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RESEARCH ARTICLE

IMPACT OF LAND USE SYSTEMS ON SOIL MACROFAUNA DIVERSITY AND ABUNDANCE IN NJALA, SIERRA LEONE.

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Abstract

The study presents data on the diversity and abundance of soil macrofauna in Njala, Sierra Leone. Four different land use systems, including secondary forests, polyculture farms, oil palm plantations, and annual crop fields, were sampled for soil macrofauna using three different sampling methods: soil monoliths, line-transect protocols, and pit-fall traps. Earthworms, termites, and ants together made up nearly 94% of all soil macrofauna collected. The diversity and distribution of these three ecologically distinct groups of soil macrofauna were compared. Estimated species richness (diversity) was highest in the oil palm plantation ($p<0.001$) as compared to the other three land uses. The number of individual macrofauna collected (out of 1728 total) was highest in the secondary forest (215 ± 0.18, $p<0.001$) than in the oil palm plantation (163 ± 0.18), the polyculture farmland (113 ± 0.86), and the annual maize plantation (86 ± 0.65). For the various macrofauna species recorded, there were significantly more earthworms (Oligocheate) (0.6864 ± 0.21 individuals/m^2, $p<0.001$) than termites, especially *Amitermes hastatus* (0.4032 ± 0.11 individuals/m^2), *Macrotermes mossambicus* (0.3648 ± 0.04 individuals/m^2), *Macrotermes natalensis* (0.3552 ± 0.25 individuals/m^2), and *Microhodotermes viator* (0.3024 ± 0.29 individuals/m^2). Besides secondary forests, monoculture plantations would be better areas for conservation of not only of aboveground biodiversity, but also of belowground biodiversity.

Introduction:-

Most biodiversity efforts focus on aboveground plant and animal species (Wardle, 2006), but it is well recognized that in most terrestrial ecosystems, the belowground biota supports much greater diversity of organisms than does the aboveground biota, because soils are the central organizing entities in terrestrial ecosystems (Coleman and Whitman, 2005).

A loss of biodiversity and ecosystems functioning through landuse conversion is an important dimension of global change, and one that is intimately linked to the changes in biodiversity in space and time (Chapin *et al.*, 2000; Dewenter *et al.*, 2007). Changes in land use exert great pressure on the natural forests, causing habitat fragmentation

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(Fahrig, 2003), a shift in the range of species, and the possibility of local extinctions (Myers and Knoll, 2001). These changes inevitably have consequences on community diversity, community structure, and ecosystem processes (Vazquez and Simberloff, 2003). These changes, which irrefutably are intensified by agriculture and forestry development, have a profound impact on soil and associated biodiversity (Bignell et al., 2005; Moreira et al., 2008). However, low-intensity landuse systems are important elements of large-scale conservation programmes (Tscharntke *et al.,* 2005).

Soil macrofauna (organisms above 2000µm) are important components of the biodiversity of many ecosystems. These macrofauna include ants, earthworms, termites, amphipods, centipedes, millipedes, snails, slugs, and sometimes mole rats (Kalisz and Powell, 2000). These soil organisms influence the decomposition and biodegradation of organic residues, the dynamics of organic matter in the soil, humification, nutrient release, and physical parameters such as bulk density, porosity, and water availability (Lavelle et al., 2001). The influence of soil fauna on soil structural properties have been considered to be the best long-term indicator of soil quality (Susilo et al., 2004). However, these organisms are impacted upon by human activities such as agriculture and forestry when the ecosystems in which they are found are disturbed. They are a significant component of the belowground biodiversity, which requires proper management for sustainable land use and also for maximum environmental benefits as food for humans, as indicators of habitat quality, as a link to the above ground biodiversity, and as soil modifiers (Brown et al., 2001).

In Sierra Leone, much research on soil macrofauna has not been done. It is against this backdrop that this study was conducted, with the aim of exploring the associations of land use, with soil macrofauna diversity, density, and biomass across four landuse systems in Njala.

Materials and Methods:-

Study Area and Study Sites:-

The study was conducted at Njala University Campus situated in the Kori chiefdom, Moyamba District, Southern Sierra Leone. Four different land use systems were assessed: agricultural ecosystems, agroforestry ecosystems, plantations, and secondary forest ecosystems. The agricultural ecosystems consisted of mainly annual crop fields. Agroforestry practices consisted of polyculture farms and cultivated grass land with plants like *Tectonia grandis* (Teak), *Terminalia ivorensis* (Baji), *Gmelina arborea* (Yemani), *Azadirachta indica* (Neem), *Eucalyptus camadulensis* (exotic), and *Ceiba peatandra* (cotton tree).Secondary forests (or second-growth forests) have re-grown after a major disturbance such as slash-and-burn agriculture, and they tend to have closely-spaced trees and less undergrowth than primary forests. The plantations consist of oil palms, primarily the African oil palm *Elaeis guineensis*.

Faunal sampling:-

Soil monoliths:-

For the sampling of soil fauna, protocols suggested by the Tropical Soil Biology and Fertility programme (TSBF) were followed (Swift and Bignell, 2001). Soil monoliths (25cm x 25cm x 30cm) were removed by digging out the soil. Sampling was done on the 4 land use systems within the four main ecosystems described above. In each land use type, four spatially different plots were taken. From each plot, four soil monoliths were taken randomly, making a total of 16 samples of each land use type. Soil was placed over a polythene sheet, and soil macrofauna were hand sorted and preserved in alcohol.

Initially, soil fauna were grouped into higher taxonomic levels *(i.e.,* supra-specific taxa, including families and above), then detailed taxonomic and community composition studies were attempted for three major groups of soil invertebrates (ants, earthworms, and termites). For the remaining groups, only higher taxonomic order was considered. Sampling was conducted from August 2015 to October (in the rainy season) 2015.

Pit fall trapping:-

A total of 8 pit fall traps were placed in each land use type studied. Each had a 10 cm mouth diameter and 15 cm depth. The traps were placed in such a way that the rim of the bottle was not projecting out of the ground surface. Water was added to the bottle along with a bit of detergent in order to reduce surface tension and prevent the escape of organisms from the trap.

Line transect for termite sampling:-
In addition to the hand sorting method for collecting termites, a one-time line transect sampling method was also employed for termites. Each transect was 40 m long and 2.5 m wide, and divided into 10 contiguous sections, each 4 m x 2.5 m in area. Each section was sampled for one hour. Within each section, the following microhabitats were searched: surface soil up to 10 cm depth, dead logs, dead branches and twigs, mud plaster on dead logs, and tree stumps. All castes of termites were collected if present. Care was taken to collect the soldier caste, as they are required for identification. The collected termites were kept in vials containing 80 per cent alcohol and labelled with the section number.

Data Analysis:-
Data collected were analyzed using the statistical analysis system (SAS, version 6.12). Output was presented as summary statistics in the form of frequency tables and bar charts. Post hoc means separation was then carried out where necessary using analysis of variance (ANOVA) and the Student-Newman-Keuls test with a significance level of alpha = 0.05.

Results and Discussion:-

Soil macrofauna recorded across the various landuses:-
During the study, different types of landuse systems with varying land-use intensifications were sampled for soil macrofauna. The landuse systems vary in cropping pattern, management, inputs, and landuse conversion history. This includes pure agriculture at one end to secondary forest at the other end. In total, 1728 soil macrofauna comprising ten (10) families were recorded in this study, with eight (8) identified to species level (Table 1). There was a significant (*P = 0.0001*) interaction between landuse (sites) and soil macrofuana species, implying significant differences in macrofauna species composition among the four landuse practices. The secondary forest had the highest (215; 1.0320 ± 0.18 individuals per square meter) in terms of macrofuana individuals and corresponding density, followed by the oil palm plantation (163; 1.0320 ± 0.18 individuals/m^2), the polyculture farmland (113; 0.5424 ± 0.86 individuals/m^2), and the annual maize crop plantation (86; 0.4148 ± 0.65 individuals/m^2). This result corresponds with the findings of Conacher *et al*. (2011), in which highest biomass values were typically recorded from sites located in rainforest regions or secondary forest in Honduras. Soil macrofauna densities found in this study were similar to those noted by Barros *et al.* (2002) in the Brazilian Amazon, and by Decaëns *et al.* (1994) in the eastern plains of Colombia.

In terms of macrofauna species richness, there were more species in the oil palm plantation (13; -2.1854 ± 0.11) than in the secondary forest (11; -1.9470 ± 0.13), polyculture farmland (9; -1.7938 ± 0.13), and maize crop plantation (9; -1.7515 ± 0.13). This result corresponds with the findings of (Ayuke, 2000), in which the agroecosystems of both Embu and Taita were found to be richer in macrofauna diversity and abundance than forest ecosystems. A popular assumption is that the richness and abundance of soil fauna increase with the increasing heterogeneity of the systems and decreasing disturbances. However, the results of this study seem to contradict this assumption about soil species richness. Mujeeb (2010) found no statistically significant difference in richness of supra-specific taxa across habitats, with the mean number of taxa and the total number of individuals (abundance) increasing from agricultural systems to natural forest.

Table 1:-Soil macrofuana recorded in the study areas

Family	Species	Site 1: Annual crop (Maize) plantation	Site 2: Oil palm plantation	Site 3: Secondary forest	Site 4: Polyculture farmland
Formicidae	Tetramorium capense	01	0	03	0
	Plectroctena mandibularis	0	14	25	09
	Camponotus fulvopilosus	03	0	01	0
Termittidae	Amitermes hastatus	10	30	32	12
	Macrotermes natalensis	18	20	15	21
	Macrotermes mossambicus	15	19	25	17

Hodotermidae	Microhodotermes viator	13	16	20	14
	Pteronia spp.	09	10	23	10
Oligocheate	Earthworm	14	35	68	26
Gryllacrididae	Cricket	0	01	0	01
Drilidae	Selasia pulchra	0	05	0	0
Nicdetidae	Silverfish	0	01	0	0
Japygidae	Bristletail	0	06	01	0
Chilopoda	Centipede	03	02	02	0
Diplopoda	Millipede	0	03	0	03
No. of individuals		**86**	**162**	**215**	**113**
Species richness		**09**	**13**	**11**	**09**
Shannon-Weiner Index (H')	P = 0.0001	**-1.7515** ± 0.13[B]	**-2.1854** ± 0.11[A]	**-1.9470** ± 0.13[B]	**-1.7938** ± 0.13[B]

Soil macrofauna species recorded:-

For the various macrofauna species recorded, there were significantly (*P = 0.0001*) more earthworms (Oligocheate) (0.6864 ± 0.21 individuals/m^2), followed by termites, especially *Amitermes hastatus* (0.4032 ± 0.11 individuals/m^2), *Macrotermes mossambicus* (0.3648 ± 0.04 individuals/m^2), *Macrotermes natalensis* (0.3552 ± 0.25 individuals/m^2), and *Microhodotermes viator* (0.3024 ± 0.29 individuals/m^2) (Table 2). Earthworms, termites, and ants together made up nearly 94% of all soil macrofauna sampled. Other soil macrofauna comprised 6% of all soil macrofauna biomass. Across the various landuse types, there were more earthworms, termites, and ants in the secondary forests than the other landuse systems (Figure 1). Other studies have also found these groups to be amongst the dominant soil macrofauna taxa (Mathieu *et al*. 2004, Rossi *et al*. 2006). The highest densities of termites and ants are likely to lead to networks of underground tunnels that allow infiltration of water and air and create channels for root growth. The burrowing habits of earthworms are also likely to increase soil macroporosity. Earthworms feed on soil organic matter, which speed up decomposition and nutrient cycling. The high densities of these organisms found in this study are likely to have an important effect on soil quality and soil macromorphology.

Table 2:-Soil macrofauna species recorded

Macrofauna species	Number of individuals	Density (Individuals/m^2)
Tetramorium capense	12	0.0192 ± 0.13[GHI]
Plectroctena mandibularis	144	0.2304 ± 0.95[F]
Camponotus fulvopilosus	12	0.0192 ± 0.13[GHI]
Amitermes hastatus	252	0.4032 ± 0.11[B]
Macrotermes natalensis	222	0.3552 ± 0.25[C]
Macrotermes mossambicus	228	0.3648 ± 0.04[C]
Microhodotermes viator	189	0.3024 ± 0.29[D]
Pteronia spp.	156	0.2496 ± 0.61[E]
Oligocheate (earthworm)	429	0.6864 ± 0.21[A]
Gryllacrididae (cricket)	06	0.0096 ± 0.52[HI]
Drilidae (Selasia pulchra)	15	0.0240 ± 0.23[GH]
Nicoletiidae (silverfish)	03	0.0048 ± 0.45[I]
Japygidae (bristletail)	21	0.0336 ± 0.26[G]
Chilopoda (centipede)	21	0.0336 ± 0.14[G]
Diplopoda (millipede)	18	0.0288 ± 0.17[G]
Total	**1728**	
P-values		***P = 0.0001***

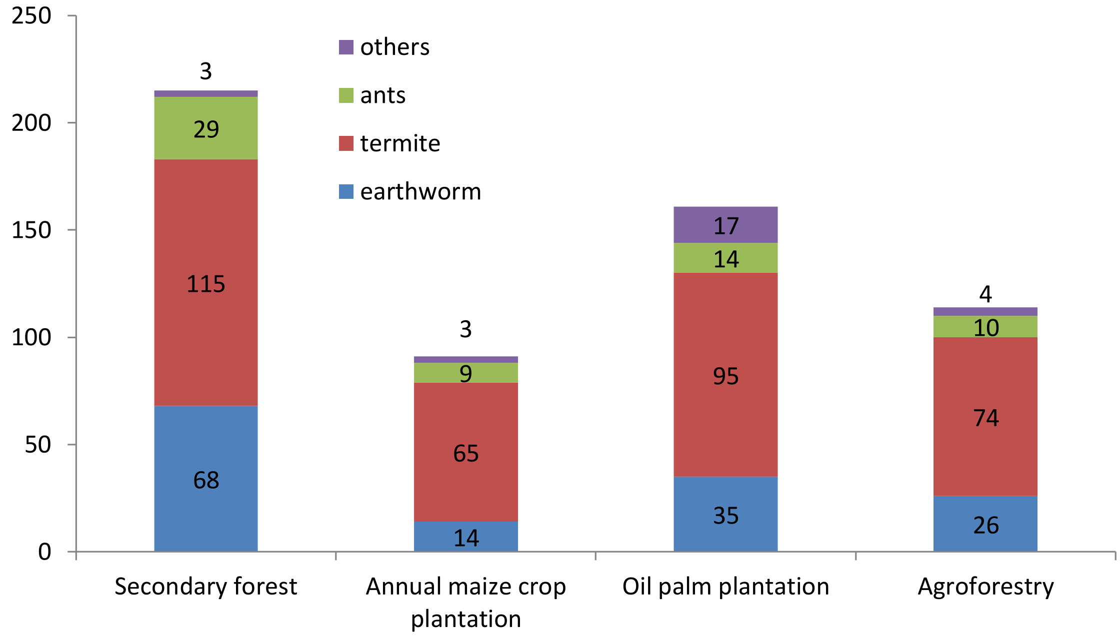

Figure 1:-Soil macrofauna species (Individuals/m^2) among the various landuse systems in the study area

Implications for Conservation:-

Secondary forests and tree plantations are of particular importance for biodiversity conservation, as their coverage is rapidly expanding in the tropics (Barlow.*et al.*, 2007). Conceptually, and also based on the result obtained, the sampled habitats are represented in terms of production or conservation aspects.

Agriculture systems aim mainly for production, while natural and secondary forests are considered valuable for conservation and protection of wild habitats and biodiversity. Agroforestry and plantations have mixed use goals and value sustainable production that can be enhanced by healthy populations of macro fauna.

Conclusion:-

Besides the secondary forests, monoculture plantations and agroforests are areas where conservation of both aboveground biodiversity and belowground biodiversity should be promoted. The depletion of pristine habitats and patterns of accelerated landuse conversion, raised concerns about macro fauna biodiversity.

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