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Physico-chemical and Carbon Stock Analysis of Soil under Forest Ecosystem

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ABSTRACT

Temperature and moisture levels in the soil are two of the most important factors that determine the rate of soil respiration. Changes in the microclimate of the soil throughout the year play an essential part in determining seasonal fluctuations in the amount of carbon dioxide that is emitted from the soil at individual locations, and climatic variances because varying rates of soil respiration at distant sites. In forest ecosystems, one essential step in the cycling of carbon is the transfer of carbon dioxide from the soil to the atmosphere. The in-situ measurement of the increase in CO_2 concentration at the soil's surface is often what is meant when people talk about "soil respiration." At the level of soils, CO_2 emission is induced by both plant and microbial activities, including root respiration and the breakdown of organic matter in soil and litter. According to some reports, soils are responsible for between 60 and 80 percent of the overall respiration of an ecosystem. Microorganisms that live in the soil and the litter are responsible for the vast majority of heterotrophic respiration that occurs in forest ecosystems. A measurement of soil respiration in a substrate that is deteriorating has been recognised as a helpful indication of the rate of decomposition and mineralization of organic matter, as well as the cycling of carbon in an ecosystem, and as an index of relative soil biological activity. In order to investigate the physicochemical properties, bacterial and fungal populations, and soil respiration of various land use zones in Indian forest, the present study was carried out.

Key words : *Soil respiration, Soil profile, SOC, SOM, Forest ecosystem, Nutrient composition*

Introduction

India is now ranked third in the world with a share of 7 percent of total CO_2 emissions. However, India is ranked 20th in the world for per-capita yearly CO_2 emissions, which is roughly 1.94 tonnes, which is less than half the worldwide average of 4.8 tonnes CO_2 (Ritchie and Roser, 2019). When compared to the world's other major contributors to CO_2 emissions, India's per-capita CO_2 emissions are significantly lower than those of those other countries (except China). During the time period 1880–2020, India saw a decrease in forest land of 18 million hectares (from 89 million hectares in 1880 to 71 million hectares in 2019) and an expansion of cropland land of 49 million hectares (from 92 million hectares in 1880 to 141 million hectares in 2019) as a result of conversion from forest land, grassland, and boggy land into cropland (Tian *et al.*, 2014). As a result of these conversions, there has been an appreciable decrease in the SOC stocks, which has had an effect on both the quality of the soil and the overall health of the ecosystem. The trend in the proportion of land covered by FL and CL systems relative to the total land area is illustrated in Supplemental Figure S1, which covers the years 1990 through 2017. Even if the scale of the change is relatively little, the patterns are positive. For example, the percentage of people living in the FL region has climbed from 21.5 percent to 23.7 percent, while the percentage of people living in the CL area has declined from 61.1 percent to 60.4 percent. Recent initiatives taken by the Indian government have assisted in slowing the rate of deforestation in the country. These initiatives have focused on reducing deforestation, reversing the effects of deforestation through reforestation, and increasing afforestation by establishing forests in previously unforested areas (Don *et al.,* 2011). This is clear from the efforts that governments are making to expand the amount of land that is covered by forests in order to meet the long-term goal of having 33 percent of the total land area covered by forest and woodland. However, during the previous several years, throughout the period of 2000–2017, the net emissions/removals of CO_2 by the FL have grown (from 18 104 gigatons to 11 104 gigatons), whilst the net emissions/removals of CO_2 by the CL and GL have stayed stable and constantly positive (Figure 1).

Forest lands that have favourable physical and chemical features are vital for maintaining productivity in terrestrial ecosystems and driving processes that preserve the quality of the environment. Without an understanding of the soil, it is impossible to comprehend the expansion and reproduction of forests. Due to the fact that both the soil and the plant develop over an extended period of time together, there is a complicated interrelationship between the two. The physical and chemical qualities of a soil make up its characteristics, and the behaviour of a soil is often determined by the amount and organisation of these components. Soil characteristics are made up of both physical and chemical features. Minerals, air, water, and organic matter are the four primary components that make up soils. In the majority of soils, minerals account for around 45 percent of the overall volume, while water and air take up approximately 25 percent each, and organic matter ranges from 2 percent to 5 percent. The characteristics of the soil in terrestrial ecosystems are determined by a wide range of abiotic and biotic elements, which change according to location and time of year. The total ion content, acidity, carbon, nitrogen, and total phosphorous all change on a geographical scale in the topsoil. Other abiotic components include nitrogen and total phosphorous. Additional elements such as temperature, land shape, topography, soil texture, soil moisture, and the mix of plant communities all have an impact on soil composition. The overall ionic contents of an area as well as its acidity are two factors that have an independent impact on the geochemistry of the soil and, as a result, the distribution pattern of the region's flora. The climate does not have any direct influence on the composition of the soil; however, it may have an indirect effect on the soil through the composition of the plant community and/or the soil wetness. In the event that the environment becomes drier, it is anticipated that the ground would become less acidic and fertile in addition to suffering from a loss of moisture. .

In a similar manner, there is a significant and positive correlation between the high levels of soil carbon, nitrogen, total ion content, and acidity and

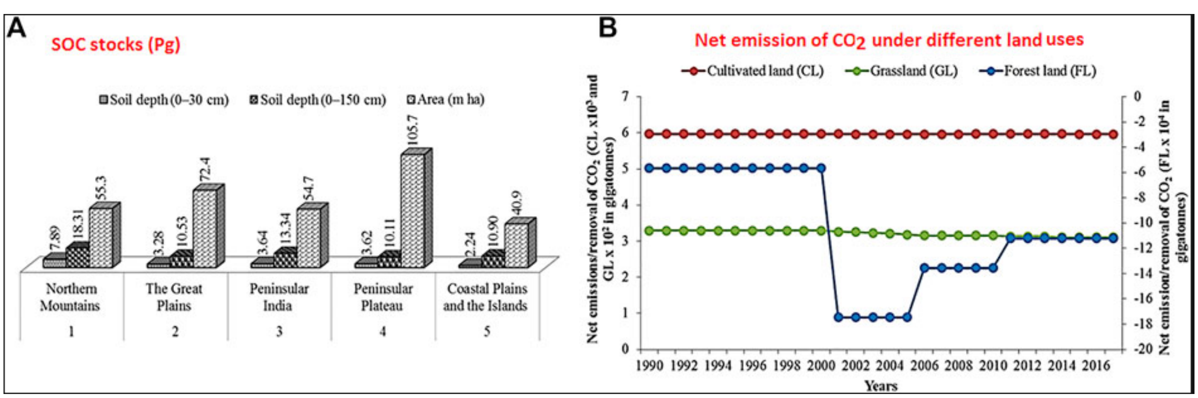

Fig. 1(A). Carbon reserves in the soil across India's various physiographic regions (source: Bhattacharyya *et al.,* 2000). (B) Trend of net emissions/removals of CO_2 from forest land (FL), cultivated land (CL), and grassland (GL) (1990–2017) of India (Y1-axis indicate CL and GL; Y2-axis represent FL), FAO (http://faostat.fao.org/

the composition of plant communities. The forest floor is the most active element of soil organic matter, and global soils contain more carbon than any other terrestrial carbon pool. Soils contain more carbon than any other terrestrial carbon pool.

Materials and Methods

Description of the Research Site

Achanakmaar Amarkantak Biosphere Reserve lies between 210 15' - 220 58' north lat. furthermore, 810 25'- 820 5' longitude. It is generally around related by road from Bilaspur and Raipur in Chhattisgarh and Anuppur and Pendra road railroad station in Madhya Pradesh. Pendra Road, Belgahana and Kota are progressing zone and move can be engineered from these areas in addition. The biosphere save has vital in light of the fact that it is the beginning place of primary stream frameworks of focal Indian, viz. Johilla, Sone and Narmada, and their feeders. Narmada River frequently called the life saver of the Madhya Pradesh, run around 1177 KM in Madhya Pradesh and rest in Gujarat states, lastly falls into Arabian Sea. The divisions of biosphere start from south forest area of Bilaspur locale in Chhattisgarh state to Rajendragram forest area of Anuppur (Madhya Pradesh) in the northest and Belgahana forest area of Chhattisgarh in the eastest to Dindori forest area of Dindori region in Madhya Pradesh.

Taking Samples of the Ground

In order to conduct physicochemical and carbon stock, soil samples were taken with a core sampler that had a diameter of five centimetres and were taken from a depth of zero to twenty centimetres in three different types of land use zones: natural sal forest, bamboo plantation, and wet land during the dry season (March-April). The dimensions of each subplot were 20 x 20 x 30 centimetres, and two soil samples were taken at random from each one. As a result, a total of 24 soil samples were obtained, one from each of the sampling zones. In order to create a composite sample, the soil samples taken from each of the land use zones were completely combined. The samples were sent to the Environmental Sciencelaboratory under the Department of Environmental Science, IGNTU, Amarkantak, MP for the purposes of conducting physico-chemical analysis. For the purposes of microbiological research, the samples were kept in the refrigerator at a temperature of four degrees Celsius to inhibit the growth of any microorganisms until they were inoculated. In order to conduct physicochemical analysis, air-dried soils were first screened to remove plant roots and macrofauna, and then sieved through a mesh size of 2 millimetres. Nutrient and macrofauna concentrations were determined using the serial dilution method and the spread plate method, with nutrient agar and potato dextrose agar serving as the media, respectively. In order to quantify the evolution of carbon dioxide in soil samples, 0.25 N potassium hydroxide, 0.25 N hydrochloric acid, and phenolphthalein were used as indicators.

Statistical Analysis and Interpretation

Using the SPSS-6.0 programme, we performed statistical analysis on the data, including analysis of one way variance (ANOVA), and analysis of correlation.

Analysis of the Physicochemical and Microbiological Properties of the Soil, as well as Measurements of the Soil's Respiration

The sand, the silt, and the clay in the soil were all evaluated with the use of a Bouycos hydrometer. The pH was obtained using digital pH metre as per Van Reeuwijk. According to Walkley and Black, measurements were taken of both organic carbon (OC) and soil organic matter (SOM). The SOM was determined by multiplying the Van Bemmelen factor, which was 1.724, by the percentage of OC. The titration technique, using 0.5 M HCl and 0.2 M NaOH, was utilised in order to determine the $CaCO_3$ concentration of the soil. bacterial and fungal communities found in the soil

Results and Discussion

Physical and Chemical Analysis of the Soil

Table 1 contains representations of the soil samples' textures in addition to the numerous chemical analysis findings obtained from the samples. According to the results of the textural investigation, the soils that were present in the bamboo plantation were varieties of loamy-sand, sal forest, sandy and wet land, and sandy loam (Table 2). As a consequence, the findings suggested, in general, that the soil texture exhibited only slight differences throughout the various land use zones of the forest. Because of the varying elevations and undulating forest floors in different parts of the biosphere, the soil may leach and deposit different types of sand, silt, and clay at different times during the wet season. This could be the cause of the textural differences that exist between land use zones.

The soil taken from the wetland had the highest mean pH value of 7.44, followed by the soil taken from the bamboo plantation with 7.20 and the soil taken from the sal woodland with 6.46 (Fig. 2). It is hypothesised that the microbial population and soil respiration would indicate noticeable differences between the various land use zones because soil pH is thought to be an important factor influencing the density and diversity of soil biota. This is because soil pH is considered to be an important factor influencing the density and diversity of soil biota (Table 1). According to the findings of this study, the pH value of the soil in bamboo plantation was moderately acidic, but the pH value of the soil in sal forest was extremely acidic. However, the pH of the samples taken from the wetland soil was found to be alkaline. The sal forest may have a low pH value because it has a higher proportion of sand, which has a higher porosity and more rapid leaching of nutrients as a result of precipitation. Higher pH values were found in soil samples taken from bamboo forests and wetland areas, most likely as a result of the comparatively smaller amount of sand present and the slower rate of leaching. The differences in the kinds of organic wastes that are created by the various land use zones may potentially be another factor that contributes to the pH shifts that are seen. Because forest and bamboo residues contain more lignin than wetland residues, forest and bamboo residues may contribute to the creation of more acidic residue. The greater quantities of calcium carbonate found in the soils of bamboo plantations and wetlands, in comparison to the soil found in sal forests, may be another factor that contributes to the higher pH seen in these types of soils. Historically, the pH of the soil has been regarded as the most reliable indicator of the bacterial community composition and diversity over a wide range of land use types, with the greatest bacterial diversity occurring near to neutral pH values. These findings lend credence to the findings of prior studies, which stated that the pH of different land use zones might differ greatly due to differences in the soil's physical and chemical composition.

The percentages of organic carbon and soil organic matter were found to be highest in bamboo plantations, followed by sal forests, and were found to be at their lowest in wetland environments (Table 1). The soil from bamboo plantations had the greatest percent OC value (0.45) and the highest SOM value (0.66 mg/g soil), whereas the soil from wet lands had the lowest percent OC value (0.22) and the lowest SOM value (0.28 mg/g soil). The organic carbon found in soil is the biggest contributor to the terrestrial portion of the global carbon budget (Thakur *et al.,* 2014, 2017, 2019, 2021, 2022). The top metre of soil in every region of the world contains two to three times the amount of carbon that is stored in all plant that grows above ground. Research on soil carbon and microbial communities often focuses on the top 20 to 30 centimetres of soil since this is thought to be the biologically most active part of the soil profile. In the current investigation, the soil from bamboo plantations had the greatest overall percentage of OC and SOM, followed by the soil from sal forests and wet land (Fig. 3). There is a strong connection between the intake of litter mass in a forest and the OC and SOM levels in the soil. Accordingly, the greater levels of organic car-

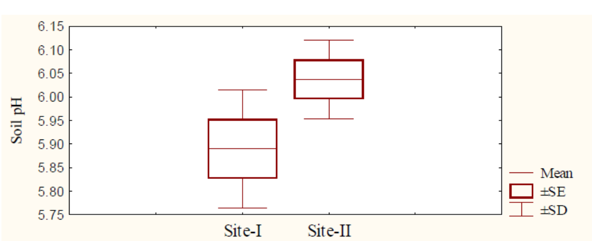

Fig. 2. Comparison of soil pH in the two sites of the study area

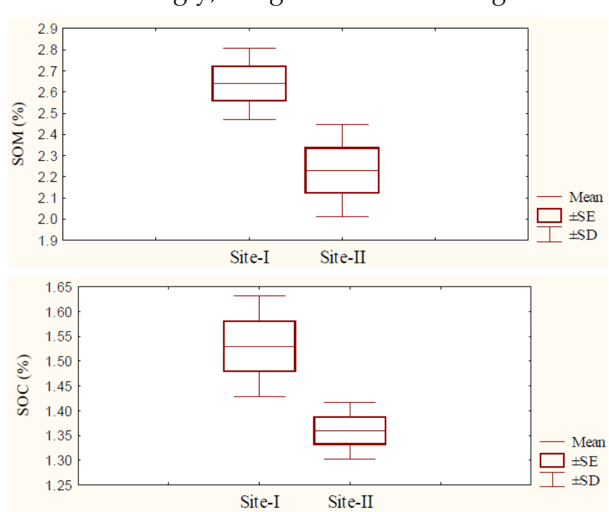

Fig. 3. Comparison of SOM (%) and SOC (%) in the two sites of the study area

bon and secondary organic matter in the soils of bamboo plantations and sal forests might be attributed to increased litter biomass in these regions in compared to the wet land, which is in keeping with a previous study on the subject.

The CaCO3 concentration of the soil was found to be highest in bamboo plantations (7.15 mg/g soil), followed by wet lands (7.1 mg/g soil), and sal forests (7.22 mg/g soil) had the least amount of CaCO3 in their soils. A one-way analysis of variance (ANOVA) was performed on the various soil chemical parameters, and the results showed that there was a significant variation in value (P =.05) between the sampling zones.

According to Atiku and Noma's research, the organic carbon, nitrogen, and potassium levels in the forest varied greatly depending on the zone of land use and similar results were found by many researchers (Kumar *et al.*, 2017a,b; Bijalwan *et al.*, 2017, 2019; Thakur *et al.*, 2019a,b). Vishnu *et al.* (2017) examined the physico-chemical features of evergreen, wet deciduous, scrub jungle, shoal, and grass land systems in Kerala, India. They discovered substantial differences in organic matter and primary and secondary soil nutrients across the different types of ecosystems. Earlier, Islam and Weil studied the effects that a shift in land use had on the soil quality of a natural sal forest in Bangladesh. They found that the amount of silt and clay in the soil, as well as the amount of nitrogen and labile carbon, reduced when the natural forest was cleared to make way for grassland and agricultural areas (Kumar and Thakur, 2017; Thakur *et al.*, 2021a,b,c). Unanaonwi *et al.* (2013) conducted their research in the forest soil of Southern Guinea, Nigeria, and came to the same conclusions. As a result of changes in land use in different parts of the world, a number of studies have found that the percentages of organic carbon (OC) and soil organic matter (SOM) in different ecosystems can vary widely (Thakur *et al.* 2020a,b; Kumar *et al.* 2021; Rawat *et al.*, 2022). These prior claims have been validated by the findings of the current study which measured the percentage of organic carbon and soil organic matter in the sanctuary (Thakur *et al.*, 2014a,b).

Soil Microbiological and Respiration Studies

Figure 1 provides a visual representation of the bacterial population as well as the respiration of the soil. The greatest bacterial colony count was found in the soil from the bamboo crop, which was 10.5 x 10^4 CFU per gram of soil. The soil collected from the sal woodland had the lowest count of CFU per gram of soil (8.66 x 10^4 CFU/g soil), while the soil collected from the marsh had the second greatest population (8.23x 10^4 CFU/g soil). The soils from sal forests had the greatest fungal colony count (7x 10^4 CFU/g soil), followed by those from bamboo plantations (7x 10^4 CFU/g soil) and wet lands (4x 10^4 CFU/g soil) (Fig. 2). The rate of soil respiration followed the same pattern throughout the study, ranging from a high of 756 mg/hr/m^2 in bamboo plantations to a low of 554 mg/hr/m^2 in sal forests. The data were analysed statistically using a one-way analysis of variance (ANOVA), and the results showed that there was a significant difference between the land use zones in terms of the soil bacterial population, the fungal population, and respiration. The percentage of organic carbon and the number of bacteria in the soil were shown to have a substantial positive association (r =.111, P =.03) as well as a significant positive correlation (r =.98, P =.03).

Table 1. The average values of the physicochemical soil characteristics in the forest

Land use zones	Sand (%)	Slit (%)	Clay (%)	pH	OC (%)	$CaCO_3$ (mg/g soil)
Bamboo plantation	76.6 ± 4.5	4.2±2.2	9.4±2.4	7.2±0.5	0.45±0.11	7.15±2.3
Sal forest	79.2±3.4	4.2±0.17	8.4±1.5	6.46±0.9	0.26±0.12	7.22±2.4
Wet land	71.4±3.5	4.8±0.19	16±2.5	7.44±0.2	0.22±0.14	7.14±3.6

Table 2. Soil textural analysis of the study area

Site	Composition %			Types of Soil
	Sand	Silt	Clay	
S1	59.38±0.06	28.39±0.08	12.23±0.03	Sandy loam
S2	60.12±0.07	26.33±0.10	13.38±0.06	Sandy loam

The value of pH was shown to have a significant negative association (r = -.109, P =.031) with the number of fungal populations.

Structure and activity of the microbial community in soil are both dependent on the condition of their habitat. The habitat of the soil is envisioned as a complicated matrix that has holes of varying widths and soil particles of varying sizes. Each ecosystem has a microbiological community that is slightly distinct from the others due to the fact that each ecosystem's soil community and its habitat are controlled by a linked network of factors that vary from ecosystem to ecosystem. The relative microbiological potential of a sal forest, a bamboo crop, and a wetland may be inferred from their respective habitats. In a dry tropical forest in Rajasthan, India, Kumar *et al.* found a significant amount of variation in the physicochemical makeup of the soil at various sites across the forest (Tariyal *et al.*, 2022). The forest's varied soil textures and high chemical quality are thought to be responsible for this phenomenon. The findings from our research are consistent with the findings presented here.

There are reports available on the influence that changes in land use have had on the composition of microbial communities in tropical environments. In the eastern Amazonian region, Borneman and Triplett found that the organisation of the soil microbial community was significantly different in a mature forest soil and in a pasture soil that was close to the forest. Nusslein and Tiedje found that when the plant cover of a Hawaiian soil went from forest to pasture, there were considerable changes in the bacterial community composition of the soil. Bossio *et al.* (2055) came to the same conclusions after doing their research in eastern Kenya. In addition, they discovered that the bacterial community in the soil of a secondary forest that was in the process of recovering at one location was more comparable to that of an indigenous forest at another site than it was to agricultural sites that were located nearby. This was linked to shifts in the characteristics of the soil rather than land usage. In their study, Singh *et al.* investigated the soil microbial population, enzyme activity, and microbial biomass of natural, secondary, and restored forests in Malaysia. They found substantial differences between the three types of forests.

The pH, organic matter, and moisture levels of the soil are three of the most critical environmental elements that influence the distribution and population of bacteria in the soil (Fig. 4). In general, the population of bacteria is highest in soils that are either neutral or slightly acidic and have an appropriate amount of organic matter. In the current investigation, the researchers found that the soil from the bamboo plantation had the highest bacterial population, followed by the soil from the sal forest, and the wet land had the lowest. The soil from the bamboo plantation had a pH that was in the neutral to slightly acidic range, and it had a high organic carbon and biological carbon content, all of which are indicators of a robust bacterial population. The wetland, which had an alkaline pH and a moderate amount of organic carbon content, was probably a less appropriate habitat than the dry ground, and as a result, it had the smallest bacterial population.

It has been reported that the micro fungal biomass in the soil of a tropical forest has been found to be the greatest in the region. This soil also contains the highest concentration of organic carbon (Bijalwan *et al*. 2010, 2020; Kumar *et al.*, 2021; Mishra *et al.* 2021; Sahoo *et al.* 2021; Rawat *et al.* 2022; Thakur *et al.* 2022). According to this study's findings, the highest number of soil fungal populations was found in sal forests, followed by bamboo plantations, while the lowest numbers were found in wetland areas. In comparison to the wet land, bamboo and sal forests had proportionally larger levels

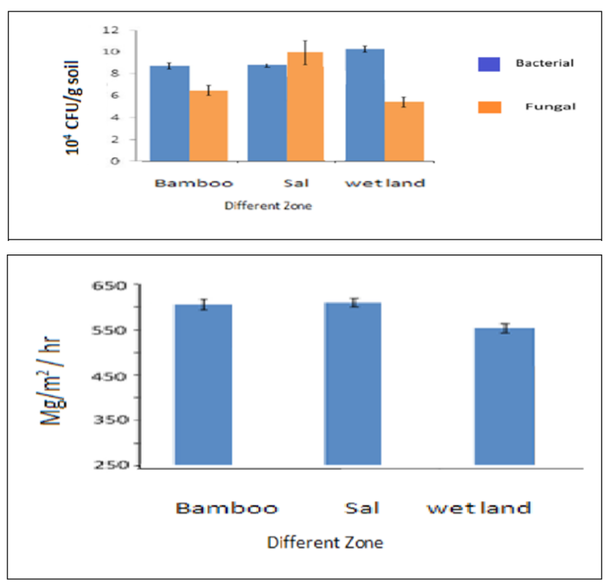

Fig. 4.(a)The population of bacteria and fungi (b) The amount of carbon dioxide that isreleased from the soil in different land use zones within the forest

of both organic carbon and soil organic matter in the soil. There is some speculation that the live and most dynamic component of soil organic matter - the microbial biomass - could be an indicator of the capacity for the soil to support biological activity. This activity is mirrored in the soil's ability to respire, which is shown in the current study by the development of CO2. The rate of soil respiration is often associated to large populations of bacterial and fungal species in the soil. It was discovered that the bamboo plantation had the highest rate of soil respiration, whereas the sal woodland had the lowest rate. Since ancient times, the rate of soil respiration has been regarded as a reliable indicator of the number of organisms present in soil as well as their level of activity.

Conclusion

The findings of this study provided empirical support for the hypothesis that soil physico-chemical characteristics such as texture, pH, organic carbon content, and soil organic matter (SOM) might have an effect on the bacterial population and the rate of soil respiration in forest ecosystems. The research also showed that the bacterial and fungal population as well as the rate of soil respiration varies greatly across the different land use zones in subtropical forest soil. Further research on the vertical and horizontal variation in the microbial population, biomass, and metabolism in forest soil with variation in available nutrients will shed more light on microbial dynamics and their functional roles in these ecosystems and provide information that will substantially help in the sustainable management of subtropical forests. This is because the soil nutrient status, bacterial population, and metabolism are all good indicators of the soil's health. In addition, the soil nutrient status is a good indicator of soil health.

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