Soil health analysis using earthworms as the indicator- Possibilities and constraints

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1. Soil

Soil is a fundamental resource base for agricultural systems besides being the main medium for plant growth. Soil functions to sustain crop productivity, maintain environmental quality and support animal and plant life as well. Briefly, soil is composed of four basic components: mineral solids, water, air and organic matter (including living biota) (Gugino et. al. 2007).The mineral solids are stone fragments, sand, silt, and clay. It is the proportion of the latter three that determines the soil's texture. For example, a soil that is composed of 70 per cent silt, 20 per cent sand and 10 per cent clay can be classified as a silt loam using the soil texture triangle. Soil texture contributes to the inherent soil quality, the characteristics of the soil that result from soil forming processes. These characteristics are difficult to change through soil management. Water is essential for soil life. Water is the medium that facilitates nutrient transport through the soil and enables plant nutrient uptake. Water also enables/facilitates the movement of microbes such as nematodes and bacteria through the soil. Air is constantly moving in and out of the soil. Air provides oxygen required for cell functioning in aerobic organisms including plant roots. Both air and water occupy the pore spaces created within and between soil aggregates (clusters of sand, silt and clay particles bound together by particle surface chemistry and microbial and plant exudates). Organic matter is any material that is part of or originated from living organisms. Organic matter may be divided into three fractions, the living, the dead (active fraction) and the very dead (stable fraction). The living soil organic matter fraction includes microorganisms and soil-dwelling faunal elements. The dead fraction consists primarily of fresh residues from crops, recently dead microorganisms and insects, sloughed-off root cells, leaf litter, and manure, etc. This fraction is considered active. The sugars, proteins, cellulose and other simple compounds are quickly broken down – degraded- by soil microbes and used as a food source which fuels the soil microbial population. The exudates (sticky substances) produced by the microbes (and roots) as well as the microbes themselves (e.g. fungi) help to bind the mineral particles together to form soil aggregates. Good soil aggregation is important for maintaining good (crumbly) soil structure and enabling adequate air exchange and water drainage. The very dead organic matter fraction is also called humus. Humus is very stable and resists further degradation. Although it is not an important food source for microbes, it is important for storing nutrients and water, binding toxic chemicals and contributing to improved aggregate stability.

2. Soil health or soil quality

In agricultural context, soil health (SH) and soil quality are often use interchangeably and it is defined as the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health. However, the National Resource and Conservation Service (USDA-NRCS) defines soil quality or soil health similarly, but add inherent and dynamic soil quality to the definition. The inherent soil quality is defined as "the aspects of soil quality relating to a soil's natural composition and properties influenced by the factors and processes of soil formation, in the absence of human impacts." While dynamic soil quality "relates to soil properties that change as a result of soil use and management over the human time scale". This distinction between inherent soil health and dynamic soil health is important while correlating a given soil health parameter with the other parameter, where one parameter may be due to the inherent property of soil (example abundance of a indicator organism) and the other one may be due to human impacts (soil organic carbon).

Some of the soil characteristics expected in healthy soil include:

- Good soil tilth
- Sufficient depth
- Sufficient but not excess supply of nutrients
- Small population of plant pathogens and insect pests
- Good soil drainage
- Large population of beneficial organisms
- Low weed pressure
- Free of chemicals and toxins that may harm the crop
- Resistant to degradation
- Resilience when unfavorable conditions occur

It may be pointed out here that management practice, cropping pattern, local climate etc. greatly contribute to the soil health. Similarly, what is considered good soil quality for one farming practice may not be appropriate for another system. In this context both defining the soil health for a cropping system and also recommending good soil quality management practices for a set of landuse systems at a landscape level is complicated. However, minimum data sets of soil physical, chemical and biological properties that can be used as measurable, quantitative as well as discrete values while determining soil health are identified. Some of the soil characters which are of general interest in the context of soil health determination are discussed below;

3. Soil physical characters

a) Aggregate stability

Aggregate stability is a measure of the extent to which soil aggregates resist falling apart when wetted and hit by rain drops. This method tests the soil's physical quality with regard to its capacity to sustain its structure during most impactful conditions: a heavy rain storm after surface drying weather. Soils with low aggregate stability tend to form surface crusts which can reduce both water infiltration and air exchange. This poor soil aggregation also makes the soil more difficult to manage, and reduces its ability to dry off quickly. In heavy soils, enhanced friability and crumbliness from good aggregation makes the soil seem lighter. Growing a green manure cover crop or adding animal manure can stabilize soil aggregates.

b) Available water capacity

Water storage in soil is important for plant growth. Water is stored in soil pores and in organic matter. In the field, the moist end of water storage begins when gravity drainage ceases (field capacity). The dry end of the storage range is at the ‘permanent wilting point’. Water held in soils that is unavailable to plants is called hygroscopic water. Clay soils tend to hold more water than sandy soils. Sandy soils tend to lose more water to gravity than clays.

The available water capacity is an indicator of a soil’s water storage capacity in the field. A common constraint of sandy soils is their ability to store water for crops between rains. The addition of composts or manures (green or animal) adds to the water storage, which is especially important during droughty periods. Note that total crop water availability is also dependent on rooting depth, which is considered in a separate indicator, penetration resistance.

In heavier soils, the available water capacity is less critical because they naturally have high water retention ability. Instead, they are typically more limited in their ability to supply air to plant roots during wet periods. These soils often respond favorably to the addition of composts or manures (green or animal) but not in the same manner as the coarser textured soils above.

c) Field penetration resistance

Field penetration resistance is a measurement of the soil's strength measured (in psi) with a field penetrometer pushed through the soil profile. Field penetration resistance is a measure of soil compaction. The amount of pressure needed to push the probe through the soil can be measured at any desired depth but is most useful for identifying the depth of the compaction layer, if present. Roots can not penetrate the soil with penetrometer readings above 300 psi. Field profiles of penetration resistance can be created by recording the measured psi every inch through the soil profile and then plotting them on a chart.

4. Soil chemical characters

a) Active carbon

Active carbon is an indicator of the fraction of soil organic matter that is readily available as a carbon and energy source for the soil microbial community. Research has shown that active carbon is highly correlated with and similar to "particulate organic matter", which is determined with a more complex and labor-intensive wet-sieving and/ or chemical extraction procedure. Active carbon is positively correlated with percent organic matter, aggregate stability, and with measures of biological activity such as soil respiration rate. Research has shown that active carbon is a good "leading indicator" of soil health response to changes in crop and soil management, usually responding to management much sooner (often, years sooner) than total organic matter percent. Thus, monitoring the changes in active carbon can be particularly useful to farmers who are changing practices to try to build up soil organic matter (e.g., reducing tillage, using new cover crops, adding new composts or manures).

b) Organic matter

Organic matter is any material that is derived from living organisms, including plants and soil fauna. Total soil organic matter (SOM) consists of both living and dead material, including well decomposed humus. As discussed earlier, soil organic matter in its various forms greatly impacts the physical, chemical and biological properties of the soil. It contributes to soil aggregation, water-holding capacity, provides nutrients and energy to the plant and soil microbial communities, etc. It has been argued that organic matter management is soil health management.

Increasing the percent organic matter in the soil takes time and patience. It is unlikely that a single incorporation of a green manure or compost will noticeably increase the percent organic matter. However repeated use of organic amendments in combination with reduced tillage (depending on the constraints of the production system) will build soil organic matter levels.

c) Other soil chemical parameters

The chemical analysis is integral part of the Soil Health test. It is a traditional soil fertility test analysis package that measures levels of pH and plant macro and micro nutrients. Measured levels are interpreted in the framework of sufficiency and excess but are not crop specific.

5. Soil biological characters

a) Root health assessment

Root health assessment is a measure of the quality and function of the roots as indicated by size, color, texture and the absence of symptoms and damage by root pathogens and plant-parasitic nematodes. Healthy roots are essential for vigorous plant growth and high yield by being efficient in mining the soil for nutrients and water, especially during stress-full conditions such as drought. Good soil tilth, and low populations and activities of root pathogens and other pests are critical for the development of healthy roots. Healthy roots also contribute to the active fraction of soil organic matter, promote rhizosphere microbial communities, contribute to increased aggregation, and reduced bulk density and soil compaction.

b) Soil fauna

Soil fauna is an integral part of living soil, which performs a variety of functions in soil. Not all the groups of soil fauna are equally important in terms of agricultural production and soil health. Invertebrate group like earthworms, termites, ants, nematodes etc. are thought to be most important biotic component of the living soil.

Ground ants together with earthworms and termites; belong to the principal groups of invertebrates that influence soil processes in terrestrial ecosystems (Lavelle et. al. 1997) and they are often called ecosystem engineers (Jones et. al. 1994). Ecosystem engineers have a major influence on the structure of a soil, creating a network of pores and contributing to aggregation, or the way elementary soil particles (clay, silt and/or sand) stick together (Hairiah, 2001). Earthworms, termites and some ants can create macropores by pushing their bodies into the soil (and thus compacting a zone of soil around the channel that can persist for some time), or by eating their way through the soil and removing soil particles. Earthworms and other animals that feed on soil produce excrement that contains resistant organo-mineral structures that may persist for long periods of time (from months to years) and which profoundly affect the environment for smaller organisms. Earthworms and termites can do this because they have a gut flora of bacteria. These activities of soil biota, which include moving particles from one horizon to another, and which affect and determine the soil's physical structure and the distribution of organic material in the soil profile, are termed 'bioturbation'. This in turn can have an effect on plant growth. Ants change physical and chemical parameters of the soil by bioturbation and by accumulation of organic material (Dostal et. al. 2005).Due to the building of below-ground galleries, mounding and material mixing, the soil of ant nests is characterized by the impeded formation of soil horizons, increased porosity, drainage and aeration, reduced bulk density and modified texture and structure. Increased content of organic matter, N P, and K in the nests is due to food storage, aphid cultivation, and accumulation of faeces and ant remains (Lavelle et. al. 1997; Folgarait, 1998). Termites are important component of tropical soil (Basu et. al. 1996), which also contributes to litter degradation; nutrient cycling etc. and they are some time referred as tropical analogue of earthworms. They also make underground galleries, which help in water and air infiltration.

Earthworms are the most important soil invertebrates in most soils worldwide, in terms of both biomass and activity (Rombke et. al. 2005). They help in litter degradation, soil bioturbation, water infiltration and much more. Earthworms are generally regarded as highly suitable biomonitors because they fulfill these criteria (e.g. Stork and Eggleton, 1992; Abdul Rida and Boucher, 1995; Cortet et. al. 1999; Paoletti, 1999). Their main advantages are:

1. Nearly all earthworms are true soil inhabitants and many of them are key to ecosystem functioning, notably for decomposition and soil structure maintenance. Several species like *Lumbricus terrestris* (Lumbricidae) are considered ecosystem engineers (Lavelle et. al. 1997).
2. Earthworms are globally distributed, but at one site fewer than 20 species occur; i.e., such species numbers are practical. In Central Europe, usually up to 10 earthworm species are found at one site (Rombke et. al. 1997).

3. Identification keys are available, mainly for temperate regions. Like many parts of Europe (in particular Central and Northern regions) (e.g., Sims and Gerard, 1985).
4. Breeding and handling of some species are easy.
5. Standardized guidelines have been developed by OECD and International Organization for Standardization (ISO) for several levels of investigation
6. Because of their behavior and morphology, they are in contact with both the aqueous phase and the solid phase of the substrate.
7. Most species are not extremely sensitive to low levels of contamination.
8. Their reactions to stress are measurable and reproducible at various levels of organization, under both laboratory and field conditions.
9. There is a vast and growing body of knowledge on their biology, ecology, and eco-toxicology, and oligochaetes are non-controversial as test animals.

In addition, they are not highly mobile, and are sensitive indicators of anthropogenic stress factors (in particular chemicals). For example, they have been successfully used as bio-indicators for (at least): chemicals (e.g., pesticides, biocides, drugs) (Edwards and Bohlen, 1992; Edwards et. al. 1996), mixed soil contamination (e.g., heavy metals) (Carter et. al. 1980; Emmerling et. al. 1997; Stephenson et. al. 1998; Hund-Rinke and Wiechering, 2001), physical factors (e.g., compaction, hydrology) (Pizl, 1992; Lowe and Butt, 1999), and land use (e.g., agriculture, forestry, orchards) (Lee, 1985).

Though there are many advantages, few disadvantages make the concept difficult. A main constraint is the often quite small number of species which might complicate the differentiation between different sites or soil qualities. Therefore, and despite their overwhelming ecological importance, soil classification and assessment with earthworms alone is not possible (Muys and Granval, 1997).

The idea to use earthworms as indicators of soil quality is old (Ghilarov, 1949), which was used in various forest sites was characterized. However, several ecological studies confirmed the close relationship between the occurrence of earthworm species and soil and site properties. For instance, Irmler (1999) was able to characterize earthworm communities from various habitats based on the abiotic soil parameters moisture, pH, calcium, carbon, and C:N. Such data may be used for the development of an indicator system because they allow, at least in principle, a comparison of the potentially occurring community with the actual one. Yet, because of the inherent complexity in field studies of oligochaete communities with respect to the relations between community composition, soil characteristics, and management practices, it is often problematic, if not impossible, to ascribe changes recorded to any particular factor or factors (e.g., Tarrant et. al. 1997). It is believed that, earthworms are more abundant in soil with high organic content. However, Rossi and others (2006) had gained no information on the dynamics of the earthworm spatial pattern or about carbon dynamics. Therefore the apparent relationship between soil carbon content and earthworm abundance remains to be supported by additional data. In this context, an attempt has been made to anayse the relationships between earthworm distribution and soil properties in different landuse systems in the Kerala part of Nilgiri Biosphere Reserve.

7. Earthworm population in different landuse systems (LUs) in the Kerala part of Nilgiri Biosphere Reserve

The study area was located in Vazhikkadavu Panchayat (76^0 19′ to 76^0 23′ E longitude and 11^0 23′ to 11^0 25′ N latitude), Malappuram District. Here, an area of 2.6 x 1.4 km in the Karakkode micro-watershed was selected where 12 landuse systems namely, paddy fields paddy fields (Pa), Areca farms mixed with annual crops (Av), Areca farms mixed with perennials (Am), coconut mixed with perennials (Cm), polyculture farms (Og), polyculture homegardens (Hg), Areca plantation (Ar), Coconut plantation (Co), rubber plantation (Ru), Cashew plantation (Ca), teak plantation (Te) and degraded forest (Df). For each landuse system, four plots were selected. In each plot, one transect of 40 x 5 m were laid which was further divided into four quadrats each of 10 x 5 m in size. From each quadrat, soil monolith of size 25 cm x 25 cm and 30 cm depth were excavated and all the worms were hand-sorted and counted.

In the study area, earthworm abundance (number of individuals /25 cm^2) ranges form 1 to 26 (Figure 1) with highest value in the plot 2, which represent the coconut perennial crop cultivation system.

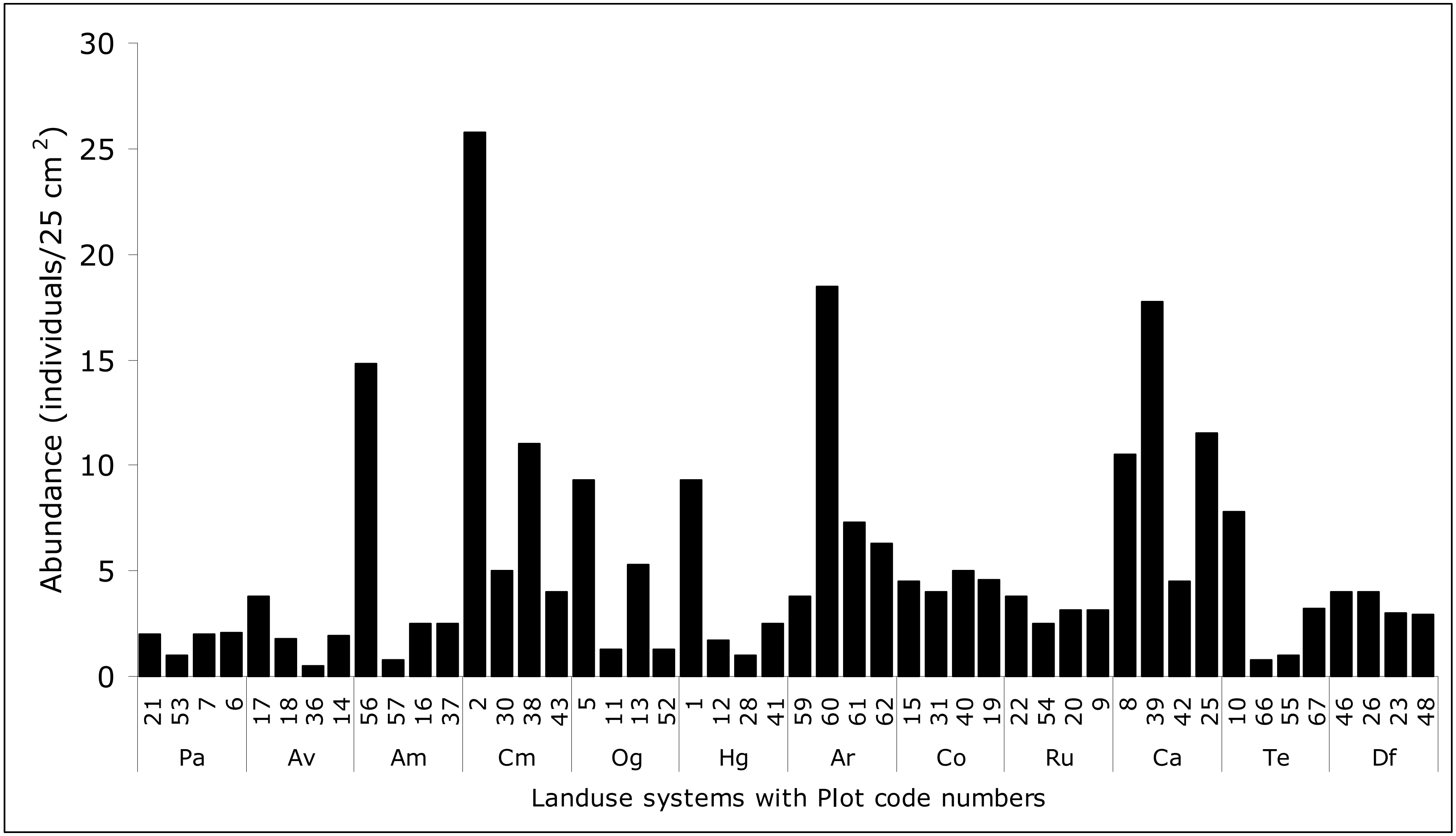

Figure 1. Mean abundance (individuals/25 m^2) of earthworms in different plots in the Kerala part of Nilgiri Biosphere Reserve.

Even in a given landuse system, a wide variation in earthworm abundance is recorded. When the mean abundance of earthworm in different landuse system were compared by taking 4 plots of each landuse system it was observed that the values obtained for paddy field, degraded forest, teak plantation, rubber plantation, coconut plantation, areca mixed with perennials, areca with annuals, polyculture farms and homegarden were not different significantly. However, earthworm abundance values in coconut mixed with perennials, areca plantation and cashew plantation were significantly different from those recorded for many other landuse systems, particularly paddy fields and areca with annuals (Figure 2). It may be pointed out that majority of the landuse systems and the plots studied, with exception being degraded forest, teak and cashew plantations are derived from the paddy fields. Thus further analysis was done to compare the earthworm abundance in paddy fields and plots of landuse systems which were transformed from paddy fields (Figure 3). The study indicates that mean abundance of earthworms in areca mixed with perennials, Coconut mixed with perennials, coconut and areca plantations were not different but significantly higher than in paddy fields.

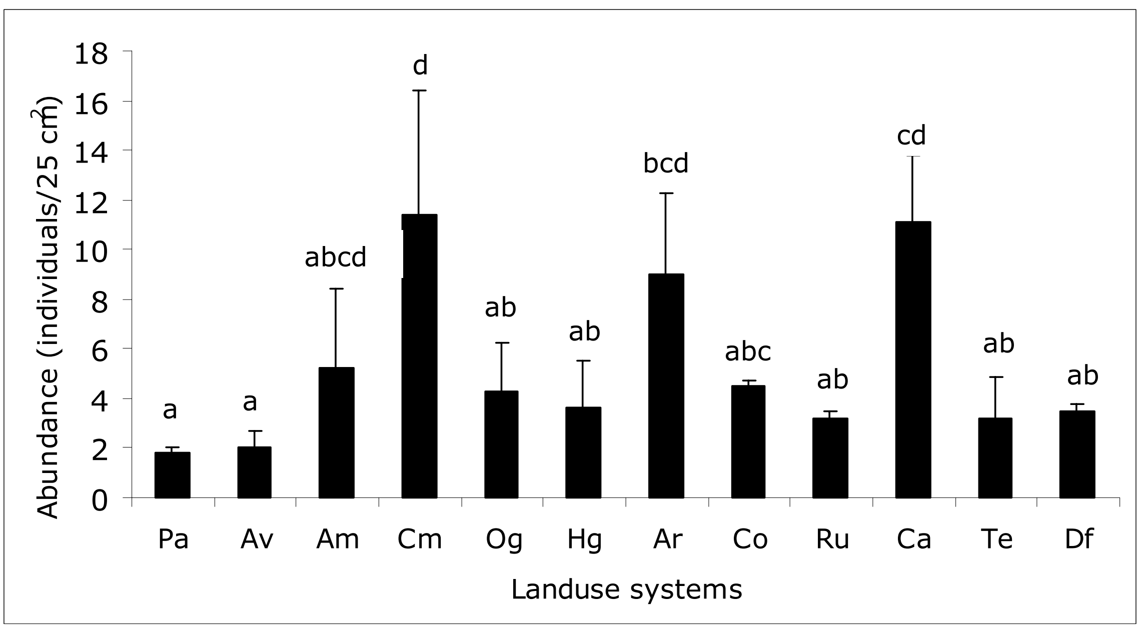

Figure 1. Abundance (mean ± SE) of earthworms in different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. Values with same alphabet are not significantly different ($p<0.05$).

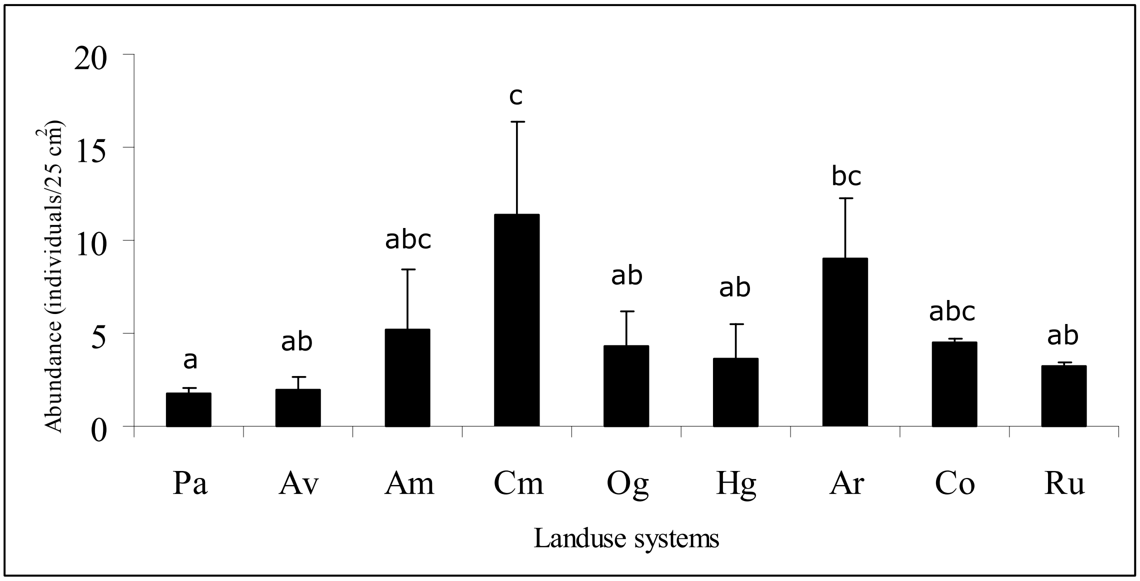

Figure 2. Abundance (mean ± SE) of earthworms in paddy fields and landuse systems derived from paddy fields in the Kerala part of Nilgiri Biosphere Reserve. Values with same alphabet are not significantly different ($p<0.05$).

It is reported that the soil type, pH, organic matter content and related physical/chemicals factors can influence survival, growth and reproduction of earthworms (Kale, 2005) and soil that poor in organic matter are also poor in earthworm abundance (Kale, 1997). However, in the present study no such trend was observed, except in one or two landuse systems for one or few soil parameters. For instance, significant correlation between earthworm abundance and nitrogen and potassium was recorded only in areca with annual cropping systems. Organic carbon showed significant correlation with earthworm abundance only in coconut mixed with perennial systems and teak plantations while correlation was observed between earthworm abundance and phosphorous in polyculture farms. In coconut plantation, significant correlation was observed between earthworm abundance with exchangeable acidity, organic carbon, calcium and magnesium. In rubber plantations, significant correlation was recorded between earthworm abundance and soil pH. According to Rombke and others (2005), establish the dependence of earthworms and most frequently studied soil parameters organic carbon, soil texture etc. are difficult. Rossi and others (2006) concluded that the lack of clear relation between earthworm abundance and soil parameters may be due to difference in spatial scales in terms of earthworm population and soil properties. It may also be pointed out here that soil nutrient status may vary both spatially and temporally as it depends on the type, quality, quantity, and frequency of nutrient input. Thus, any given plot may not be stable in terms of nutrient status. Due to this instability, it is difficult observe any significant correlation with soil faunal abundance.

As already pointed out, among different plots derived from paddy fields, one plot which is currently under coconut perennial crops (Plot code no. 2) showed highest earthworm abundance (26 individuals/25m^2). Thus further analysis was made to characterize the agronomic aspects of different landuse systems by considering earthworm abundance in a gradient (Figure 4).

This study showed that the plot 2 is characterized by sandy soil with high moisture content even during post monsoon. Here the organic input in the form of green leaf manure is regular with minimal disturbance to the soil. Inorganic fertilizer and pesticide application are totally absent in this plot. Some or all the above mentioned soil characters management practices are lacking in other plots. In this context, it is also possible to conclude that the paddy field transformed landuse systems in the study area have the potential to have abundant earthworms (25 or more than 25 earthworm/25 cm^2) provided the present management system are re-oriented to enrich the soil with organic input adopt several other management practices, which are discussed below.

a. Consider the soil as part of a complete agro-ecological system

A healthy, diverse soil food web actively decomposes organic matter and cycle nutrients, ensuring soil and plant health. Thus maintain conditions of the soil conceptually healthy.

b. Maintain ground cover

Bare ground is prone to moisture loss and, high temperature and lacks a supply of organic material to feed soil organism. Keeping the soil covered with mulch, straw, or leaf litter is the first step to encourage the soil biota. A living ground cover of plant is better. That is why continuous removal of weed may be a mechanical stress to the soil, because it is persistent through out the year. It may cause the continuous mixing of the top soil, which part greatly support soil biota.

Thus replacing weed with suitable cover crops have a dual role here, first, it replace weed thus reduce the pressure of weeding and subsequent mechanical stress to the soil. Secondly, it will provide a mulch and organic source which directly enhance soil fauna.

c. Minimize physical disturbance

As we discussed in the previous section, physical disturbances have negative effect. So use reduced tillage, which reduces the rate of organic matter breakdown. Minimize the surface abrasion, which may also lead to reduction in the beneficial microbial population also.

d. Build up soil organic matter

Soil organic matter and other carbon sources are the premier source of food to the soil organisms. The amount, quality and extend are directly related to the many vital function in the soil. Adding mulch or compost is the better practice to improve the soil organic carbon.

e. Maintain adequate moisture

Water content in the soil play key role in litter beak down and survival of microorganisms, and microarthropods. Cover crops, mulching and SOM will help in retention of optimum moisture content in the soil.

f. Crop rotation

Monocropping may cause reduction of some nutrients and reduce supply of food source to the soil organisms. Crop rotation if needed will enhance a diverse soil population, reduce chance of disease.

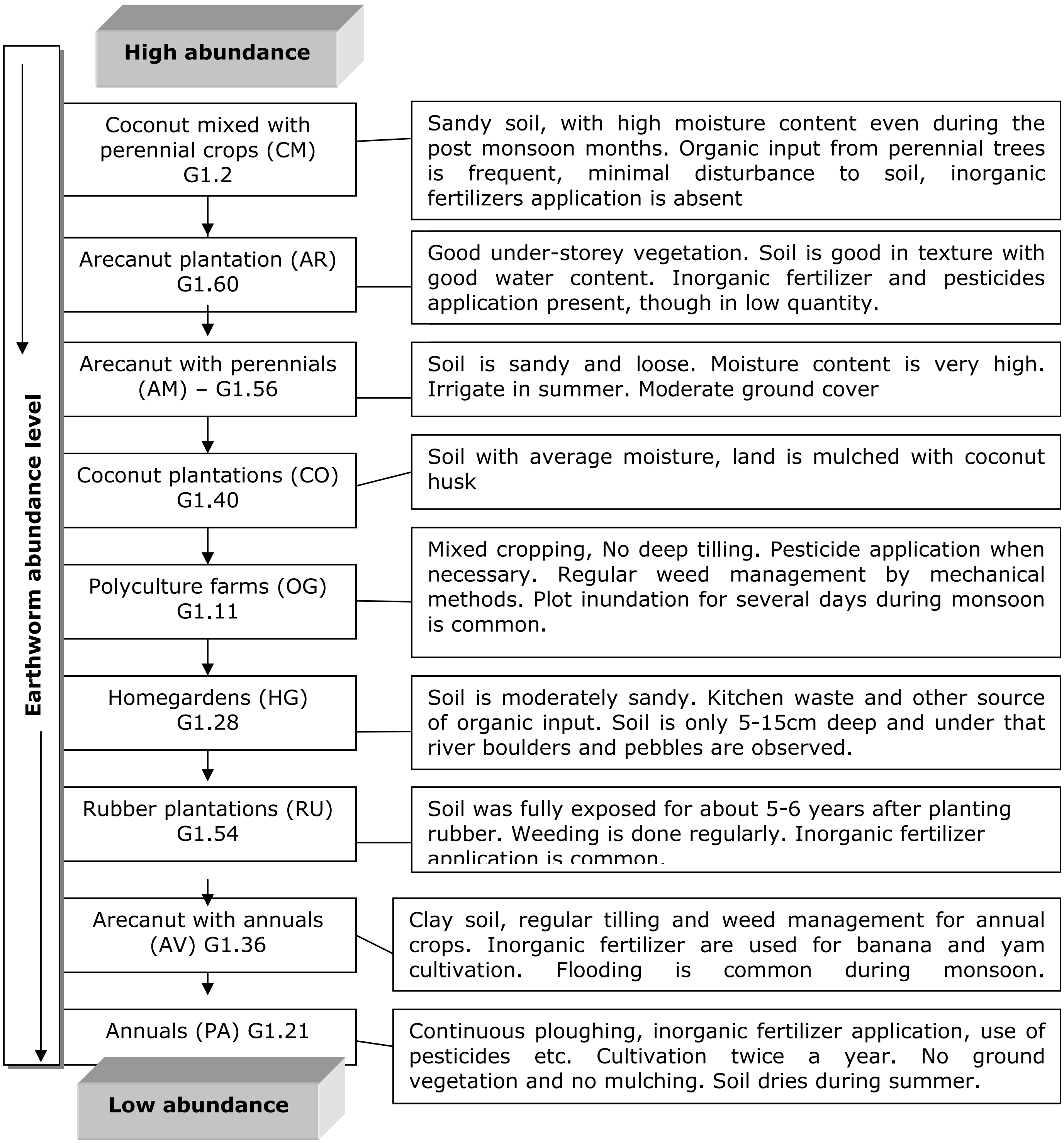

Figure 4. Schematic representation of earthworm abundance level in different landuse systems derived from the paddy fields in Kerala part of Nilgiri Biosphere Reserve

g. Reduce the use of chemicals

Pesticides and agrochemicals affect the soil community negatively. Frequent use of chemicals may eliminate some soft bodied groups like earthworms. Some pesticides have long term residues which may cause total elimination of soil fauna.

h. Use fertilizer in small amount

Use fertilizer in required amount, other wise excess amount may leach out from the soil and cause pollution and contamination of the soil. Chemical fertilizers are also harmful to soil fauna.

i. Use organic fertilizers

Organic fertilizers are good source of beneficial microbes and also help in the build up SOM, which inturn enhances the soil physicochemical qualities as discussed above. Organic fertilizers have no adverse impact on soil fauna. Green manure is the best source of organic source of soil and so growing cover crops/biomass species are ideal one.

j. Maintain proper sanitation system

Poor drainage cause water logging and subsequent damage to plant root. More over, it provides a poor habitat to many soil biota.

k. Monitor the soil PH

Extreme soil conditions are harmful to both crops and fauna. Most of the soil organism like earthworms prefers neutral pH. Maintain optimum pH value is can be maintained by liming. It is good management tactics to manage earthworm population in the soil.

Conclusion

Despite the fact that the earthworm abundance does not show positive significant correlation with several soil parameters which are generally consider while determining the soil health, earthworm abundance itself can be a good indictor of soil health as we noticed in this study. Transformation of paddy fields into tree based/perennial crop based system seems to help in building up of earthworm population. However, when the suitable agronomic practices are adopted comparatively high earthworm abundance can be seen as recorded in the plot number 2 of the present study. Such plots can be considered as the benchmark plots. Necessary soil management practices may be adopted in other plots too to enhance the earthworm abundance similar to that recoded in the benchmark plot/s.

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