land use/cover classification scheme using ground-truthed data collected in September 2015 with the locations picked using a calibrated Garmin Global Positioning Systems (GPSMAP® 64st).

The land-use/cover classification scheme adopted was based on expertise knowledge and literature of land-use/cover activities. The images composites were generated to facilitate the extraction of features and understand pixel spectral representations. The images were classified using unsupervised image classification procedure following the K-means clustering algorithm in TerrSET software platform with the aim of statistically clumping spectral features in each image into discrete classes. The Hill-climbing K-means clustering method with 10 clusters at an iteration of 5 deemed suitable for all the selected images utilized. The classified images were cleaned for pixel noise by performing majority filtering method. The confusion matrix-based accuracy assessment method was used in image classification accuracy assessment. The number of reference points used for the computation of Kappa and overall accuracy were 120. The overall accuracy values for 1985 to 2015 were 0.995686, 0.999539, 0.98629, 0.997133, 0.985557, 0.998207 and 0.92147.

Soil sampling and analysis

A systematic sampling design was adopted. Soil samples were collected from natural forest, tea, maize, grassland, sugarcane and regenerated forest land-uses. In each land-use, four samples were randomly collected from 50 m by 50 m quadrat plots using a standard soil auger at a depth of 0 to 30 cm. The samples from each land-use were mixed thoroughly into one composite sample before being dried and grounded into fine powder before finally sifting through a 2-mm sieve. Soil parameters such as organic carbon, nitrogen, potassium, calcium and phosphorus were determined for each land-use. Organic carbon, nitrogen content, potassium and calcium were determined following the protocol of Okalebo *et al*. (2002). Extractable soil phosphorus was determined according to Olsen *et al*. (1954).

RESULTS AND DISCUSSION

This study analyzed land-cover/land-use changes and their effect on the dynamics of soil chemical parameters in Kakamega-Nandi Forest Complex (KNFC). Figure 1 and 2 show the changes in vegetation cover for the different land-uses. Notably, the acreage of small-scale agriculture increased significantly from 1985 to 2015. Unfortunately, bush-land decreased from 15.1 ha in 1985 to less than 1.2 ha in 2015. The acreage of natural forests has remained relatively constant throughout the years (Fig. 1 and 2). Soil parameters varied in different land-uses. A significant decrease in soil organic carbon was observed in maize, grazing and sugarcane land-uses. However, in regenerated forest plantations, there was a significant increase in soil organic carbon (Table 2). In maize plantations, total nitrogen increased significantly, while in grazing, sugarcane and regenerated forest, a significant reduction of total nitrogen was observed (Table 2). The amount of potassium was only significantly reduced in tea plantation as compared to the control, while calcium was significantly reduced in sugarcane and regenerated forest plantations. Total phosphorus remained unchanged in all tested land-uses (Table 2).

Tellen and Yerima (2018), observed that conversion of natural forest or savanna to farmland reduces organic matter and organic carbon. Cultivation and land-use changes have been shown to decrease soil C stocks (Deng *et al.*, 2016; Smith, 2008; Guo and Gifford, 2002; Ellert and Gregorich, 1996). Further, clearing of forests to provide agricultural land causes huge losses of soil C stocks (DeGryze *et al*., 2004). However, the key findings of this study suggest that changes in Soil C stocks depend on the land-use types. Carbon is released into the soil through decomposition of plant biomass. Annual crop plantations contribute less plant biomass as most of it is harvested as fodder or cane for sugar processing. Perennial tree plantation provides litter in form of plant biomass. Decomposition of these materials adds carbon and other nutrients such as nitrogen into the soil (Guo and Gifford, 2002). It is logical to find more carbon in regenerated forest plantations. The conversion of agricultural land to secondary forest has been shown to increase soil C stocks (Deng *et al*., 2016; Powers *et al.*, 2011). Other studies have reported accumulation of C stock after afforestation of farmlands (Post and Kwon, 2000). It has been suggested that conversion of forest to agricultural land disrupts the soil natural structure leading to improved mineralization of soil organic carbons and emission of carbon dioxide to the atmosphere, hence the decrease of carbon in annual crop plantations.

Moreover, soils from different land-use types have different carbon carrying capacities and equilibrium carbon content (Jobbágy and Jackson, 2000). Changing land-use alters the equilibrium and takes considerable time for equilibrium to be achieved in the new ecosystem (Guo and Gifford, 2002). As the process occurs, carbon stocks in the soil are either changed into carbon source or carbon sinks (Deng *et al*., 2016). Initially, soil C stock decline rapidly after land-use change especially within the first 5 to 7 years, followed by a gradual return of soil C stocks to levels comparable to those in stable forests and then further increase to generate net soil C gains (Deng *et al*., 2014). Farmers in shamba system are allowed to

Table 2. Soil chemical parameters in different land covers.

Parameters		Natural Forest (Control)	Tea Plantation	Maize Plantation	Grazing (pasture)	Sugarcane	Regeneration Forest Plantation
SOC (%)	Mean	3.60 ±0.183	3.05±0.158	2.53±0.227	2.53±0.217	1.38±0.068	4.18±0.096
	Difference		-0.552	-1.065	-1.073	-2.217	0.585
	P-value		0.08	**0.003***	**0.001***	**0.000***	**0.000***
Total N (%)	Mean	0.14±0.014	0.01±0.014	0.18±0.016	0.11±0.010	0.08±0.041	0.10±0.010
	Difference		-0.128	**0.034**	-0.028	-0.057	-0.040
	P-value		0.110	**0.019***	**0.01***	**0.011***	**0.011***
Av P (ppm)	Mean	8.81±1.030	7.73±0.988	8.20±0.771	7.47±0.657	9.05±1.857	11.56±0.815
	Difference		-1.087	-0.612	-1.346	0.238	2.744
	P-value		0.240	0.397	0.440	0.574	0.124
K^+ (ppm)	Mean	4.85±0.410	3.84±0.214	4.38±0.184	4.49±0.288	5.65±0.345	4.51±0.288
	Difference		-1.010	-0.477	-0.365	**0.798**	-0.347
	P-value		**0.038***	0.124	0.105	0.075	0.106
Ca^{2+} (ppm)	Mean	12.41±0.644	10.56±0.310	11.44±0.216	12.14±0.482	12.12±0.353	4.85±0.410
	Difference		-1.855	-0.966	-0.267	-0.290	-7.558
	P -value		0.112	0.06	0.132	**0.017***	**0.03***
C/N ratio		25	218	14	22	16	41

Mean values ± standard error. The symbol (*) indicates significance difference at P≤0.05. n= 6.

cultivate annual crops for 2 to 3 years or up to when the trees are large enough to suppress crop growth. It can be argued that decline in soil C in maize, sugarcane and pasture plantations in Kakamega-Nandi Forest Complex is temporal. However, it remains unknown how long it takes for the restoration of soil C stocks. Studies done elsewhere have shown that up to 35 years may be required (Deng et al., 2016; Paul *et al.*, 2002). This time is considerably long and can completely change the climate of the area.

The effect of carbon dioxide influx into the atmosphere and its contribution to climate change need to be addressed. In the first three years of land-use change, the shamba systems contribute to emission of carbon dioxide to the atmosphere which may eventually lead to climate change. Moreover, bush clearing commonly practiced in shamba system may cause huge influx of carbon dioxide into the atmosphere. Further, more than 40% of the reported forest fires in Kenya originate from the forest shambas, particularly during land clearance (Oduol, 1986; Nair and Nair, 1984). On the basis of these findings, the Kenya forest service is advised to consider modifying the shamba system to only include cultivation of perennial tree plantations.

Plant re-growth and carbon assimilation by plants is strongly influenced by nitrogen availability (Jain *et al.*, 2013). Less nitrogen in all land-uses except in maize plantation cause poor accumulation of C in plant biomass and less soil C stocks upon decomposition of organic matter. Maize cultivation requires huge input of nitrogen fertilizers. The exogenous application (top-dressing) of N-fertilizer above the natural N input could lead to rapid plant growth and accumulation of C in plant biomass through photosynthesis which is harvested together with the fodder or maize grain leaving behind less carbon input in the soil. Further land-use change alters the dynamics of soil nitrogen. Considerable

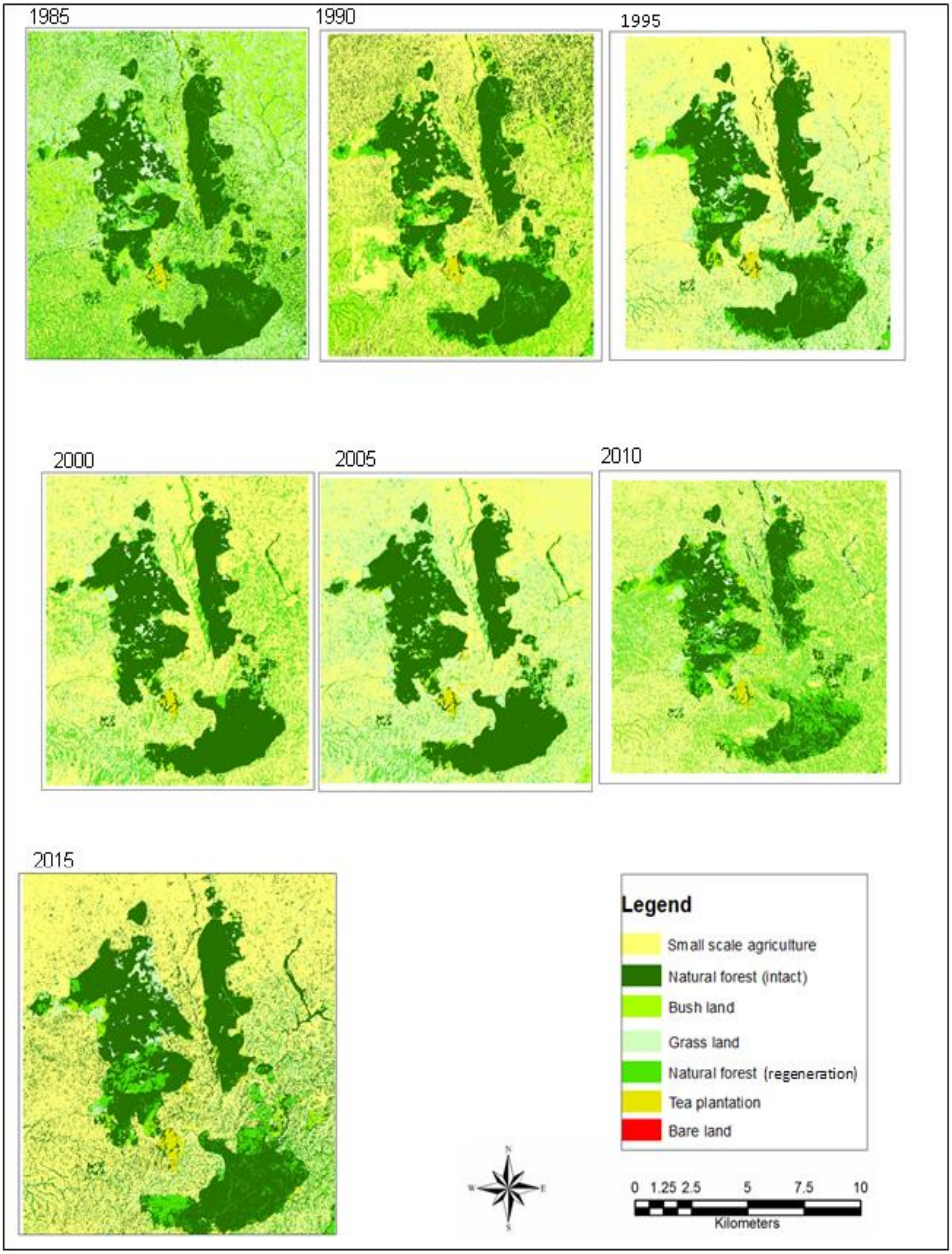

Figure 1. Changes in land cover around Kakamega-Nandi forest complex.

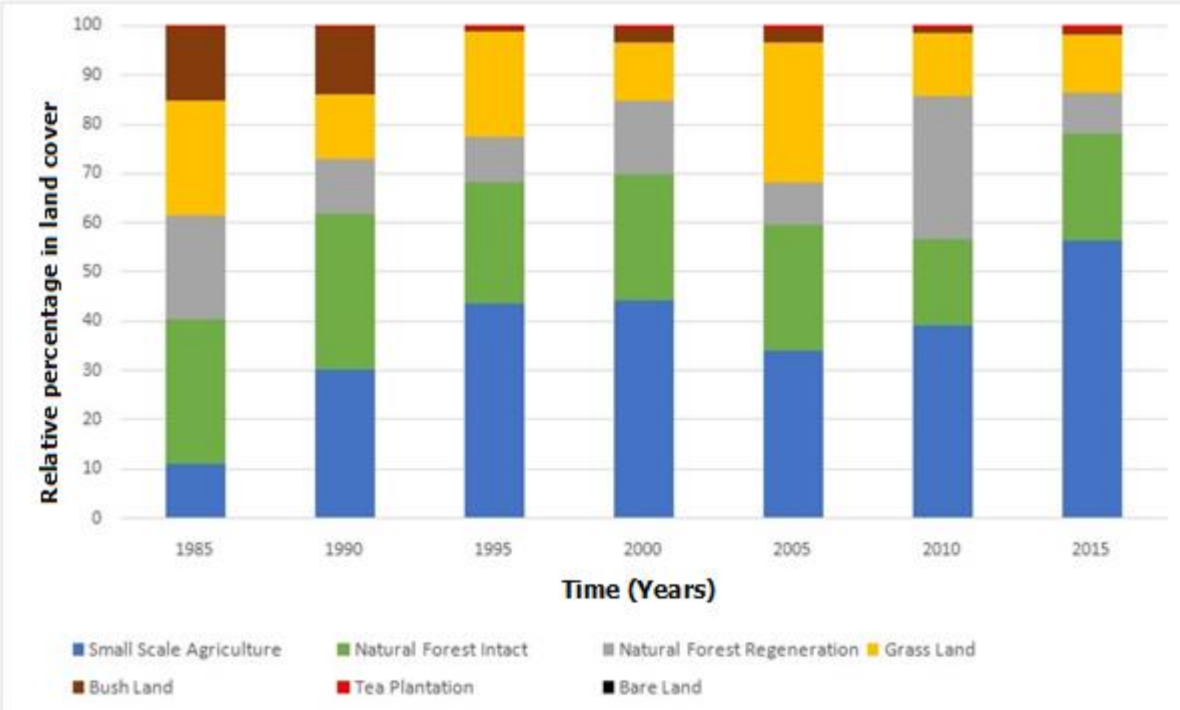

Figure 2. Relative percentage in land covers around Kakamega-Nandi forest complex.

amount of nitrogen is lost when a natural forest is converted to cultivated land (Murty *et al*., 2002). Additionally, a low C/N ratio indicates a rapid decomposition of organic matter, but since less organic matter is available, low amount of carbon and other essential elements will be generated. Johnson, (1992) and Nyborg *et al*. (1997) have shown a positive correlation between changes of soil C and concomitant changes in soil nitrogen. Whenever, C is lost, N is also lost and vice versa. A linear correlation was also observed for soil C stocks and calcium. Generally, calcium decreased in all land-uses, but the results were only significant for sugarcane and regenerated forests. Calcium ions stabilize soil organic carbon (Rowley *et al*., 2018). These ions co-associate with organic carbon by increasing its sorption process in soils (Sowers *et al*., 2018).

CONCLUSION

In summary, our study has shown that land-use changes through the application of the shamba system alter the dynamics of soil chemical parameters key among them are SOC, nitrogen and calcium. Cultivation of annual crops decreases soil C stocks which may lead to an influx of carbon dioxide in the atmosphere and increased vulnerability to climate change. The system requires review to mitigate the effects of climate change.

Acknowledgements
We thank various data providers, notably, the Kenya Forest Service, Kakamega, Regional centre for mapping of resources for development and the farmers for allowing us to collect soil samples within the forest complex.

Funding. The study was supported by grant from NACOSTI, Kenya.

Conflict of interest statement. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Compliance with ethical standards. As part of PhD thesis, the research proposal was approved by the Graduate School of Moi University after meeting the post-graduate guidelines of the university.

Data availability. Data are available with Mr. Wabusya (e-mail: wabusyam@yahoo.com) upon request.

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