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SOIL CARBON AND NITROGEN STOCKS IN TRADITIONALLY MANAGED RANGELAND BIOMES IN KARAMOJA SUB-REGION, UGANDA

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ABSTRACT

Rangelands are known for their potential in mitigating rising atmospheric carbon dioxide (CO_2) concentrations in the world. The objective of this study was to investigate the patterns of soil organic carbon (SOC) and nitrogen (N) in rangelands under traditional management systems in Karamoja sub-region in Uganda, with a view to facilitating the development of appropriate and strategic management practices for the rangeland resources. The study was conducted during the wet season of the sub-region. Four land use/cover types (cropland, grassland, woodland and thickets/shrubland) were laid out in a completely randomised design. Soil samples were collected from four plots each one measuring 50 m x 40 m in each land use/cover type. A diagonal design was used for sample collection at depths of 0 - 15 and 15 - 30 cm. Results showed that at both soil depths, croplands had the lowest mean SOC and highest N; while grasslands had the highest SOC. Also, cropland recorded the highest mean soil bulk density at both depths. Based on soil analysis only, this study showed that conversion to cropland over a specified period of time can considerably reduce the ability of rangelands to sequester carbon. Further studies to include assessment of carbon stocks in the respective vegetation biomass are recommended.

Key Words: Carbon sequestration, land cover/use, thickets, woodlands

RÉSUMÉ

Les pâturages sont connus pour leur potentiel d'atténuation des concentrations croissantes de dioxyde de carbone (CO_2) atmosphérique dans le monde. L'objectif de cette étude était d'étudier les modèles de carbone organique du sol (COS) et d'azote (N) dans les pâturages sous les systèmes de gestion traditionnels dans la sous-région de Karamoja en Ouganda, en vue de faciliter le développement de pratiques de gestion appropriées et stratégiques pour les ressources des pâturages. L'étude a été menée pendant la saison des pluies de la sous-région. Quatre types d'utilisation/de couverture des terres (terres cultivées, prairies, terres boisées et fourrés/arbustes) ont été définis dans un plan complètement aléatoire. Des échantillons de sol ont été prélevés dans quatre parcelles mesurant chacune 50 m x 40 m dans chaque type d'utilisation/couverture des terres. Une conception diagonale a été utilisée pour la collecte d'échantillons à des profondeurs de 0 - 15 et 15 - 30 cm. Les résultats ont montré qu'aux deux profondeurs du sol, les terres cultivées avaient le COS moyen le plus bas et le N le plus élevé ; tandis que les prairies avaient le COS le plus élevé. De plus, les terres cultivées ont enregistré la densité apparente moyenne du sol la plus élevée aux deux profondeurs. Basée uniquement sur l'analyse des sols, cette étude a montré que la conversion en terres cultivées sur une période de temps spécifiée peut réduire considérablement la capacité des terres des pâturages à séquestrer le carbone. D'autres études pour inclure l'évaluation des stocks de carbone dans la biomasse végétale respective sont recommandées.

Mots Clés: Séquestration du carbone, couverture/utilisation des terres, fourrés, terres boisées

INTRODUCTION

Land use changes such as conversion of grasslands to croplands significantly contribute to elevated atmospheric CO_2 concentrations (Shiferaw *et al.,* 2019). Moreover, rangelands have potential to remove 198 million metric tonnes of CO_2 from the atmosphere per year for 30 years (McDermot and Elavarthi, 2014). Globally, rangeland biomes occupy about half of the world's land area, and contain more than a third of above and below ground carbon reserves (Allen-Diaz, 1996). The recent rapid losses of soil carbon and nitrogen in tropical savannas are attributed to land use change for agricultural uses (Yusuf *et al.*, 2015).

According to IPCC (2007), the potential of rangelands to store carbon in the soils and vegetation has been acknowledged and lies within the natural state of rangelands or rangelands specifically moderately disturbed by grazing. Fortunately, plant species adapted to relatively dry soil conditions and species adapted to relatively wet soil conditions coexist in most rangelands and this is important for maintaining the long-term stability of forage production that enhances ecosystem services of carbon and nitrogen sequestration/storage (Sala *et al.*, 2017).

Grassland soils have the potential to store more than 100 metric tonnes and 10 per hectare of soil organic carbon (SOC) nitrogen (N), respectively (Gervasio *et al.*, 2010). Soil is the largest terrestrial carbon and nitrogen sink; with 2 - 3 times more carbon and nitrogen than in the atmosphere and vegetation, respectively (Yusuf *et al.*, 2015; Thangavel *et al.*, 2019). Each metric tonne of carbon stored in soil removes or retains 3.67 metric tonnes of CO_2 from the atmosphere (Fynn *et al.*, 2009). Soil sequestered carbon is mainly from decomposed plant litter and residues enhanced by nitrogen. Interactions of management, climate and vegetation affect ecosystem responses such as the rate and amount of soil carbon sequestered and the dynamics of individual carbon pools (Derner and Jin, 2012). Improved rangeland management strategies and practices greatly improve environmental benefits (Schumana *et al.*, 2001), including soil carbon and nitrogen sequestration among other benefits.

In Uganda, rangelands are estimated to cover 44% of land cover, and are mostly dominated by pastoralists (Byakagaba *et al.*, 2018). In Karamoja sub-region, the current on-going cropland expansion directly compromises the potential of traditionally managed rangeland biomes to provide such environmental benefits. In the sub-region, cropland expansion is being indiscriminately promoted without strong extension programmes and major investments in climate-smart options (Nakalembe *et al.,* 2017). This will continue to cause negative climatic conditions as the potential of the rangeland biomes to regulate the sequestration of carbon and nitrogen into the soil is being jeopardised. Crop cultivation is a major threat to rangelands affecting pastoralism, as well as causing carbon emission and rapid soil nitrogen reduction (Shiferaw *et al.*, 2019). This is accelerated by oxidative respiration of soil organic matter (SOM), owing to greater tillage frequency and ultimate exposure to aerobic respiration. Worldwide, an estimated 4.7 million Km^2 grassland areas have been converted to croplands and about 3.4 million Km^2 of woody vegetation in dryland zones of Africa have become degraded through human activities such as agricultural expansion and deforestation (Tsegaye *et al.*, 2010). The East African semi-arid and sub-humid areas, Karamoja rangeland inclusive, are experiencing significant land use and land cover change from extensive livestock production to crop cultivation (Osaliya *et al.*, 2018). In Karamoja sub-region, conversion of woodlands and bushlands rangeland biomes into small-scale croplands steadily rose from 9.67% area coverage in 1984 to 15.69% in 2013 with an annual rate of increase in this period at 2.1% (Osaliya *et al.*, 2018). In the same sub-region, 299% increase in cropland was reported between 2000 and 2011 (Nakalembe *et al.*, 2017). However, no effort has been made to assess the effects of such land use changes on the biome's capacity to sequester C and N from the atmosphere into the soil.

Several studies have shown that changes in rangeland use/cover management practices such as conversions to croplands can cause reduced rangeland potential to sequester carbon (NARO, 2017; Byakagaba *et al.*, 2018; Shiferaw *et al.*, 2019). In Karamoja sub-region, studies have been conducted on some soil physical and chemical parameters, land use and land cover change (Osaliya *et al.*, 2018; Egeru *et al.*, 2019) without delving much into soil carbon and nitrogen stocks, in spite of the recognition of dramatic land use and land cover change taking place in the sub-region. Thus, the objective of this study was to ascertain the impact of increasing cropland cover on soil organic carbon and nitrogen sequestration potential in relation to the rangeland biomes of woodlands, grasslands and thickets/shrublands in Karamoja sub-region.

MATERIALS AND METHODS

The study area. This study was conducted in Karamoja sub-region, north-eastern Uganda, during the wet season. The sub-region consists of nine districts including; Kaabong, Kotido, Abim, Moroto, Napak, Amudat, Karenga, Nabilatuku and Nakapiripirit. It lies at latitudes $1^{O}30'$ and 4^{O}N and longitudes $33^{O}30'$ and 35^{O}E, covering an estimated area of 27,511 Km^2 most of which is semi-arid savannah covered with seasonal grasses, thorny plants, and occasional small trees and mountains (Mubiru, 2010). Karamoja is set on a large plateau at an average elevation of 1,000 meters above sea level. The land plain rises to northeast towards the hilly terrain bordering the escarpment above the neighboring Turkana district in Kenya (Nakalembe *et al.,* 2017). The semi-arid lands of Karamoja are traditionally inhabited largely by pastoralist and agro-pastoralist communities.

Karamoja sub-region is characterised by highly variable climate, with sporadic rainfall and high temperatures all year round. Annual rainfall ranging from 350 to 1,500 mm (Nakalembe *et al.*, 2017); temperatures are generally high, ranging from 28 - 33 ^{O}C (average maximum) and 15 - 18 ^{O}C (average minimum) (Sagal and Grade, 2012; Grade, 2012; Egeru *et al.*, 2014).

The vegetation is dominated by indigenous tropical grasses and mostly composed of Acacia species, in addition to other woody vegetation covers, such as thickets/shrubs and bushes. The natural vegetation of Acacia-Hyparrhenia has been overgrazed due to the over reliance on livestock that has led to overstocking. Seasonality, land cover types, soil properties (both physical and chemical) have a significant influence on forage/ vegetation quantity in the sub-region (Egeru *et al.,* 2014; 2019).

Among the sedentary communities in the Karamoja sub-region, crops grown include sorghum, sun-flower, bulrush millet, maize, beans and ground-nuts. Within these croplands, weed species can be classified as herbs and grass species. Woodland contains trees often with a height range of 5 - 20 m relative to their crown depth and form an open canopy. The intervening area are occupied by shorter vegetation/grass and tree species such as *Combretum binderianum* and *Bauchinia thoningii* with interwoven Acacia sp. (Egeru *et al.*, 2015).

The soils of Karamoja sub-region are generally poor, with very low water retention capacity. They crack during the dry season and become waterlogged during the wet season. They are generally highly compacted, often forming a dense mass called hardpan. The only exception is the less compacted and more nutrient-rich soils along dry river courses (USAID, 2017). The soils are part of the ferruginous tropical soils that are freely drained and weakly developed Lithosols (Egeru *et al.*, 2019). The dominant soils are black clays and dark grey clay. Although they are low in organic matter, they may be productive when irrigated (Mubiru, 2010; Egeru *et al.*, 2019).

Data collection. Data collection was mainly from samples collected from the four land use/ cover types from the districts of Moroto, Kaabong and Kotido. The soil dataset was complemented by use of satellite data.

Soil sampling. Nine sub-soil samples were diagonally collected from the plots of 50 m × 40 m at the depths of 0 - 15 cm and 15 - 30 cm using an auger. The sub-soil samples from each depth per plot were thoroughly mixed to form composite samples. The composite samples were saved in labelled polythene bags for subsequent laboratory analyses. Laboratory analysis included soil organic carbon concentration determined by the Walkley-Black (1934) method; and nitrogen content by Kjedhal method (Okalebo *et al.*, 2002). The laboratory results were used to calculate stocks of soil organic carbon and nitrogen as illustrated in the Equations 2 and 3, respectively

$$BD = \frac{\text{ODWsample (g)}}{\text{V (cm3)}} \quad \text{.............. Equation 1}$$

Where:

ODW = Oven Dry Weight of the sample,
V = Volume of the core sampler ($\pi r^2 h$)

$$C\ ha^{-1}) = BD \times \%SOC \times d \times 10000 \quad \text{..................... Equation 2}$$

Where:

SOC_{stock} = Total soil organic carbon content/ stock (t C ha^{-1}), BD = Bulk density (g cm^{-3}),

SOC% = soil organic carbon concentration (%), d = soil sampling depth (cm).

$$N_{stock}\ (t\ N\ ha^{-1}) = BD \times \%N \times d \times 10000 \quad \text{..................... Equation3}$$

Where:

N_{stock} = soil organic nitrogen content/stock (t N ha^{-1}),
BD = Bulk density (g cm^{-3}),
N = sample nitrogen concentration (%),
d = soil sampling depth (cm).

Additionally, core samples were randomly collected at the same depths (0 - 15 and 15 - 30 cm) for bulk density determination using the procedure described by Okalebo *et al.*, (2002).

Satellite data acquisition. Cloud free sentinel-2a image archived by United States Geological Survey (USGS) earth explorer (https://earthexplorer.usgs.gov) was down loaded, for detailed understanding of the variability in the spatial distribution of the studied soil properties in Karamoja sub-region. The high resolution (10 m) sentinel image captured was considered for the wet season of the study area. The image bands 4,3,2 were stacked to produce an RGB composite in ArcGIS 10.4. The Sentinel RGB composite was classified using unsupervised image classification to get 100 classes. The resulting classes were grouped into four information classes (cropland, grassland, woodland and thickets/shrubland) for Karamoja sub-region as indicated in the land use/cover map (Fig. 1). These classes are in line with the FAO classes (http://www.fao.org/3/x0596e/x0596e00.htm). Figure 2 indicates on-ground land use/cover types (biomes) studied. The map indicates grassland as the dominant (1,235,932.97 ha); followed by thickets/shrubland with total land area of 690,544.53 ha; and then woodland with total land area of

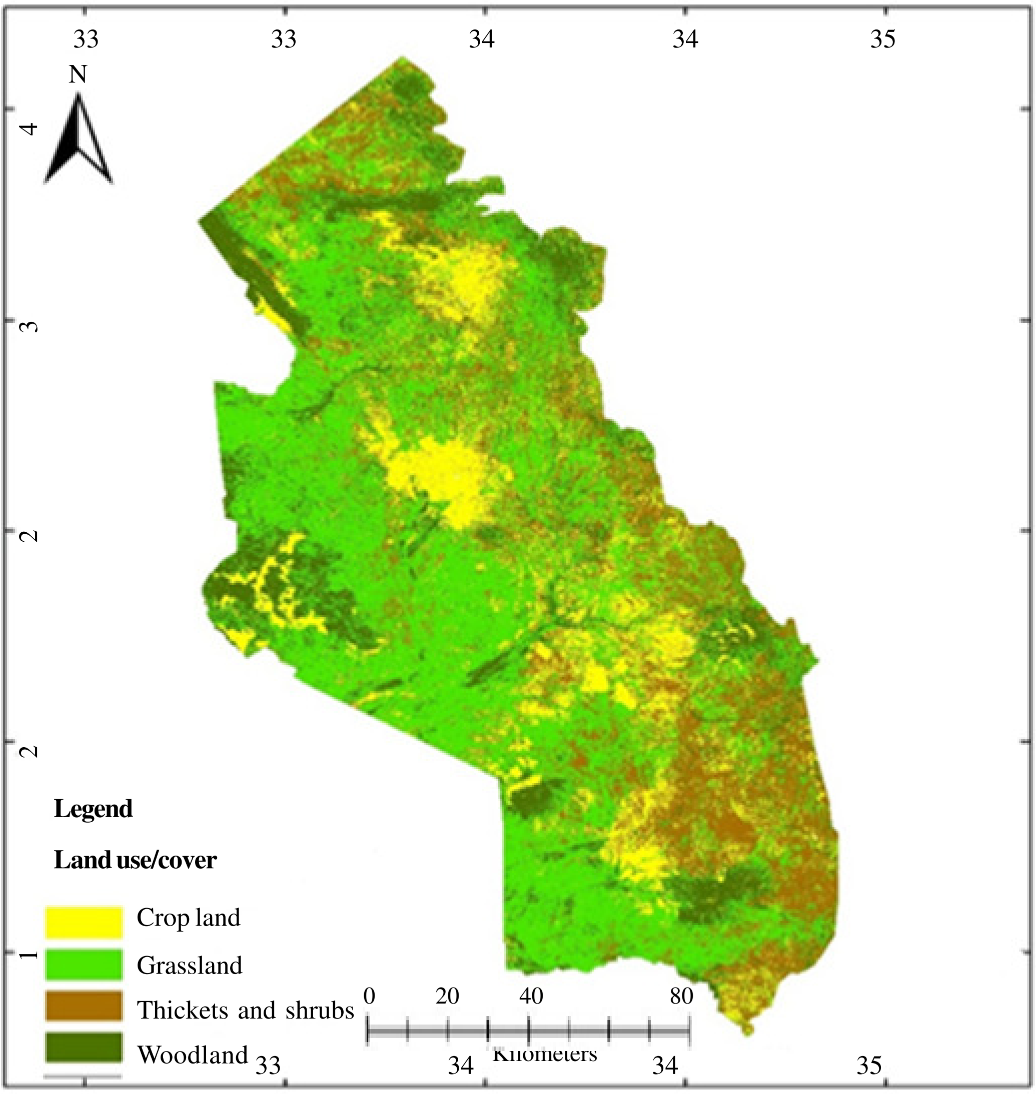

Figure 1. Map showing studied land use/cover types in Karamoja sub-region (2020).

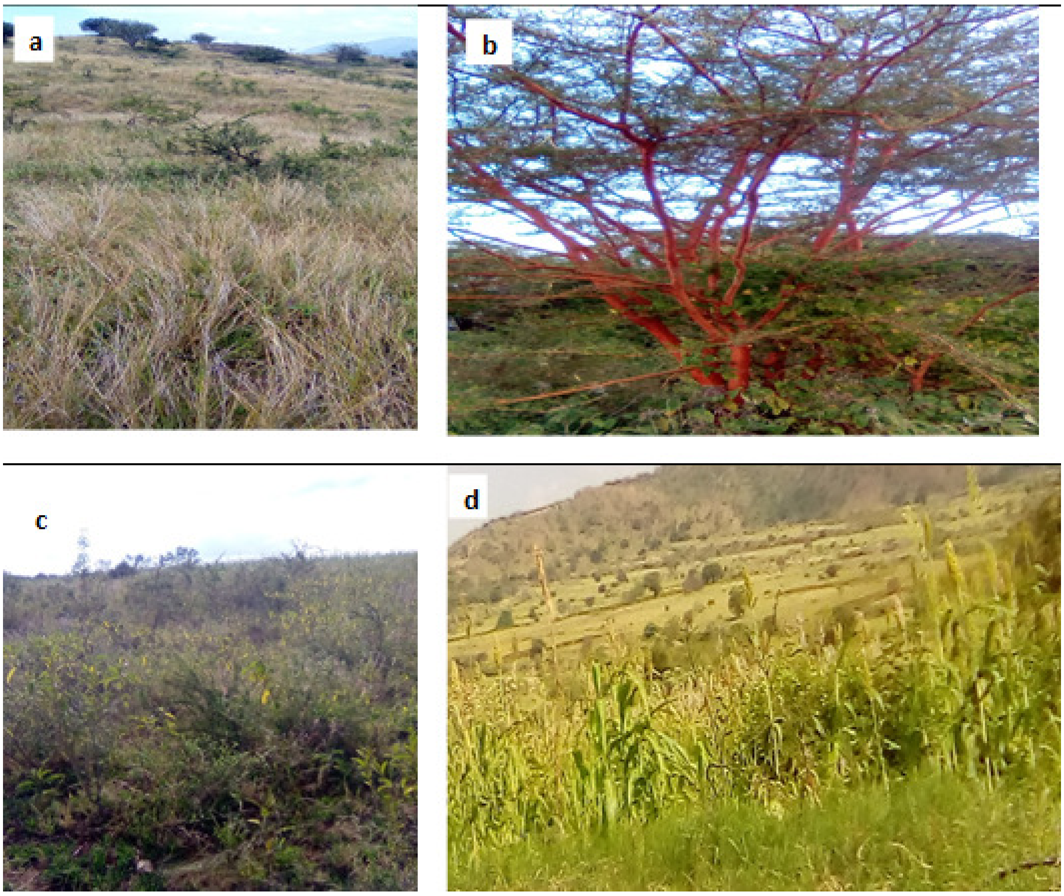

Figure 2. Pictorial Land use/cover types: (a) *Grassland*; dominated by grass species like hyperhania species, *Cenchrus ciliaris, Cynodon dactylon* and scattered short acacia species. (b) *Woodland*; characterised by woody acacia species. (c) *Thickets/shrubland*; characterised by short woody shrubs and herbs. (d) *Cropland* (bulrush garden).

381,200.36 ha; and emerging scattered croplands with the lowest total land area of 354,690.29 ha.

Soil data acquisition and interpolation. A soil map of the same study area was acquired from FAO website (http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/en). In the GIS environment, 100 random points were generated and used to extract soil organic carbon and nitrogen data. The extracted data were used for interpolation using Kriging method to generate the spatial distribution maps for each of the soil properties at for both the top and lower soil depths for Karamoja sub region.

Data analysis. The soil data collected were subjected to analysis of variance (ANOVA) across the different land use/covers (biomes) and at different depths at $P < 0.05$ significance level. Tukey's post hoc test was used to compare the group means of the studied soil properties. The statistical analyses were carried out using R version 4.0.2 statistical package.

RESULTS

Soil organic carbon and nitrogen across land use/cover types. Cropland had the least stocks of SOC (5.32 ±2.62 t ha^{-1}); while in contrast grassland and woodland had the highest stocks of SOC (15.99±6.46 and 15.48±8.83 t ha^{-1}, respectively at a depth of 0-15 cm. At the same depth, cropland soil had the highest N (2.9±1.52 t ha^{-1}) and the least N stock was recorded in grassland (2.33 t ha^{-1}) (Table 1). At a soil depth of 15-30 cm, cropland had the lowest stock of SOC (7.43±7.7 t ha^{-1}) and the highest in grassland and woodland (14.55±6.41 and 14.14±6.15 t ha^{-1}, respectively); and N was highest in cropland and lowest in woodland (Table 1).

Although there were significant differences (P<0.05) in SOC between soil at depths 0 - 15 and 15 - 30 cm, no such differences (P>0.05) with N stock means existed between soil at the same depths across the different land uses/ covers (Table 1). At both depths, the Post hoc test (Table 2) showed significant differences with SOC stocks between cropland and the other land use/cover types. However, there were no significant differences with regard to soil organic nitrogen stocks. At both soil depths, cropland showed the highest bulk density, while grassland showed the lowest and was significantly different across the land uses/covers studied (Table 1).

Overall, grassland soil contained/stored more SOC in both top and subsoil (19,762,568.11 and 17,982,824.64 metric tonnes, respectively); followed by woodland and thickets/shrubland soil. Cropland soil had the lowest total SOC at both depths (Table 3a). It was also observed that conversion of either grasslands, woodlands or thickets/shrublands to cropland leads to reduction in SOC stocks, in contrast with soil organic nitrogen stocks (Table 3b).

Locational distribution of soil organic carbon and nitrogen. At the soil depth of 0-15 cm, SOC was relatively higher in the southern and central parts of the sub-region

TABLE 1. Descriptive statistics of soil organic carbon and nitrogen, and bulk density for the different soil depths in land use/cover types (biomes) in Karamoja sub-region, Uganda

Land use/cover	Depth	Soil Organic Carbon (t C ha^{-1})					Soil Organic Nitrogen (t N ha^{-1})					BD (g cm^{-3})				
		Mean	Std	Var	Max	Min	Mean	Std	Var	Max	Min	Mean	Std	Var	Max	Min
Cropland	0-15	5.32	2.61	6.8	10.46	2.12	2.9	1.52	2.32	7.09	0.97	1.55	0.1	0.01	1.69	1.36
	15-30	7.43	7.17	51.47	22.39	0.76	3.1	1.4	1.97	5.89	1.57	1.51	0.1	0.01	1.73	1.34
Grassland	0-15	15.99	6.46	41.76	28.65	5.14	2.33	1.4	1.97	6.16	0.37	1.37	0.1	0.01	1.57	1.24
	15-30	14.55	6.41	41.04	28.5	10.13	2.9	1.92	3.68	7.29	1.4	1.37	0.12	0.02	1.72	1.27
Thickets/Shrubland	0-15	12.66	7.37	54.27	26.24	3.28	2.69	1.45	2.11	6.45	1.38	1.39	0.09	0.01	1.54	1.29
	15-30	9.11	3.15	9.9	13.29	3.01	2.5	2.4	5.77	8.86	1.06	1.39	0.08	0.01	1.54	1.27
Woodland	0-15	15.48	8.83	77.9	32.74	1.99	2.56	1.89	3.58	7.15	0.54	1.42	0.11	0.01	1.56	1.25
	15-30	14.15	6.15	37.83	23.19	4.81	2.47	1.09	1.18	5.32	1.31	1.41	0.09	0.01	1.53	1.21
Significance (P<0.05)	0-15	0.00105					0.843					0.000281				
	15-30	0.00869					0.783					0.0127				

TABLE 2. Tukey post-hoc test for the studied soil properties under land use/cover types at 0-15 and 15-30 cm soil depth

Land use/cover types		Soil properties mean differences (I-J)					
		0-15 cm			15-30 cm		
I	J	SOC	N	BD	SOC	N	BD
Grassland	Thickets/Shrubland	3.3291667	-0.363	-0.022	5.448	0.399	-0.020
	Woodland	0.5100000	-0.229	-0.050	0.399	0.423	-0.033
	Cropland	10.6716667*	-0.570	-.182*	7.118*	-0.202	-.133*
Thickets/Shrubland	Grassland	-3.3291667	0.363	0.022	-5.448	-0.399	0.020
	Woodland	-2.8191667	0.133	-0.028	-5.048	0.024	-0.013
	Cropland	7.3425000*	-0.208	-.160*	1.670	-0.601	-.112*
Woodland	Grassland	-0.5100000	0.229	0.050	-0.399	-0.423	0.033
	Thickets/Shrubland	2.8191667	-0.133	0.028	5.048	-0.024	0.013
	Cropland	10.1616667*	-0.341	-.132*	6.718*	-0.625	-0.100
Cropland	Grassland	-10.6716667*	0.570	.182*	-7.118*	0.202	.133*
	Thickets/Shrubland	-7.3425000*	0.208	.160*	-1.670	0.601	.112*
	Woodland	-10.1616667*	0.341	.132*	-6.718*	0.625	0.100

*The mean difference is significant at the 0.05 level

TABLE 3a. Soil organic carbon gained/lost per land use/cover type from either grassland, woodland or thickets/shrubland converted to cropland in Karamoja rangelands in Uganda

Land use/cover types	Area (ha)	Soil depths	Average SOC (t ha^{-1})	Total SOC per land use/cover (metric tonnes)	Loss/gain of SOC/ha to cropland conversion (%)
Cropland	354,690.29	0-15	5.32	1,886,952.36	N/A
		15-30	7.43	2,635,348.88	N/A
Grassland	1,235,932.97	0-15	15.99	19,762,568.11	66.7292
		15-30	14.55	17,982,824.64	48.9347
Thickets/Shrubland	690,544.53	0-15	12.66	8,742,293.73	57.9779
		15-30	9.11	6,290,860.65	18.4413
Woodland	381,200.36	0-15	15.48	5,900,981.64	65.6331
		15-30	14.15	5,393,985.15	47.4912

TABLE 3b. Soil organic nitrogen gained or lost per land use/cover types converted to cropland in Karamoja rangelands, Uganda

Land use/cover types	Area (ha)	Soil depths	Average N (t ha^{-1})	Soil organic nitrogen per land use/cover (metric tonens)	Loss/gain of N/ha to cropland conversion (%)
Cropland	354,690.29	0-15	2.9	1,028,601.852	N/A
		15-30	3.1	1,099,539.91	N/A
Grassland	1,235,932.97	0-15	2.33	2,879,723.809	24.5
		15-30	2.9	3,584,205.599	6.9
Thickets/Shrubland	690,544.53	0-15	2.69	1,857,564.781	7.8
		15-30	2.5	1,726,361.321	24
Woodland	381,200.36	0-15	2.56	975,872.9326	13.3
		15-30	2.47	941,564.8998	25.5

and lower in the northern parts of Karamoja rangelands. At the soil depth of 15-30 cm, only Kaabong rangelands had fairly high stocks of SOC; while the rest of regions had uniformly low stocks of SOC (Fig. 3). As for soil N, the top soil of the northern parts of the sub-region (Kaabong and Karenga) had high stocks of N. At a lower soil depth (15 - 30 cm), N was moderately high with a relatively uniform distribution across the Karamoja sub-region rangeland except for the Northern and Southern parts of Karenga and Nakapiripiti respectively that showed low N stocks (Fig. 3).

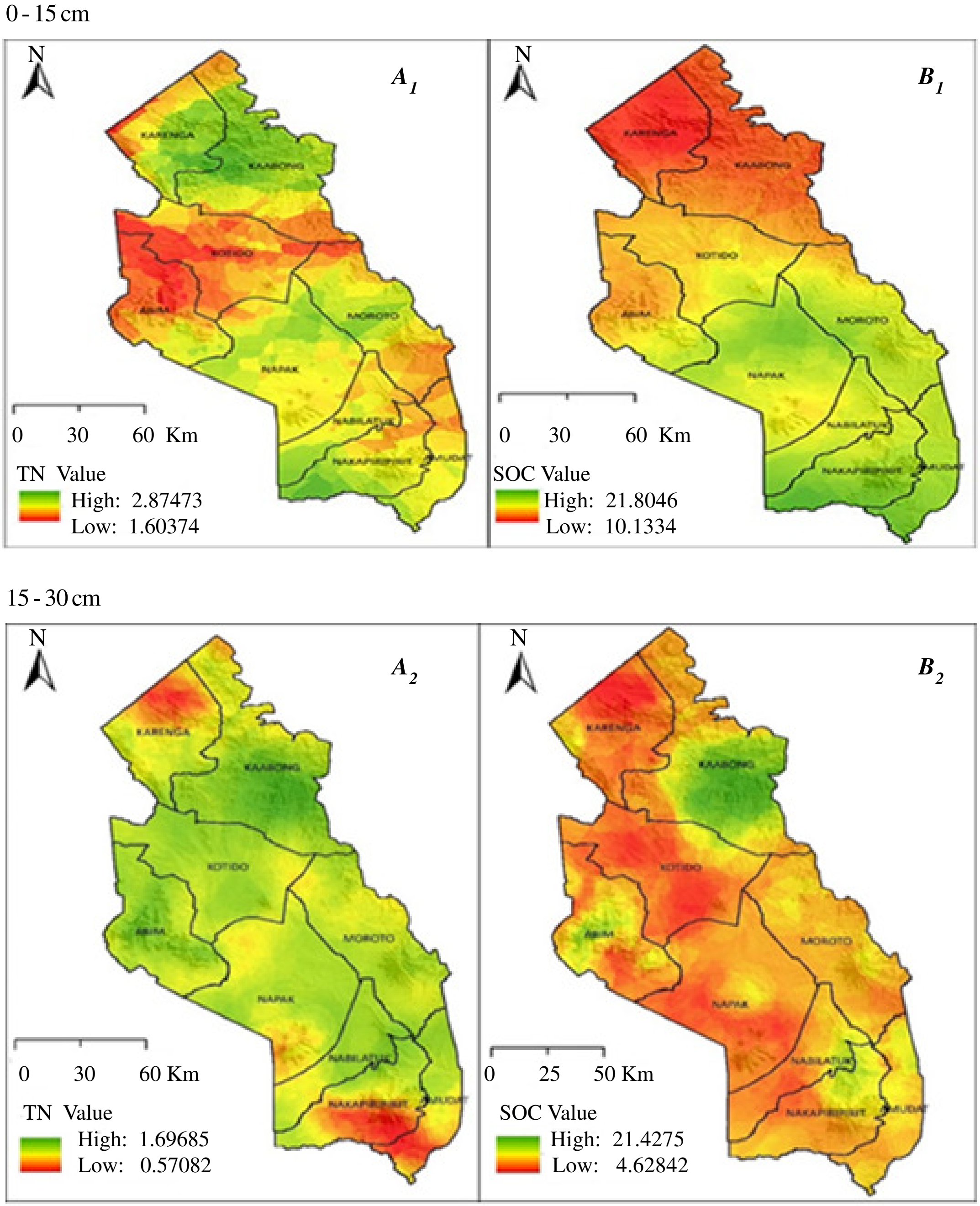

Figure 3. Spatial distribution of soil organic and nitrogen stocks at 0-15 and 15-30 cm (A_1 = soil nitrogen at 0-15 cm; A_2 = soil nitrogen at 15-30 cm; B_1 = soil organic carbon at 0-15 cm; B_2 = soil organic carbon at 15-30 cm) in the rangelands of Karamoja sub-region in Uganda.

DISCUSSION

Soil organic carbon (SOC). The considerably higher SOC stocks in grassland and woodland at both depths of 0-15 and 15-30 cm than in the cultivated plots could be attributed to grasslands' continuous capacity to sequester and store carbon (Omara, 2012). The observed higher SOC in top soil depth (0-15 cm) than the lower depth, except for croplands, is in agreement with earlier report that cultivation of rangeland soils significantly reduces SOC in the upper surface of the soil horizon (Derner and Schuman, 2007; McDermot and Elavarthi, 2014). Similar results were reported by Shiferaw *et al.* (2019) in a study about changes in SOC stocks under different land use types in Semiarid Borana rangelands. The more relatively stable ecosystems of grassland and woodland may be responsible for the higher SOC stocks, compared to the cultivated counterparts which are exposed to frequent tillage and associated rapid SOC oxidation through aerobic respiration (Zheng *et al.,* 2018).

Moreover, the grassland and woodland ecosystems tend to possess increased input from the decomposing excreta of grazing animals, since these rangeland biomes are mainly used for pastoralism in the Karamoja sub-region. Additionally, there is tremendous foliage senescence from these land cover types. Fresh material decomposition of some parts of above ground foliage is reportedly the main pathway of input of new soil organic carbon into the soil (Shiferaw *et al*., 2019). The limited soil disturbance in grassland and woodland enhances soil microorganisms' activities leading to increased SOC stocks. Hence, the decision to convert Karamoja's rangelands into cultivated fields needs to be pursued with maximum caution to avert environmental contradictions in these fragile ecologies.

The situation of depletion of low SOC due to cultivation is not helped by the common practice in the Karamoja sub-region of removing and burning of plant residues that would otherwise decompose *in-situ* and contribute to SOC stocks as organic matter. This fundamentally signifies that cultivation affects carbon sequestration and provides avenue for increased loss of soil carbon into the atmosphere. Subsequently, the higher soil bulk density in cropland could have been triggered by diminution of SOC resulting from burning of bush and crop residues, in addition to continuous cultivation of the same fields.

Soil organic nitrogen (N). The lack of significant differences in soil N stocks across land use/cover and soil depths in the rangelands of Karamoja sub-region could be attributed to possible intense volatilisation attributed to high and prolonged temperatures caused by droughts; and frequent bush burning aimed at generating new pastures. Liu *et al.* (2020) observed volatilisation to be a major pathway for N loss in dryland ecosystems. Also, Veldhuis *et al.* (2016) indicated that repetitive burning of vegetation cover leads to N loss to the atmosphere through smoke.

The increased N levels in cropland could be attributed to the diversification from mono-cropping of sorghum to other leguminous crops such as beans, soya beans, ground nuts, cow peas in the sub-region (Nakalembe *et al*., 2017). Leguminous plant materials have previously been considered as readily available sources of N (Palm and Sanchez, 1990), these materials could be leguminous plant residues and root nodules. McDermot and Elavarthi (2014), indicated that inter-seeding with leguminous species in rangelands significantly increases total soil N parallel to increase in SOC. This corresponds with the results obtained.

CONCLUSION

The low SOC in cropland is an indication that conversion of the rangeland to cropland significantly reduces soil organic carbon stocks. The high SOC in grassland and woodland implies that limited or no soil cultivation disturbances in addition to decomposition of livestock excreta and parts of foliage increases SOC. A non-significantly different N across the four land use/cover types and depths is an indication that the sub-region experiences relatively uniform environmental effects such as prolonged droughts, fires and anthropogenic rangeland use effects of pastoralism that lead to relative evenness in soil nitrogen distribution across the rangeland biomes.

Owing to decreased soil organic carbon in cropland associated with disturbance from cultivation, there is need to promote sustainable and improved crop cultivation and management practices in Karamoja sub-region without compromising the rangeland's potential and ability to sequester carbon. This can be achieved through controlled rangeland to cropland conversions by introduction of other livelihood sources other than cropping, restoration of degraded croplands through afforestation and tree planting programs, controlled or no burning of crop residuals (can be used as mulch), among others.

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