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FOREST POST FIRE IMPACT ON EARTHWORM BIOMASS AND ABUNDANCE IN ZAWITA (DUHOK PROVINCE) FORESTS KURDISTAN REGION

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ABSTRACT

Little is known about earthworms (*Lumbricus terrestris*) (Oligochaeta: Lumbricidae) in Duhok Governorate/ North Iraq. This study examines the effect of fire on earthworm abundance and biomass at different times of burning forests compared with unburnt forests in Duhok Governorate. Wildfires have a significant impact on shaping the structure and makeup of forests, especially in areas characterized by extended periods of dry and hot summers. In the context of Northern Iraq and the Kurdistan Region, the relatively brief wet seasons of autumn and winter lead to a higher incidence of wildfires during the summer months. To test the post-fire effects on earthworm's abundance and biomass, soil cores were collected from four different villages (Zawita, Bajlor, Bade) that have been burnt in different years (before five, three and one year) respectively and a control site. Earthworm abundance and biomass, and some physical and chemical soil properties (soil moisture, soil texture, organic matter (OM), pH, available phosphorus P, exchangeable potassium K and total nitrogen N,) were measured. Based on the outcomes of this study, the earthworm abundance and biomass showed significantly positive correlation ($P < 0.01$) with the availability of measured physio-chemical properties. Furthermore, forest fire had a significant ($P < 0.01$) effect on the earthworm population by determining higher content of measured physio-chemical properties (organic matter NPK). Data suggest that fire can alter the structure of earthworm communities in soil by affecting the availability of food resources or the burning of waste and soil organic matter. Furthermore, future studies will need to have replications of control in all burnt sites as long they have different soil physio-chemical properties.

KEYWORD: Earthworm, Abundance, Biomass, Forest fire, physio-chemical properties.

1. INTODUCTION

One of the most dangerous hazards to the Duhok forests is fire. The vast majority of wildfires are started by both man and nature. Duhok governorate including Duhok district is highly disposed to forest fire, as the Iraqi climate is subtropical semi-arid type. According to the Directorate of Forestry and Rangelands in Duhok Province (2022) around 1,126 fire incidents occurred between 2007 to 2022 in Duhok governorate, as a result, causing of burning 122,681 dunams of area. Wildfire has numerous immediate and long-term impacts on ecosystems (Datta, 2021); it affects both vegetation and forest soil. The impact of fire on the chemical, physical, and biological characteristics of soil is crucial for ecosystem sustainability and future productivity. (Neary et al., 2005). Fire can alter the diversity, content, and structure of plants (Kittur et al., 2014), destroy biomass and organic matter, and alter the physio-chemical characteristics of soil, such as by reducing soil porosity and increasing pH (Jhariya and Raj, 2014).

The effects of wildfires are either hazardous or beneficial to the ecosystem depending on the severity of the fire (Datta, 2021). The magnitude and duration of the detrimental impacts of a fire on soil properties are influenced by several factors. These include the fire's intensity, duration, and severity (Certini, 2005), the nature of the fuel involved, the level of soil moisture (Parson et al., 2010), and the frequency of fires (Osman, 2008). The influence of the long-term and the short-term will differ intensively (Datta, 2021). The fire intensity depends on the fire duration and the temperature (dwell time) and signifies the energy release of a fire (Neary, 2005). As a result, topography, weather, fuel quantity and flammability, and other factors all have a significant role in fire intensity (Jordán et al., 2011). The surface temperature of low-intensity fires reaches up to 250 °C, while the surface temperatures of medium-intensity and high-intensity fires reach up to 450 °C and 650 °C, respectively (Araya et al., 2016). According to Verma (2012), during low-intensity fires, the burning of litter and soil organic matter increases the nutrients available to plants, resulting in rapid herbaceous plant growth and a significant increase in plant nutrient stores. On the other hand, high-intensity fires can lead to complete loss of soil organic matter, volatilization of nitrogen, phosphorus, sulfur, and potassium, and death of microorganisms. Intense forest fires can lead to the formation of some hydrophobic organic compounds, resulting in highly water-resistant soils. Low-intensity fires that deposit ash on the soil surface can result changes in soil chemistry, including increases in pH and available nutrients. High-intensity fires are characterized by comprehensive combustion of natural organic matter and have extreme negative impacts on forest soils. High-intensity fires lead to nutrient volatilization, collapse of soil aggregate stability, increased soil density, and increased hydrophobicity of soil particles, resulting in increased erosion and reduced water infiltration and destruction of soil biota. Strong soil warming (>120°C) caused by high-intensity forest fires is harmful to soil ecosystems, particularly their biological and physical properties (Agbeshie et al., 2022).

Soil organisms play a vital role in a variety of ecosystem functions that are necessary for natural and managed ecosystems (Wardle, 2004). Soil invertebrates are involved in the decomposition of litter, the mineralization of carbon and nutrients, the turnover of soil, and the formation of soil structure (Neary et al., 1999). Earthworms perform a significant role in a wide range of ecosystem processes and functions. Earthworms conduct a vital function in the creation and upkeep of soil structure, and their actions have a significant impact on soil functioning, such as the regulation of water and the cycling of nutrients (Agbeshie et al., 2022). Earthworms perform a major function in improving soil fertility in different ways (Thomas et al., 2004). Earthworms have a beneficial effect on the physical and chemical properties of soil. Soil, as an important component of forest communities, is also affected by fire in multiple ways. Soil micro-organisms is one of the main components of soil in response to fire, which is reflected in variable species composition and proportion between vegetative groups and reduced animal density (Bezkorovaynaya et al., 2007; Jhariya and Raj, 2014). Fire enables the effect of invertebrates and micro-organisms in a direct and indirect way (Jhariya and Raj, 2014). Direct impact, including the introduction of forest fauna to high temperature, which changes the species composition and declines the abundance of some groups (Kudryasheva and Laskova, 2002), with surface-dwelling animals being the most vulnerable. Food resources are the biggest stress factor for the species after the fire. High intensity fires that destroy the food supply for diverse soil biota representatives are most damaging, especially in the early years (Bezkorovainaya, 2007).

In this study we hypothesized that burnt forests would have fewer earthworms than those not burnt because 1) With less organic matter in the soil and less leaf litter coming from trees and plants, there would be less food for earthworms, reducing their growth and fertility 2) Through direct mortality of earthworms from fire. Furthermore, a prolonged period following a forest fire would likely lead to an increased abundance and biomass of soil earthworms, as the ecological soil structure becomes fully restored or recovered.

2. MATERIAL AND METHODS

2.1 The Study Area

This study was carried out in the natural forests of Duhok Governorate. Duhok Governorate located in the north-west of Iraq and forms the western governorate in Iraqi Kurdistan Region. Climatically the study sites typically characterized by hot weather in summer, where temperatures ranging 35 °C to 40 °C and sometimes up to 45°C, and extremely cold during winter; while it has a moderate climate in other seasons. Rainfall averages 619.49 mm yearly (Dohuk metrology stations 2012-2023). The study area was dominated by mixed natural forests containing native tree species of *Quercus aegilops* and *Pinus brutia*. Three sites (Zawita, Bajlor and Bade) were selected for this study, which were burnt in different durations and a control site, map showed below.

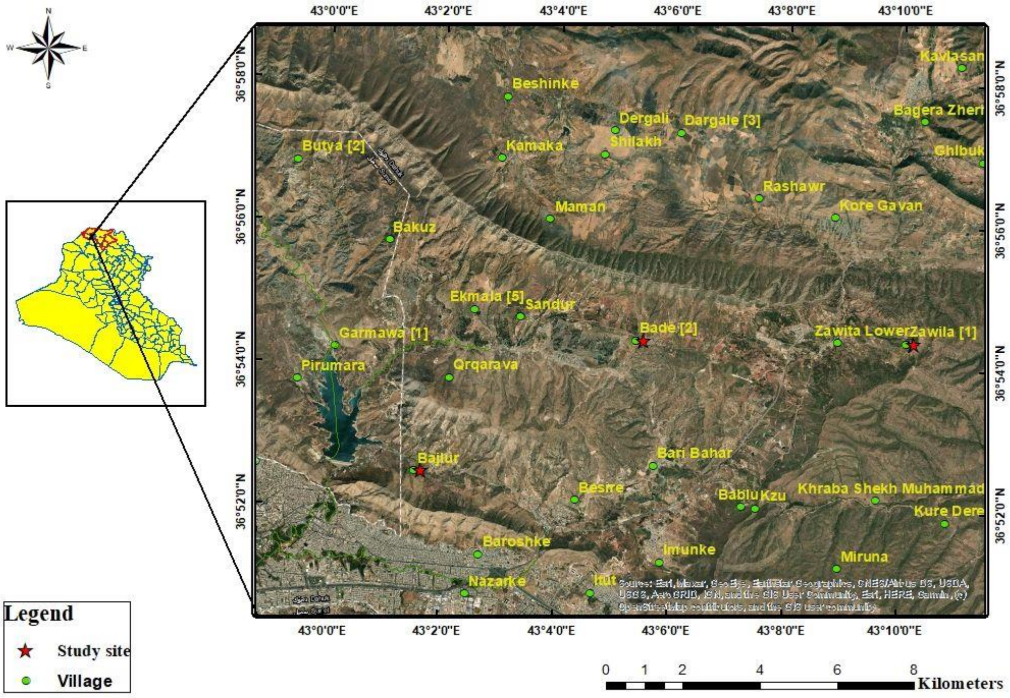

Fig. (1): Map illustrating study sites (★study site and ● Village)

2.2 Experimental Design, Soil Sampling And Analyses

2.2.1. Earthwormm Sampling

The forest fires experiment of different post burnt duration were carried out in (Zawita after 5 years, Bajelor after 3 years and Bade after 1 year) and unburnt forests in Bade location showing in figure (1). In May 2022, ten soil samples were randomly taken from each burnt and unburnt forest sites. Earthworms were sampled using monoliths of soil measuring 25cm*25cm*25cm (=0.0625m2) depth from each of the sampling points. Litter layers were removed before the soil was sampled and worms were collected from the organic matter. Then each soil sample was hand-searched for earthworms and they were killed in 50% of ethanol in the field and transported to the laboratory, then preserved in 4% formaldehyde. Hand-sorted lumbricids earthworms were grouped into two categories based on the absence and presence of the clitellum; juveniles and adults (fully developed clitellum). However, the majority of earthworms (77 %) did not have a clitellum, indicating immature individuals that were either very hard or impossible to identify at a species level. Consequently, collected earthworms were pooled together for statistical analyses. Due to the higher number of juveniles and fewer adults, all earthworms were combined and counted and weighed and then they were oven dried at 60°C for 24 h. All the dried earthworms were weighed to the nearest 0.0001 g to determine their biomass weight (Welke and Parkinson 2003).


Fig. (2): Two sampling sites (1) Bade forest one year after burnt (2) Zawita forest five years after burnt

2.2.2. Soil Physical And Chemical Analysis

In addition to sampling earthworms at every site, soil samples were collected to examine some soil physical and chemical properties. As a result, 40 soil samples were collected from all four locations burnt and unburnt and sent to the soil lab for analysis. All soil samples were air dried and then passed through a 2 mm mesh. The soil was analyzed for texture, pH, electrical conductivity (EC), nitrogen (N) mg/kg, phosphorus (P) mg/kg, potassium (K) mg/kg, organic matter (OM) % and soil moisture %.

In the laboratory, the following soil properties were determined: soil pH was measured using the pH-meter model Hans Herbert Mennerich (geotechnik) Hanover as described by (Van Reeuwijk, 1995), soil texture by hydrometer method (Bouyoucos 1962), available nitrogen (N) using Kjeldahl – distillation method according to (Bremner and Mulvaney1982), available phosphorus by using Olsen procedure as described in Ryan et al., (2001), exchangeable potassium is analyzed after extraction with natural salt, 1M NH4OAC minus the water soluble potassium (Knudsen et al., 1982) organic carbon (OC) was determined by Walkley and Black method described by (Nelson ad Sommers, 1982). While soil water content was measured by oven drying method (Rasheed et al., 2022).

2.2.3. Statistical

The obtained data were submitted to the one-way analysis of variance (ANOVA) and mean values of the site effect on both earthworm abundance and Biomass were compared by Duncan's multiple range test ($p<0.05$), when a significant difference was detected. The statistical analysis was performed using SPSS 13.0 for Windows (SPSS, Chicago, IL, USA).

Linear regression analysis was used to detect the relationships between the earthworm abundance and Biomass with soil properties (pH, N, K, P, Organic Matter, Soil Moisture, Soil Texture, and EC).

3. RESULTS

3.1 Effect Of Post-Fire On The Number Of Earthworms

Large differences in the number of earthworms were found under burnt and unburnt forests. From a total of 40 samples were collected from all study locations, 191 individual earthworms were collected. According to the field observations, 83 and 87 % of the overall number of earthworms was under burnt Zawita and Bade forest locations, after 5 and 1 years of Burnt, respectively. The abundance of earthworms was significantly higher under all burnt forests (Zawita, Bade, Bajlor) compared with unburnt forests regardless of the duration of the burn (8.3, 8.7, 1.6, 0.5) individual/ m^2 respectively. Furthermore, comparisons of mean earthworm catches at each three burnt forest locations using one way ANOVA test for the multiple comparisons of means detected the following trends of soil earthworms' abundance variations: (1) One year after the fire, the mean abundance of earthworms was significantly higher (with a value of 8.3 individual/m^2) than after 3 years of burn (1.6 individual/m^2) (2) Five years after burning, the mean abundance of earthworms was significantly higher (with a value of 8.7 individual/m^2) than after 3 years of burn(1.6 individual/m^2). Thus, the populations of earthworms in the post-fire period of three years were consistently lower compared to those in the post-fire period of one and five years.

3.2 Effect Of Post-Fire On The Biomass Of Earthworms

Burning history had important effects on earthworm abundance. Biomass was faithfully linked to mean earthworm catch; therefore, as for abundance, mean biomass was significantly lower at the control site compared with all three burnt forest locations. Analysis of the mean earthworm biomass using one way ANOVA test indicated a significant increase in forest burnt after one year (mean ± SEM) (1.1933± 0.4401) compared to three and five years post-fire periods(Figures 3).

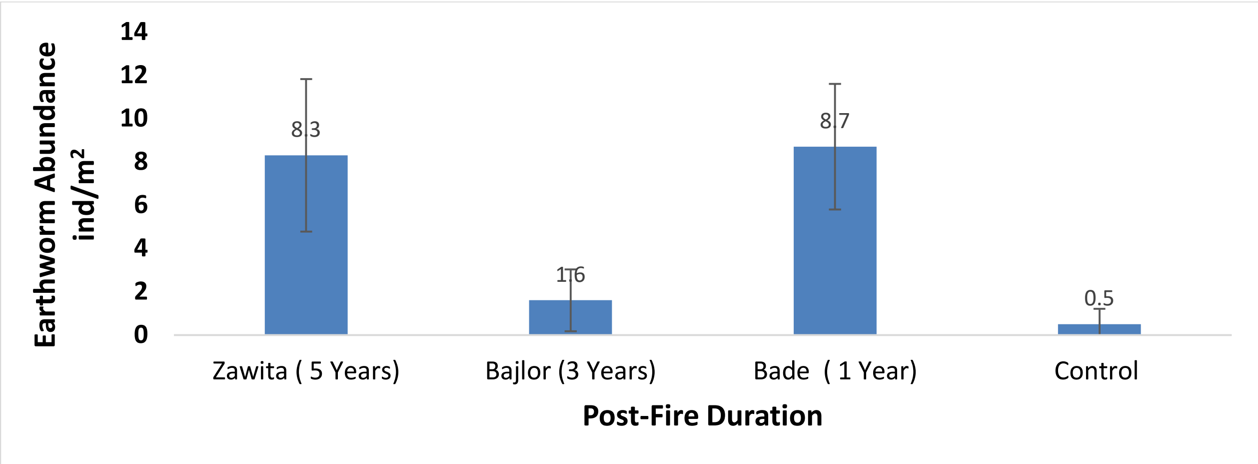

Fig. (3): Post-fire population dynamics of earthworms in experimental plots (mean ± SEM).

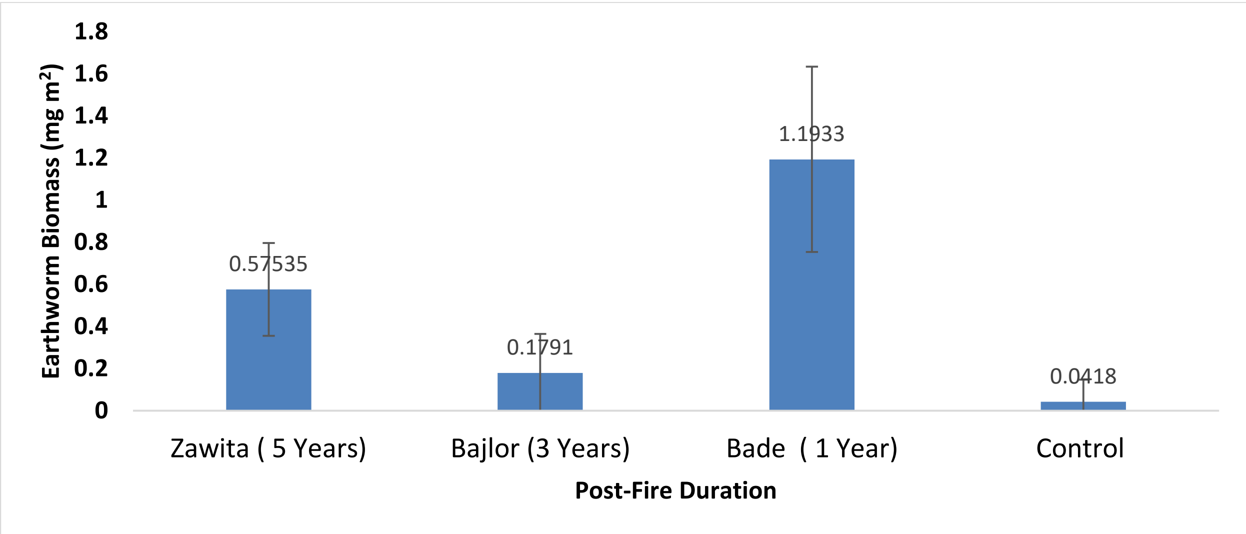

Fig. (4): Post-fire biomass dynamics of earthworms in experimental plots (mean ± SEM).

3.3: Correlation Of Physio-Chemical Properties Of Soil And Earthworms Abundance And Biomass

The measured physical and chemical analysis of soils of all sampling sites is given in Table 1. The texture of soil was found to be clay to loam at all burnt forest locations, while loam in unburnt forest pH from 8.26-8.59, EC from 0.533- 0.569, OM from 2.50%- 4.36%, 4.36%–2.50%, Soil moisture from 18%-23%, N from 94.4 -144.62mg/Kg, P from 7.88 - 9.36mg/Kg, and K from 24.22 -33.12 mg/Kg. The abundance and biomass of earthworm and the range of physical and chemical properties of soil at different sampling sites is given in figure (5).

Positive but not significant correlations were found between soil properties and abundance of earthworms in all study sites indicating that more worms were found with higher physio-chemical in the soil. The results also showed a positive but weak correlation of all measured soil properties pH, soil texture, Organic Matter, soil moisture, EC, N, K, and P with earthworm biomass (Figure 4).

Table (1): Physical and chemical properties of soil samples collected from each sites.

Location	Soil Properties							
	PH	Organic Matter %	EC	Soil Texture	Soil moisture %	N mg/kg	P mg/kg	K mg/kg
Zawita	8.59	4.36%	0.596	Clay loam	21	144.62	9.36	33.12
Bjelor	8.26	3.20%	0.533	Clay loam	20	116.8	8.09	29.19
Bade	8.51	3.07%	0.57	Clay loam	23	110.5	7.88	28.4
control	8.6	2.50%	0.562	Loam	18	94.4	6.14	24.22

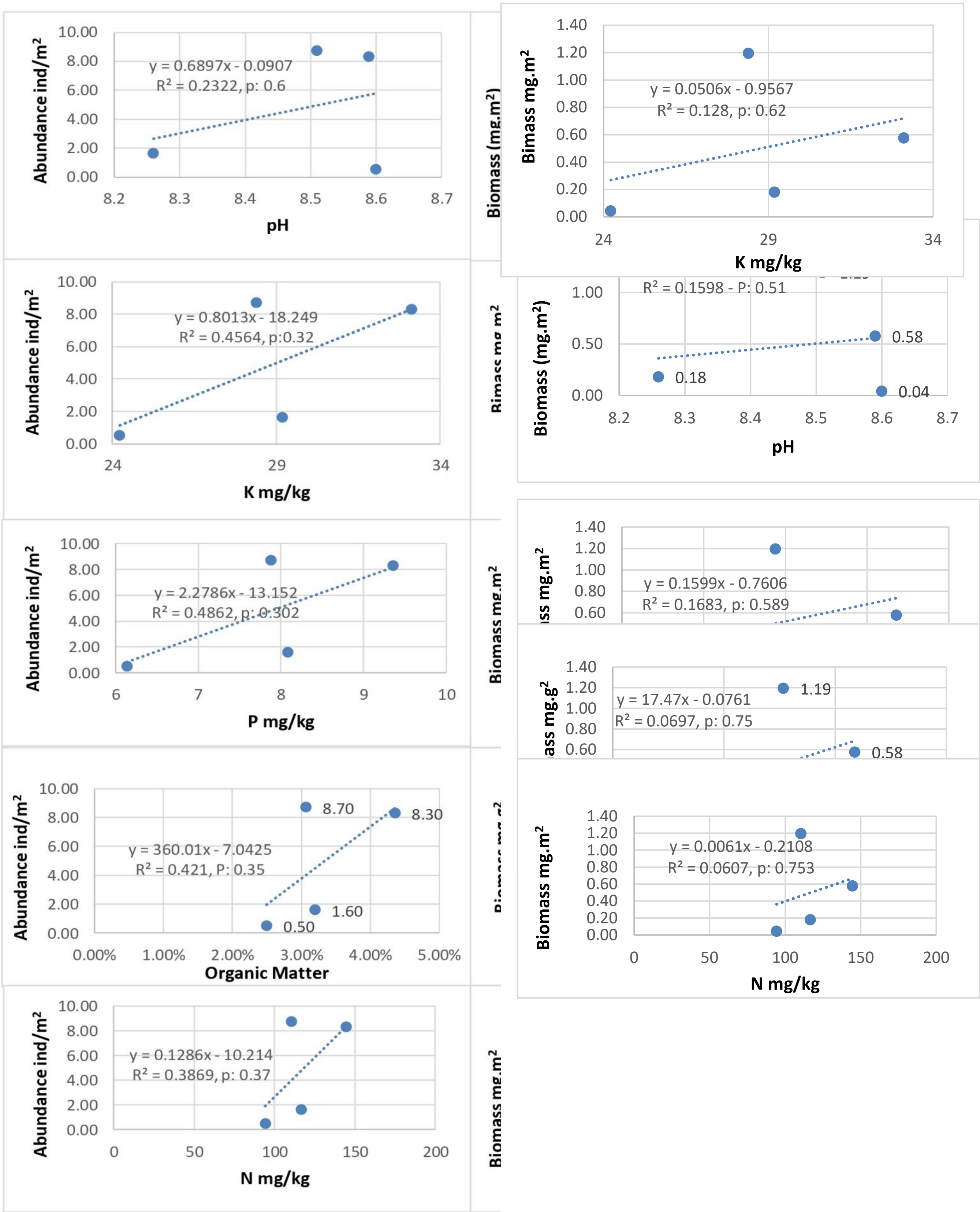

Fig. (5_: The relationship between earthworm abundance and biomass and measure ed soil properties.

4. DISCUSSION

Earthworms play a vital role as soil taxon engineers and are responsible for a wide range of important ecosystem functions and services (Phillips et al., 2021). A low sample size of earthworms was collected and recorded during May period of the year 2022.

The lack of soil-dwelling earthworms in our samples during this timeframe is likely attributed to their vertical movement into deeper soil layers this behavior was observed specifically for Lumbricidae; (based on personal observations). Our hypothesis suggested that earthworms would exhibit higher abundance and biomass in the unburnt forest compared to the burnt forest. Overall, the fire showed to have a positive effect on soil earthworm abundance and biomass compared to unburnt forest, as can be seen in figure (3). A potential explanation for the decline in earthworm abundance and biomass in the unburnt forest is the lowest soil organic matter as well as the content of nutrients (NPK) in this site or because of soil texture of control plots which is loamy compared to burnt plots which are clay loam as it is shown in table (1). Thomas et al. (2004) claim that the structure of the earthworm cast is very important for the dynamics of SOM in the intermediate range of months to years. Similar effects have been observed by Giraddi et al. (2014) indicating that organic matter content of soil and soil moisture has an influence on earthworm abundance in soils. Moreover, the less abundance and biomass of earthworms in unburnt forest might be due to soil compaction (for example trampling by animals and/or recreation forests), as this site was quite close to Bade village and noticed during digging samples process (personal observation). Cropland, grassland, and forest soil are all subject to soil compaction, which is a growing global environmental issue (Beylich et al., 2010). It is caused by the use of heavy machinery (Horn et al., 2000), also by livestock trampling (Chan and Barchia, 2007) and human leisure activities (Kissling et al., 2009). Furthermore, the moisture is also significant factor for earthworm survival as earthworms usually respire through their skin due to cutaneous respiration mode and thus they always prefer moist soil (Berry and Jordan, 2001). Thus, the lower water content was recorded in unburnt forest site compared to all burnt sites (Table 1). Ivask et al. (2007) proved in their study in Estonia that the soil moisture impacts the abundance of earthworm communities more than soil type.

Furthermore, fires that occurred in different durations had significant effects on soil abundance and biomass of earthworms. It shows that fire had a significant influence on their populations. This could be related to the intensity of the fire and the more frequent fires that occurred in Bajlor site (burnt after three years) in comparison with one year after burnt (Bade site) and five years after burnt (Zawita site). The response of soil dwellers to fire shows an enormous variability and depends on the intensity, frequency, and period of burning (Ahlgren, 1974). The high-intensity fires with extended durations, for example in mixed conifers forests with high fuel loads or where slash is stacked, because the highest impact on soil microorganisms (Neary et al. 1999). The decline in microbial activity in soils is a common observation following high-intensity fires (Fernandez-García ´ et al., 2019). However, these outcomes contrast with stated growths in microbial resulting low to medium-intensity burning (Goberna et al., 2012). Low-intensity fires that leave ash on the surface of the soil cause chemical changes in the soil, such as an increase in pH and availability of nutrients. (Agbeshie et al., 2022). In a study conducted by Bezkorovainaya (2007) over a period of 4-5 years, the abundance, ecological and nutritional structure of the sand podzol community was nearly completely recovered after medium and low intensity surface fires, while the recovery is delayed afterward high-intensity fires. Research shows that low-impact burning in different terrains around the world can promote herbaceous flora, which is important for preserving underground soil sustainability (DeBano et al., 1998). The impact of fire can be beneficial or harmful to the ecosystem, depending on its severity (Datta, 2021). Such intensification may be caused by incomplete combustion of organic matter, releasing labile forms of C, N and macronutrients, and thus possibly causing microbial recolonization and activity in the short-term. As it is mentioned before due to not many adults of earthworms found in this study, species were not identified according to ecological groups. Soil-dwelling earthworms fall into three main niche groupings: epigeic, endogeic and anecic, according to types and depths of the various burrows. Epigenic species living on the surface of the litter can be killed by fire, whereas anecic and endogenic species burrowing into the soil are less likely to be killed by fire (Edwards, 2022). Additionally, fire only raises the soil temperature a few degrees near the surface and a few inches below, the temperature remains unchanged (Ikeda et al., 2015). In this study, in Bade site (one year after burnt) the direct effect of fire can be considered less significant, since higher earthworm's abundance and biomass where found. Moreover, the above ground vegetation cover and amount of accumulated litter might be higher in this site compared with Bajlor and Zawita locations (burnt after three and five years respectively). The impact of fire on earthworm abundance and biomass can be direct, through the immediate death of earthworms, or indirect, through microhabitat and microclimate changes, mainly is due to the destruction of aerial vegetation cover and litter layer (Sgardelis et al., 1995).

Additionally, in this study apositive linear relationship was found between measured soil properties concentrations (N, P, K, EC, soil moisture, organic matter and soil texture) and the mean earthworm abundance and biomass. This pattern of higher abundance and biomass of earthworms with increasing physical and chemical essential elements is in contract with the results of a previous study on the influence of soil physical and chemical properties on the dissemination of earthworm populations across diverse land use patterns in southern India by Sankar and Patnaik (2018) and there was a significant positive correlation between earthworm abundance and all the soil physical and chemical parameters also observed as a whole. The accumulation of large amounts of detritus on the soil surface of agricultural and forestry systems may provide sufficient space, food, shelter, and protection from predation by other animals for earthworm populations, which will also contribute to improving earthworm diversity (Ruan, Li, & Zou, 2005), especially soil habitat conditions. In short, our results suggest that forest fire of different duration has a significant influence on the abundance and biomass of earthworms. Nevertheless, the available data show a positive correlation between earthworm abundance and biomass with physical-chemical properties. This effect of fire on the soil earthworm population might be depended on fire intensity and the duration of combustion and these variations in soil properties may be beneficial or harmful to the complete soil ecosystem.

5. CONCLUSION

In conclusion, we assessed earthworm abundance and biomass in burnt forests at diverse times in addition to the influence of some soil chemical and physical properties on them. It is concluded that fire can change the structure of soil earthworm communities through its effect on the availability of food resources or the combustion of litter and soil organic matter that increases plant available nutrients (this is the case of low intensity fires). Therefore, it is important to determine the severity, intensity and frequency of fire in study sites to establish the linkage between fire effect and invertebrate community structure. As well as, future studies will need to have replications of control in all burnt sites as long they have different soil physio-chemical properties.

6. REFERENCES

Agbeshie, A. A., Abugre, S., Atta-Darkwa, T., & Awuah, R. (2022). A review of the effects of forest fire on soil properties. *Journal of Forestry Research*, *33*(5), 1419-1441.

Ahlgren, C. E. (1974). Effects of fires on temperate forests: North Central United States. *Fire and ecosystems*, 195-223.

Berry, E. C., & Jordan, D. (2001). Temperature and soil moisture content effects on the growth of Lumbricus terrestris (Oligochaeta: Lumbricidae) under laboratory conditions. *Soil Biology and Biochemistry*, *33*(1), 133-136.

Beylich, A., Oberholzer, H. R., Schrader, S., Höper, H., & Wilke, B. M. (2010). Evaluation of soil compaction effects on soil biota and soil biological processes in soils. Soil and Tillage Research, *109*(2), 133-143.

Bezkorovainaya, I. N., Krasnoshchekova, E. N., & Ivanova, G. A. (2007). Transformation of soil invertebrate complex after surface fires of different intensity. *Biology Bulletin*, *34*, 517-522.

Bouyoucos, G.J. (1962). Hydrometer Method Improved for Making Particle Size Analysis of Soils. Agronomy Journal, *54*, 464-465.

Bremner, J.M. and Mulvaney, C.S. (1982). Nitrogen-Total. In: Methods of soil analysis. Part 2. Chemical and microbiological properties, Page, A.L., Miller, R.H. and Keeney, D.R. Eds., American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin, 595-624.

Certini G (2005). Efects of fre on properties of forest soils: a review. Oecologia *143*(1):1–10.

Chan, K. Y., & Barchia, I. (2007). Soil compaction controls the abundance, biomass and distribution of earthworms in a single dairy farm in south-eastern Australia. *Soil and Tillage Research*, *94*(1), 75-82.

Datta, R. (2021). To extinguish or not to extinguish: The role of forest fire in nature and soil resilience. *Journal of King Saud University-Science*, *33*(6), 101539.

DeBano, L. F., Neary, D. G., & Ffolliott, P. F. (1998). *Fire effects on ecosystems*. John Wiley & Sons.

Edwards, C. A., Arancon, N. Q., Bohlen, P. J., & Hendrix, P. (2022). *Biology and ecology of earthworms*. New York, NY, USA:: Springer.

Fernández-García, V., Marcos, E., Fernández-Guisuraga, J. M., Taboada, A., Suárez-Seoane, S., & Calvo, L. (2019). Impact of burn severity on soil properties in a Pinus pinaster ecosystem immediately after fire. *International Journal of Wildland Fire*, *28*(5), 354-364.

Giraddi, R. S., Kale, D., Patil, N. B., & Waseem, M. A. (2014). Earthworm population dynamics as influenced by crop ecosystem and agricultural practices. *Journal of Experimental Zoology, India*, *17*(2), 571-574.

Goberna, M., García, C., Insam, H., Hernández, M. T., & Verdú, M. (2012). Burning fire-prone Mediterranean shrublands: immediate changes in soil microbial community structure and ecosystem functions. *Microbial ecology*, *64*, 242-255.

Ikeda, Y., Shirakabe, A., Maejima, Y., Zhai, P., Sciarretta, S., Toli, J., ... & Sadoshima, J. (2015). Endogenous Drp1 mediates mitochondrial autophagy and protects the heart against energy stress. *Circulation research*, *116*(2), 264-278.

Jhariya, M. K., & Raj, A. (2014). Effects of wildfires on flora, fauna and physico-chemical properties of soil-An overview. *Journal of Applied and Natural Science*, *6*(2), 887-897.

Jordán A, Zavala LM, Mataix-Solera J, Nava AL, Alanís N (2011). Efect of fre severity on water repellency and aggregate stability on Mexican volcanic soils. CATENA 84(3):136–147.

Kissling, M., Hegetschweiler, K. T., Rusterholz, H. P., & Baur, B. (2009). Short-term and long-term effects of human trampling on above-ground vegetation, soil density, soil organic matter and soil microbial processes in suburban beech forests. *Applied soil ecology*, *42*(3), 303-314.

Kittur, B. H., Swamy, S. L., Bargali, S. S., & Jhariya, M. K. (2014). Wildland fires and moist deciduous forests of Chhattisgarh, India: divergent component assessment. *Journal of Forestry Research*, *25*, 857-866.

Knudsen, D., Peterson, G.A. and Pratt, P. (1982). Lithium, Sodium and Potassium. In: Page, A.L., Ed., Methods of Soil Analysis, American Society of Agronomy, Madison, 225-246.

Kudryasheva, I. V., & Laskova, L. M. (2002). Oribatid mites (Acariformes, Oribatei) as an index of postpyrogenous changes in podzol and peat soils of boreal forests. *Biology Bulletin of the Russian Academy of Sciences*, *29*, 92-99.

Neary, D. G., Klopatek, C. C., DeBano, L. F., & Ffolliott, P. F. (1999). Fire effects on belowground sustainability: a review and synthesis. *Forest ecology and management*, *122*(1-2), 51-71.

Neary, D. G., Ryan, K. C., & DeBano, L. F. (2005). Wildland fire in ecosystems: effects of fire on soils and water. *Gen. Tech. Rep. RMRS-GTR-42-vol. 4. Ogden, UT: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 250 p.*, *42*.

Nelson, D.W. and Sommer, L.E. (1982). Total Carbon, Organic Carbon and Organic Matter. Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, 2nd Edition. ASA-SSSA, Madison, 595-579.

Osman, A. (2008). *Effects of Fires on the Soil Physical and Chemical Properties and the Soil Seed Bank in Albaja Area at White Nile State, Sudan* (Doctoral dissertation, UOFK).

Phillips, H. R., Bach, E. M., Bartz, M. L., Bennett, J. M., Beugnon, R., Briones, M. J., ... & Webster, E. R. (2021). Global data on earthworm abundance, biomass, diversity and corresponding environmental properties. *Scientific data*, *8*(1), 136.

Rasheed, M. W., Tang, J., Sarwar, A., Shah, S., Saddique, N., Khan, M. U., ... & Sultan, M. (2022). Soil moisture measuring techniques and factors affecting the moisture dynamics: A comprehensive review. *Sustainability*, *14*(18), 11538.

Ruan, H., Li, Y., & Zou, X. (2005). Soil communities and plant litter decomposition as influenced by forest debris: Variation across tropical riparian and upland sites. *Pedobiologia*, *49*(6), 529-538.

Ryan, J., Estefan, G., & Rashid, A. (2001). *Soil and plant analysis laboratory manual*. 2nd edition, international center for agriculture research in the dry areas (ICARDA).

Sankar, A. S., & Patnaik, A. (2018). Impact of soil physico-chemical properties on distribution of earthworm populations across different land use patterns in southern India. *The Journal of Basic and Applied Zoology*, *79*(1), 1-18.

Sgardelis, S. P., Pantis, J. D., Argyropoulou, M. D., & Stamou, G. P. (1995). Effects of fire on soil macroinvertebrates in a Mediterranean Phryganic ecosystem. *International Journal of Wildland Fire*, *5*(2), 113-121.

Thomas, F., Folgarait, P., Lavelle, P., & Rossi, J. P. (2004). Soil macrofaunal communities along an abandoned rice field chronosequence in Northern Argentina. *Applied Soil Ecology*, *27*(1), 23-29.

Van Reeuwijk, L. R. (1995). Procedures for soil analysis: 3-8. 5thedition. International Soil Reference and Information Center, technical paper 9.

Verma, S., & Jayakumar, S. (2012). Impact of forest fire on physical, chemical and biological properties of soil: A review. *proceedings of the International Academy of Ecology and Environmental Sciences*, *2*(3), 168.

Wardle, D. A., Bardgett, R. D., Klironomos, J. N., Setala, H., Van Der Putten, W. H., & Wall, D. H. (2004). Ecological linkages between aboveground and belowground biota. *science*, *304*(5677), 1629-1633.

Welke, S. E., & Parkinson, D. (2003). Effect of Aporrectodea trapezoides activity on seedling growth of Pseudotsuga menziesii, nutrient dynamics and microbial activity in different forest soils. *Forest ecology and management*, *173*(1-3), 169-186.

Dohuk metrology stations period between (2012-2022)

Parsons, A., Robichaud, P. R., Lewis, S. A., Napper, C., & Clark, J. T. (2010). *Field guide for mapping post-fire soil burn severity* (Vol. 243). Fort Collins, CO, USA: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49 p. 243.

Jordán, A., Zavala, L. M., Mataix-Solera, J., Nava, A. L., & Alanís, N. (2011). Effect of fire severity on water repellency and aggregate stability on Mexican volcanic soils. *Catena*, *84*(3), 136-147.

Araya, S. N., Meding, M., & Berhe, A. A. (2016). Thermal alteration of soil physico-chemical properties: a systematic study to infer response of Sierra Nevada climosequence soils to forest fires. *Soil*, *2*(3), 351-366.

Horn, R., Van den Akker, J. J. H., & Arvidsson, J. (2000). *Subsoil compaction: distribution, processes and consequences* (No. 32). Catena Verlag.

Ivask, M., Truu, J., Kuu, A., Truu, M., & Leito, A. (2007). Earthworm communities of flooded grasslands in Matsalu, Estonia. *European Journal of Soil Biology*, *43*(2), 71-76.