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Research Article

Herbaceous Layers and their Potentials in Carbon Sequestration and Climate Change Mitigation

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Abstract

Trees and herbs are important components of forests and urban parks have been reported as vital carbon sequesters in terrestrial ecosystems. However, there is limited data on carbon credit of herbaceous plants within the study area. Carbon credit potentials of 1532 herbs belonging to 68 species and 20 plant families were evaluated in ten parks in Joseph Sarwuan Tarka University Makurdi, Benue State, Nigeria. Samples were collected using 1 m^2 quadrats; herbaceous and litter biomass [dry biomass] were determined as 50% of oven dry weight. Total sequestrated carbon [TSC] of herbs was estimated as 50% of dry biomass. Sequestered carbon dioxide equivalent SCO_2E (kg) was assessed using the equation: TSC x 3.67. Soil organic carbon [SOC] was determined by Walkley–black method and subjected to One-way Analysis of Variance [ANOVA]; Tukey-HSD [post-hoc] was done for means separation. The relative richness/diversity of species was estimated using Shannon-Weiner Diversity Index was represented in all 10 parks while recorded the highest species frequency (137). Forestry Park gave the highest species frequency (251). Also, family Poaceae gave the highest family frequency (561), followed by family Asteraceae (295). Veterinary Park gave the highest species diversity index (2.96). Furthermore, NUBESS Park gave the highest herbaceous biomass (0.111 kg), TSC (0.056 kg) and SCO_2E (0.204 kg); while Student Union Park gave the highest herbaceous litter biomass (0.115 kg), TSC (0.057 kg) and SCO_2E (0.21 kg) respectively. The total herbaceous biomass, TSC, and SCO2E of all parks (kg/m^2) were 0.74 kg, 0.37 kg and of 1.37 kg respectively; while the total herbaceous litter biomass, TSC and SCO_2E were 0.46 kg, 0.23 kg and 0.85 kg respectively. Soil organic carbon was significantly different ($P < 0.05$) between NUBESS and Forestry parks. The average SOC of JOSTUM parks was 0.85 g kg^{-1}. JOSTUM parks are a good repository of SCO_2E and SOC, which is indicative of their carbon credit potentials, and should be properly utilized for biodiversity conservation and climate change mitigation.

Keywords: Herbaceous Plants, Urban Parks, Carbon Credit, Climate Change Mitigation

1. Introduction

Climate change, caused largely by anthropogenic activities leading to increase concentration of carbon dioxide [CO_2] and other greenhouse gases [GHGs], is one of the most widely discussed contemporary issues of the new millennium [1]. The Environmental Protection Agency [EPA] posited that effects of climate change on humans and other organisms in the ecosystem were more devastating than Covid-19, hence deserving more attention [2]. The effects of climate change are seen and felt the world over with dramatic increase in natural disasters such as flooding, drought, extreme temperature [heatwaves] and forest fires, causing enormous destruction of lives and properties, and the ecosystem [3, 4].

Carbon sequestration is the capture and long-term storage of atmospheric carbon dioxide [5]. It entails the continuous storage of carbon dioxide or other forms of carbon to mitigate the ever-pressing problem of climate change and global warming [6]. It has been proposed as a cost effective and efficient way of slowing atmospheric and aquatic accumulation of greenhouse gases [6]. In nature, carbon dioxide is sequestered from the atmosphere through various processes including biological, chemical, and physical. Terrestrial ecosystems are major carbon sinks due to photosynthesis and storage of CO_2 in living plants and dead organic matter. Terrestrial carbon sequestration, due to its numerous ancillary benefits such as improved soil and water quality, and restoration of degraded ecosystems, is often termed a win-win or no-regrets strategy [7]. Three principal components of terrestrial carbon sequestration exist – forest, wetland, and soils. Forest carbon is sequestered not only in harvestable timbers, but also in woody debris, wood product and other woody plants encroaching upon grassland and shrubs [7, 8].

Grasslands are also vital for agriculture. A large part of grasslands is used for crop cultivation and as meadows. Animal production is of major economic importance in many states in Nigeria. Apart from the aforementioned, grasslands deliver many other ecosystem services including as repositories of carbon [9]. Much of the above ground biomass in grasslands is eaten by grazing animals and the below ground biomass, including roots, will eventually return to the soil as manure or to the atmosphere via enteric fermentation [10]. Grasslands could therefore be net contributors to CO_2 sequestration and climate change mitigation [9]. The projected increase in CO_2 emission is buttressed by the current Russian-Ukrainian war with its knock-on effect on global energy supply, which has led many nations to reactivate hitherto less desirable 'dirty' energy sources such as coal [11, 12]. The extent to which additional carbon can be taken out of the atmosphere by herbaceous plants and stored in the soil will determine their overall role in mitigating the impact of ever-increasing global carbon dioxide emissions [13, 14].

Urban parks have been highlighted as carbon dioxide sinks [15, 16]. A previous study had elucidated the diversity, importance value indices and carbon credit assessment of parks in Joseph Sarwuan Tarka University Makurdi, Nigeria. Total sequestered carbon [TSC] and sequestered carbon dioxide equivalent [SCO_2E, kg] were estimated as 264.35 kg and 970.16 [tonnes] respectively [17]. Likewise, another study highlighted the carbon credits of trees in urban parks [18]. Within those parks exist plethora of herbaceous plants that were reported as rapid carbon sequesters than their woody counterpart [13]. Consequently, it was imperative to assess the carbon credit of herbaceous plants/soil organic carbon of parks in Joseph Sarwuan Tarka University Makurdi.

2. Materials and Methods

2.1. Study Area/Diversity Index

The study was carried out at various parks in Joseph Sarwuan Tarka University Makurdi, Nigeria (7°47'24.4"N, 8°37'02.9"E). The sampled parks included: Forestry, Fishery, National Association of Science Students [NASS], Food Science and Technology [FST], Engineering, Veterinary [VET], Science, Science Extension, Student Union [SU], and NUBESS. The richness/diversity of species in the various parks was estimated using Shannon-Weiner Diversity Index [19].

2.2. Herbaceous and Litter Biomass

Destructive sampling method was used in evaluating biomass of grasses and herbs by harvesting whole parts of fresh samples within each quadrat (1 m x 1 m), using a sickle. Herbaceous vegetation emerging within the quadrats were cut at the ground level, weighed, and a composite sample was obtained from each quadrat for oven-dry weight determination in the laboratory [20]. Similarly, surface litter was sampled from the sub-quadrats (1 m^2) and composite litter was collected and analyzed following the method of [21]. Herbaceous/litter carbon stock was calculated as 50% of oven-dried herbaceous/litter biomass [22].

2.3. Estimation of Carbon Sequestration

Total sequestrated carbon of herbs [TSC] was estimated as 50% of total dry biomass [dry weight]. Sequestered Carbon dioxide equivalent SCO_2E (kg) was estimated as TSC x 3.67 [22].

2.4. Soil Organic Carbon Stock

The soil samples were collected in each quadrat along the transect line at soil depths of 1 - 15 cm using soil auger. The soil samples were air dried for 24 hours and passed through a 2 mm sieve to separate debris and gravel. The samples were subsequently packed in plastic bags, labelled, sealed, and transported to the soil laboratory. Soil organic carbon [SOC] was determined by Walkley–black method [23].

2.5. Statistical analysis

One-way Analysis of Variance [ANOVA] was carried out using SPSS 25 statistics software. Tukey-HSD [post-hoc] was used for means separation; $P < 0.05$ was considered statistically significant.

3. Results

3.1. Species/Family Distribution and Species Diversity Index

The species distribution and family classification of grasses in the various parks were provided in Table 1. The study recorded 68 herbaceous species belonging to 20 plant families. Synedrella nodiflora was represented in all 10 parks while Sporobolus pyramidalis gave the highest species frequency (137; Table 1). Forestry Park gave the highest species frequency (251) while FST gave the least (91; Figure 1A). Furthermore, family Poaceae gave the highest frequency (561) followed by family Asteraceae (295), while family Labiatae had the least frequency (1; Figure 1B). Species diversity of the individual parks was presented in Figure 1C. VET park had the highest diversity index (2.96) while Forestry Park had the least (2.08).

3.2. Herbaceous Biomass, TSC and SCO_2E

Herbaceous biomass, TSC and SCO_2E of the various park were presented in Figure 2. NUBESS Park gave the highest herbaceous biomass (0.111 kg; Figure 2A), TSC (0.056 kg; Figure 2B) and SCO2E (0.204 kg; Figure 2C) while NASS park gave the least herbaceous biomass (0.045 kg; Figure 2A), TSC (0.023 kg; Figure 2B) and SCO2E (0.083 kg; Figure 2C) respectively.

3.3. Herbaceous Litter Biomass, TSC and SCO2E

Herbaceous litter Biomass, TSC and SCO_2E of the various parks were presented in Figure 3. Student Union Park gave the highest herbaceous litter biomass (0.115 kg; Figure 3A), TSC (0.057 kg; Figure 3B) and SCO2E (0.021 kg; Figure 3C), while Forestry Park gave the least herbaceous litter biomass (0.024 kg; Figure 3A), TSC (0.012 kg; Figure 3B) and SCO2E (0.044 kg; Figure 3C), respectively.

3.4. Soil Organic Carbon (SOC)

Soil organic carbon was significantly different ($P < 0.05$) between NUBESS and Forestry parks. However, there was no significant difference ($P > 0.05$) in SOC between all other parks (Figure 4).

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Table 1: Species and family distribution, park of occurrence and frequency of herbaceous plants in JOSTUM Parks

S/N	Species	Family	Park of Occurrence	Frequency
1	*Acalypha fimbriata*	Euphorbiaceae	8	4
2	*Ageratum conyzoides*	Asteraceae	8, 9	9
3	*Albizia zygia*	Leguminosae	4, 9	2
4	*Amaranthus viridis*	Amaranthaceae	2, 8	3
5	*Andropogon gayanus*	Poaceae	2, 3, 4, 6, 7, 9	70
6	*Asystasia gangetica*	Acanthaceae	3	6
7	*Axonopus compressus*	Poaceae	1, 2, 3, 4, 5, 9	69
8	*Bidens Pilosa*	Asteraceae	6, 7, 10	33
9	*Biophytum petersianum*	Oxalidaceae	1, 6	9
10	*Boerhavia diffusa*	Nyctaginaceae	2, 3, 4, 6	17
11	*Brachiaria lata*	Poaceae	6, 9	21
12	*Calopogonium mucunoides*	Fabaceae	1, 3, 8, 9	10
13	*Commelina benghalensis*	Commelinaceae	4, 7	7
14	*Commelina diffusa*	Commelinaceae	1, 2, 4, 9	18
15	*Corchorus olitorius*	Malvaceae	4, 5, 7, 9, 10	24
16	*Cynodon dactylon*	Poaceae	2, 5, 6	41
17	*Cyperus esculentus*	Cyperaceae	1, 2, 3, 4, 7	24
18	*Dactyloctenium aegyptium*	Poaceae	5, 7, 13	25
19	*Delonix regia*	Fabaceae	6	1
20	*Desmodium scorpiurus*	Papillionoideae	2, 3, 6	28
21	*Desmodium velutinum*	Papillionoideae	1, 2, 4, 5, 6, 7	31
22	*Digitaria longiflora*	Poaceae	10	2
23	*Eleusine indica*	Poaceae	2, 5, 8, 9, 10	47
24	*Euphorbia heterophylla*	Euphorbiaceae	4, 9	4
25	*Euphorbia hirta*	Euphorbiaceae	4, 6, 7, 10	34
26	*Flueggae virosa*	Phyllanthaceae	8, 10	5
27	*Gomphrena celosioides*	Amaranthaceae	2, 3, 4, 6, 7, 9, 10	47
28	*Hyparrhenia rufa*	Poaceae	7	4
29	*Imperata cylindrica*	Poaceae	3, 8	16
30	*Indigofera hirsuta*	Fabaceae	8	7
31	*Kyllinga bulbosa*	Cyperaceae	5	6
32	*Kyllinga pumila*	Cyperaceae	1, 3, 6, 8	31
33	*Kyllinga squamulata*	Cyperaceae	2	23
34	*Laggera aurita*	Asteraceae	1, 5, 6, 7, 8, 10	28
35	*Laportea aestuans*	Urticaceae	4, 8, 9	12
36	*Malvastrum coromandelianum*	Malvaceae	1	62
37	*Mariscus alternifolius*	Cyperaceae	9	6
38	*Mariscus flabelliformis*	Cyperaceae	5	5
39	*Mimosa pudica*	Fabaceae	3	5
40	*Mitracarpus villosus*	Rubiaceae	2, 4, 6, 10	9
50	*Physalis micrantha*	Solanaceae	8	1
51	*Platostoma africanum*	Labiatae	9	1

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52	*Pycerus lanceolatus*	Cyperaceae	5	26
53	*Rottboellia cochinchinensis*	Poaceae	4	2
54	*Schwenckia americana*	Solanaceae	6, 7	3
55	*Sesanum indicum*	Pedaliaceae	10	2
56	*Setaria barbata*	Poaceae	1, 3, 5, 6, 7, 8, 10	75
57	*Sida acuta*	Malvaceae	3, 5, 7, 8	29
58	*Sida corymbosa*	Malvaceae	2, 3, 7, 9	45
59	*Sida garckeana*	Malvaceae	2, 6	7
60	*Sida rhombifolia*	Malvaceae	6, 10	7
61	*Spermacoce ocymoides*	Rubiaceae	6	6
62	*Spigelia anthelimia*	Loganiaceae	2, 8, 10	12
63	*Sporobolus pyramidalis*	Poaceae	1, 3, 4, 5, 8 9	137
64	*Synedrella nodiflora*	Asteraceae	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	94
65	*Tridax corymbose*	Asteraceae	7, 8	8
66	*Tridax procumbens*	Asteraceae	1, 2, 3, 4, 5, 6, 7, 8, 10	65
67	*Vernonia ambigua*	Asteraceae	1, 5, 8	8
68	*Vernonia cinerea*	Asteraceae	1, 4, 6, 9, 10	50

Parks Legend: 1: Forestry; 2: Fishery; 3: NASS; 4: Food Science and Technology (FST); 5: Engineering; 6: Veterinary (VET); 7: Science; 8: Science Extension; 9: Student Union (SU); 10: NUBESS

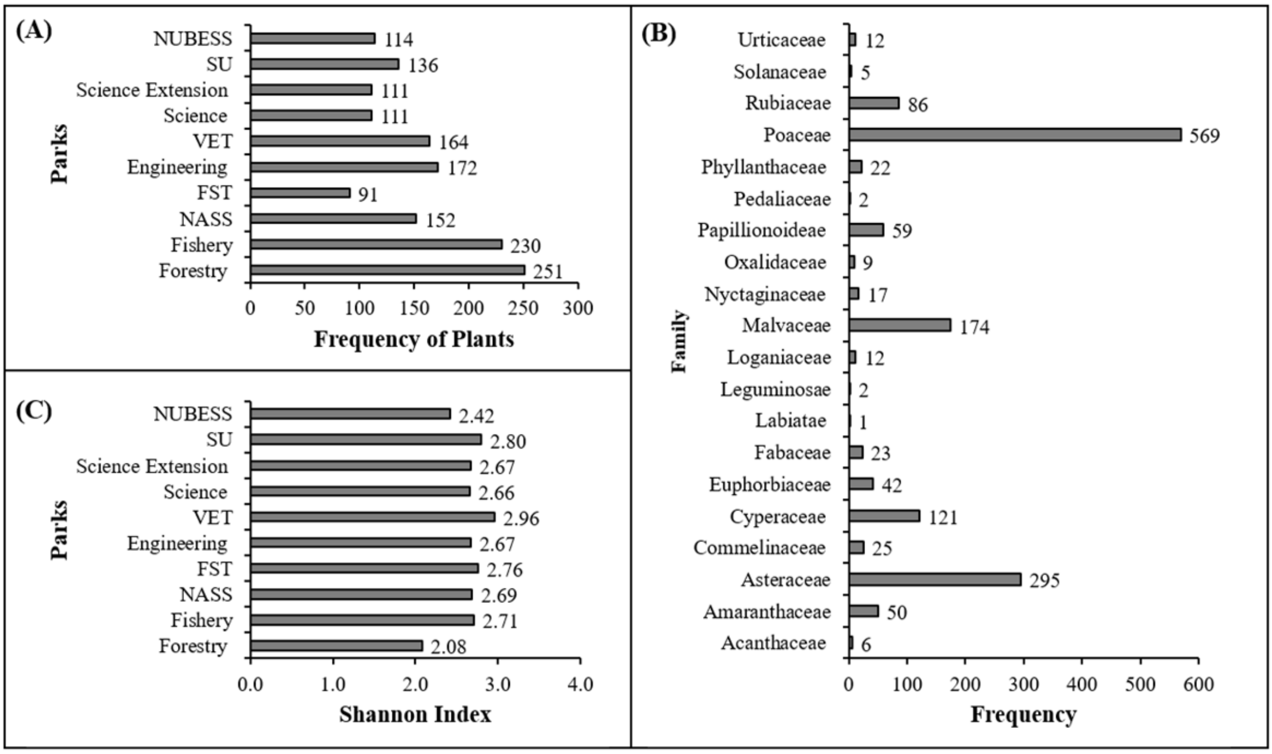

Figure 1: Frequency, family distribution and Shannon Index of herbaceous plants in various parks in JOSTUM. (A) Frequency of plants in parks; (B) Family distribution of herbs; (C) Shannon diversity index of parks.

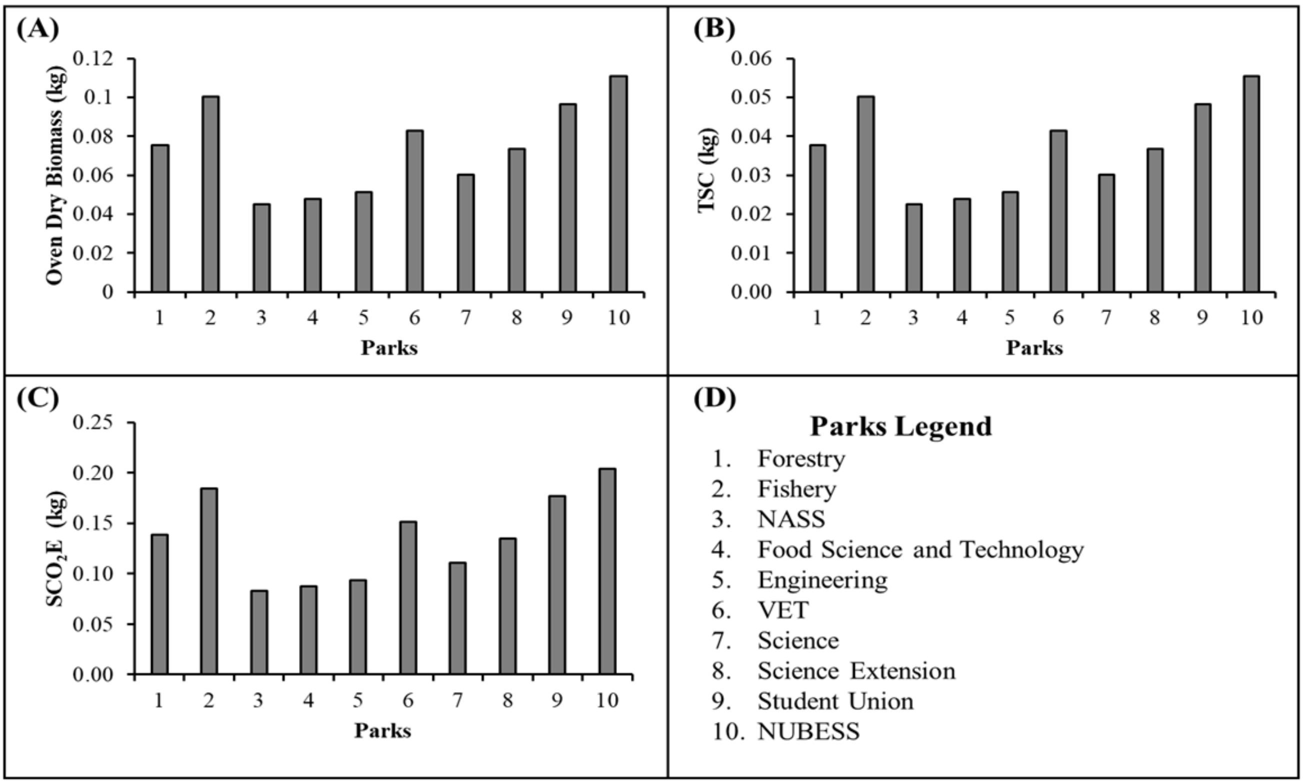

Figure 2: Sequestered Carbon in Herbaceous Biomass in various parks in JOSTUM. (A) Oven Dry Biomass (g); (B)Total Sequestered Carbon, TSC (kg); (C) Sequestered Carbon dioxide Equivalent, SCO_2E (kg); (D) Parks Legend. All values are in kg/m^2

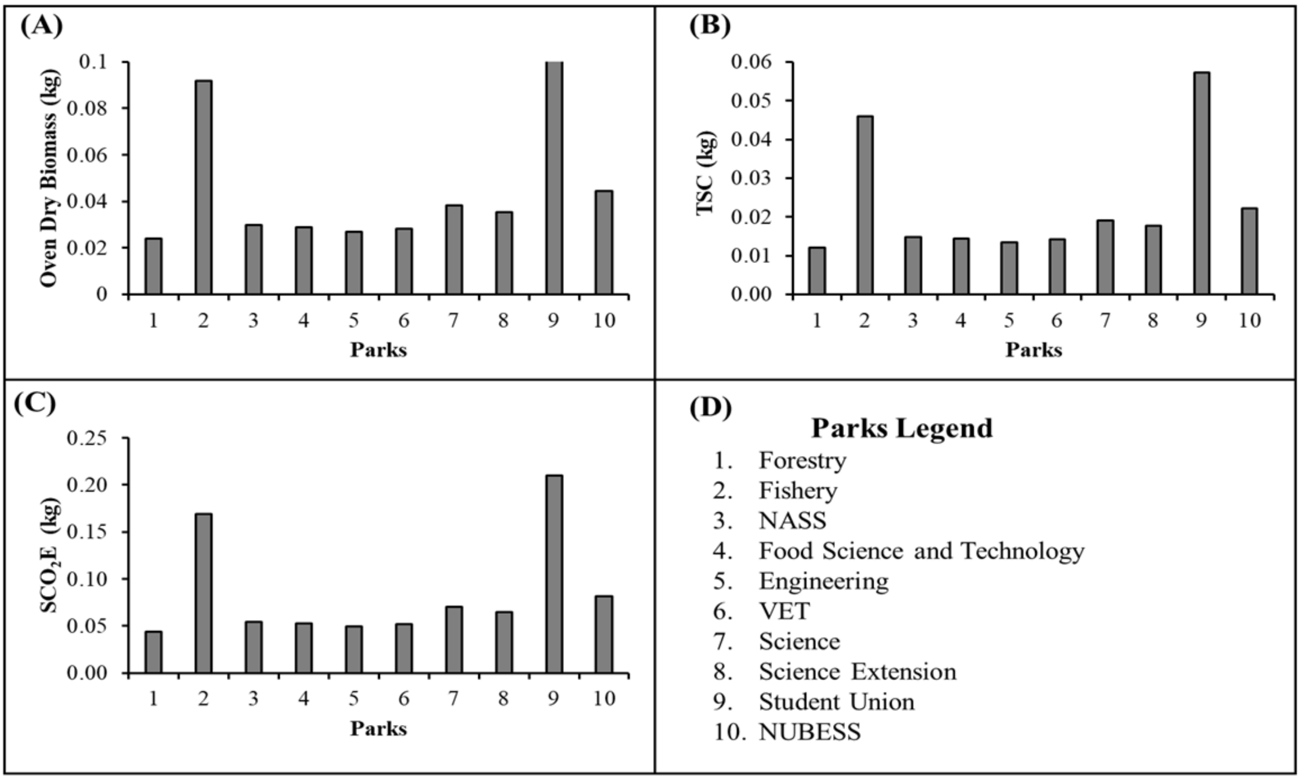

Figure 3: Sequestered Carbon in Herbaceous Litter Biomass in various parks in JOSTUM. (A) Oven Dry Litter Biomass (g); (B) Total Sequestered Carbon, TSC (kg); (C) Sequestered Carbon dioxide Equivalent, SCO_2E (kg); (D) Parks Legend. All values are in kg/m^2

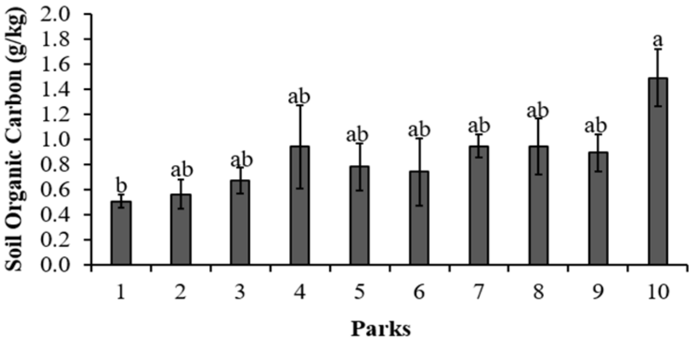

Figure 4: Soil Organic Carbon of the various parks in JOSTUM. Vertical bars represent means; error bars represent standard error of the means; means with the same alphabet are not significantly different (P > 0.05) from each other [Tukey-HSD post hoc]. Parks legend: 1: Forestry, 2: Fishery, 3: NASS, 4: FST, 5: Engineering; 6: VET, 7: Science, 8: Science Extension; 9: Student Union, 10: NUBESS.

4. Discussion

Trees species have been shown to promote the growth of herbaceous species in sub-tropical grasslands by increasing the nitrogen content available to herbaceous plants [24]. That might underpin the large numbers of herbaceous species found in the various parks in the study area and the rich species diversity recorded. Numerous environmental factors interact and affect the abundance of trees and herbaceous species. These complex interactions include rainfall, temperature, soil nutrient, soil texture/structure etc. JOSTUM parks are in guinea savanna ecological zone with moderate rainfall, which supports herbaceous growth. Poor nutrient/soil quality have been shown to promote the distribution of grasses, while trees species grow in nutrient rich and quality soils [25, 26]. Furthermore, canopy gaps have been highlighted to affect herbaceous biomass, diversity, and soil physical properties [27].

JOSTUM parks have a rich mix of small to moderate-sized trees species, thereby allowing suitable canopy gaps for growth of herbaceous species. Consequently, parks with large canopy gaps such as VET and SU, had the highest effective species diversity. Also, family poaceae was the most abundant in the studied parks, taking advantage of the canopy gaps [17]. The highest herbaceous biomass/litter biomass, herbaceous/litter TSC and herbaceous/litter SCO_2E were recorded in NUBESS and Student Union parks respectively. Those parks recorded the highest species occurrence frequencies as well. Accordingly, that could be attributed to their high species diversity and high number of grasses with large vegetative parts that have been designated to sequester more carbon than other herbaceous species [28].

The processes affecting the spatial and temporal fluxes in soil carbon ought to be evaluated to properly highlight the variation of SOC in the studied parks and account for the significant difference observed between NUBESS and Forestry parks. For instance, spatial and vertical distribution of SOC have been reported to vary between climatic zones and biomes [29]. Furthermore, vegetation and soil texture were revealed to significantly influence spatial pattern of SOC distribution [30]. Although the studied parks fall within the same climatic zone, the effects of vegetation and soil texture need to be assessed to understand their roles in variation of SOC between some of the parks. Furthermore, the significant difference in SOC between some parks could be because of the disparity in species richness/composition and its effect on biomass accumulation and soil organic carbon sequestration [31, 32].

5. Conclusion

The carbon credit potentials of 1532 herbs belonging to 68 species and 20 plant families were evaluated in Joseph Sarwuan Tarka University Makurdi parks. The total herbaceous biomass, TSC, and SCO_2E of all parks were 0.75 kg, 0.37 kg, and 1.37 kg respectively; while the total litter biomass, TSC and SCO_2E were 0.46 kg, 0.23 kg, and 0.85 kg respectively. The average SOC of JOSTUM parks was 0.85 g kg 1. JOSTUM parks are a good repository of SCO_2E and SOC, which is indicative of their carbon credit potentials and can be properly utilized for biodiversity conservation and climate change mitigation.

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