

Soil biological activity under different land-uses in Leyte, Philippines

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ABSTRACT

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On seven sites in Western Leyte, Philippines, different land-uses, namely reforestation with indigenous tree species ('rainforestation'), reforestation with exotic tree specie *Gmelina arborea*, and traditional fallow / grassland use were compared with respect to soil biological activity. Analysed parameters were Basal Respiration (BR), microbial carbon (Substrate-Induced Respiration method, C_{mic} SIR) and leaf litter decomposition. Correlations between BR, SIR, metabolic quotient (qCO_2), soil organic carbon (C_{org}), soil N (N_r) and pH were assessed. BR and C_{mic} SIR as well as the metabolic quotient qCO_2 (BR/SIR) proved to be sensitive parameters and the methods gave reproducible values to distinguish sites and land-uses in most cases. However, due to differences among fallow / grassland treatments, a uniform tendency between these and rainforestation was not observed. On the other hand, BR and C_{mic} SIR were significantly higher under *Gmelina* than under either of the other land-uses. Correlations between parameters were strongest for BR vs. C_{org} and BR vs. pH as well as for C_{mic} SIR vs. C_{org} and qCO_2 vs. C_{org} .

Keywords: soil biological activity; basal respiration; Substrate-Induced Respiration; land-use; reforestation.

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INTRODUCTION

One of the central postulates of agroforestry systems with respect to nutrient cycling is that the tree component would access nutrients from deeper soil layers and, through litterfall, make them available for shallow-rooting undergrowth crops (Cannell *et al.* 1996). This could be of particular relevance on sites with depleted topsoils but underlain by subsoils with higher nutrient levels. In the case of many volcanic soils in Leyte the limiting factor is P although it may be found in relatively higher concentrations in the andesitic parent material found in the BC or Cv horizons. Additionally, many of the studied soils are Luvisols and Acrisols which are characterised by a clayey argic B horizon difficult to penetrate by roots of annual plants. Once nutrients have been taken up by trees and shed as leaf litter, they need to pass through different pools of decomposers or mineralisers to become available once again for plants. In this context, soil meso- and macrofauna as primary decomposers as well as microbial organisms and their respective activity are of interest.

Soil microbial parameters are often referred to as easily observable indicators of soil quality or fertility status. The microbial population of a site as a whole quickly reacts in its composition and metabolic activity to environmental changes (Anderson & Domsch 1986). Basal respiration reflecting metabolic activity during equilibrium stage and C_{mic} , size of the microbial population, are often combined with activity of specific enzymes characteristic for certain processes or specialised microbial populations. Metabolic quotient (qCO_2) has been suggested as indicator for stress / efficiency within a microbial population (Anderson & Domsch 1989). Insam & Haselwandter (1989) stated that qCO_2 decreases during succession of an ecosystem as decomposers become more efficient. Consequently, secondary succession after land-use changes would also be reflected by soil microbial parameters (Wardle *et al.* 1999; Mao *et al.* 1992).

The presented data form part of an ongoing research project relating to carbon sequestration of reforestation and traditional fallow across different soil units in Leyte. Apart from the performance of different tree species and biomass build-up, it was of particular interest to gather data on leaf litter production and its decomposition in the soil. The aim of this study was to characterise the different land-use systems on different sites with respect to

microbial C (i.e. the size of the active microbial pool determined by Substrate-Induced Respiration method) and microbial activity (Basal Respiration method), amongst others (e.g. leaf litter production and decomposition, phosphatase activity - data not shown). The selected parameters were expected to show quicker response to land-use changes than the overall soil carbon pools or pH value, which were also determined.

MATERIALS & METHODS

Soil samples from seven sites along Leyte's West coast were collected in 2005. Each site covered at least 'rainforestation' and fallow land-uses (denominated as *plots*), some additional *Gmelina* plantation. The different land-uses were i.) reforestation with native species ('rainforestation'), ii.) reforestation with exotic tree specie *Gmelina arborea* and, iii.) traditional grassland/fallow. At one site annual and perennial crops (*Ipomoea batatas* plus *Musa textilis*) were included as traditional system. Rainforestation and *Gmelina* plots had been planted in the mid 1990s, the crops in 2004.

Sampling for Basal Respiration (BR) and Substrate-Induced Respiration (SIR): Five to eight composite soil samples of 5-20 single samples each (to a depth of 20cm) were collected with a Pürckhauer auger at representative places within each plot excluding margins, pathways and former landslide areas. Samples were stored at 4-8°C while processing took place. Roots were discarded manually and for SIR the fresh soil was sieved to 2mm. After these preparations samples were frozen at approx. -10°C. Five days before analysis, soil samples were conditioned (placed in the dark at room temperature of 20-32°C) and water content was adjusted to 55% of water holding capacity. Due to the large number of replicates, only samples of one site were analysed per batch.

BR as described by Schinner *et al.* (1993) is used to determine microbial respiration in a soil at equilibrium state. Soil samples are incubated in the laboratory under controlled conditions (with respect to amount of soil, water content of the soil and ambient temperature) and CO₂ set free through respiration processes during a defined time period is trapped and quantified. Differing from the original procedure, incubation of 30g soil was at room temperature and samples were analysed in four technical replicates.

SIR as developed by Anderson & Domsch (1978) makes use of the same respiration principles as BR. However, this procedure allows to estimate the size of the microbial population from the increase of respiration after amendment of the soil with glucose (an easily processable and thus preferred substrate). Population size is usually expressed as microbial C or C_{mic} applying a conversion factor CO_2, C_{mic} . In contrast to other methods, SIR includes only the actively metabolising microbial biomass. This is of relevance as, depending on environmental conditions, a large proportion of the microbial population is found in a dormant state, not contributing to processes like decomposition. SIR was carried out according to the description given by Schinner *et al.* (1993), including a pre-test to determine the minimal dose of glucose causing a maximum increase in respiration. The main experiment was then done in five fold technical replicates including one unamended control. Incubation temperature was 22°C (air-condition) after 4h adaptation from ambient temperature (30-32°C). For both aforementioned methods the robust and low-budget Isermeyer approach (s. Schinner *et al.* 1993) was used to determine rates of released CO_2 : Respired CO_2 is trapped in NaOH, then precipitated with $BaCl_2$ and NaOH not consumed before is back titrated with HCl.

Soil pH was determined potentiometrically in 0.01M $CaCl_2$ solution and soil organic carbon and N_T contents with a Leco C-N analyser.

Leaf litter production on dry matter basis was monitored in litter traps of 50x50cm size (Anderson & Ingram 1993). Recollection of litter was every two weeks during the transition from rainy to dry season (Feb-May 2006). Litter samples were then oven-dried (70°C until constant weight) and weighed.

Litter decomposition was assessed using the mini-container method as developed by Eisenbeis (2004). Plastic cylinders were filled with 0.1500g of oven-dry litter each. Cylinders were closed with a 0.1mm or 4mm mesh net to allow access to the encapsulated litter by different decomposer groups (namely bacteria and fungi for the 0.1mm and additionally soil meso- and macrofauna for the 4mm mesh). Exposition of the capsules was at 5cm soil depth during 14 days. After recovery of the mini-containers, the remaining litter was oven-dried (70°C) and weighed again.

In addition, profile description and soil classification were carried out for every site (the profile pits being excavated on the respective rainforestation plots) after Jahn *et al.* (2003) and ISSS-ISRIC-FAO (1999).

Table 1. Soil pH, C_{org}, N_T and C/N ratio 0-20cm for different sites and land-uses in Leyte.

Location	Cienda	Pangasugan	Marcos	Patag	LSU
Soil unit	Haplic Acrisol	Chromic Acrisol	Stagnic Luvisol	Stagnic Cambisol	Haplic Cambisol
Texture	Heavy clay	Clay over heavy clay	Clay	Silty clay over clay	Clay loam
Land-use*	Rain	Rain	Rain	Gme	Fall
pH	4.7	5.0	5.4	4.8	5.0
Corg [%]	3.50	2.77	2.67	3.32	2.29
NT [%]	0.29	0.26	0.26	0.32	0.19
C/N	12.1	10.7	10.3	10.4	12.1
					9.0
					9.7
					8.9

*Rain = rainforestation, Gme = Gmelina, Fall = traditional fallow / grassland, Crop = cropped

RESULTS AND DISCUSSION

Table 1 shows selected soil physical and chemical parameters of five sites on volcanic parent material in Western Leyte. Additional soil profiles in Punta (on calcareous rock) and Maitum were analysed. These are however not shown in Table 1 since C_{org} and N_T analyses were still being carried out during the writing of this paper, but samples are included in BR and SIR experiments (Fig. 1).

In contrast to entire profiles, pH in topsoils did not vary strongly between plots and sites. C_{org} content was generally high in Cienda and low in Patag and in both cases connected with a wide C/N ratio. Generally C/N ratio did not vary in a wide range. At LSU a relatively tight C/N ratio coincided with locals' perception of high soil fertility.

Basal respiration as indicator of microbial activity was assessed for all plots (Fig. 1). Due to the necessary number of replicates, only plots on the same sites were compared against each other (t-test, $\alpha = 0.05$). During an additional experiment, samples from all sites (but with less replicates) were analysed simultaneously. No significant difference ($P = 0.848$, $\alpha = 0.01$) was found to the results shown in Fig. 1, so it is assumed that values can also be related across plots.

Especially soils in Punta and Cienda showed high BR rates, for Marcos and Patag sites the *Gmelina* plots showed clearly higher BR values than the other land-uses.

Across the aforementioned seven sites, correlation coefficients and P-values of individual samples were computed pairwise for relevant combinations of parameters (Table 2).

Correlations were pronounced between pH and activity-related BR and qCO_2 values as well as C_{org} and microbial carbon (C_{mic} SIR) and activity (BR). However, metabolic quotient qCO_2 (BR per unit C_{mic} SIR) was correlated to pH but not to C_{org} . Soil pH could be correlated to BR, but not to C_{mic} SIR or C_{org} (see Table 2). In contrast to C_{org} contents, N_T was only weakly correlated to C_{mic} SIR and BR and even less to qCO_2 .

With respect to soil C_{org} , BR and C_{mic} SIR showed a similar correlation (Fig. 3), but at different slopes; in contrast, qCO_2 , the quotient of BR / C_{mic} SIR, was not (linearly) correlated to C_{org} .

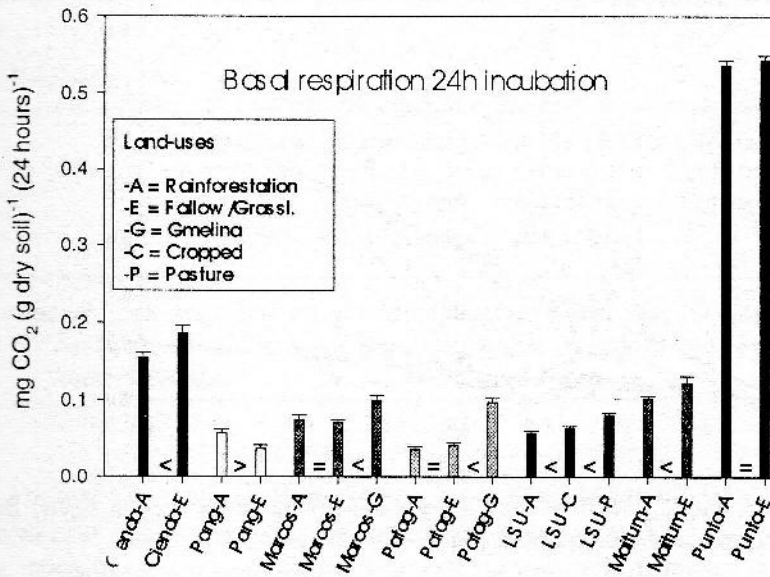


Figure 1. Basal respiration on different sites and land-uses in Leyte. Symbols between columns show t-test results ($\alpha = 0.05$).

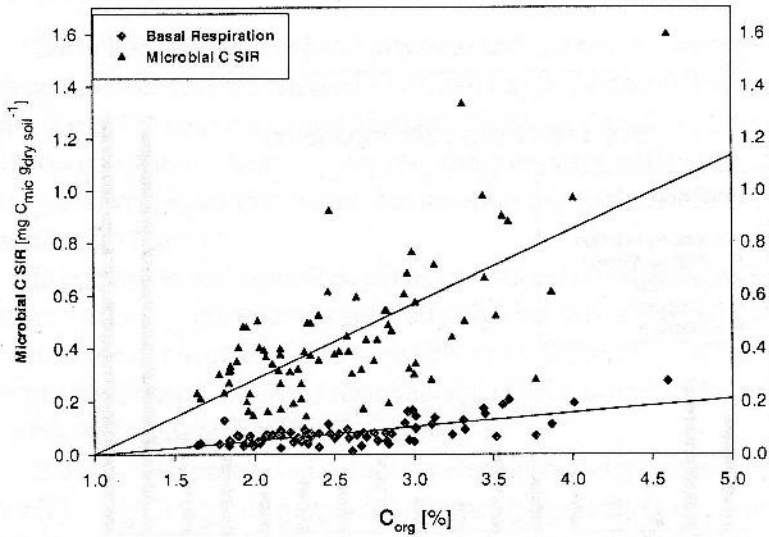
Basal Respiration and Microbial C as Related to C_{org} 

Figure 2. BR and C_{mic} (SIR) plotted against soil pH for seven sites in Leyte. Both regressions refer to BR vs. pH

Basal Respiration and Microbial C as related to pH

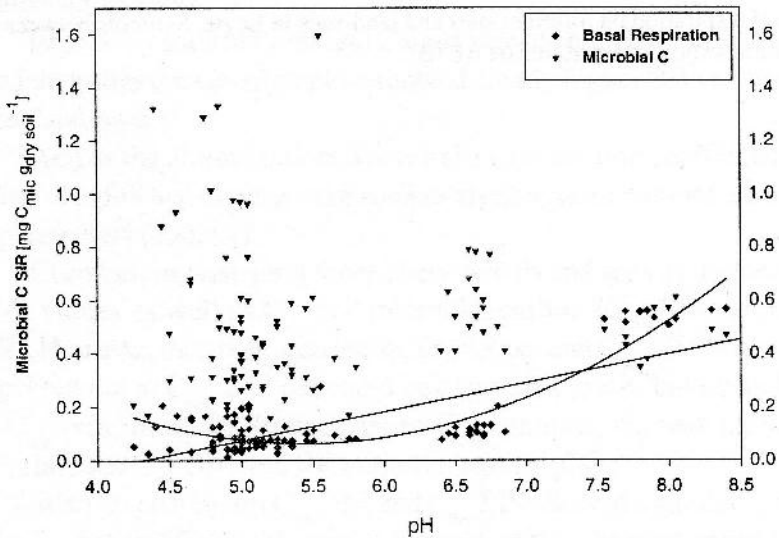


Figure 3: BR and C_{mic} SIR correlation lines plotted against C_{org} for five sites in Leyte.

Table 2. Correlation coefficients of different parameter pairs

Correlation Coefficient / P-value ¹	C _{org}	N	C/N	pH	C _{mic} SIR
BR	0.69 / 0.000	0.49 / 0.000	0.48 / 0.000	0.76 / 0.000	0.74 / 0.000
CO ₂	-0.05 / 0.646	-0.07 / 0.512	0.07 / 0.520	0.72 / 0.000	
SIR	0.68 / 0.000	0.50 / 0.000	0.43 / 0.000	0.02 / 0.016	
pH	0.08 / 0.507	0.19 / 0.089	-0.22 / 0.051		

¹A P-value < α indicates, that H₀ ('a correlation exists') can be accepted at the respective confidence level. For some pairs, quadratic regressions fitted better, but at higher P-levels.

BR and SIR methods (Isermeyer approach) proved to be simple, robust and low cost options to assess microbial activity of different land-uses and soils. Results are reproducible and can be compared across different experimental batches. Both methods were sensitive enough to allow distinction between dissimilar land-use as already stated by Svensson & Pell (2000) for temperate regions. In most cases differences between sites outweighed those between land-uses. However, for Punta our results (at adjusted water contents) might have overestimated respiration rates on this excessively drained site during dry season. There was no overall uniform tendency for rainforestation vs. traditional fallow / grassland, probably due to plot variability within the latter category, which served as reference. This group was not homogeneous enough with respect to vegetation (e.g. some plots contained leguminous plants like *Pueraria sp.*) and management (e.g. burning, which affects pH and C_{org}). Between *Gmelina* vs. rainforestation and *Gmelina* vs. fallow / grassland, however, the first one was markedly higher across the available sites.

As expected and in agreement with earlier findings of Joergensen & Scheu (1999) and v. Noordwijk et al. (1997), BR was correlated to pH. Mathematically a quadratic regression fitted best to describe the relationship between both parameters (Fig 2). A minimum of microbial activity at pH 5 and increase towards higher and lower pH would coincide with a minimum of

C_{org} as substrate for microbial metabolism as has been found by v. Noordwijk et al. (1997) for a broad range of soils in Sumatra. Towards the lower end of the pH range, an increase in C_{org} can be explained by stabilisation of soil organic matter through complexation with Al as has been shown for Andisols in Costa Rica (Veldkamp 1994). On the other hand our data for pH and C_{org} for five of the seven sites (Table 1) do not support this hypothesis.

High BR can be a sign of stress, when coupled with high qCO_2 , as was the case for Punta probably due to the effect of drought. In contrast, high BR at low qCO_2 , as in Cienda, might be the long-term effects of low pH.

Further statistical analyses are necessary to describe and interpret the relation of qCO_2 with C_{org} , which is not linear as C_{org} vs. BR and C_{org} vs. C_{mic} SIR. For BR and qCO_2 , C/N ratio of litter might be more revealing than C/N ratio of soil, because differences in litter C/N were more pronounced for a number of rainforestation species and *Gmelina* (data not shown) than they were between the different soils (Table 1).

Results obtained from leaf litter traps at Marcos site indicate that leaf litter production on a dry matter basis was not significantly higher in the *Gmelina* plot than under rainforestation. In an experiment on litter decomposition with a standard substrate, a tendency towards faster decomposition under *Gmelina* compared to rainforestation was observed (data not shown). These first experiments also indicated, that the predominant share of litter is consumed by the meso- and macrofauna. For this portion local variability is much higher than for the very uniform microbial decomposition, which on the other hand might differ to a higher degree under different seasonal soil moisture regimes. *Gmelina* leaves are easily decomposable compared to those of many Dipterocarps (Aragon, 2004; Batistel, 2004). Decomposition experiments using site-specific leaf litter on the respective plots are being carried out to compare turn-over under given circumstances. For Marcos site with its relatively high amounts of available P in the subsoil rapid turnover of litter would indeed contribute to better P supply for a crop component.

CONCLUSION

BR and SIR methods have the potential to assess soil biological activity and fertility as they integrate C_{org} , pH, water and air supply in the soil. qCO_2 data can give additional information on succession stage and environmental stress for the decomposer communities. Under practical aspects, BR and SIR methods proved to be appropriate under low-tech low-budget conditions. They are simple and sensitive, and results were reproducible when carried out in at least four technical replicates (not including blanks). In order to obtain 'absolute' values for C_{mic} , calibration of SIR method, preferably with Fumigation-Extraction method (leading to an adapted K_C factor) would be desirable. It was not possible to perform this procedure during the present study as ethanol-free chloroform and equipment for the evacuation of desiccators could not be obtained.

With respect to nutrients, recycling occurs at a faster rate in *Gmelina* plantations, when compared to rainforestation. This might be of advantage in the case of limiting P supply. On the other hand, stabilisation of soil organic matter (as opposed to rapid decomposition) would often be preferable regarding aspects of cation exchange capacity and storage of nutrients, water and air capacity of soil, and aggregate stability.

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