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Macrofauna contributes to organic matter decomposition and soil quality in Himalayan agroecosystems, India

Madhuri Pant, Girish C.S. Negi*, Pramod Kumar

G.B. Pant National Institute of Himalayan Environment and Sustainable Development, Kosi-Katarmal, Almora, Uttarakhand, 263 643, India

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A B S T R A C T

In agroecosystems, rich soil biodiversity performs a variety of ecological services and contributes to sustainability of agriculture. In spite of the vast knowledge on this subject globally, the Himalayan mountain agroecosystems remain almost unexplored, and the agriculture is practiced on a subsistence level in the desire of suitable soil fertility management practices. This study was conducted on the soil macrofauna community and its influence on litter decomposition, nutrient release and soil quality in rainfed wheat-paddy cropping systems in two major agroecosystems in the central Himalayan mountains. Following local farmers' practice, Oak leaf litter (agroecosystem-I) and Pine forests leaf litter (agroecosystem-II) were used for farm yard manure (FYM) preparation for soil fertility restoration. Control (traditional cropfields) and treatment (macrofauna excluded plots) were maintained in this study. In both the agroecosystems, 11 soil macrofauna groups were recorded across 0–30 cm soil depths over an annual crop cycle. Total macrofauna density in the rhizosphere zone of agroecosystem-I was significantly greater ($P < 0.01$) than in agroecosystem-II (2477 vs. 2241 ind m^{-2}), and it was particularly significantly greater ($P < 0.01$) in the top soil (0–10 cm depth) of agroecosystem-I (2321 vs. 1877 ind m^{-2}). With regards to macrofauna taxonomic groups and population density our study area falls in the middle range reported for the world (taxonomic groups = 11-22; population density = 1637–9500 ind m^{-2}). Decomposition of the Oak and Pine leaf litter was significantly lower ($P < 0.01$) in macrofauna-excluded litter bags in agroecosystem-I (63.4 vs. 49.4%) than in agroecosystem-II (44.4 vs. 29.2%). Levels of available nutrients (NO_3-N,NH_4-N, PO_4-P and available K) were significantly higher in the soil of control plots than in treatment plots. This study concludes that soil macrofauna plays an important role in litter decomposition and soil quality maintenance, and recommends that nutrient rich Oak leaf litter should be preferred over Pine leaf litter to promote macrofauna diversity and abundance and soil quality enhancement in the rainfed farming of Central Himalaya.

1. Introduction

A major goal of agriculture is to maximize productivity of food crops that calls for better understanding the cycling of C and N, mediated through the decomposer biota in the soil ecosystem (Bearea et al., 1997; Swift, 1997; Lavelle et al., 2001). This understanding of soil ecology is crucial for the management of organic matter inputs in agroecosystems (Mafongoya et al., 1997; Adl, 2016). Soil organisms, due to their ability to fragment organic matter, work as extrinsic modifiers, and significantly alter decomposition processes and nutrient cycling (Swift et al., 1979; Scheu, 1997), making the nutrients available for microorganisms (Petersen and Luxton, 1982), and plants (Anderson and Ingram, 1993), and sustaining ecological niches and trophic pyramids. The abundance and diversity of organisms in the rhizosphere depend on the cropping environment, the plant species, and the chemicals exuded from their roots that can stimulate or inhibit soil organisms, infect the root, or modify plant growth (Watt et al., 2006). When re-ingesting their excretions, mesofauna and some macrofauna serve as incubators for bacteria (Swift et al., 1979). Assimilation of metabolites liberated by microbial actions makes the basis of the biological systems that determine soil functioning (Lavelle and Spain, 2001). The macrofauna forms the link between the primary decomposers (i.e., microorganisms) and the mesofauna in the detritus food web in the soil and lives mostly in upper 30 cm of soil. It facilitates symbiotic and asymbiotic relationships with plants and their roots (Ruiz et al., 2008). Therefore, any discussion on rhizosphere and plant nutrition is incomplete without understanding the ecology of the soil and its biota.

The rhizosphere is a unique micro-ecological zone in direct proximity of plant roots that represents a reservoir of biodiversity. Rhizosphere contains many less studied as well as more numerous

* Corresponding author.
E-mail address: negigcs@gmail.com (G.C.S. Negi).

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Table 1
An overview of soil macrofauna research in agroecosystems of the world.

Crop/Site	Macrofauna abundance (ind./m^2)	Reference
Himalayan countries		
Vegetable land, China	Earthworms- 340	Tao et al. (2013)
Agricultural land, Nepal	Earthworm < 100; high density during June and low during October	Kalu et al. (2015)
High and low input wheat crop cultivation, Pakistan	Species richness in high input = 62 Species richness in low input = 102 Pulmonata, Hymenoptera, Coleoptera, Isoptera & Dermoptera were most abundant groups	Rana et al. (2010)
Central Himalayan cropfields, India	Earthworms (8–147)	Bhadauria et al. (2012)
Tarai agriculture, central Himalaya, India	Earthworm (204–1033 in 0–10 cm depth; 3–92 in 10–20 cm depth)	Bisht et al. (2003)
Jorhat (Assam), India	High proportion (51% of Collembola followed by soil mites (27%) and other soil arthtropods (22%) recorded from Agricultural field. Forest land recorded high proportion of soil mites (33%) and other soil arthropods (31%).	Akoijam and Bhattacharya (2015)
Annual crops, Western Ghats, India	Earthworm (24), Ants (40), Termites (16), Bettles (3.2), Millipede (1.6), Centipede (8), Spiders (1.6)	Rahman et al. (2011)
Traditional crops, Central Himalaya, India	2240–2475	Present study
Other Countries of the world		
Oil Palm plantations, Uganda	Ants (3190), Termites (1530), Bettles (910), Snails (300), Spider (130), Centipedes (130), Milipedes (120), Crickets (100), Flies (100)	Nambuya et al. (2013)
Fig and Olive groves, North Algeria	Total macro-invertebrate density (40–380)	Nait-Kaci et al. (2014)
Forest converted to agricultural land, Indonesia	Earthworms (Food crop = 235; Vegetables = 325; Coffee = 463)	Dewi and Senge (2015)
Cropfields in Kenya	Maize = 820; Tea = 755; Coffee = 1170)	Ayuke et al. (2009)
Agro-ecological area, Cote d'Ivoire	Total = 3088–5008 across slope	Olayossimi et al. (2016)
Semi-arid environment, Central Queensland	Earthworms in 3-yr pasture (211), and cropping control (29), old fallow (66)	Radford et al. (2001)
Agroforestry plots (2-yr old), Central America	Dry season (1924 ± 436); Wet season (1637 ± 358)	Pauli et al. (2011)
Cropfields applied with Pig slurry, Brazil	200–1400 per 30 m^2 plots	Ferreira da Silva et al. (2016)
Northern Argentina	Abandoned rice fields (2208); Natural grassland (288)	Folgarait et al. (2003)
Cropping, Peruvian Amazonia	730	Lavelle and Pashanasi (1989)
Conventional tillage system (20 × 20 m^2), Zimbabwe	Termite = 6–81; Ant = 6-13; Beetle larva = 6-7	Mutema et al. (2013)
Conventional tillage (CT), and no-tillage (NT), Pampas region, Argentina	Coleoptera (CT = 45.7 − 80.2; NT = 31.7 − 38.9); Diptera (CT = 17.5 − 73.3; NT = 10–24.5); Hymenoptera (CT = 19.2 − 72.9; NT = 37.8 − 44.2); Aranae (CT = 1.7 − 3.6; NT = 2.2 − 4.3); Geophilomorpha and Scolopendromorpha (CT = 15.7 −65.8; NT = 13.2 − 56.9)	Manetti et al. (2010)
Integrated crop-livestock system (Continuous crop system), Brazil	Coleoptera adult (152), Coleoptera larvae (229), Formicidae (240), Isoptera (251), Oligochaeta (35), Diplopoda (43), Diptera larvae (5), Hemiptera (16), Lepidoptera larvae (6), Arachnida (8), Blattodeae (2), Gastropoda (6), Orthoptera (3)	Marchão et al. (2009)
Cotton cropping system, Cameroon	22 groups (406–484)	Brévault et al. (2007)
Traditional maize crop, France	Earthworms = 121; Termites = 2632; Ants = 597; Milipedes = 21; Centipedes = 2.7; Coleoptera adults = 8; Coleoptera larvae = 5.3; Dermaptera = 8; Hemiptera = 8; Isopoda = 2.7; Diplura = 16	Blanchart et al. (2006)

mesofauna, such as micro-arthropods (Behan-Pelletier and Newton, 1999) and nematodes (Ettema and Yeates, 2003). The mesofauna interacts with elements of the microbiota such as mycorrhiza in a variety of different types of symbioses (Wall and Moore, 1999). Its interaction with soil biota contributes to a variety of ecosystem functions (Coleman and Whitman, 2005) and services (mainly availability of soil nutrients; Bearea et al., 1997). Important among these are maintenance of biological diversity (Altieri, 1999), increase in soil ecosystems' resilience and resistance to pest outbreak, degradation etc. (Pankhurst et al., 1997; Paoletti, 1999). Thus biodiversity performs a variety of ecological services in agroecosystems beyond the production of food, including recycling of nutrients (Lavelle et al., 1997, 2001), counteracting physical and chemical processes of soil degradation (Lee and Foster, 1991), suppression of undesirable organisms and detoxification of obnoxious chemicals (Altieri, 1999) and providing resilience to environmental risks (e.g., drought and fire; Giller et al., 1997). Both fauna and microbiota are also considered bioindicators of soil health (Pankhurst et al., 1997), and agricultural sustainability (Brussaard et al., 2007).

Soil micro- and mesofauna are often aggregated spatially indicating the distribution of favoured resources, such as plant roots and organic debris (Swift et al., 1979; Goodell and Ferris, 1980; Noe and Campbell, 1985). Microbial-grazing mesofauna affect growth and metabolic activities of microbes and alter community composition, thus regulating decomposition rate of organic matter (Seastedt, 1984). The functional dissimilarity among detritivorus species, not species numbers, drives community compositional effects on leaf litter mass loss (Hou et al., 2005), and soil respiration, two key soil ecosystem processes (Heemsbergen et al., 2004). Influence of soil physico-chemical properties and predator populations on the distribution of soil animals across soil depth has frequently been emphasized (Yeates et al., 1993; Angel et al., 2004). Also, change of agricultural practices, tillage and farmyard manure (FYM) application influence the composition, species abundance and functioning of the soil fauna (Dekkers et al., 1994; Filser et al., 1995; Jordan et al., 1997). Certain macrofaunal groups are more responsive to tillage system (Manetti et al., 2010), however, zero tillage favours macrofauna density (Marchão et al., 2009).

In spite of vast knowledge on soil physico-chemical characteristics, and the role of soil biota in organic matter decomposition and soil fertility (Heneghan et al., 1999; Gonzalez and Seastedt, 2001), understanding of soil biodiversity and ecosystem functioning is far from complete (Swift, 1997; Brussaard et al., 2007), except perhaps for earthworms (e.g., Groenigen et al., 2014), and nitrogen fixing bacteria (Crossley et al., 1992). This is partly due to the huge diversity of soil organisms and the difficulties faced to extract organisms from soil efficiently and to identify juvenile stages (Lavelle and Spain, 2001; Neher, 1999). Despite this diversity of rhizosphere organisms already reported, approximately 80% of soil bacteria and 90% of soil microarthropods have yet to be characterized (André et al., 2002; Hugenholtz, 2002),