International Journal of Research in BioSciences
Vol. 1 Issue 2, pp. (20-26), Oct 2012
Available online at http://www.ijrbs.in
ISSN 2319-2844

Research Paper

Impact of land use changes to a natural forest on some soil microbiological properties

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(Received 28 August, 2012, Accepted 01 October, 2012)

Abstract

The major aim of this study was to assess the value of parameters associated with the total microbial biomass as indicators of changed soil quality following various changes in land use to a dry mixed evergreen forest in Sri Lanka. The most striking effects of land disturbances are seen in the data for total Nitrogen and available phosphate. While there were no consistent changes in total microbial biomass associated with changes in season, there was generally higher total microbial biomass in the Natural Forest and plantation soils than in the disturbed sites. Data on metabolic quotient of the microbial biomass, % contribution of microbial C to total soil C and time for microbial biomass to achieve peak CO_2 evolution did not indicate any consistent pattern of stress due to the disturbance of the Natural Forest. However, the results clearly confirmed that both chemical and biological properties of soil are highly vulnerable for any stress caused by land use changes there by reducing the quality of soil.

Keywords Forest, Soil quality, microbial biomass, metabolic quotient.

Introduction

Sri Lanka is a tropical island of continental origin which shares tectonic plates with peninsular India. The island covers about 65,610 sq. km. Sri Lanka falls under an equatorial climatic region modified by monsoons. The distribution of rainfall throughout the country is governed by the occurrence of the monsoons. The mean annual rainfall for the whole country varies from 1094mm to 5500mm [1]. Soils in tropical forests are many meters in depth since they have developed over millions of years without disturbances. The soil profiles are well mixed by earthworms. The absence of a thick forest floor in the dry zone does not indicate that these soils are low in soil organic matter contents. Throughout the lower soil layers, light colour fulvic acids are complexed with mineral soil and yield a significant storage of soil carbon in the organic form [2]. The diverse climate, soil types and altitudes have provided the basis for high range of vegetation types and plant diversity [1]. The flora includes 192 families of flowering plants with 1290 genera and 3268 species of which 25% are endemic to the island [3].

Sri Lanka has about eight kinds of natural vegetation formations [4]. Dry zone forests are one of those and found in northern, eastern and southern provinces. The dry zone covers about 77% of the land mass and extends from sea level to 1000m elevation. During the last two decades, there has been increasing alarm over the rate at which the world's tropical biomes are being depleted. It has been suggested that perhaps as much as half of the lands historically covered by tropical moist forests have been deforested [5] and there is much public concern about this deforestation. However deforestation appears to be proceeding throughout the tropics at an alarming rate. Further, processes like erosion, desertification and salanization are causing soil degradation on an international scale.In Sri Lanka, shifting cultivation is termed Chena cultivation. It is an unirrigated rainfed cultivation practice based on slashing and burning, preferably of forests but also of scrub or grassland.

Traditionally, it involves shifting from plot to plot and long term fallowing of plots following one year of crop production [6]. In Sri Lanka, normal events in chena cultivation are that following slashing and burning, crops are grown for one season. Then the land is left fallow for 4 - 6 years during which time natural secondary succession begins. After this fallow period, slashing and burning recurs and crops are grown again. In some circumstances, the land is completely abandoned following harvesting of the first crop and naturally secondary succession occurs ultimately leading to the development of new secondary forests.From the standpoint of safeguarding primary forests, the most appropriate strategy is to establish plantations in forest territories that have already been exploited and have become poor quality secondary forests in degraded grasslands. In the dry zone of Sri Lanka, primary forest exploitation is mainly caused by shifting cultivation. The Forest Department has developed afforestation schemes to overcome this problem by planting Teak (*Tectona grandis* L.) which is a valuable timber and *Eucalyptus Camaldulensis* Dehn. which is also a valuable for poles and gum production. In addition, some areas exploited by shifting cultivators are regenerating naturally.

From the recent past, the dry zone forests have been receiving special attention as very few work has been carried out in these forests both regarding upper and lower biomass. Over the last twenty years, there have been regular studies on the effects of both physical and chemical disturbances of soils and of land rehabilitation on a range of soil microbiological properties. This work has been reviewed and pointed out that diverse soil microbiological criterion may indicate changing soil quality; and that these criteria fall into three levels of study i.e. population, community and ecosystem levels [7] [8]. Zak *et.al*. (1992) concluded that at the community level, microbial abundance distributions plus annual variability are useful for assessing short and long term soil recovery rates during land reclamation. However, ecosystem parameters could provide the best assessment of ecosystem recovery and stability. Visser and Parkinson(1992) further suggested that ecosystem level approaches give the best chance for rapid assessment of soil quality changes; and that information obtained using these approaches would indicate whether or not population or community level studies should be carried out.

Ecosystem level studies have generally emphasized three major sets of processes e.g. organic matter(Carbon) cycling, nutrient cycling and nutrient retention efficiencies. With respect to carbon cycling, three areas have been investigated e. g. organic matter decomposition rates, soil respiration and microbial biomass. Rates of organic matter decomposition are determined by the physical and chemical quality of the material being decomposed, climatic-microclimatic factors (temperature and moisture) and the nature of the community of the decomposers (microbes and fauna) [9]. Frequently, studies of organic matter decomposition are made over several years in temperate climates and are usually carried out in the field. However, the considerable seasonal and annual variations in climatic conditions over the course of these studies may have greater impacts on decomposition rates than those caused by slow changes in soil quality.

Ever since the early days of soil microbiology [10], soil respiration (CO_2 efflux) has been viewed as potentially providing an index of soil quality. Soil respiration can be measured in either the field or the laboratory; and the pros and cons of these two approaches have been discussed by Anderson (1982). For the reason presented for organic matter decomposition, laboratory studies using constant, standard conditions of temperature and soil moisture have been considered most appropriate for studies of soil quality change.Until recently, the many studies of basal respiration of soil samples have not been related to data on the microbial biomass in those soil samples. Since 1976 “physiological” methods have been developed for measurements of total microbial biomass carbon in soil samples. These methods are fumigation incubation [11], fumigation extraction [12] and substrate induced respiration [13]. These methods have allowed a large increase in the studies of microbial biomass dynamics in agricultural and natural ecosystem soils, mainly because of their simplicity in comparison with the direct observation methods that have been in use for nearly fifty years [14].

Visser and Parkinson (1992) concluded that the Substrate Induced Respiration (S.I.R.) method has the greatest potential for monitoring soil quality changes for two reasons. It is quick and simple to carry out basal respiration measurements followed by S.I.R. measurements on the same soil samples. This allows calculation of the amounts of carbon respires as CO_2 (Cresp) per unit mass of microbial biomass carbon (Cmicro). These data allow the calculation of metabolic quotient (qCO_2= Cresp/ Cmicro) [13]. For stressed ecosystems an increase in the respiration/biomass ratio is expected while in ecosystems being reclaimed a decrease in this ratio is expected (Odum 1985). Increasing soil maturity also allows a decrease in the qCO_2 value [15, 16]. Zak *et al.* (1992) considered this metabolic quotient to provide the best approximation of overall system recovery and stability; and, presumably, of the reverse.

However, useful data can be obtained if the respiratory response of soil samples is followed for at least 48 hours following glucose addition and the time taken to achieve peak respiratory response is recorded. Visser and Parkinson (1989) have shown that increasing stresses on soil increase the time taken to achieve peak CO_2 efflux, and consider this parameter to be a sensitive indicator of stress on soils. When measurements of total microbial biomass carbon (C_{micro}) can be made quickly, together with measurements of total soil carbon (C_{org}), it is possible to get good, replicated data on the contribution of C micro to C org.It appears that only a small proportion (1-4%) of the total soil organic carbon is made up of microbial biomass carbon. Nevertheless Anderson and Domsch (1986) hypothesized that, in a given soil, changes in C_{micro} / C_{org} would indicate changes in the stability of that soil system. Zak *et al*. (1992) suggested that measurements of C_{micro} / C_{org} are valuable in soil monitoring because they integrate several important ecosystem functions. However, they consider measurements of qCO_2 to be a more powerful measure of ecosystem stability.

The aim of the work was to assess the impact of various types of land use changes (Chena cultivation (involving slashing and burning), replacement of natural forest by single species forest (Teak and Eucalypt) and deforestation and abandonment) to the dry zone forest on some soil chemical and biological properties. The main focus of this study was to assess the impacts of land use changes on soil microbiological properties, and to gain some insight into the value of these properties as indicators of various degrees of soil disturbances.

Materials and Methods

All measurements were made on soil samples (0-10c.m. depth) collected both wet and dry seasons over a period of two years. The soil samples were kept at 60%mhc for one hour prior to study. Soil chemical analysis (total N, available Phosphate phosphorous, soil moisture, soil organic matter, total soil microbial biomass through Basal respiration(BS), Substrate Induce Respiration(SIR) and calculations to obtain metabolic quotient, % Contribution to microbial C to total C (C_{micro} / C_{org}) and the time to peak CO_2 efflux following glucose addition were done using standard methods.

Results and Discussion

All data were compared with those from the natural forest. The most striking effects of land disturbances were seen in the data for total N and available phosphate (Table 1). Under dry conditions, decompositions rates are very high and high values of total N has been recorded in this study. This may be attributed to the high decomposition rates prevailing in the top soil in the dry season. However the values for total phosphorus were very low due to the land preparations with slashing and burning technique for most of the sites.

Table 1: Soil total N content in the dry and wet seasons at five sampling sites

Study site	N content(ppm)		Available Phosphate	
	Dry	Wet	Dry	Wet
Nat. Forest	970	740	15.2	12.7
Derelict	830	500	6.3	7.6
Chena I	940	1000	4.1	3.8
Chena II	750	830	6.3	3.9
Teak	1260	790	4.2	2.9
Eucalypt	1120	890	4.5	4.2

The soil organic matter contents varied inconsistently having lowest variation for the natural forest and the highest for the two plantations. The highest variations for the plantations could be due to high decomposition rates of the broad leaves for Teak and frequent light fires for the eucalypt site. However, the data are generally within the range of organic matter given by Srivastava and Singh (1988) for tropical forests in India.

There were no consistent changes in total microbial biomass associated with changes in season. However, there was higher total microbial biomass in the Natural forest and plantation soils than in the disturbed sites. However, it is very strange that there were no any significant differences in microbial biomass values of natural forest between seasons. In the derelict site, the microbial biomass values ranged from 228 to 250µg C g^{-1} contributing to the fact that the reduction of organic C and other nutrients occurs with savannization. When considering two chenas with different times after abandonment, it was very clear that microbial biomass of Chena I (5 years following slash and burn) was always less than that of Chena II (8 yrs following slash and burn). At the same time, soil microbial biomass of natural forest was always significantly different from that of Chena II indicating the reaching the equilibrium with regeneration over the time.

With respect to two plantations, mean microbial biomass values(359 – 409µg C g^{-1}) were very close to those obtained for natural forest in both seasons (Figure1).

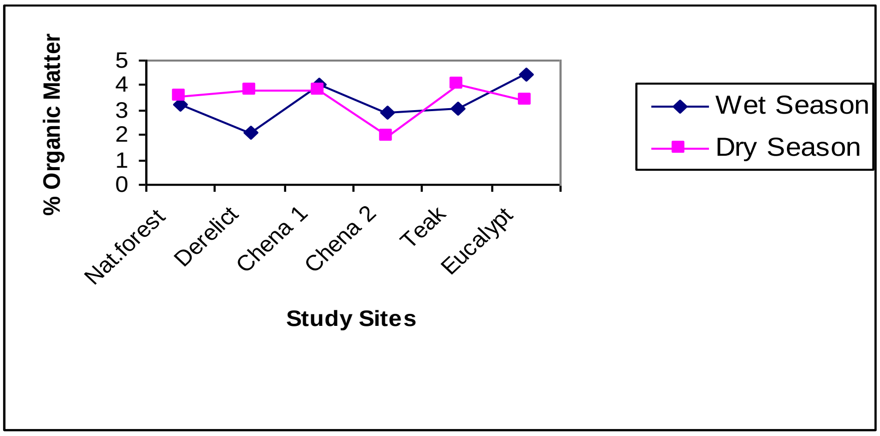

Figure 1: % Organic matter data for six study sites for dry and wet seasons

When compared to the natural forest, none of the five sites which are results of land use changes showed any significant difference in soil microbial biomass between wet and dry seasons. The total microbial biomass under substrate induced respiration was always higher compared to the basal respiration data thus indicating the lack of suitable resources for utilization for microorganisms (Figure 2).

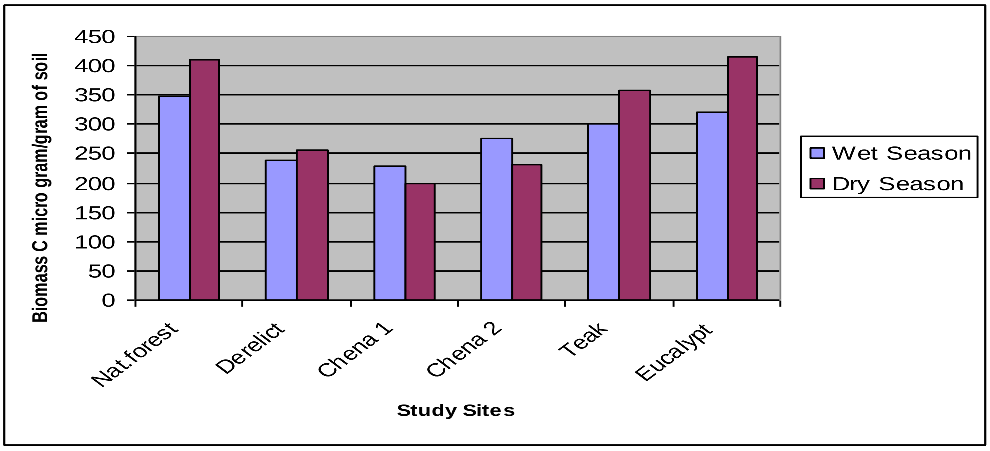

Figure 2: Mean Substrate Induced Respiration(SIR) for different sites

As stated earlier, metabolic quotient is the measure of the efficiency of the microbial biomass which is a sensitive measure of ecosystem stress. qCO_2 values in this study was always higher in the dry season than in the wet season for all the sites (Table 2). This could be attributed to the stress caused by less moisture and less nutrient availability during dry climatic zones. The data further indicates that the microorganisms in the derelict site is under little stress and also the oldest chena shows less efficient microbial biomass compared to the younger chena.

Table 2: Seasonal and overall mean metabolic quotient (qCO_2) values for the study sites

Study sites	Wet	Dry	Overall
Nat. Forest	1.15	2.63	2.04
Derelict	1.50	1.73	1.64
Chena I	2.30	3.30	2.90
Chena II	3.80	4.0	3.90
Teak	1.60	3.10	2.50
Eucalypt	0.38	2.06	1.39

However, metabolic quotient values indicated that microbial biomass under Chena sites were the least efficient and the stability of the dereliction/abandonment with time has not taken place despite heavy regeneration of upper biomass. The percentage contribution of microbial C to total organic C (C_{micro} / C_{org}) in soil is normally between 1 – 5%[17]. Deviation from this level signals that the soil is either loosing or accumulating carbon. The data for natural forest (1.6 – 2.6%) indicates that it is in steady state. From the data of this study for the disturbed sites, chena I shows the lowest mean value signaling some sort of disturbance where as the rest is nearer to the natural forest values indicating less disturbance irrespective of land use changes.Time to peak CO_2 production following amendation with optimal glucose is a useful parameter to assess stress of soils [8]. In this study, Natural forest showed the shortest time to achieve peak CO_2 indicating that it is in the equilibrium. All the other five disturbed sites took more time to achieve highlighting some limitations either inorganic nutrients or amount/type of microorganisms (Table 3).

Table 3 Mean time to peak CO_2 Production during Substrate Induced Respiration at five sampling sites (hrs)

Study site	Wet season	Dry season
Nat. Forest	11	8
Derelict	18	13
Chena I	15	12
Chena II	11	10
Teak	14	-
Eucalypt	19	14

It was also established the fact that the % Contribution of microbial C to total C is a good parameter to assess the land degradation. If peak CO_2 is achieving fast, it is a good sign to indicate that particular environment is not much disturbed.

Conclusion

Both total Organic matter and N contents in this study indicates high decomposition rates in the plantation sites. Total N content was always higher during dry season further justifying high mineralization rates due to high temperature. Microbial biomass indicated that land use changes have not much affected on the mean value except Chena I exhibiting high recovery after disturbance. The microbial biomass at Chena II has reached up to the Natural Forest within 8 years showing high rate of plant regrowth. However, overall qCO_2 indicated that Chena II has the least efficient microbial biomass highlighting the prevalence of disturbance in soil. The least stressed microbial biomass was recorded with the abandonment thus indicating possible adaptations over the time. %contribution of microbial biomass C to total soil C showed that land disturbance is not much affected. Finally, Mean time to achieve peak CO_2 evolution following glucose amendment indicated that all the sites except natural forest are experiencing some form of disturbance. Therefore, the measurements on system stability indicated different results, qCO_2 indicated that Chena II is the most stressed; C_{micro} / C_{org} suggested that Chena I and Derelict are the most stressed and time to peak CO_2 suggested that derelict is the most stressed.

Acknowledgement

The author wishes to acknowledge the financial assistance provided by Canadian International Development Agency (CIDA) through Kelaniya – Calgary link programmed of University of Kelaniya, Sri Lanka.

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