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CONSEQUENCES OF PROLONGED AGRONOMIC PRACTICES: FAUNAL COMPOSITION AND ABUNDANCE IN CULTIVATED AND FALLOWED SOILS

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Abstract

Composition and abundance of soil fauna were compared between continuously cultivated and fallowed soils with a view to determining the impact of prolonged agronomic activities on biodiversity. The cultivated soils had been under continuous use for over a decade for arable crop production whereas the fallowed soils had been undisturbed for about twenty years. Soil samples were collected from selected plots using a soil auger and standard methods were applied in the laboratory to extract different types of soil fauna. Pitfall traps were also set up in the plots to collect surface-dwelling arthropods. Members of three phyla were identified in the study, namely, Annelida, Arthropoda (Class Arachnida, Chilopoda, Diplopoda, Entognatha, Insecta, Malacostraca, Pauropoda) and Nematoda (Class Adenophorea, Enoplea, Secernentea, Tylenchoidea). Nematodes were the most abundant fauna (50.7%) in sampled soils followed by Collembola (Entognatha) (15.2%) and Acari (Arachnida) (12.3%) while Pseudoscorpionida (Arachnida) (0.1%) was the least abundant. Generally, fallowed soils were significantly richer in soil fauna compared to cultivated ones. It was concluded that agronomic practices, especially on a continuously-cropped soil, would have a negative impact on faunal biodiversity. Environment-friendly farming systems that entail minimum tillage of the soil, adoption of non-chemical pest control strategies and regular soil tests were suggested as viable ways of conserving faunal biodiversity.

Keywords: *Biodiversity; Minimum tillage; Non-chemical pesticides; Soil fauna; Species abundance.*

Introduction

Human activities cause wholesale transformation of the local environment, affecting it at a fundamental level by altering habitat, climate, hydrology, and primary production [1, 2]. An important consequence is change in the composition of species assemblages, generally reducing native species richness across plant and animal taxa [3, 4]. Prominent ecologists had been warning of a massive human-caused extinction event since the 1970s, giving a dire prognosis. Meyers [5] suggested that we might be losing as many as 40,000 species a year whereas Wilson [6] speculated that extinction rates might be between 27,000 and 100,000 species per year. Although these alarming estimates have come under considerable criticism in recent decades [7], loss of biodiversity remains a major concern. The 2010 target to achieve a significant reduction in biodiversity loss was never attained. The resolution was first adopted by EU Heads

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of State in June 2001 and later endorsed by the World Summit on Sustainable Development and the United Nations General Assembly in 2002 [8]. Across the globe, natural systems that support economies, lives and livelihoods are at risk of rapid degradation, with significant further loss of biodiversity becoming increasingly likely.

Biodiversity and soil are strongly linked because soil is the medium for a large array of organisms [9]. Soil fauna is an important measurement for biodiversity and because the organisms play essential roles in several soil ecosystem functions, they are often used as a measure of soil quality. The common soil fauna belong to phyla Annelida, Arthropoda, Nematoda and Protozoa, and they participate actively in decomposition of organic matter, formation of humus and recycling of many nutrient elements such as carbon, nitrogen and sulphur [10, 11]. Farmers rely on these and other services provided by the ecosystems to produce food that we eat every day. However, the yearly addition of 67.5 million people [12] poses many extremely difficult challenges for human beings, especially in producing adequate supplies of food without damaging our environment. In order to obtain higher yields per unit time and area, farmers adopt intensive cropping practices such as monoculture, continuous cropping and conventional tillage [13]. Historically, farmers have alternated cultivation with long fallow periods or rotations with other crops to manage soil fertility. In response to rising demand for food and reduced space for agricultural expansion, farmers have shortened or abandoned fallow periods and crop rotations in favor of continuous production [14]. While the ability to produce two or three crops per year on a single plot has significantly increased global food supply, continuous cropping can have detrimental impacts on soil conditions. It reduces soil fertility due to nutrient mining and it encourages pesticide use with the accompanying adverse effects on biodiversity.

Production of sufficient food and conservation of biodiversity are both critical to ensuring human welfare in the face of ever-shrinking resources. We hypothesized that agricultural ecosystems undergo a significant loss of biodiversity as a result of intensive agricultural practices. This study was, therefore, aimed at quantifying the impact of continuous cultivation on biodiversity using the Obafemi Awolowo University Teaching and Research Farm, Nigeria as a case study.

Materials and Methods

Study site

Sampling was carried out at the Obafemi Awolowo University Teaching and Research Farm (7°28'06"N, 4°33'22"E, 224m above the sea level) in Osun State with a land area of approximately 1400ha. It falls within the tropical evergreen rainforest (TER) region of southwestern Nigeria and the rainfall pattern is bimodal with peaks in June and September [15]. The vegetation of TER is characterized by tall trees with dense undergrowth of shorter species dominated by climbing plants.

Sampling plots

Two experimental plots, each measuring 100m × 50m, were chosen from portions of the farm that had been continuously cropped with cowpea, maize, okra and leafy vegetables for over a decade. Usually, the soil was ploughed and harrowed at the beginning of each planting season and chemical products such as insecticides and fertilizers were often applied to ensure optimal yield. Two other plots, of similar size, were selected from portions that had been left uncultivated for about two decades. The resulting secondary forest is dominated by trees of different strata (emergent, canopy, understory) alongside climbers, shrubs and leaves litter which makes up the forest floor. The four plots were at least 100m away from one another and four sampling points were selected randomly within each plot, giving a total of sixteen points per replicate. There were three replicates in the study and they were separated by at least 500m from one another.

Sampling and extraction techniques

a. Soil and litter sampling

An auger was used to take soil samples from each sampling point for Berlese-Tullgren funnel extraction of fauna in the laboratory. The soil, with the surface litter, was taken to a depth of 15cm. Another sample was collected from each sampling point, using the auger in a similar manner, for extraction of nematodes in the laboratory. The third soil sample collected from each point was for the extraction of macro- and megafauna by handpicking. The collection was made by digging a soil core of 16cm × 16cm × 16cm. All soil samples were kept in well labeled black polythene bags before being taken to the laboratory.

b. Pitfall trapping

White plastic bowls, 80mm high and 130mm wide at the rim, were used for pitfall traps to capture surface-dwelling and crawling soil fauna. They were placed in each sampling point and half-filled with 70% ethanol. The rim of each bowl was made to flush with soil surface to ensure that movement of soil fauna was not hindered by it. The traps were removed from the field after six days and the contents were poured into labelled containers for sorting in the laboratory. Captured fauna were sorted into separate taxa, under a dissecting microscope, and representatives of each taxon were counted and recorded.

c. Berlese-Tullgren funnel extraction

This is a popular method for extracting soil and litter arthropods [16]. The collected soil samples were poured into metal cups sitting directly on smooth-surfaced metal funnels and the electric bulbs suspended above the samples were powered. Each cup had wire mesh at its base, just big enough for the fauna, and the setup was left undisturbed for 72h. The device exploits the general tendency of soil and litter arthropods to actively avoid increased temperatures, desiccation, and high light levels. A temperature and moisture gradient is established within the sample, driving organisms downwards and into a collection container at the base of each funnel, filled with 70% ethanol. The content of each collection container was examined under the microscope and soil fauna were separated into different taxa and quantified accordingly.

d. Baermann's method of nematode extraction

The field-collected soil samples were subjected to modified Baermann's method of nematode extraction as described by Adekunle [17]. Facial tissues were placed in-between a pair of clean plastic sieves and 250mL soil sample was poured into the upper sieve. Clean water (500 mL) was poured into a modified Baermann extraction tray and the sieves with the soil sample were then placed in the extraction tray. This procedure was replicated for each soil sample and each set-up was left undisturbed for 24h. The resulting nematode suspension in each tray was poured through a 28μm sieve to collect the extracted nematodes. The trapped nematodes in the sieve were then washed into a 50 mL beaker with clean water and left undisturbed for 5 h. The nematode suspension was concentrated to about 20-25mL by removing excess water. The recovered nematode population was counted under a microscope using the counting dish. The nematodes were sorted into distinct classes and genera using standard keys prepared by Mekete et al [18] and lucid keys described by Bell [19].

e. Handpicking

Each soil sample was spread on a table where it was thoroughly examined for soil fauna. Macro- and megafauna present in each sample were picked using a pair of forceps. The soil fauna were categorized into appropriate taxa and representatives of each category were counted. Soil fauna that were not sorted immediately were preserved in vials containing 70% ethanol.

f. Statistical analyses

Number of fauna, per taxon, extracted from each soil sample was subjected to natural log transformation before analysis of variance (ANOVA) was carried out using SAS v. 9.0 [20]. The ANOVA was followed by comparison of mean values between fallowed and cultivated plots using Tukey's Studentized Range (HSD) Test at $p < 0.05$.

Results and Discussion

Relative abundance of different faunal taxa in sampled soils

The relative abundance of members of three phyla identified in sampled soils of the University Teaching and Research Farm is presented in Table 1. The nematodes (50.7%) were the most abundant soil fauna followed by Collembola (15.2%) and Acari (12.3%) in descending order while Pseudoscorpionida (0.1%) was the least abundant. This is in agreement with Harding and Studdart [21] and Samways [22] who reported that nematodes, springtails (Collembola) and mites (Acari) predominate in total numbers, biomass and species of fauna in soil. The numerical dominance of nematodes, often exceeding a million individuals per square meter, and their presence at various trophic levels point at an important role they play in many ecosystems [23]. Phylum Annelida had the lowest proportion of soil fauna (0.8%) and this corroborates an earlier report made by Neher [24].

Table 1. Relative abundance of soil fauna in sampled soils at the Obafemi Awolowo University Teaching and Research Farm, Ile-Ife, Nigeria.

Phylum	Class	Subclass/Order	Abundance (%)
Annelida	Oligochaeta	NI	0.8
Arthropoda	Arachnida	Acari	12.3
		Araneae	1.3
		Pseudoscorpionida	0.1
	Chilopoda	NI	2.1
	Diplopoda	NI	0.7
	Pauropoda	NI	0.5
	Entognatha	Collembola	15.2
		Diplura	0.8
	Insecta	Coleoptera	5.7
		Hymenoptera	9.1
		Isoptera	0.5
	Malacostraca	Isopoda	0.2
Nematoda	Adenophorea	NI	50.7
	Enoplea	NI	
	Secernentea	NI	
	Tylenchoidea	NI	

NI: Identification was not made at the subclass or order level.
The extracted hymenopterans were ants (Formicidae).

Comparative faunal abundance in cultivated and fallowed soils

A significant agronomic effect was found in the number of soil fauna collected from cultivated and fallowed plots of the farm. The only exceptions were recorded for Acari and Isopoda where the population of collected fauna did not vary significantly between the two types of plots, irrespective of extraction technique used (Table 2). There was no replicate effect ($p > 0.05$) on the number of fauna extracted from collected soil samples. Apart from the annelids, isopods and nematodes, other soil fauna were obtained using more than one extraction technique and wherever applicable, Berlese-Tullgren funnel extracted smaller cohorts. The average number of soil fauna extracted using the four techniques were also separated with respect to soil type (Table 3).

a. Pitfall trapping

The population of Pseudoscorpionida ($p < 0.001$), Isoptera ($p < 0.01$), as well as Collembola and Diplopoda ($p < 0.05$) varied significantly between the two plot types. On the other hand, the presence of other faunal taxa was comparable ($p > 0.05$) between fallowed and cultivated soils of the Teaching and Research Farm. Where significant differences were evident, faunal population was higher in fallowed plots than in the cultivated plots.

Table 2. Mean square values for soil fauna obtained from sampled soils using four extraction techniques.

Soil fauna	Pitfall trapping	Berlese-Tullgren funnel	Baermann's method	Handpicking
Annelida	-	-	-	5.74***
Acari	1.80	4.98	-	-
Araneae	0.21	-	-	5.29*
Pseudoscorpionida	2.66***	4.29***	-	-
Chilopoda	0.09	6.04***	-	10.49***
Diplopoda	3.36*	1.24	-	2.64
Pauropoda	0.23	6.99*	-	0.20
Collembola	18.72*	7.49	-	-
Diplura	0.67	5.88***	-	11.01***
Coleoptera	5.60	-	-	1.39***
Hymenoptera	0.10	-	-	0.54**
Isoptera	8.58**	-	-	2.91*
Isopoda	-	-	-	1.31
Nematoda	-	-	3.01*	-

*, **, *** Significant F-test at 0.05, 0.01 and 0.001 levels of probability, respectively.

Table 3. Average number of soil fauna extracted from selected fallowed and cultivated soils of the Obafemi Awolowo University Teaching and Research Farm, Nigeria.

Soil fauna	Pitfall trapping		Berlese-Tullgren funnel		Baermann's method		Handpicking	
	Fallowed soil	Cultivated soil	Fallowed soil	Cultivated soil	Fallowed soil	Cultivated soil	Fallowed soil	Cultivated soil
Annelida	-	-	-	-	-	-	18.13a	4.83b
Acari	2.50a	0.85a	91.00a	79.00a	-	-	-	-
Araneae	13.67a	15.00a	-	-	-	-	1.58b	6.63a
Pseudoscorpionida	1.50a	0.00b	2.38a	0.00b	-	-	-	-
Chilopoda	4.13a	5.92a	3.63a	0.17b	-	-	8.25a	2.00a
Diplopoda	4.50a	1.50b	1.88a	0.58a	-	-	3.88a	1.00a
Pauropoda	0.63a	0.17a	8.50a	3.42b	-	-	0.50a	0.08a
Collembola	67.86a	13.75b	92.13a	55.17a	-	-	-	-
Diplura	4.00a	5.92a	4.00a	0.42b	-	-	6.88a	1.25a
Coleoptera	42.58a	112.38a	-	-	-	-	9.17b	17.25a
Hymenoptera	64.67a	67.63a	-	-	-	-	14.92b	21.13a
Isoptera	6.00a	0.33b	-	-	-	-	3.75a	0.17b
Isopoda	-	-	-	-	-	-	2.00a	0.00a
Nematoda	-	-	-	-	637.13a	336.33b	-	-

For each method of extraction, values having similar alphabets in the same row are not significantly different at 0.05 level of probability.

b. Berlese-Tullgren funnel extraction

Significant differences ($p < 0.001$) were recorded in the number of *Pseudoscorpionida, Chilopoda* and *Diplura* collected from the two experimental soil types. Similarly, the number of Pauropoda varied ($p < 0.05$) between the cultivated and fallowed portions. In each case, just like with pitfall trapping, the population of members of each taxon was higher in fallowed plots.

c. Baermann's method of nematode extraction

Nematode population varied significantly ($p < 0.05$) between fallowed and cultivated plots of the farm. The fallowed plots had a higher number of nematodes (637) than the cultivated plots (336).

d. Handpicking

This method, like pitfall trapping, helped in extracting a larger number of taxa compared with Berlese-Tullgren funnel and Baermann's techniques. The population of Annelida, Chilopoda, Coleoptera and Diplura differed significantly ($p < 0.001$) between fallowed and cultivated plots. In addition, members of the Orders *Hymenoptera* ($p < 0.01$), *Araneae* ($p < 0.05$) and *Isoptera* ($p < 0.05$) varied significantly between the two types of plots. There were more annelids and isopterans in fallowed soils while araneids, coleopterans and hymenopterans were more abundant in cultivated soils.

The significant reduction in population of soil fauna (Acari, Annelida, Chilopoda, Collembola, Diplopoda, Diplura, Isopoda, Isoptera, Nematoda, Pauropoda, and Pseudoscorpionida) in cultivated plots could be attributed to prolonged agronomic activities that the plots had been subjected to. This corroborates the work of Bedano et al [25] which reported a higher number of soil fauna in fallowed soils compared to cultivated ones. Cultivated soils at the Teaching and Research Farm had been subjected to frequent soil tillage and application of synthetic chemical products such as pesticides and fertilizers. This was more intense during the cowpea planting seasons as the crop is often severely attacked by insect pests at every stage of its growth [26] and its production cannot be successful without insecticide application [27, 28]. Continuous application of synthetic chemicals, without a conscious effort to improve the soil health, would invariably lead to soil pollution with adverse consequences on biodiversity. Many synthetic chemical products are toxic to soil fauna because they alter soil conditions [29].

A large number of araneids, coleopterans and hymenopterans (Formicidae) are carnivores, feeding on other organisms that are attracted to cultivated crops. Some of them also feed on by-products of their preys. For instance, aphids are major pests of cowpea and they produce honeydew which serves as an important source of sugar for ants. The need to be near food sources, among other factors, explains why these arthropods were more abundant in cultivated plots. Kosmas et al [30] was of the opinion that Formicidae would always be found in a cultivated farmland irrespective of pesticide application. The build-up of predatory araneid population in cultivated plots may also be due to abundance of ants, beetles and orthopterans that served as suitable preys.

Conditions in the fallowed plots supported a higher number of nematode genera and higher nematode population (not shown) per genus (Table 4).

Table 4. Genera of nematodes found in sampled soils of the Obafemi Awolowo University Teaching and Research Farm, Nigeria

Class	Genus	Fallowed soil	Cultivated soil	Mode of existence	*Damage potential
Adenophorea	Dorylaimellus	+	+	Parasitic	NA
	Hirschmaniella	+	+	Parasitic	NA
	Mononchus	+	+	Free living	NA
	Tylenchus	+	+	Parasitic	Low
Enoplea	Longidorus	+	+	Parasitic	High
	Xiphinema	+	-	Parasitic	High
Secernentea	Belonolaimus	+	-	Parasitic	Moderate-high
	Dolichodorus	+	+	Parasitic	Moderate-high
	Helicotylenchus	+	+	Parasitic	Low-moderate
	Hemicycliophora	-	+	Parasitic	Low-moderate
	Meloidogyne	+	+	Parasitic	High
	Panagrolaimus	+	+	Free living	NA
	Paratylenchus	+	+	Parasitic	Low-moderate
	Radopholus	+	+	Parasitic	Moderate
	Rhabditis	+	+	Free living	NA
Tylenchoidea	Ditylenchus	+	+	Parasitic	Low-moderate

* Source: [19]; NA: not available; +, - signify presence and absence of nematodes in sampled soils, respectively.

There were a total of 15 genera in fallowed plots compared to 14 in cultivated ones. The class Secernentea was represented by more genera while Tylenchoidea had just one genus. This was not unexpected because Secernentea is the main class of nematodes; its members are characterized by numerous caudal papillae and an excretory system possessing lateral canals. Apart from genera Mononchus, Panagrolaimus and Rhabditis which have free living members, others are parasitic in nature. Indeed, out of over 25,000 nematode species that have been identified so far, more than half are parasitic [31, 32]. Depending on the species, a nematode may be beneficial or detrimental to plant health. Many free living nematodes are predatory and they kill garden pests like cutworms and corn earworm moths while the parasitic ones attack plants and occasionally transmit viruses between crop plants [33]. Nematodes do not decompose organic matter but they can effectively regulate bacterial population and community composition, eating up to 5,000 bacteria per minute. Also, they play an important role in the nitrogen cycle by way of nitrogen mineralization [34].

Conclusions

The outcomes of this work support our hypothesis convincingly and indicate that unceasing cultivation of a piece of land, without taking conscious precautions to improve the soil quality, affect faunal biodiversity negatively. The importance of agriculture to human existence cannot be overemphasized but there is a need to maintain a balance between agricultural practices and conservation of biodiversity. Although soil tillage practices are crucial to optimum yield, excessive and frequent turning of the soil can lead to a reduction in faunal population [35]. In the same vein, a careless application of pesticides and fertilizers could make these agents of optimal yield produce adverse effects on diversity and species abundance of soil fauna [36]. Therefore, to achieve good agricultural output while conserving biodiversity at the same time, efforts should be taken to ensure minimum soil disturbance. This could be attained by embracing innovative minimum tillage practices such as rotational and strip tillage, and applying environment-friendly pest control strategies such as biological control as an alternative to chemical application. Regular soil tests would also help in monitoring soil health and serve as a guide to timely soil amendment whenever necessary. This way, both health status of the soil and faunal biodiversity would be optimized.

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