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REVIEW ARTICLE

Soil Arthropods in Maintaining Soil Health: Thrust Areas for Sugarcane Production Systems

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Abstract Maintaining high agricultural production on a sustainable basis requires conservation of natural resources, including soil quality. Nowadays global interest is growing for improvement in soil quality on the one hand and adoption of sustainable land management system, including farming systems on the other. Since the physical and chemical properties of soil respond slower to change in soil use and its management, the soil biological and biochemical properties along with soil organisms have emerged as indicators of soil quality. In particular, the soil arthropods are now used as indicators of soil quality and also in comparing various land-use systems as they are regulated by anthropogenic impacts. The availability and type of food primarily govern their community structure, abundance and dynamics. Although the interactions between soil invertebrates and land-use management are fundamental for soil quality assessment, such aspects are largely unaddressed in India. Like any other intensive agriculture system, sugarcane cultivation may have negative impacts on soil in terms of loss of quality and soil biodiversity. So there is a need to evaluate such systems from the angle of sensitivity of soil fauna to soil management practices like tillage, fertilizer use, land-use changes, etc. Such an understanding will be of value in designing production system that is sustainably productive. In the paper, present knowledge on soil arthropods, their function and available reports from sugarcane production system are reviewed and approaches to enhance soil biodiversity are discussed. Strategies for designing sustainable sugarcane production system and future thrusts are also presented.

Keywords Agrochemicals · Ecosystem approach · Land preparation · Microarthropods · Organic amendments · Plant diversification

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Introduction

Productivity of any agricultural production system and maintenance of soil fertility are dependent on many factors, i.e. genetic ability of plant, resource availability, environmental factors and withstanding competition with pests and weeds. The availability of resources is directly linked with the soil fertility. The quality of soil is a product of interaction between basic and intrinsic soil properties. The basic soil characters include parent material and topography, while intrinsic properties include organic carbon, pH, bulk density and biological activities. The anthropogenic activities and environmental factors have greater influence on soil intrinsic properties and soil biological activities. The general perception about depleting soil organic matter (SOM) and comparative non-response of inputs on agriculture productivity have forced the researchers to relook into the management of agricultural systems, especially from the point of view of exploiting inherent ecosystem processes in natural ecosystems. In nature, soil biodiversity has positive correlation with productivity and sustainability of the system (Hunt and Wall 2002). The loss in soil biodiversity and simplification of soil community composition lead to reduced plant diversity, plant decomposition, nutrient retention and nutrient cycling (Wagg et al. 2014).

Sugarcane is an important food-producing commercial crop cultivated in tropical and subtropical regions of the world (36°7′N to 31°0′S). Out of hundred and fifteen countries in the world that are growing sugarcane, Brazil is the largest producer in terms of cultivated area (9.83 Mha) followed by India (5.06 Mha), China (1.83 Mha), Thailand (1.32 Mha) and Cuba (0.36 Mha). Brazil and India together produce 37% of the global sugar production. In India, sugarcane occupies 3% of the gross cultivated area and shares about 7% of the total value of agriculture output and supports second largest agro-based industry. Besides the sugar production (75% for human consumption), the crop is gaining importance as a major ethanol-producing and feedstock crop (Goldemberg et al. 2014) and being a C_4 plant is also known as to produce more under elevated CO_2 conditions (De Souza et al. 2008). This long-duration crop is input intensive and depletes soil nutrients heavily. Research indicates that in obtaining a production of 100t/ha of sugarcane production, nutrient removals are to the tune of approximately 205 kg N, 275 kg P, 30 kg S, 3.5 kg Fe, 1.2 kg Mn, 0.2 kg Cu and 0.6 kg Zn (Soloman et al. 2014). The questions of long-term sustainability of soil production ability are very relevant. The crop is important, but the earlier approach of spreading horizontally that is increase in acreage to meet the demands may not be feasible on account of other requirements of the society, and a substantial increase in the area under sugarcane cultivation is difficult. This calls for intensification of research efforts to manage the existing production systems in a way that soil's sustainability is appropriately maintained.

The biotic component of soil is only 0.5% of total soil volume. Out of this, 5–15% is represented by soil organism and 85–95% constitutes plant roots. This small proportion of soil organisms plays an important role in supporting human society. The essential ecosystem functions like decomposition, SOM dynamics and nutrient mobilization are actually performed by this biotic component (Lussenhop 1992; Wurst et al. 2012). Soil contains wide array of microflora and fauna. Microflora consists of archaea, bacteria, fungi, etc. Along with microflora soil contains diverse and abundant fauna such as earthworms, nematodes, arthropods and mammals. Soil arthropods are integral part of below-ground ecosystem. For example, oribatid mites, a common microarthropod feed on plant litter, are found in large number as high as 25,000–500,000 individuals m^{-2} (Coleman et al. 2004).

In agricultural systems, arthropods are generally studied as pests, pollinators, predators and to some extent as provider of usable products like honey, silk and lac. Their recognition as part of ecosystem regulators performing vital functions in nutrient dynamics and maintenance receive little attention. In this article, soil arthropods diversity and dynamics are discussed in the context of soil health maintenance and highlight its scope for sugarcane production systems by regulating them for soil quality improvement.

Soil Arthropods

Soil arthropods are invertebrates, have jointed legs, can be microscopic or quite large and perform many different functions in the soil community. Based on body widths classification, soil arthropods come under mesofauna and macrofauna. They may also be termed as microarthropods (0.2–2 mm) or macroarthropods (> 2 mm). As per traditional taxonomy, soil arthropods fall under class Insecta (e.g. Protura, Diplura, Collembola and larger insects), class Myriapoda (Symphyla and Pauropoda), class Crustacea (Tardigrada, Copepoda and Isopoda) and class Arachnida (Pseudoscorpiones, Araneae and Acari).

The most abundant soil microarthropods, in terms of number of individuals and species, are the Acari (mites) and collembolans (springtails). Springtails are wingless insects and have a segmented body of 0.2–6 mm with specialized appendages, including a spring-like tail used for jumping. Most species are soil or litter dwellers, whilst only few species live on the surface or on the vegetation (mainly Entomobryidae and Symphypleona). In mature soil, their abundance may range 50–100,000 individuals m^{-2}. Protura and Diplura are also wingless insects and resemble to Collembola. Protura feed by sucking on the outer coating of fungal hyphae and prefer organic soils. The diplurans represented by two families (Campodeidae and Japygidae) are predatory in nature, feeding on small fauna. They also scavenge dead organic matter, roots, etc. The other predominant macroarthropods are dipteran, coleopteran and hymenopteran and their juveniles. The ants, millipedes and termites do fragmentation and transportation of organic matter in deeper soil layers by burrowing and are considered as engineers of soil system.

Pauropods are whitish millipede-like (size < 1 mm), feed on decaying plant materials, fungi and carrion. Some species may be predatory in nature. The Symphyla are 1–8 mm in length and prefer organic loam soils. They feed on living plant tissues. Tardigrada, Copepoda and terrestrial Isopoda are abundant in moist forest floors, playing an important role in leaf litter and wood residue decay. Chilopoda are generally predators in the soil and litter layer and feed on small arthropods. Millipedes enrich soil system through coprophagy that leads to mineralization. Their excrements were found enriched with mineral contents.

Spiders and pseudoscorpiones are the predaceous arachnids. Mites live in litter and air-filled soil pores. Their density in forest soils can reach hundreds of thousands of individual m^{-2}. However, they often go unnoticed because of their small size. About 50,000 mite species are known, but it is believed that up to 1 million species could be in this group.

Diversity

Diversity of organisms is directly related to the capacity to cope up with their habitat, environment and the food availability. In this process, they develop distinct traits and the interactions (interspecific and intraspecific) that direct various ecosystem functions operative over evolutionary timescale. Soil as habitat regulates soil arthropod diversity based on its physical structure (porosity), availability of nutrients, water (soil moisture), environment (temperature, pH) and chemical composition (Van Straalen 1998). The acclimatization to living, moving and feeding has reportedly generated higher diversity than the above-ground plant and animal diversity (Bardgett et al. 2005; Bardgett and Wardle 2010). This vast diversity (Table 1) of soil organism is largely unknown because of the difficulty in their isolation, owing to small size and diverse adaptation to soil habitat.

Functions

Basically, two biological processes, i.e. photosynthesis (composition or the fixation of carbon) and respiration (decomposition or release of energy in the form of reduced carbon), are important for life in this planet. This release of energy from detritus depend on the abiotic and biotic constituents of a given soil ecosystem. The complex functioning in soil food web follows distinct channels either via fungi or via bacteria (Hunt et al. 1987; Scheu et al. 2005) followed by higher groups of animals. The activity spheres of soil organisms have distinct properties and regulate interactions among them at spatial and temporal scales. Surface soil litter provides habitat for mycorrhizal activity, grazing and predating by the fauna. In small patches within detritus layer, burrowing insects, earthworms and other macrofauna are involved in litter mixing and movements of water and nutrients across soil horizon and alter soil structure and hence are commonly termed as ecosystem engineers. The rhizosphere, water films in pores and voids of soil aggregates are occupied by soil microflora and microarthropod fauna.

In soil food web, arthropods occupy higher trophic levels and act as detritivores, decomposers, predators, soil structure engineers and biological population regulators (Roy and Faruqui 1995; Swift et al. 2004) (Fig. 1). It was reported that in the presence of microarthropod fauna the mass loss and mineralization of detritus are enhanced by about 23% (Seastedt 1984), while exclusion of large

Table 1 Soil biodiversity and their functions

Functions	Biota*
Decomposition and SOM dynamics	Microphytic feeders
Transformation	Microflora—Fungi, bacteria, actinomycetes
Nutrient cycling	Microfauna—Protozoa, nematode
Atmospheric CO_2 regulation	Litter transformers (Saprophagous, Phytophagous)
	Mesofauna—Collembola, mites, pauropoda, etc.
	Macrofauna—Millipede, isopoda, etc.
	Symbionts—VAM, endophytes
	Predators
	Microfauna—Nematode
	Mesofauna—Mites, etc.
	Macrofauna—Centipede, spider, earwig, etc.
	Parasites
	Microbe, nematode, insect, etc.
	Omnifeeders
Soil structure maintenance	Ecosystem engineers
Erosion control	Roots
Safeguarding soil and water quality	Macrofauna—ant, termite, cricket, earthworm, etc.
	Megafauna—snake, mole, rabbit, etc.
Biological population regulation	Predators
Biodiversity conservation	Parasites
Pest control	Pathogens

*Based on body width, microflora = < 2µm, microfauna = < 100µm, mesofauna = 100µm to 2 mm, macrofauna = < 2 mm to 20 mm, megafauna = > 20 mm arthropod fauna affected litter decomposition (Joergensen 1991). Because of critical positions of soil arthropods in soil food web, they may serve as a useful monitoring tool for biological interventions and effective functioning of soil ecosystem.

Their role in the primary productivity can be categorized in (i) facilitating nutrient acquisition, (ii) regulating the flow of nutrients through decomposition, mineralization and immobilization, (iii) mediating the breakdown of organic matter, (iv) modification of soil structure which influence water availability to the plants and (v) modifying the plant health by parasitism and pathogenicity (Fig. 2). Fungal distribution and abundance are controlled by selective periodical grazing by microarthropod fauna. The periodic grazing induces compensatory fungal growth and releases over-grown fungi population from equilibrium. Due to this feeding and movement, they carry fungal propagules to root surface and disperse inoculums to newer places, besides stimulating microbial activities through direct supply of mineral nutrients in the form of urine and faces (Swift et al. 1979; Hunt and Wall 2002).

The selective grazing was found effective in suppression of soil pathogens as well (Scheu et al. 2005). Decomposer invertebrates alter plant secondary metabolism and the defence of plants against herbivores (Megias and Muller 2010). For instance, Collembola, the most abundant decomposer invertebrates in soil, affect plant by affecting the activity and growth of rhizosphere microorganisms, alter nutrient mineralization and distribution and thus affect plant nutrient uptake and tissue nutrient concentration, ultimately resulting in changes in plant growth (Cole et al. 2004; Tiunov and Scheu 2005; Chamberlain et al. 2006). Detailed analyses of the structure of the root system showed that plants respond to Collembola by increasing root elongation and branching even though total biomass

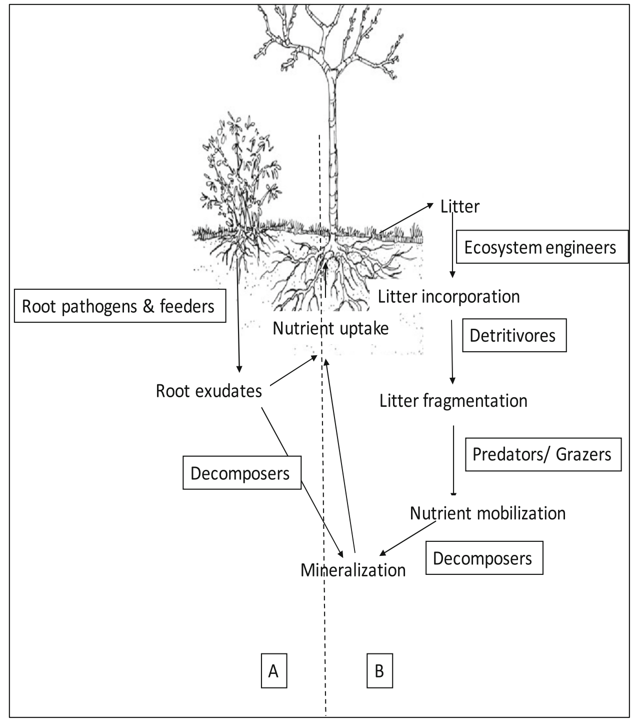
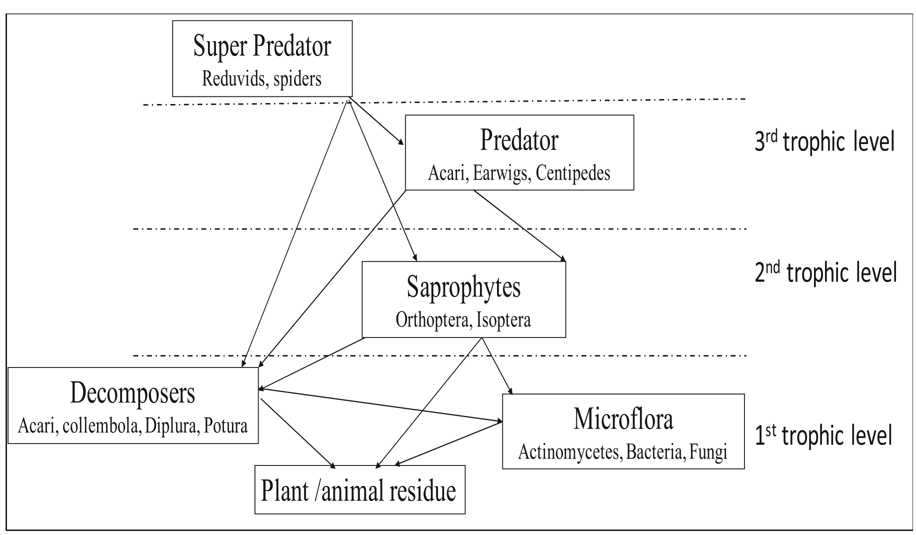


Fig. 2 Schematic depiction of soil arthropods in nutrient mineralization from litter (**b**) and from living plant tissues (**a**)

and nutritional status remained unaffected (Lussenhop and Bassirirad 2005). This is likely caused by changing the expression of genes reprogramming plant growth and inducing plant defence (Endlweber et al. 2011).

Soil arthropods are highly flexible in their diet, and it may be difficult to assign a certain species or a community to a particular trophic level (Scheu 2001; Gormsen et al. 2004; Friberg et al. 2005; Murray et al. 2009). Different species may complement one soil function (Schneider et al. 2004; De Olivera et al. 2010) or maybe specific species is

Fig. 1 Arthropods in soil food web



responsible for certain soil functions (Cragg and Bardgett 2001; Schuurman 2005). In the process of their activity, a species may simultaneously generate different effects on plants, e.g. root feeders may be harmful to plant growth but stimulate defence response in the plant against herbivory (Bezemer and van Dam 2005). Also, different life stages of a species may be associated with different functions, e.g. Elateridae larvae are predators, while adults are herbivores. Many experimental evidences indicated their potential impact on nutrient cycling of agro-ecosystems (Murray et al. 2009; Srivastava and Bell 2009) with synergistic effects on crop production (Eisenhauer et al. 2010). Soil arthropods in general are sensitive to the land-use management (Black et al. 2003; Roy and Roy 2006; Roy and Bano 2007a, b, Rutgers et al. 2009; Keith et al. 2012; Souza et al. 2012) and offer an excellent scope for their effective management for the advantage of agricultural systems (Roy et al. 2009, Endlweber et al. 2011; Brussard 2012).

Reports on Soil Arthropods from Sugarcane Systems

Sugarcane crop is a heavy demanding crop requiring intensive management for optimum yields. It is grown under diversified climatic, soil and management conditions in different parts of the world making each system unique in terms of its biodiversity. Being a cash crop, studies are mainly concentrated to the arthropod pest and their biological control agents (David et al. 1986; Kumarasinghe 1999; Ahmed et al. 2004). Only a few studies are available on soil-dwelling beneficial arthropods in such systems when compared to other cropping systems (Table 2).

Isa (1963) presented a detailed account on diversity, abundance and seasonality of soil arthropods in sugarcane culture and impact of chlordane on their dynamics at Louisiana (USA). Shakir and Ahmed (2015) observed abundance of soil arthropods among various crops (sugarcane, cotton, wheat, alfalfa fodder and citrus orchards) in Faisalabad district of Pakistan. Collembola was the dominant fauna (38%), followed by Hymenoptera (15%), Acarina (15%), Myriapods (11%), Coleoptera (6%), Orthoptera (5%) and Araneae (5%). The abundance was significantly different in crops ((49%) > citrus (17%) > sugarcane (16%) > cotton (10%) > wheat (8%)). In India, Lal and Gangwar (2000, 2002) reported a significant variation in the arthropods population in different months or seasons of the year. Further population was significantly higher in ratoon crops than in plant crop. Rao (1958) reported Symphylids damage 30–40% roots in sugarcane nursery from Coimbatore, Tamil Nadu. The few studies available on arthropod population in soil in context of sugarcane production systems indicate that there is a need to have appropriate management practices in place for sustained production in the long run. Durai et al.'s (2017) study from West Bengal (India) revealed that sugarcane production system has not significantly changed soil microarthropods population in comparison with adjacent natural vegetation land and fodder production field.

Ponge et al. (2013) evaluated sugarcane crop under a gradient of intensification (from permanent meadows to permanent crops, with rotation crops and meadows as intermediary steps) on soil biota and concluded that abundance and diversity of macro- and microarthropods except epigeic springtails increased with the decreased intensification of agriculture and increased plant cover. Further, application of pig and chicken slurry in the study region, alone or in complement to mineral fertilization, supported population growth of saprophagous macrofauna and bacterivorous nematodes.

In Florida (USA), 3- to 5-year cycle involves planting and replanting of sugarcane. The recommended practices include burning of the field, mechanical harvesting, disking and use of soil insecticide. The studies have shown that the tillage practices reduce the predator population (fire ants, spiders, earwigs, centipedes) significantly. However, they resurged after 5–6 months to pre-harvest levels (Cherry and Nuessly 1992; Rossi and Fowler 2002, 2004; Cherry 2003; Sandhu et al. 2004).

Ants are most abundant predators in sugarcane fields. Their abundance is influenced by soil type and cultural practices (Ali et al. 1986; Long et al. 1987; Saad et al. 2017). In Nigeria, predator ant (*Camponotus acvapimensis* and *Phiedole species*) abundance was low in sugarcane fields compared to the adjacent Savanna grassland (Goshie 2009). Franco et al. (2016) also reported that cultivation of sugarcane in areas previously occupied by pastures in Brazil reduced the diversity of soil macrofauna.

Irrigation pattern too has an impact on soil collembolan and mites in a complex and nonlinear way as it modifies soil moisture regime and is dependent on the soil type. The diversity and abundance in sugarcane fields with high and low inputs have been studied. Results showed that species that were recorded more than 50% in the low input practice were absent in under high input conditions (Rana et al. 2006).

Environmental problems associated with conventional sugarcane agriculture due to the use of fire prior to harvest and use of pesticides are well documented. Only a few studies have characterized deleterious effect on the soil-dwelling arthropods by such disturbances (Makhdum et al. 2001; Castelo Branco et al. 2010; Pasqualin et al. 2012; Benazzi et al. 2013; Abreu et al. 2014). The trash burning/burning of field before planting significantly reduces arthropod predators' diversity and abundance. However,

Table 2 Soil arthropod biodiversity and their functions on sugarcane systems

Organisms	Functions	Country	References
Collembola (*Onvchiurus armatus*, *O. fimertarious*, *Tullbergia iowensis*, *T. granulate*, *Hypogastrura armata, Isotomurua palustris*, *Folsomia onychiurina*, *Proisotoma minuta*, *P. cognata*, *Folsomides parvus*, *Orchesella ainsliei*, *Entemobrya* sp., *Lepldocyrtus cyaneous*, *Pseudosinella petterseni*, *Sminthurides aquaticus,S. niger*, *Neanura* sp.)	Saprophytic, predatory, phytophagous	Louisiana (USA)	Isa (1963)
Acarina (Laelaptidae, Rhagidiidae,Cunaxidae, Macrochelidae, Pachygnathidae, Uropodidae, Galumnidae, Eremobelbidae, Camisiidae, Acaridae, Oribatidae, Lohmaniidae, Tetranychidae)	Saprophytic, predatory		
Symphylla (*Scutigerella immaculate*, *Symphylella* sp.)	Predator, Phytophagous		
Diplura (*Japyx* sp., *Campodea* sp.)	Scavengers, Saprophytic		
Coleoptera (Carabids, Staphylinids, *Pleurophorous* sp., *Phyllophaga* sp., *Cyclocephala* sp., *Pachystethus* sp. *Aeolus* sp., *Glyplonyx* sp. *Diabrotica longicornis*, *D. undecimpunctata*)	Phytophagous		
Hemiptera (*Pangaeus bilineatus*, *Sehirus cinctus)*	Scavengers,		
Diptera (Sciaridae, Scatopsidae, Psychodidae, Phoridae, Asilidae, *Lapharia* sp., *Tipulid* sp.)	Saprophytic		
Millipedes (*Pseudopolyclegus serratus*)	Saprophytic		
Ants (*Brachymyrmex obscurior*, *Monomorium pharaonic*, *Odontomachus ruginodis*, *Pheidole moerens*, *Solenopsis invicta*, *Strumigenys louisianae*, *Tetramorium simillimum*, *Wasmannia auropunctata*)	Predatory	Florida (USA)	Cherry (2003)
Earwigs	Predatory		
Coleoptera (Ground Beetles, Rove Beetles)	Predatory		
Spiders (Corinnidae, Gnaphosidae, Linyphiidae, Lycosidae)	Predatory		
Centipedes	Predatory		
Orthoptera (Blatellidae spp. Acrididae spp., *Gryllus assimilis*)	Omnivore	Brazil	Santos et al. (2017)
Coleoptera (*Laxandrus* spp., *Pseudabarys* spp., Carabidae spp., *Megacephala* sp., *Cincidelinae* spp., Brichinae sp., *Metamasius hemipterus*, Curculionidae sp., *Conoderus scalaris*, *Conoderus* spp., Passalidae sp., Rhizophagidae sp., *Ataenius* spp., *Canthon* spp., *Cyclocephala* spp., Staphylinidae spp.)	Predatory, Detritivore, Herbivore		
Dermaptera (*Doru* sp., Forficulidae spp., *Labidura* sp.)	Omnivore, Detritivore, Predatory		
Diptera (Agromyzidae sp., Asilidae sp., Culicidae spp., *Condylostylus* sp., Dolichopodidae sp., Drosophilidae spp., Muscidae spp., Mycetophilidae spp., Phoridae spp., Piophilidae sp., Psychodidae sp., Sciaridae spp., Sphaeroceridae spp., Tachynidae sp., Ulidiidae sp., Diptera spp.)	Herbivore, Predatory		
Hemiptera (Aphididae sp., Aetalionidae sp., Coreidae sp., *Mahanarva fimbriolata*, *Scaptocoris castanea*, *Cyrtomenus mirabilis*, *Rasahus* sp., Reduviidae sp., Hemiptera sp.)	Predatory		
Hymenoptera (*Apis millifera*, *Acanthognathus* sp., *Acromyrmex* sp., *Anochetus* sp., *Atta* spp., *Brachymyrmex* sp., *Camponotus* spp., *Dolichoderus* spp., *Crematogaster* spp., *Dorymyrmex* spp., *Ectatomma* spp., Gnamptogenys spp., *Hypoponera* sp., *Odontomachus* sp., *Pachycondyla* sp., *Paratrechina* sp., *Pheidole* spp., *Pseudomyrmex* sp., *Solenopsis* sp., *Tapiona* sp., *Trachymyrmex* sp., *Wasmania* sp. Formicidae sp., Vespidae sp.)	Detritivore		
Isoptera (Termitidae sp.)	Herbivore		
Lepidoptera (Hesperiidae spp., Noctuidae sp., Pieridae sp., Lepidoptera spp.)	Omnivore		
Neuroptera (*Chrysoperla externa*, Hemerobiidae sp.)	Herbivore		
Thysanoptera sp.	Predatory		
Araneae (Araneidae sp., *Corinna* sp., Corinnidae spp., Castianeirinae sp., Ctenidae sp., Gnaphosidae spp., Hahniidae spp., *Lepthyantes* sp., *Meioneta* spp., Linphiidae sp., *Lycos* asp., Lycosidae spp., *Teminius insularis*, Miturgidae sp., Onopinae sp., *Berlandiella* spp., Philodromidae sp., Salticidae spp., *Scytodes* sp., *Scytodes ytu*, Scytodidae sp., Tetragnathidae sp., *Coleosoma* spp., *Dipoena* spp., Theridiidae sp., *Goeldia* spp.) **Opiliones** sp.	Predatory		
Myriapoda (Diplopoda sp. Chilopoda spp.)	Detritivore		
Ants (*Dorymyrmex brunneus*, *Brachymyrmex admotus*, *Solenopsis* spp.*)*	Predatory	Brazil	Saad et al. (2017)
Ants (*Camponotus acvapimensis*, *Pheidole* sp.)	Predatory	Nigeria	Goshie (2009)

Table 2 continued

Organisms	Functions	Country	References
Ants, beetles, collembolan, dipluran, spiders, termites, diptera	Predatory, saprophytic	Thailand	Thongphak et al. (2015)
Ants, Spiders, Ladybird beetles	Predatory	Pakistan	Sajjad et al. (2012)
Ground beetles, Sow bugs, Cockroaches,	Scavengers		
Hairy caterpillars, Crickets	Phytophagous		
Orthoptera (*Nemobius fasciatus*, *Gryllotalpa orientallis)*	Phytophagous	Pakistan	Rana et al. (2010)
Dermaptera (*Forficula auricularia*, *Forficula. Spp.)*	Predatory		
Hemiptera (*Pangaeus bilineatus*, *Tritomegas sexmaculatus*, *Thynata custator*, *Penta. Sp.*)	Phytophagous		
Coleoptera (*Scaphinotus angulatus*, *Oryctes rhinoceros*, *Carabus auratus*, *Paedurus littoralis*, *Adalia decempunctata*, *Gonocephalum stocklieni*, *G. vagum*, *G. depressum*, *G. elderi*, *G. misellum*, *G. terminale*, *Eleodes hirtipennis*, *Balps muronota*, *Heleus waitei*, *Blastinus sp.*, *Tribolium confusum*, *Platydema subcostatum*, *Promethis nigra*, *Pentodon bispinosus*, *P. idiota*, *P. punctatus*, *Gymnopleurus miliaris*, *Hispellinus moestus*, *Chrysochus auratus*, *Hypolixus truncatulatus*, *Esamus princeps*, *Cleonusj aunus*, *Liophoeus tessulatus*, *Cleonus riger*)	Phytophagous, Predatory Predatory Predatory Predatory, Decomposer		
Hymenoptera (*Formica sanguinea*, *F. exsectoides*, *F. rufa*, *Formica spp.*, *Solenopsis Invicta*, *Manuelantonio*, *Camponotus pensylvanicus*, *C. herculeanus*, *Dolichoderus taschenbergi*)			
Araneae (*Hibana sp.*, *Hippasa madhuae*, *H. partita*, *Phintella piatensis*, *Spartaeus uplandicus*, *Oxyopes javanus*, *Cheiracanthium tigbauanensis*, *Dyschiriognatha hawigtenera*)			
Isopoda (*Trachelipus rathkei*, *Armadillium nastum*, *Armadillium sp.*, *Geophilomorpha*, *Schendyla nemorensis*)			
Acari (Acaridida, Actinedida, Gamasida, Oribatida, Araneida)	Predatory, decomposer	India	Durai et al. 2017
Pseudoscorpionida			
Insecta (Collembola, Diplura, Pscoptera, Hemiptera, Hymenoptera, Coleoptera)			
Crustacea (Isopoda)			
Myriapoda (Chilopoda, Diplopoda)			
Symphyiella sp.	Phytophagous	India	Rao (1958)
Collembola (*Folsomides* sp., *Isotomides* sp., *Onychiurus* sp., *Samina* sp., *Sminthurus* sp., *Drepaneera* sp.)	Decomposer	India	Lal and Gangwar (2000)
Diplura (*Campodea* sp., *Japyx* sp., *Anajapyx* sp., *Parajapyx* sp., *Heterojapyx* sp.)			
Protura sp.			
Symphyla (*Scutigerella* sp., *Scolopendrella* sp.)			
Acarina (*Gamasiphis* sp., *Pachylaelaps* sp., *Parasitus* sp., *Coccotydeus* sp., *Microtrombidium* sp., *Tydeus* sp., Tyrophagus sp., *Cryptacarees* sp., *Eplihmannia* sp., *Fosseremus* sp., *Protorobates* sp., *Schelorobates* sp., *Oppia* sp.)			
Pauropoda (*Decapauropus* sp., *Eurypauropus* sp., *Pauropus* sp.)			

few arthropods hiding inside stalks remained unaffected, e.g. field crickets, cockroaches, hairy caterpillars, ground beetles and borers (Srikanth et al. 1997; Sajjad et al. 2012). Sugarcane cultivation with straw burning initially promoted those taxa better adapted to drastic changes in the system (e.g. Formicidae). Moreover, as the sugarcane growth year went by, a biological equilibrium compared to the adjacent natural vegetation areas was achieved (Siqueira et al. 2016).

The shift from a burned to a non-burned sugarcane harvest system provides good scope for biological fertility management apart from the environmental angle (Carvalho et al. 2017), but pest control is among the parameters favoured by straw removal. However, complete removal may influence abundance and diversity of macrofauna (Cerri et al. 2004). Abrao (2012) found that soil macrofauna were strongly influenced by the amount of straw present, demonstrating greater density, richness and diversity when soil was covered by more than 50% straw (i.e. 7.6 Mg ha^{-1}). Similar results were reported by Abreu et al. (2014), who observed a greater density of individuals when more than 50% of straw (equivalent to 5.1 Mg ha^{-1} of dry basis) was maintained on the soil surface. The increased diversity of soil macrofauna may be attributed to high levels of nutrients in soil under sugarcane cultivation (Franco et al. 2016).

The agronomical practices like crop diversity, mulching and organic farming support faunal diversity. An analysis of diversity and abundance of edaphic arthropods from conventional and organic sugarcane crops in Brazil supported the view that the organic management in sugarcane increased the abundance (66.8%) and diversity (142 morphospecies in 13 orders and 45 families) of decomposers, pollinators, herbivores and predators (Santos et al. 2017). These predators are reported as important natural control agents of several pests that occur in different stages of sugarcane development (Mendonca and Marques 2005; Costa et al. 2007). The straw mulching enhanced the abundance and diversity of macrofauna (Cerri et al. 2004). White et al. (2011) had also reported that ants and earwigs were generally more abundant where the blanket of post-harvest crop residue was not removed or repositioned to the row sides, while burning to remove the residue appeared to have a detrimental impact on their numbers. Brushing the tops of rows to remove crop residue was intermediate in effect. Ground beetles (Coleoptera: Carabidae), spiders (Araneida), and crickets (Orthoptera: Gryllidae) were impacted minimally by the treatments. The positive impact may be due to the milder microclimate variation and food abundance (Portilho et al. 2011; Pasqualin et al. 2012). Reports have highlighted that the extant of coverage (optimum 50% coverage of soil) also has an impact on density, richness and diversity of arthropods sugarcane ecosystem in Brazil (Abrao 2012; Abreu et al. 2014). Thongphak et al. (2015) observed significantly higher density of soil invertebrates in the areas of spent wash liquor application than those in the control plot. Saad et al. (2017) reported that vinasse application in sugarcane plots has not influenced predator arthropods diversity but enhanced their abundance in Brazilian landscape.

Approaches to Enhance Arthropod Diversity

Globally, managed ecosystems represent about 40% of agriculture ecosystem. The economical production is generally associated with reduced plant diversity (monoculture, weed management), provision of external nutrients, regulation of pest population. Such actions influence subterranean biodiversity and their resilience to abiotic/biotic stresses (Butler et al. 2007; Roy et al. 2007, 2008a, b, 2014). With the growing concern of sustainability and soil health of managed systems, interest is growing to augment managed systems more like natural system. Research and experiments need to be planned to reveal mechanistic links between system constituents and their interactions with soil community and functions. Understanding on factors of natural ecosystem may provide range of entry points for biological management of existing sugarcane production systems.

Challenges

Agricultural intensification has detrimental effects on taxonomic richness and diversity across the taxonomic groups with most deleterious effect on soil biota (Postma-Blaauw et al. 2010, 2012). Negative effect of agricultural management operations like tillage (Van Eekeren et al. 2008), fertilizer (Arroyo et al. 2003; Badejo et al. 2004; Roy et al. 2012), pesticide (Roy et al. 2004) and reduced crop diversity (Wardle et al. 2003) is reported on biotic composition and abundance in intensive systems when compared to the natural landscape (Table 3).

Ecological Tactics

The most prominent factors in natural landscapes are the plant diversity, least disturbance in soil environment and closed nutrient cycling. These factors need to be focused in modulating soil biodiversity in any ecosystem.

Plant Diversification

Globally on-farm crop diversity has decreased since 1940. Out of approximately 7000 edible crop species, only 309 were grown in 2010 at a measureable scale (FAO STAT 2011). Crop diversity influences quality and quantity of litter which provide food for diverse subterranean life forms and control soil moisture through transpiration and evaporation. Also, based on their architecture plants intercept rainfall which not only influence water quantity but also reduce the impact of rainfall-oriented soil erosion (De Deyn et al. 2009).

The nutrient requirement of crops differentially influences surrounding microbial composition and associated fauna (Larink 1997). Paustian et al. (1997) observed higher SOC under continuous corn rotation in comparison with corn–soybean rotation as soybean produces less residue that is lower in C: N and lignin: N ratio than corn. Increasing plant diversity in the form of intercropping helps in additional crop yield, weed control, habitat for various herbivores and associated predator–parasite complex, improved N fixation, etc. (Butler et al. 2007). Sileshi and Mafongoya (2007) reported soil biota community response in relation to quality of the plant residue. Earthworms and beetles were more under fast-decomposing legume residue, millipedes under slow-decomposing legume residues and predators, i.e. spiders and centipedes, were not affected by the litter quality. Increasing the understanding of functional traits of plants will be useful in judicious selection of crop diversity in agriculture. Judicious mixture of crops or non-crop plants and introduction of perennial crops in farmlands may help in replicating

Table 3 Crop management practices and their deleterious impact on soil biota

Management	Reason	Impact on soil biodiversity
Mono-cropping	Plants with desired traits enhance production	Reduced diversity of predators/parasites of pests Ponge et al. (2013)
	Easy management of planting/harvest timings, water, nutrient, pests and other resources	Loss of detrital fauna and microflora St John et al. (2006) and Roy et al. (2008a, b)
Tillage	Prepare soil for planting or seeding	Repeated tillage reduces SOC Hanegraaf et al. (2009)
	Reduces pest disease incidences disperse soil macroaggregates, crop residues, fertilizer	Reduced biodiversity Wardle (1995), Kladivko (2001), Trenois et al. (2010) and Surendran et al. 2016
	Alters soil water and temperature	
	Weed management	
Agrochemicals	Manages crop nutrient requirements	Alter soil chemical environment Rousk et al. (2010)
	Suppresses weeds, pests and pathogens	Loss of plant diversity Aletto et al. (2009)
		Loss of symbiotic flora Fox et al. (2007)
		Loss of arthropod richness Peterson and Krogh (1987)
Burning	Economical field cleaning	Environmental pollution Arbex et al. (2007)
	Ratoon keeping easier after harvest	Loss of soil fertility Souza et al. (2012)
	Destroys pests and pathogens	Loss of biodiversity Srikanth et al. (1997)
	Add small amount of potassium and phosphate to soil	

advantages of natural ecosystems to agriculture with optimized production and improved soil qualities.

The emphasis on selection or breeding of varieties is usually laid on the yield and pest resistance. However, studies need to be based on the interaction of genotype/s with environment. Briones et al. (2002) reported greater ammonia-oxidizing bacteria in the rhizosphere of modern rice cultivar in comparison with two traditional varieties. This indicates that the interaction at the species level may be exploited to ecosystem level with the targeted studies at zone/region level.

Fertilizers

The addition of nitrogen in soil has been more than double since preindustrial times (Galloway et al. 2004). Additions of inorganic N elevate soil C initially, but a long-term negative impacts on biologically active soil organic matter, microbial biomass and soil N pools lead to soil compaction, reduced resource utilization efficiency, disruption of internal nutrient cycling with increased leaching of nutrients and production of greenhouse gases (Weil and Magdoff 2004). The increase in N shifts soil food web from fungal to bacterial pathway (Frey et al. 2004) and is responsible for quick release in available form of N. The shift from fungal to bacterial pathway of resource utilization orients whole biota chain, resulting into overall reduction in soil carbon stalk. Studies have shown that N-limited environment promotes enzymes for efficient utilization of C and N from recalcitrant material (Magnani and Mencuccini 2007; Wilson et al. 2009). The low input systems with a more heterogeneous habitat and resource contain a more diverse fauna, characterized by species that are more persistent (Wardle et al. 2004; Roy et al. 2010). Primarily, fertilizers increase plant growth and induced plant growth increases productivity and SOM, but this also reduces soil moisture (Murray et al. 2006), creates nutritional imbalance in plants and disturbs plant metabolism. The enhanced N increases the level of free amino acids in plants which affect insect herbivores in multiple ways (Phelan 2004, 2009). The reduced soil moisture influences reproduction and locomotion of microarthropods (Sjursen and Holmstrup 2004; Tsiafoulia et al. 2005).

In view of various studies, comprehensive study on the effect of fertilizers based on soil type at regional basis is important to spell out the actual benefits of fertilizers in sugarcane agro-ecosystem. In this regard, creating a dynamic national database on soil chemical and biological qualities, at regional scale, will be useful to the end-users to pave way for optimization of nutrient resources.

Biocides

The pesticides are usually toxic to particular organisms and thus selective but have impact on other associated parasitoid species (Sushil et al. 1997; Jaiswal et al. 2013, 2014; Singh et al. 2014). Species-specific reaction of pesticide may, however, alter community composition of arthropods (Peterson and Krogh 1987; Larink 1997; Roy et al. 2004; Shah et al. 2007, 2011). Studies are therefore needed on impact of biocides usage, and their residues build up in soil, soil flora and fauna over long period, e.g. long-time repeated use of glyphosate (supposedly have no long-term effect on soil microbial biomass, soil enzyme activity and respiration) showed decrease in beneficial microflora and plants become more susceptible to soil-borne fungal pathogens (Kremer and Meanes 2009).

Land Preparation

Land preparation practices in general kill or destroy habitats of biota and redistribute them in soil profile, like tillage breaks root and fungal hyphae network, and this disturbs the whole soil food web interaction and dynamics. In these practices, organisms with high metabolic rate and short life cycle tend to be less affected. But k-strategic species may be worst hit. Wardle (1995) reported that tillage favours nematodes and some soil mites habituating soil surface. Kladivko (2001) found that groups of mites were respond differently to tillage. Oribatida were sensitive to the plough and Gamasina to the chisel plough, while Uropodina or Astigmata were not affected by tillage. No species-specific response patterns were detected among oribatid mites, but the adverse effects of soil cultivation on microphytophagous species were strong. Badejo et al. (2004) reported adverse effect of tillage on large arthropod fauna. In Ireland, winter wheat cultivation under reduced tillage improved abundances of most collembolan species compared to conventional tillage practices but has little effect on species richness (Brennana et al. 2006). Minor and Cianciolo (2007) at central New York (USA) reported that lands under a gradient of management intensity (from corn fields, herbaceous old fields, shrubby old fields to hard wood forest) have significantly influenced Oribatid mite diversity within individual soil cores and at the site scale.

The impact of tillage and inter-culture operations on soil community structure and function is not much clear and needs focus on system-based approach. Biota may show resilience to chronic disturbances until a threshold reaches after which resilience becomes almost impossible.

Organic Amendments

Organic amendments augment soil SOC and micronutrients which directly influence soil organisms (El Titi and Ipach 1989; Scholte and Lootsma 1998; Arroyo et al. 2003; Minor et al. 2004; Roy et al. 2012), but their impact on community structure and function is complex. For instance, the addition of detritus in a cucumber/squash system increased Collembola and other detritivores, as well as carabid beetles and spiders, although increase in fruit yield was not found (Halaj and Wise 2002). Rypstra and Marshall (2005) increased the density of spiders in soybean plots by the addition of compost. Spiders in the compost plots had larger abdomens, suggesting a greater availability of prey, and leaf damage was significantly reduced although herbivore numbers were not. Similarly, spiders were reported more in rice plots treated with neem products (Baitha et al. 2000a) while providing good control for various pests of rice and higher grain yield (Baitha et al. 2000b, c).

A number of on-farm studies and controlled greenhouse experiments reported that organic farming stimulates resistance in plants. This was claimed for a range of crops and pests: leaf beetles and plant hoppers on rice (Andow and Hidaka 1989), various pests on tomato (Drinkwater et al. 1995), European corn borer on maize (Phelan et al. 1995, 1996), European corn borer and aphids on maize (Bedet 2000), aphids on maize (Morales et al. 2001) and Colorado potato beetle on potato (Alyokhin and Atlihan 2005). The varied kinds of responses of pest and predators from different studies were comprehended in meta-analysis by Hole et al. (2005), who compared 76 studies, and Bengtsson et al. (2005), who analysed 42 studies. They concluded that the increased biodiversity in organic farming might not be the result of organic farming per se but may be due to the limited uses of agrochemicals, cover crops, manure application, greater plant diversity.

The benefit of organic nutrient management on soil biodiversity needs to focus on mechanism of increase in overall soil biodiversity, increase in beneficial organism, increase in pest mortality, reduction in damage and increase in yield.

Suggested Strategies

Despite the present incomplete understanding on the role of soil arthropods specific to the sugarcane systems, there is scope to enhance arthropods diversity through existing practices and available information from other cropping systems. Sugarcane systems may be designed to exploit inherent soil biological processes for sustainable productivity (Table 4). However, research is needed to develop much more understanding on the basic biology and ecology of associated arthropods so that link between soil biodiversity and ecosystem functions may be used in more useful manner by the farmers and land managers.

Conclusion

Agriculture management practices influence the community structure, abundance and dynamics of soil arthropods on account of alteration in soil environment. This impact varies with the soil type, climate, taxonomic/functional group of the organisms and cropping systems. Hence, there is a need of linking soil biodiversity and its ecosystem

Table 4 Potential biological intervention points and future research challenges to enhance soil arthropods diversity in sugarcane-based production system

Intervention points	Rationale	Scientific challenges
Choice of trait-based variety and introducing functionally diversified crop/non-crop plants at spatial and temporal scales	Habitat for diversified fauna Plant species with different temporal patterns of nutrient uptake, to reduce seasonal variation in nutrient demands and site-specific nutrient retention Support below-ground biodiversity by maintaining quantity and quality of crop residue	Studies on genotype–management–environment-based interactions Habitat for alternate non-pest host of biocontrol agents
Fertilizer application synchronized with the crop requirement	To reduce seasonal variation in nutrients demands, Retention at local level of application	Utilization cycle of nutrients by soil biota Impact on soil moisture, aggregate structure and arthropods Studies on arthropod-based soil quality index to find out the impacts of various nutrient application practices Impact of N fertilizer on plant metabolism and effectiveness of plant defence mechanism
Application of organic matter	Greater above- and below-ground diversity Energy source for beneficial soil biota To make soil environment amicable to food web for more efficient utilization of energy and nutrients For plant health and above-ground interactions with pests and disease	Site-specific studies on extends of SOM to buffer soil physical parameters (moisture, pH) to biological interactions involving soil communities, plants and herbivores Exploration of mechanisms of plant resistance to pests (modulation of plant mineral nutrient availability by the soil food web, and/or enhanced plant systemic defence induced by beneficial flora/fauna interacting with plant roots Mechanism of behavioural disruption of herbivore in response to predators
Least soil disturbances during field preparations, planting and inter-culture operations, etc.	Less disturbance to rhizosphere biota Enhanced interaction with ecosystem engineers, predator–prey interaction in soil food web By reducing erosion-oriented biodiversity losses	Studies on impact of different practices on soil arthropods in terms of soil disturbance intensity and aggregate stability index Suitable cover crops, perennial crops, etc.
Reducing dependence on biocides	Unintended negative effect on non-target arthropods Pesticides resistance	Long-term studies on impact of specific biocides on different soil functional groups Studies on ecosystem approach to enhance natural control agents

functions in the land-use context so that it becomes relevant to land managers and farmers. It is required to have in-depth knowledge about spatial and temporal distribution of keystone species of a system, functional traits of most of the taxonomic groups and their interactions. In this pursuit, newer methods and techniques are needed to describe the soil biota and account their variability in experimental manipulations of communities. Also, crop designing approaches by including detailed traits of system and associated arthropods may provide comprehensive information for managing productive sugarcane agro-ecosystem with healthy soil concept.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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