Vol. 16(1), pp. 1-10, January-March 2024
DOI: 10.5897/IJBC2023.1604
Article Number:6D9A72E71716
ISSN 2141-243X

http://www.academicjournals.org/IJBC

ACADEMIC JOURNALS
expand your knowledge

International Journal of Biodiversity and Conservation

Full Length Research Paper

Soil physicochemical properties and macroarthropod abundance across two segments of a temperate forest in Darma Valley, Kumaun Himalaya, India

Priya Bisht[1], Pardeep Kumar Sharma[2], Narendra Singh Lotani[1], Chandra Singh Negi[1]*

[1]Ecology and Biodiversity Laboratory, Department of Zoology, M B Government Postgraduate College, Haldwani (Nainital)- 263139, Uttarakhand, India.
[2]Institute of Mountain Environment, University of Jammu Bhaderwah Campus, Jammu and Kashmir- 182222, India.

Received 13 August, 2023; Accepted 4 January, 2024

The study focused on soil macroarthropods, exploring their characteristics, environmental interactions, and role in soil nutrient dynamics—a subject that has been relatively understudied. To fill this gap, research was conducted in a temperate forest of Darma Valley, District Pithoragarh, Kumaun Himalaya, India. The forest was divided into two segments: A (disturbed) and B (undisturbed), based on anthropogenic pressure related to tree felling and lopping. The study spanned three months (July to September) over two consecutive years, 2020 and 2021. Soil properties, including soil organic carbon (SOC), total nitrogen (TN), available nitrogen (AN), available phosphorus (AP), soil moisture content (SMC), and pH, were analyzed. Data analysis employed techniques such as analysis of variance, total abundance, relative abundance, and correlation. The findings revealed significant differences in SMC, SOC, pH and AP between the two forest segments. A total of 2871 soil macroarthropods were sampled, representing 5 classes and 14 orders, with higher abundance found in the undisturbed forest segment B. While the species richness of soil macroarthropods remained relatively consistent, noticeable variations were observed in terms of total abundance and relative abundance across different orders. The relative abundance of soil macroarthropods was primarily influenced by soil pH and soil temperature.

Key words: Environmental factors, Forest ecosystem, relative abundance, species richness, soil properties.

INTRODUCTION

The soil-litter system, considered a major biodiversity pool (André et al., 1994; Lee, 1994), serves as a crucial pathway for nutrient exchange between soil and plants (Swift et al., 1979; Vitousek and Sanford, 1986). The release of nutrients from decaying plant matter is influenced by the abundance and diversity of soil biota, including soil macroarthropods (Ghilarov, 1977; Pimm, 1994), which is essential for maintaining ecosystem function (Cuevas and Medina, 1986; Jordan, 1985). Soil macrofauna, including macroarthropods, are sensitive to habitat changes, and human-induced disturbances can significantly impact their diversity and functioning (Beare

*Corresponding author: E-mail: csnsacred1@gmail.com.

et al., 1995; Jones et al., 1994; Lavelle et al., 1997; Matson et al., 1997). Selective removal of vegetation, as reported by Martin and Sommer (2004), has shown changes in macroarthropod diversity and community structure.

Soil macroarthropods are a critical component of soil biodiversity, playing a fundamental role in regulating ecosystem functioning (Brown et al., 2001). They contribute significantly to soil biomass and influence various soil processes (Lavelle and Spain, 2001; Susilo et al., 2004), including organic matter decomposition, mineralization, and nutrient cycling. Their activities also influence carbon flux from the soil (Ganjegunte et al., 2004; Wardle et al., 2003). Furthermore, soil and litter arthropods contribute to physical soil rearrangement, improving water and nutrient infiltration, and gaseous emissions (Lavelle and Spain, 2001; Paoletti and Bressan, 1996; Susilo et al., 2004). Soil biota encompass a diverse array of organisms, fulfilling various functional roles such as decomposers, microbial regulators, soil engineers, and predators (Chapuis-Lardy et al., 2011; Lavelle et al., 2006). The biological functioning of soils, crucial for providing ecosystem goods and services, involves a wide range of biological processes carried out by soil organisms in conjunction with the physical and chemical components of the soil (Chapuis-Lardy et al., 2011).

A review of the literature highlights a predominant focus on soil microarthropods rather than macroarthropods, particularly examining aspects such as spatial or vertical distribution and abundance (Price, 1975; Sarkar, 1991). Studies on soil macroarthropods are often limited to specific insect groups, primarily collembolans and acarine (Alfred et al., 1991; Edwards and Lofty, 1974; Janetschek et al., 1976; Mukharji and Singh, 1970; Steinberger and Whitford, 1984). Despite their significance in natural and man-made habitats (Gillison et al., 2003), soil macroarthropods remain a poorly understood component of terrestrial ecosystems (Ruiz et al., 2008).

This study delves into the impacts of changes in the abundance of all soil macroarthropods on soil physicochemical characteristics across two forest segments of a temperate forest, differing in anthropogenic pressure magnitude. The investigation aims to understand the resultant effects on soil nutrient dynamics. Unfortunately, due to a lack of expertise, macroarthropods were identified only up to the order level. The identification of specimens down to the species level would have provided a more comprehensive assessment of the variation in abundance and richness across the two forest segments.

MATERIAL AND METHODS

Description of the study site

The study site is situated above Baling village in Darma Valley, District Pithoragarh, Kumaun Himalaya, India. It encompasses an old-growth forest spanning 4,527.585 km^2, located between 30°12'37" N latitude and 80°32'5" E longitude, within an altitudinal range of 3200 to 3400 meters (Figure 1). The current study was conducted over three months, from July to September, for two consecutive years in 2020 and 2021. The present forest is dominated by West Himalayan blue fir (*Abies spectabilis*), which is represented by thick litter, characteristic of a temperate coniferous forest. The forest was divided into two segments; that is, disturbed (forest segment A) and undisturbed (forest segment B), based on the magnitude of the anthropogenic pressure, primarily in terms of tree felling, lopping, and relative exploitation of the fuelwood (Figure 2). A bridle path effectively demarcates the two forest segments. To minimize other environmental variables, apart from tree felling, lopping and exploitation of fuelwood in the two forest segments, care was taken so that other features were commonly shared between the two segments. For instance, distinctive characteristics of the forest segments include the absence of atypical tree species, a near homogeneous vegetation cover, and the prevalence of common dominant tree species, particularly *Abies spectabilis*. The extent of anthropogenic disturbance, identified through visual observation, can be attributed to the fact that the disturbed forest segment is in close proximity to and above the village. Therefore, it experiences relatively higher human activities compared to the far-flung and relatively undisturbed forest segment. The latter is situated above the temple, surrounding the water source, and is considered 'sacred,' resulting in enrichment with leaf litter content.

Throughout the study period, ambient temperatures ranged between 10 and 21°C, with recorded relative humidity ranging from 72 to 92%. The minimum and maximum soil temperatures in forest segment A were 13 and 20°C, respectively, while in forest segment B, these values were 11 and 17.3°C. These findings highlight distinct temperature profiles within the two forest segments. The average soil temperature was 16.87 and 14.59°C, and the average humidity was 80.5 and 83.67% in forest segments A and B, respectively (Table 1).

Experimental design and soil sampling

Soil analysis was done by using quadrat methods (Kent and Coker, 1992). Within each forest segment, 4 randomly chosen rectangular plots measuring 5m x 10m were established. Within each large plot, 5 sub-plots measuring 1m x 1m were established for soil sampling. Soil samples taken from five sub-plots were clumped together into one lot. In other words, 4 soil samples constituted the total number per forest segment per visit. Since the study was carried out fortnightly (every 2nd week, twice a month), the total number of soil samples would translate into 24 per forest segment, or collectively 48 soil samples (24 samples x 2 segments) from both the forest segments, for the duration of the 3-month study. Soil sampling was conducted by collecting soil samples from a depth of 0-10 cm after removing above-ground debris, using sickles, shovels, digging hoes, and bucket auger. Soil samples were then stored in airtight plastic bags and labeled. The soil samples were then air-dried and subsequently homogenized by passing through a 2 mm sieved filter to eliminate any visible roots or plant remains. Soil temperatures were recorded by a steel-tipped digital soil thermometer at 10 cm depth.

Soil physical-chemical analysis

The following soil parameters were investigated:

(i) Soil texture using the hydrometer method (Gee and Bauder, 1986).
(ii) Soil pH determined according to Black (1973).
(iii) Soil moisture content (SMC) assessed via the gravimetric

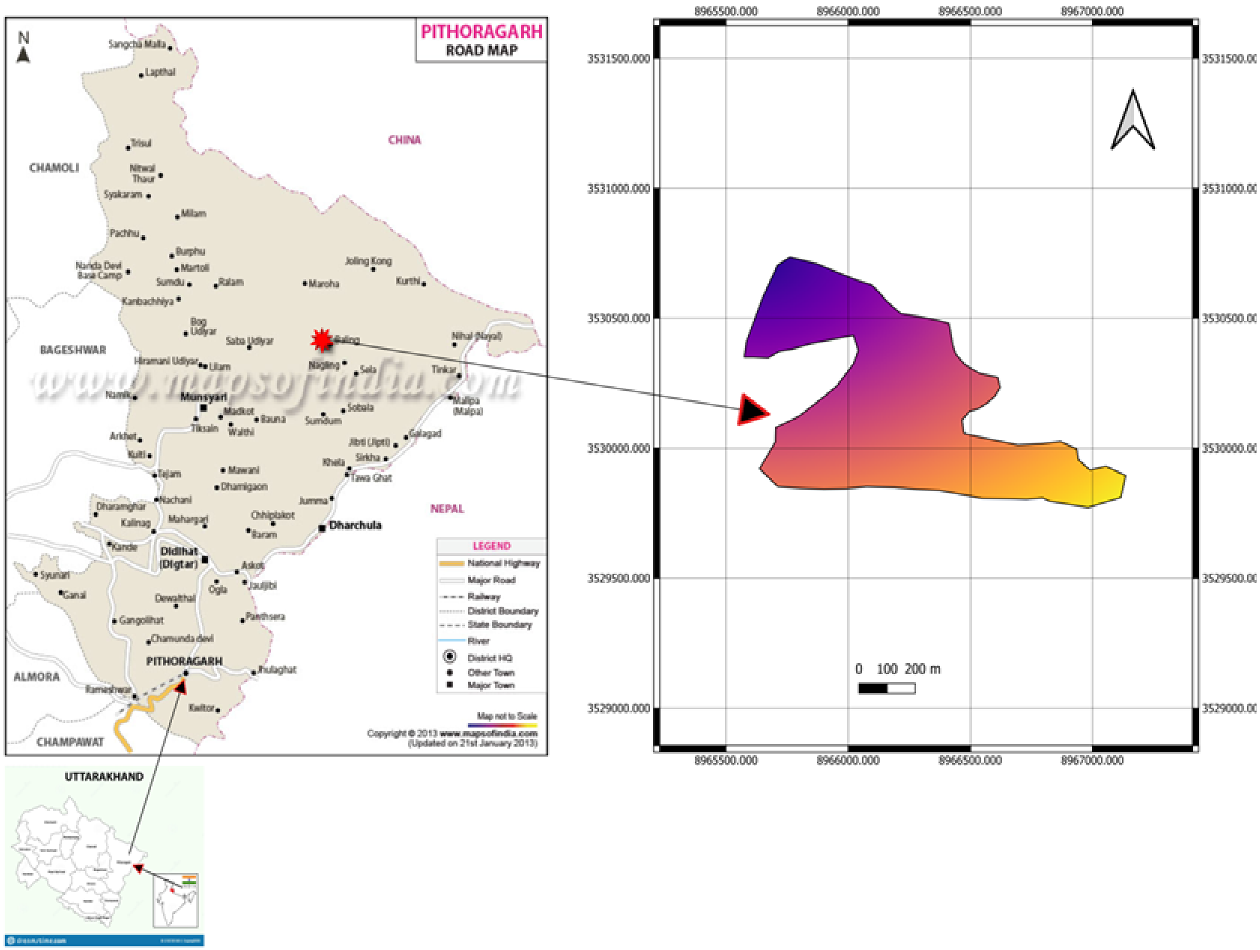

Figure 1. Map of the study site.

method (Allen et al., 1974).
(iv) Available phosphorus (AP) measured by the colorimetric method (Bray and Kurtz, 1945).
(v) Soil organic carbon (SOC) determined using the chromic acid titration method (Walkley and Black, 1934).
(vi) Total nitrogen (TN) analyzed through the Kjeldahl method (Parkinson and Allen, 1975).
(vii) Available nitrogen (AN) assessed by the alkaline permanganate method (Subbiah and Asija, 1956).

Sampling of arthropods, identification, and classification

As with soil samples, within each 4 larger plots (5 x 10 m), 5 sub-plots measuring 1m x 1m were established. While soil samples taken from five sub-plots were clumped together into one lot; macroarthropods were studied separately using a quadrat method (Kent and Coker, 1992). In other words, altogether 20 separate plots were sampled per forest segment per visit. Again, since the study was carried out fortnightly, the total number of soil macroarthropod samples would translate into 120 soil macroarthropod samples (40 sample plots x 3 months) per forest segment, or collectively 240 macroarthropods samples (120 x 2 segments) from both of the forests, for the duration of the 3-month study. The soil macroarthropods were collected using the hand sorting method. To clear above-ground vegetation, sickles, shovels, and/or digging hoes were resorted to. The macroarthropod specimens were photographed in their natural habitat and subsequently preserved in 70% alcohol. Identification of the collected specimens was chiefly carried out through a literature review, while still unidentified samples were referred to the experts. Arthropods were classified using identification keys, as outlined by Duyar (2014). To ascertain the dominant soil macroarthropods, an evaluation was conducted on abundance, relative abundance, and abundance per meter square. While abundance refers to the total number of individuals in the sample or population, relative abundance represents the proportion of individuals (macroarthropods) of each species/taxon relative to the total number of all species or taxa (x 100). Abundance per square meter refers to the average number of individuals per square meter based on the total number of individuals sampled in both forest segments A and B.

Statistical analyses

All the statistical analyses were carried out using IBM SPSS 23 software. Soil parameters and macroarthropods abundance data were log-transformed, where necessary. Soil samples were averaged within each plot to obtain representative data. The least significant difference (LSD) test with a significance level of (p < 0.05) was used to compare the means among soil variables. For

Figure 2. Tree felling combined with extensive lopping has resulted in lesser canopy cover in forest segment A (left), in contrast to dense cover in forest segment B (right).

Table 1. The average value of soil characteristics in the study sites (mean ± S.E.; N = 24).

Soil parameters	Forest segment A	Forest segment B
pH	4.95± 0.04[a**]	6.27 ± 0.08[b**]
SMC (%)	42.20 ± 1.88[a**]	62.05 ± 3.25[b**]
SOC (%)	7.52 ±0.17[a**]	9.61 ± 0.37[b**]
TN (g/kg)	0.36 ± 0.03[a]	0.39 ± 0.04[a]
AN (kg ha^{-1})	151.06 ± 9.51[a]	159.87 ± 16[a]
AP (mg/kg)	11.82 ± 0.83[a**]	18.85 ± 1.51[b**]
Gravel (%)	8.06 ± 0.85[a]	8.77 ± 0.71[a]
Sand (%)	18.18 ± 0.90 [a]	17.85 ± 1.28[a]
Silt (%)	70.76 ± 1.65[a]	70.43 ± 1.83[a]
Clay (%)	2.63 ± 0.33[a]	2.65 ± 0.23[a]
Soil temperature (°C)	16.87 ± 1.41[a*]	14.59 ± 1.36[b*]
Humidity (%)	80.5 ± 3.97[a*]	83.67 ± 4.18[b*]

*and** significant at 0.05 and 0.0001 levels. Similar letters show no significant difference, while different letters show significant difference. SMC: Soil moisture content; SOC: Soil organic carbon; TN: Total nitrogen; AN; Available nitrogen; AP: Available phosphorus.

assessing relationships between soil macroarthropods and different soil parameters, sample t-tests and correlation analyses were conducted.

RESULTS

Soil characteristics

Forest segments, A and B demonstrated comparable soil texture, with silt being the prevailing component, accounting for 70.76 and 70.43%, respectively, and thus could be defined as loam soil (Table 1). The disturbed forest segment A, exhibited SMC ranging from 37.23 to 51.26% while B showed a variation from 53.15% to 72.78%. Statistical analysis revealed significant differences in soil moisture content between the two forest segments ($p < 0.0001$), (Table 1).

A notable difference ($p < 0.05$) was observed in soil temperature between the two forest segments (Table 1). Segment A exhibited soil temperature within the range of 14.23 to 19.05 °C, while in forest segment B, the values varied from 12.2 to 14.67°C. Additionally, a significant difference at ($p < 0.05$) was observed in humidity levels across the two forest segments (Table 1). In segment A, humidity values ranged from 74.5 to 88%, whereas in segment B, the values ranged from 79 to 92%.

The disturbed forest segment A displays a soil pH ranging from 4.8 to 5.1, while in forest segment B, the pH varies from 6.2 to 6.3. The difference in soil pH between the two forest segments was significant ($p < 0.05$). These

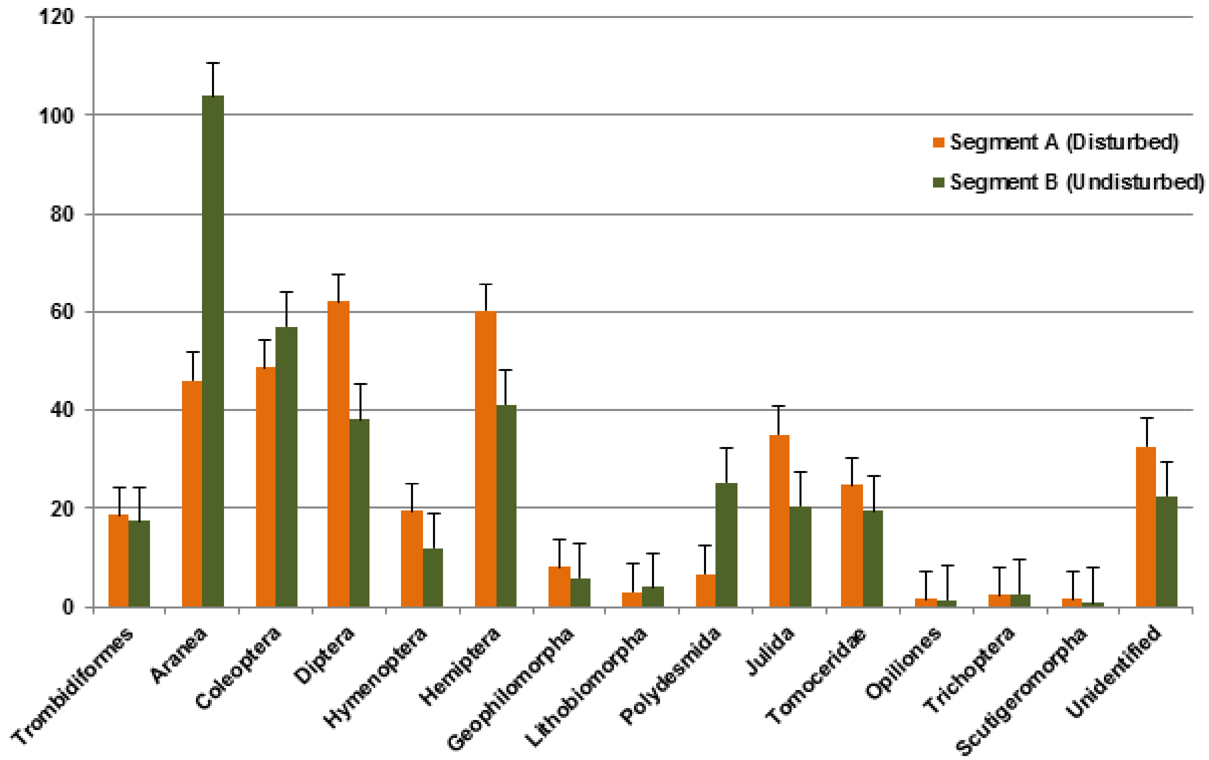

Figure 3. Variation in abundance of different orders of soil macroarthropods between disturbed (Forest segment A) and undisturbed (Forest segment B) that were sampled from July to September; error bars indicate the standard error.

findings underscore the distinct soil acidity levels in the respective forest segments (Table 1).

The soil organic carbon (SOC) content within forest segment A fluctuates between 7.11% and 8.06%, while in forest segment B, it ranges from 8.08% to 11.40% (Table 1). A significant difference in soil organic carbon content exists between the two forest segments (p < 0.0001) (Table 1).

The soil total nitrogen (TN) values within forest segment A, exhibit a range from 0.31 to 0.35 g kg^{-1}, while in forest segment B, they vary from 0.35 to 0.46 g kg^{-1}. No significant variation in soil TN was observed between the two forest segments (p > 0.05) (Table 1). These findings indicate comparable levels of total nitrogen in the soils of both forest segments.

The soil available nitrogen (AN) values within forest segment A range from 85.52 to 207.95 kg ha^{-1} while in forest segment B, the values range between 103.14 and 192.61 kg ha^{-1}. The observed differences in soil AN value between the two forest segments is statistically not significant (p > 0.05), (Table 1).

The available phosphorus (AP) values within forest segment A, exhibit a range from 8.56 to 15.51 mg kg^{-1}, while in forest segment B, they vary from 14.17 to 22.99 mg kg^{-1}. The observed variation in AP values across the two forest segments is statistically significant (p < 0.05), (Table 1).

Macroarthropod abundance

During the study period, a total of 2871 soil macroarthropods were collected, comprising 5 different classes and 14 orders. The abundance m^{-2} for disturbed forest segment A and forest segment B, was 47.95 ind. m^{-2}, and 95.6 ind. m^{-2}, respectively. Notably, the disturbed site (forest segment A) exhibited a lower number of macroarthropods compared to the undisturbed forest segment B (Figure 3). In forest segment A, Diptera (17%) and Hemiptera (16%) were more abundant. Conversely, in forest segment B, Araneae (28%) and Coleopterans (15%) were more prevalent. However, some macroarthropod taxa, such as Geophilomorpha, Lithobiomorpha, Opiliones, Trichoptera, and Scutigeromorpha, showed low abundance in both forest segments (Figure 3).

Correlation between soil macroarthropods and different soil parameters

In forest segment A, the relative abundance (RA) of soil macroarthropods exhibited a significant negative correlation with soil organic carbon (SOC) (r = -0.97, p < 0.01) and soil temperature (r = -0.99, p < 0.01). However, it showed a significant positive correlation with soil

Table 2. Pearson's correlation coefficient of soil macroarthropods' relative abundance and different soil parameters between two forest segments (disturbed A and undisturbed B).

Variable	pH	SOC (%)	TN (g kg^{-1})	AN (kg ha^{-1})	AP (mg kg^{-1})	SMC (%)	Soil temp. (°C)
Segment A	0.64*	-0.97**	-0.38	0.58*	0.38	0.85*	-0.99**
Segment B	0.86*	0.14	-0.99**	-0.42	-0.86*	0.17	-0.85*

*and**Correlation coefficient significant at 0.05 and 0.01 levels.

moisture content (SMC) (r = 0.85, $p < 0.05$) and soil pH (r = 0.64, $p < 0.05$) and available phosphorus (AP) (r = 0.61, $p < 0.05$) (Table 2). In forest segment B, the relative abundance of soil macroarthropods exhibited a significant negative correlation with soil temperature (r = -0.85, $p < 0.05$), soil total nitrogen (TN) (r = -0.99, $p < 0.01$) and soil available phosphorus (r = -0.86, $p < 0.05$). While significant positive correlations were found with soil pH (r = 0.86, $p < 0.05$) (Table 2).

DISCUSSION

Soil texture and soil moisture content

The soil texture observed in both the forest segments can be described as loam. Since the soil texture is similar across the two segments of the forest (Table 1), it can be inferred that the differences in soil moisture content were not influenced by soil texture. However, soil moisture content varies significantly, across the two forest segments A and B (Table 1). The higher soil moisture content in forest segment B could be attributed to intact vegetation cover, its sacredness, and consequent relatively more moisture content. Conversely, forest segment A, experiencing anthropogenic pressure led to variable air and soil temperatures, elevated evapotranspiration rates, and greater vapour pressure deficits caused by increased solar radiation and wind, all these factors may contribute to a relatively lower soil moisture content in forest segment A, as indicated by various studies (Chen et al., 1995; Didham and Lawton, 1999; Herbst et al., 2007).

Soil physicochemical properties

The measurement of soil pH, which indicates its acidity or alkalinity, is associated with various soil characteristics such as ion hydrolysis equilibrium (Tyler and Olsson, 2001), microbial populations (Kooijman and Cammeraat, 2010), and the amount of organic matter (Lambkin et al., 2011). The current study highlights a significant distinction in soil pH between the two forest segments, A and B (Table 1). Forest segment A, experiencing greater anthropogenic disturbance (tree felling, lopping), leads to relatively less vegetation cover, higher temperature, and relatively more compact soil, exhibiting more acidic soil, due to the faster decomposition of the organic matter that is known to release acids (de Hann, 1977; Gairola et al., 2012; Groffman et al., 2009; Gupta and Sharma, 2008) (Table 1).

Soil organic matter is the most widely used indicator of soil quality (Wander and Drinkwater, 2000). Soil carbon plays a crucial role as both a source and a sink for carbon dioxide in the atmosphere (Fisher and Binkley, 2000; Froberg, 2004; Hogberg et al., 2002), acting as a biogeochemical connection between major carbon reservoirs, such as the biosphere, atmosphere, and hydrosphere (Wilding et al., 2001). Comparing the soil organic carbon content in the current forest segments, A and B, a significant difference was observed (Table 1). In the present study, the undisturbed forest B, treated sacred and characterized by relatively more vegetation cover, and a higher litter mass, exhibited relatively more storage of carbon in the soil (Sheikh et al., 2009). Consequently, lower temperature and a higher moisture content may in turn affect the soil organic carbon values, as compared to the disturbed forest segment A, as SOC is known to be positively influenced by humidity, and precipitation, and negatively influenced by the temperature (Post et al., 1982), vegetation and the soil environment (Ravindranath and Ostwald, 2008; Baldock and Nelson, 2000).

As concerns total nitrogen (TN) and available nitrogen (AN), there was no significant difference observed between the two forest segments (Table 1). This could be attributed to the intricate processes of microbial immobilization, cation exchange capacity, and soil organic matter absorption, as highlighted by Silver et al. (2005) and Templer et al. (2008). However, there was a significant difference in soil available phosphorus (AP), comparatively higher in the undisturbed forest segment B (Table 1). This variation in AP values could be attributed to lower pH, as is exhibited by forest segment A (pH 4.95), which results in the leaching of the essential nutrients, including phosphorus (Gairola et al., 2012; Larcher, 1980).

Relationships between soil properties and soil macroarthropods

Variations in soil physicochemical properties have a significant influence on the diversity of soil-inhabiting macroarthropods. In the present study, forest segment B is a sacred forest, protection thus afforded, has resulted in relatively more intact vegetation cover, and consequently, lower temperature and higher humidity at the ground surface (Table 1). Undoubtedly, these differences exert a significant influence on the assemblages of ground-dwelling arthropods (Pinzon et al., 2012; Work et al., 2004). Furthermore, diversity and arthropod assemblages are strongly affected by vegetation composition and forest structure (Schowalter and Zhang, 2005; Work et al., 2004). In contrast, anthropogenic pressure in terms of tree felling, lopping, and mushroom harvesting, as experienced by forest segment A, consequently leading to less soil moisture content, negatively impacts the soil macroarthropods richness and abundance (Barros et al., 2002; Curry et al., 2002).

Zhao et al. (2014) observed that the abundance and distribution of soil and litter macroarthropods were significantly influenced by the physical and chemical characteristics of the soil and litter. These factors included temperature, moisture, pH, and others within temperate forest ecosystems. In the present study, soil moisture content exhibited a positive correlation with macroarthropod abundance in both forest segments. Soil moisture has been implicated in regulating diversity, distribution and abundance of macroarthropods (Abrahamsen, 1971; MacKay et al., 1986). Increased soil moisture creates a favourable condition for soil macroarthropods by providing the necessary moisture for their survival and reproduction (Johnson et al., 1995). However, it is known that certain insect orders such as Hymenoptera, Hemiptera, and Diptera can be negatively affected by both low and high soil moisture values (Adis and Junk, 2002; Ausden et al., 2001; Kajak, 1987; Tajovsky, 1999). Also, excessive moisture can sometimes lead to oxygen stress or waterlogging, negatively influencing the macroarthropod populations (Cárcamo et al., 2000; Hättenschwiler and Jørgensen, 2010). Additionally, spiders (Araneae) being predatory, are directly influenced by changes in the habitat structure and prey availability (Wise, 1993).

The existence of arthropods was significantly affected by the temperature and moisture levels in the soil. According to Medianero et al. (2007), an elevation in temperature, coupled with sufficient moisture, led to an increased abundance of arthropods. Conversely, a decrease in arthropod abundance was observed when both litter and soil experienced water loss due to heightened evaporation at higher temperatures. In the present study, a negative correlation was observed between soil temperature and the abundance of soil macroarthropods, which correlates well with the findings by Medianero et al. (2007) and Sharon et al. (2001). Forest segment A, experienced tree felling which leads to higher soil temperatures, and relatively lower SMC. Thus, it exhibited lower macroarthropod abundance, similar to observations made by Peña-Peña and Irmler (2016).

Soil pH levels varied between the two forest types. It is known that the preferences of ground-dwelling arthropods for specific habitats can be directly affected by soil pH, as is demonstrated by certain species of carabid beetles (Coleoptera) (Paje and Mossakowski, 1984), or can be indirectly influenced by the habitat preferences of their prey, such as mites (Straalen and Verhoef, 1997). Out of the 14 macro arthropod orders, Diptera, Hymenoptera, Hemiptera, Geophilomorpha, Julida, and Tomoceridae, prefer relative lower pH, as exhibited in Forest segment A, while Aranea and Coleoptera show higher abundance in forest segment B, exhibiting relatively higher pH. Since different insect orders exhibit varying preferences for pH levels (Hyvönen and Persson, 1990; Loranger et al., 2001; van Straalen, 1998; van Straalen and Verhoef, 1997), this could explain the variations in macroarthropod abundance observed between the two forest segments. Overall, a positive correlation was exhibited between soil pH and the relative abundance of soil macroarthropods, underscoring the significance of soil pH as a determinant of macroarthropod abundance (Augusto et al., 2002; Loranger et al., 2001).

A positive correlation was found between macroarthropod abundance and SOC in the undisturbed forest segment B. SOC invariably remains a source of energy and nutrients for the soil macroarthropods, which in turn contribute to the decomposition of the soil organic matter, and thus soil nutrient cycling (Ganjegunte et al., 2004; Kaczmarek et al., 1995; Wardle et al., 2003). This relationship is mutually beneficial, as SOC enhances soil structure, moisture retention, and nutrient availability, thus providing favourable conditions for the proliferation of macroarthropod populations (Ayuke et al., 2011; Suthar, 2009; Tiunov and Scheu, 2004). However, the soil parameters, as outlined above, are sensitive to disturbance, inclusive of anthropogenic pressure, and may thus influence the abundance of the soil macroarthropods (Bergeron et al., 2017; Swanson et al., 2011). For example, Apigian et al. (2006) and Sileshi and Mafongoya (2006), have reported lower species richness and population density of annelids, chilopods, arachnids, and some insects in disturbed forest patches.

Nitrogen modulates plant biomass and community structure, thereby influencing the dynamics of soil macroarthropods (Zhou et al., 2022). Several studies have exhibited a positive correlation between SOC, soil nitrogen, and the abundance of soil macroarthropods (Ayuke et al., 2011; Suthar, 2009). This is in contrast to our findings, where a negative correlation was observed between soil macroarthropods and soil nitrogen. Notwithstanding the fact, the top predator orders- Araneae and Coleopterans, were significantly more abundant in the undisturbed forest segment B. This relatively greater abundance of the predator macroarthropods remains a good indicator of ecosystem productivity and thus, biodiversity, since energy constraints are known to impact both the abundance and the diversity of the top predators (Borer et al., 2003; Arim et al., 2006). Similarly, Badji et al. (2007) and Maribie et al. (2011) highlighted that soil macro-arthropods could act as important bioindicators; these include ants (Hymenoptera), springtails (Collembola), termites (Blattodea), and Acari (mites) from the present study. Among these groups, ants and springtails were extensively studied due to their high abundance and diversity. These organisms play a crucial role in essential biological processes, such as catalyzing the decomposition of organic matter and serving as central figures in the soil food web.

Conclusion

In the present study, we observed significant differences in soil physicochemical parameters, particularly in soil pH, SMC, and SOC, between the two forest segments (A and B) that differ in the magnitude of anthropogenic pressure resulting from tree felling and lopping. These findings reinforce the observation that changes in soil physicochemical properties, induced by anthropogenic disturbance, have a substantial impact on the relative abundance of soil macroarthropods, and vice versa. Although the species richness of soil macroarthropods remained relatively consistent, noticeable variations were observed in terms of total abundance and relative abundance across different orders. The relative abundance of soil macroarthropods was primarily influenced by soil pH, SMC, soil total nitrogen, and soil temperature. In conclusion, this study underscores the significance of even minor and subtle changes in soil macroarthropod abundance, resulting from anthropogenic disturbance, in influencing soil nutrient dynamics and, consequently, forest productivity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENTS

The authors are grateful to the principal of M.B Government Postgraduate College, Haldwani (Nainital), for providing essential infrastructural support. They also appreciate Ranjana Goswami and Divya Rawat, colleagues in the laboratory, for their valuable assistance throughout the study. Their heartfelt appreciation goes to the residents of Darma Valley, especially the village of Baling, who generously supported the fieldwork and contributed significantly during the entire research period.

REFERENCES

Abrahamsen G (1971). The influence of temperature and soil moisture on the population density of Cognettia sphagnetorum (Oligochaeta: Lumbricidae) in cultures with homogenized raw humus. Pedobiologia 11:417-424.

Adis J, Junk WJ (2002). Terrestrial invertebrates inhabiting lowland river floodplains of Central Amazonia and Central Europe: a review. Freshwater Biology 47(4):711-731.

Alfred JRB, Darlong VT, Hattar JS, Paul D (1991). Microarthropods and their conservation in some north-east Indian soils. In: Veeresh GK (ed.), Advances in Management and Conservation of Soil Fauna. New Delhi, Oxford and IBH Publishing, Pvt., Ltd. pp. 309-320.

Allen SE, Grimshaw HM, Parkinson JA, Quarmby C (1974). Chemical analysis of ecological materials. Oxford, Blackwell Scientific Publications.

André HM, Noti MI, Lebrun P (1994). The soil fauna: the other last biotic frontier. Biodiversity and Conservation 3:45-56.

Apigian KO, Dahlsten DI, Stephens SL (2006). Fire and fire surrogate treatment effects on leaf litter arthropods in a western Sierra Nevada mixed-conifer forest. Forest Ecology and Management 221:110-122.

Arim M, Abades SR, Neill PE, Lima M, Marquet PA (2006). Spread dynamics of invasive species. Proceedings of the National Academy of Sciences of the United States of America 103(2):374-378.

Augusto L, Ranger J, Binkley D, Rothe A (2002). Impact of several common tree species of European temperate forests on soil fertility. Annals of Forest Science 59(3):233-253.

Ausden M, Sutherland WJ, James R (2001). The effects of flooding lowland wet grassland on soil macroinvertebrate prey of breeding wading birds. Journal of Applied Ecology 38(2):320-338.

Ayuke FO, Pulleman MM, Vanlauwe B, de Goede RG, Six J, Csuzdi C, Brussaard L (2011). Agricultural management affects earthworm and termite diversity across humid to semi-arid tropical zones. Agriculture, Ecosystems and Environment 140(1-2):148-154.

Badji CA, Guedes RNC, Silva AA, Arau´jo RA (2007). Impact of deltamethrin on arthropods in maize under conventional and no tillage cultivation. Crop Protection 23:1031-1039.

Baldock JA, Nelson PN (2000). Soil organic matter. In. Li Y, Huang PM, Sumner ME (eds.), Handbook of Soil Science. Boca Raton, FL, USA: CRC Press pp. 25-84.

Barros E, Pashanasi B, Constantino R, Lavelle P (2002). Effects of land-use system on the soil macrofauna in western Brazilian Amazonia. Biology and Fertility of Soils 35:338-347.

Beare MH, Coleman DC, Crossley DA, Hendrix PF, Odum EP (1995). In. Collins HP, Robertson GP, Klug MJ (eds.), A Hierarchical approach to evaluating the significance of soil biodiversity to biogeochemical cycling. The Significance and Regulation of Soil Biodiversity. Developments in Plant and Soil Sciences. Dordrecht, Springer pp. 5-22.

Bergeron JAC, Pinzon J, Odsen S, Bartels S, Macdonald SE, Spence JR (2017). Ecosystem memory of wildfires affects the resilience of boreal mixed-wood biodiversity after retention harvest. Oikos 126(12):1738-1747.

Black CA (1973). Methods of Soil Analysis. American Society of Agronomy, Soil Science Society of America. Madison, WI.

Borer ET, Briggs CJ, Murdoch WW, Swarbrick SL (2003). Testing intraguild predation theory in a field system: does numerical dominance shift along a gradient of productivity? Ecology Letters 6(10):929-935.

Bray RH, Kurtz LT (1945). Determination of total, organic and available forms of phosphorus in soils. Soil Science 59(1):39-45.

Brown GG, Pasini A, Benito NP, De Aquino AM, Correia ME (2001). Diversity and functional role of soil macrofauna communities in Brazilian no tillage agroecosystems: A preliminary analysis. In International Symposium on Managing biodiversity in agricultural ecosystems. Londrina, Embrapa Soja pp. 310-328.

Cárcamo HA, Abe TA, Prescott CE, Holl FB, Chanway CP (2000). Influence of millipedes on litter decomposition, N mineralization, and microbial communities in a coastal forest in British Columbia, Canada. Canadian Journal of Forest Research 30(5):817-826.

Chapuis-Lardy L, Le Bayon RC, Brossard M, López-Hernández D, Blanchart E (2011). Role of Soil Macrofauna in Phosphorus Cycling. In. Bünemann E, Oberson A, Frossard E (eds.), Phosphorus in Action. Soil Biology. Berlin, Heidelberg, Springer pp. 199-213.

Chen JQ, Franklin JF, Spies TA (1995). Growing-season microclimatic gradients from clear-cut edges into old-growth Douglas-fir forests. Applied Ecology 5(1):74-86.

Cuevas E, Medina E (1986). Nutrient dynamics within Amazonian forests. I. Nutrient flux in fine litter fall and efficiency of nutrient utilization. Oecologia 68:466-472.

Curry JP, Byrne D, Schmidt O (2002). Intensive cultivation can drastically reduce earthworm populations in arable land. European Journal of Soil Biology 38:127-130.

de Hann S (1977). Humus, its formation, its relation with the mineral part of the soil and its significance for soil productivity. In: Organic matter studies, vol 1. International Atomic Energy Agency, Vienna pp. 21-30.

Didham RK, Lawton JH (1999). Edge structure determines the magnitude of changes in microclimate and vegetation structure in tropical forest fragments. Biotropica 31(1):17-30.

Duyar A (2014). Seasonal variation of soil arthropods (Arthropoda) in fir (Abies bornmulleriana Mattf.) ecosystems in Bolu-Aladag. Istanbul University, Science Institute, Istanbul (In Turkish with English Summary).

Edwards CA, Lofty JR (1974). The invertebrate fauna of park grass plots. Rothamsted Experimental Station. Report for 1974, pp. 133-154.

Fisher RF, Binkley D (2000). Ecology and management of forest soils. New York, USA, John Wiley and Sons.

Froberg M (2004). Processes controlling production and transport of dissolved organic carbon in forest soils. PhD thesis, Department of soil science, Swedish University of Agricultural Sciences, Agraria.

Gairola S, Sharma CM, Ghildiyal SK, Suyal S (2012). Chemical properties of soils in relation to forest composition in moist temperate valley slopes of Garhwal Himalaya, India. Environmentalist 32(4):512-523.

Ganjegunte GK, Condron LM, Clinton PW, Davis MR, Mahieu N (2004). Decomposition and nutrient release from radiata pine (Pinus radiata) coarse woody debris. Forest Ecology and Management 187:197-211.

Gee GN, Bauder JW (1986). Particle Size Distribution. In: Klute A (ed.), Methods of Soil Analysis Part 1. Physical and Mineralogical Methods. Agronomy Society of America/Soil Science Society of America, Madison, Wisconsin pp. 383-411.

Ghilarov MS (1977). Why so many species and so many individuals can coexist in the soil. Ecological Bulletins 25:593-597.

Gillison AN, Jones DT, Susilo F-X, Bignell DE (2003). Vegetation indicates diversity of soil macroinvertebrates: a case study with termites along a land-use intensification gradient in lowland Sumatra. Organism Diversity and Evolution 3:111-126.

Groffman PM, Hardy JP, Fisk MC, Fahey TJ, Driscoll CT (2009). Climate variation and soil carbon and nitrogen cycling processes in a northern hardwood forest. Ecosystems 12:927-943.

Gupta MK, Sharma SD (2008). Effect of tree plantation on soil properties, profile morphology and productivity index I Poplar in Uttarakhand. Annals of Forest Science 16(2):209-224.

Hättenschwiler S, Jørgensen HB (2010). Carbon quality rather than stoichiometry controls litter decomposition in a tropical rainforest. Journal of Ecology 98(4):754-763.

Herbst M, Roberts JM, Rosier PTW, Taylor ME, Gowing DJ (2007). Edge effects and forest water use: a field study in mixed deciduous woodland. Forest Ecology and Management 250(3):176-186.

Hogberg P, Nordgren A, Agren GI (2002). Carbon allocation between tree root growth and root respiration in boreal pine forest. Oecologia 132:579-581.

Hyvönen R, Persson T (1990). Effects of acidification and liming on feeding groups of nematodes in coniferous forest soils. Biology and Fertility of Soils 9:205-210.

Janetschek H, DeZordo I, Meyer E, Troger H, Schatz H (1976). Altitude- and time-related changes in arthropod faunation (Central High Alps: Obergurgl-area, Tyrol). Proceedings of XV International Congress of Entomology, Washington, DC, USA pp. 185-206.

Johnson J, Kruszewski Z, Malvitz M, Simons J (1995). A comparison of soil arthropod communities in successional forest plots. Retrieved from the Deep Blue database pp. 2-19.

Jones CG, Lawton JH, Shachak M (1994). Organisms as ecosystem engineers. Oikos 69(3):373-386.

Jordan CF (1985). Nutrient Cycling in Tropical Forest Ecosystems. Chichester, UK, John Wiley and Sons.

Kaczmarek M, Kajak A, Wasilewska L (1995). Interactions between diversity of grassland vegetation, soil fauna and decomposition processes. Acta Zoologica Fennica 19:236-238.

Kajak Z (1987). Determinants of maximum biomass of benthic Chironomidae (Diptera). Entomologica Scandinavica pp. 303-308.

Kent M, Coker P (1992). Vegetation description and analyses. A practical approach. London, Belhaven Press.

Kooijman AM, Cammeraat E (2010). Biological control of beech and hornbeam affects species richness via changes in the organic layer, pH, and soil moisture characteristics. Functional Ecology 24(2):46-477.

Lambkin DC, Gwilliam KH, Layton C, Canti MG, Piearce TG, Hodson ME (2011). Soil pH governs the production rate of calcium carbonate secreted by the earthworm Lumbricus terrestris. Journal of Applied Geochemistry 26:64-66.

Larcher W (1980). Physiological plant ecology. Berlin, Heidelberg, New York, Springer-Verlag.

Lavelle P, Bignell D, Lepage M, Wolters V, Roger P, Ineson P, Heal OW, Dhillion S (1997). Soil functions in a changing world: the role of invertebrate ecosystem engineers. European Journal of Soil Biology 33(4):159-193.

Lavelle P, Decaens T, Aubert M, Barot S, Blouin M, Bureau F, Margerie P, Mora P, Rossi JP (2006). Soil invertebrates and ecosystem services. European Journal of Soil Biology 42(1):3-15.

Lavelle P, Spain AV (2001). Soil Ecology. The Netherlands, Kluwer, Academic Publishers.

Lee KE 1994. The biodiversity of soil organisms. Applied Soil Ecology 1(4):251-254.

Loranger G, Bandyopadhyaya I, Razaka B, Ponge JF (2001). Does soil acidity explain altitudinal sequences in collembolan communities? Soil Biology and Biochemistry 33(3):381-393.

Mackay WP, Silva S, Lightfoot DC, Pagani MI, Whitford WG (1986). Effect of increased soil moisture and reduced soil temperature on a desert soil arthropod community. American Midland Naturalist 116(1):45-56.

Maribie CW, Nyamasyo GHN, Ndegwa PN, Mungatu JK, Lagerlöf J, Gikungu M (2011). Abundance and diversity of soil mites (Acari) along a gradient of land use types in Taita Taveta, Kenya. Tropical and Subtropical Agroecosystem 13:11-26.

Martin K, Sommer M (2004). Effects of soil properties and land management on the structure of grassland snail assemblages in SW Germany. Pedobiologia 48(3):193-203.

Matson PA, Parton WJ, Power AG, Swift MJ (1997). Agricultural intensification and ecosystem properties. Science 277(5325):504-509.

Medianero E, Castano-Meneses G, Tishechkin A, Basset Y, Barrios H, Ødegaard F, Cline AR, Bail J (2007). Influence of local illumination and plant composition on the spatial and seasonal distribution of litter-dwelling arthropods in a tropical rainforest. Pedobiologia 51(2):131-145.

Mukharji SP, Singh J (1970). Seasonal variations in the densities of soil arthropod population in a rose garden in Varanasi, (India). Pedobiologia 10:442-446.

Paje F, Mossakowski D (1984). pH-preferences and habitat selection in carabid beetles. Oecologia 64:41-46.

Paoletti MG, Bressan M (1996). Soil invertebrates as bio-indicators of human disturbance. Critical Reviews in Plant Sciences 15(1):21-62.

Parkinson JA, Allen SE (1975). A wet oxidation process is suitable for the determination of nitrogen and mineral nutrients in biological material. Communications in Soil Science and Plant Analysis 6(1):1-11.

Peña-Peña K, Irmler U (2016). Moisture seasonality, soil fauna, litter quality and land use as drivers of decomposition in Cerrado soils in SE-Mato Grosso, Brazil. Applied Soil Ecology 107:124-133.

Pimm SL (1994). Biodiversity and the Balance of Nature. In. Schulze ED, Mooney HA (eds.), Biodiversity and Ecosystem Function. Praktische Zahnmedizin Odonto-Stomatologie Pratique Practical Dental Medicine. Berlin, Heidelberg, Springer pp. 347-359.

Pinzon J, Spence JR, Langor DW (2012). Responses of ground-dwelling spiders (Araneae) to variable retention harvesting practices

in the boreal forest. Forest Ecology and Management 266:42-53.
Post WM, Emanuel WR, Zinke PJ, Stangenberger AG (1982). Soil carbon pools and world life zones. Nature 298:156-159.
Price DW (1975). Vertical distribution of small arthropods in California pine forest soil. Annals of the Entomological Society of America 68(1):174-180.
Ravindranath NH, Ostwald M (2008). Carbon inventory methods-handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects. In: Ravindranath NH, Ostwald M (eds.), Advances in Global Change Research. Heidelberg: Springer.
Ruiz N, Lavelle P, Jimenez J (2008). Soil macrofauna field manual. Food and Agriculture Organization of the United Nations.
Sarkar S (1991). Studies on microarthropod community in one undisturbed habitat of Tripura (India) with special reference to oribatid mites. In: Veeresh GK, Rajagopal D, Viraktamath CA (eds.), Advances in Management and Conservation of Soil Fauna. Bangalore pp. 777-788.
Schowalter TD, Zhang YL (2005). Canopy arthropod assemblages in four overstory and three understory plant species in a mixed-conifer old-growth forest in California. Forest Sciences 51(3):233-242.
Sharon R, Degani G, Warburg M (2001). Comparing the soil macro-fauna in two oak-wood forests: does community structure differ under similar ambient conditions? Pedobiologia 45:355-366.
Sheikh MA, Kumar M, Bussman RW (2009). Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya. Carbon Balance Management 4:6.
Sileshi G, Mafongoya PL (2006). The short-term impact of forest fire on soil invertebrates in the miombo. Biodiversity and Conservation 15:3153-3160.
Silver WL, Thompson AW, Reich A, Ewel JJ, Firestone MK (2005). Nitrogen cycling in tropical plantation forests: potential controls on nitrogen retention. Ecological Applications 15(5):1604-1614.
Steinberger Y, Whitford WG (1984). Spatial and temporal relationship of soil microarthropods on a desert watershed. Pedobiologia 26(4):275-284.
Subbiah BV, Asija GL (1956). A new method of determining available nitrogen in soil. Current Science 25:259-260.
Susilo FX, Neutel AM, van Noordwijk M, Hairiah K, Brown G, Swift MJ (2004). Soil biodiversity and food webs. In: van Noordwijk M, Cadisch G, Ong CK (eds.), Below ground interactions in tropical agroecosystems: concepts and models with multiple plant components. Indonesia, ICRAF, CABI Publishing pp. 285-302.
Suthar S (2009). Impact of vermicompost and composted farmyard manure on growth and yield of garlic (*Allium sativum* L.) field crop. International Journal of Plant Production 3(1):27-38.
Swanson ME, Franklin JF, Beschta RL, Crisafulli CM, DellaSala DA, Hutto RL, Lindenmayer DB, Swanson FJ (2011). The forgotten stage of forest succession: early-successional ecosystems on forest sites. Frontiers in Ecology and the Environment 9(2):117-125.
Swift MJ, Heal OW, Anderson JM (1979). Decomposition in terrestrial ecosystems. Berkeley, University of California Press.
Tajovský K (1999). Epigeic activity of millipedes (Diplopoda) in an abandoned field. In. Pižl V, Tajovský K (eds.), Soil Zoological Problems in Central Europe. Èeské Budìjovice pp. 351-356.
Templer PH, Silver WL, Rett-Ridge J, Deangelis KM, Firestone MK (2008). Plant and microbial controls on nitrogen retention and loss in a humid tropical forest. Ecology 89(11):3030-3040.
Tiunov AV, Scheu S (2004). Carbon availability controls the growth of detritivores (Lumbricidae) and their effect on nitrogen mineralization. Oecologia 138:83-90.
Tyler G, Olsson T (2001). Concentrations of 60 elements in the soil solution as related to the soil acidity. European Journal of Soil Science 52(1):151-165.
van Straalen NM (1998). Evaluation of bioindicator systems derived from soil arthropod communities. Applied Soil Ecology 9(1-3):429-437.
van Straalen NM, Verhoef HA (1997). The development of a bioindicator system for soil acidity based on arthropod pH preferences. Journal of Applied Ecology 34(1):217-232.
Vitousek P, Sanford RLJ (1986). Nutrient cycling in moist tropical forest. Annual Review of Ecology and Systematics 17(1):137-167.
Walkley A, Black IA (1934). An examination of the Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Science 37(1):29-38.
Wander MM, Drinkwater LE (2000). Fostering soil stewardship through soil quality assessment. Applied Soil Ecology 15:61-73.
Wardle DL, Nilsson M, Zackrisson O, Gallet C (2003). Determinants of litter mixing effects in a Swedish boreal forest. Soil Biology and Biochemistry 35:827-835.
Wilding LP, Drees LR, Nordt LC (2001). Spatial variability: enhancing the mean estimate of organic and inorganic carbon in a sampling unit. In. Lal R, Kimble JM, Follett RF, Stewart BA (eds.), Assessment methods for soil carbon. Boca Raton, FL, USA, Lewis Publishers P 676.
Wise DH (1993). Spiders in Ecological Webs. New York, Cambridge University Press.
Work TT, Shorthouse DP, Spence JR, Volney WJA, Langor D (2004). Stand composition and structure of the boreal mixed-wood and epigeic arthropods of the Ecosystem Management Emulating Natural Disturbance (EMEND) land base in Northwestern Alberta. Canadian Journal of Forest Research 34(2):417-430.
Zhao HL, Li J, Liu RT, Zhou RL, Qu H, Pan CC (2014). Effects of desertification on temporal and spatial distribution of soil macro-arthropods in Horqin sandy grassland, Inner Mongolia. Geoderma 223:62-67.
Zhou Y, Liu C, Ai N, Tuo X, Zhang Z, Gao R, Qin J, Yuan C (2022). Characteristics of soil macrofauna and its coupling relationship with environmental factors in the loess area of Northern Shaanxi. Sustainability 14(5):2484.