# SOIL QUALITY INDICATORS IN A RHODIC KANDIUDULT UNDER DIFFERENT USES IN NORTHERN PARANA, BRAZIL(1)

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## SUMMARY

**Sustainable use of soil, maintaining or improving its quality, is one of the goals of diversification in farmlands. From this point of view, bioindicators associated with C, N and P cycling can be used in assessments of land-use effects on soil quality. The aim of this study was to investigate chemical, microbiological and biochemical properties of soil associated with C, N and P under different land uses in a farm property with diversified activity in northern Parana, Brazil. Seven areas under different land uses were assessed: fragment of native Atlantic Forest; growing of peach-palm (*Bactrys gasipaes*); sugarcane ratoon (*Saccharum officinarum*) recently harvested, under renewal; growing of coffee (*Coffea arabica*) intercropped with tree species; recent reforestation (1 year) with native tree species, previously under annual crops; annual crops under no-tillage, rye (*Cecale cereale*); secondary forest, regenerated after abandonment (for 20 years) of an avocado (*Persea americana*) orchard. The soil under coffee, recent reforestation and secondary forest showed higher concentrations of organic carbon, but microbial biomass and enzyme activities were higher in soils under native forest and secondary forest, which also showed the lowest metabolic coefficient, followed by the peach-palm area. The lowest content of water-dispersible clay was found in the soil under native forest, differing from soils under sugarcane and secondary forest. Soil cover and soil use affected total organic C contents and soil enzyme and microbial activities, such that more intensive agricultural uses had deeper impacts**

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**on the indicators assessed. Calculation of the mean soil quality index showed that the secondary forest was closest to the fragment of native forest, followed by the peach-palm area, coffee-growing area, annual crop area, the area of recent reforestation and the sugarcane ratoon area.**

**Index terms: bioindicators, land use, metabolic coefficient, microbial biomass, soil enzymes, soil quality.**

## RESUMO: *INDICADORES DE QUALIDADE EM UM NITOSSOLO SOB DIFERENTES USOS NO NORTE DO PARANÁ*

*O uso sustentável do solo, mantendo ou aumentando sua qualidade, é um dos objetivos da diversificação na propriedade agrícola. Nesse aspecto, bioindicadores relacionados à ciclagem de C, N e P podem ser utilizados na avaliação do tipo de uso na qualidade do solo. O objetivo deste trabalho foi avaliar atributos químicos, microbiológicos e bioquímicos do solo, associados ao C, N e P, sob diferentes tipos de uso em uma propriedade agrícola com atividade diversificada no norte do Paraná. Foram avaliados sete tipos de uso do solo: fragmento nativo de Floresta Atlântica; cultivo de pupunha* (Bactrys gasipaes)*; soqueira de cana-de-açúcar* (Saccharum officinarum) *recém colhida, em reforma; cultivo de café* (Coffea arabica) *intercalado com espécies arbóreas; reflorestamento recente (1 ano) com espécies arbóreas nativas, em área anteriormente ocupada com culturas anuais; cultivos anuais em sistema de plantio direto na palha, centeio* (Cecale cereale)*; e mata secundária, regenerada por abandono (há 20 anos) de área cultivada com abacate* (Persea americana)*. Os solos das áreas sob cultivo de café, reflorestamento recente e mata secundária tiveram os maiores valores de carbono orgânico, mas a biomassa microbiana e atividades enzimáticas foram maiores nos solos sob mata nativa e mata secundária, que também apresentaram menor coeficiente metabólico, seguidos pela área de pupunha. O menor teor de argila dispersa em água foi encontrado no solo sob mata nativa, que diferiu das áreas de cana e de mata secundária. A cobertura vegetal e o uso do solo influenciaram no teor de C orgânico total e nas atividades microbiana e enzimática do solo; as áreas agrícolas com maior intensidade de uso do solo se evidenciaram mais impactantes aos indicadores avaliados. O cálculo de um índice médio de qualidade do solo indicou que a mata secundária mais se aproximou do fragmento de mata nativa, seguidos pelo cultivo de pupunha, cultivo de café, culturas anuais, reflorestamento recente e soqueira de cana.*

*Termos de indexação: bioindicadores, biomassa microbiana, coeficiente metabólico, enzimas do solo, qualidade do solo, uso do solo.*

## INTRODUCTION

The intensity of soil use may affect soil capacity for maintaining plant yield, carbon (C) and nutrient cycling, and the role of soil as a regulator of the hydrologic cycle. Soil organic matter is an important constituent of soil fertility, especially under tropical conditions, relying on microbial action for its formation and mineralization. Soluble carbohydrates represent a labile fraction of soil C which is available to microorganisms and act as a cementing agent of soil particles, contributing to the stability of aggregates and decreasing susceptibility to erosion (Ball et al., 1996). Thus, management practices favoring C maintenance in soil are important for sustainability of agroecosystems.

Different soil use systems modify the inputs and outflow of C, changing the microbial community, C and nutrient cycling and, consequently, soil fertility. The microbial biomass represents the living fraction of soil organic C, along with roots and macrofauna. This biological property is sensitive to changes in soil use, which can be detected prior to changes in physical or chemical properties (Balota et al., 2003; 2004; Kaschuk et al., 2010). In addition, the ratio between microbial activity measured as $CO_2$ evolution (Alef, 1995) and microbial biomass gives the metabolic quotient ($qCO_2$). This index brings important insights into the metabolic state of the microbial community, in which high values may be indicative of stress conditions in the microbial community (Anderson & Domsch, 1993).

Soil enzymes act to transform organic forms of nutrients into forms that can be assimilated by plants, mainly N, P, and S. Plants and especially microorganisms are the main sources of soil enzymes (Tabatabai, 1994); they remain active for a long time after their release in soil in interaction with organic and mineral colloids, partially preserving their catalytic activity (Balota & Chaves, 2010). Factors such as the land use system, plant cover, and xenobionts may affect the activity of soil enzymes and, consequently, C and nutrient cycling (Nayak et al., 2007).

Recently, researchers have focused on indexes that may reflect soil quality (or health) in the face of the sustainability of production systems (Velasquez et al., 2007; Jakelaitis et al., 2008; Nunes et al., 2009; Cardoso et al., 2013). Changes in soil properties as a consequence of different land use systems may affect both plants and the microorganisms that live in the soil and play essential roles in the ecosystem. Depending on the intensity of changes, the environmental sustainability of the (agro)ecosystem may be impaired, which makes soil quality indicators an important tool for predicting whether a certain type of soil management or use leads to sustainability or degradation. Nevertheless, creating a soil quality index based on only one or a small pool of indicators may not be reliable. For that reason, a minimum set of indicators that represent the complexity and functionality of soil is needed to assess soil quality (Cardoso et al., 2013).

The aim of this study was to assess chemical, microbiological and biochemical soil properties associated with C, N and P on farmland with diversified activity in the northern region of Parana, Brazil, and obtain a soil quality index for different land uses in relation to a reference site with native vegetation.

## MATERIALS AND METHODS

This study was carried out in the municipality of Rolândia, PR (23° 14' S; 51° 24' W) in a soil originating from basalt of the "Serra Geral" formation [Rhodic Kandiudult - Soil Survey Staff (1999) or Nitossolo Vermelho eutroférrico - Embrapa (1999)], with a very clayey texture. The climate is classified as Cfa (humid subtropical), according to Köppen, with mean annual temperature of 20.9 °C (23.6 °C in January and 16.7 °C in July), and mean annual rainfall of 1,600 mm, concentrated in the spring-summer (October to March). The altitude ranges from 714 to 731 m asl.

The sampling sites were: a fragment of Atlantic Forest never cropped before, adopted as a reference site; an eight-year old peach-palm (*Bactrys gasipaes*) crop; sugarcane (*Saccharum officinarum*) ratoon in a site recently harvested manually after burning which had been cropped for five years and the soil subjected to heavy harrowing for renewal of the crop; coffee (*Coffea arabica*) crop with intercropping of tree species for shading; recent reforestation (one year) with native tree species in an area previously under annual crops; annual crops (soybean - *Glycine max* or maize - *Zea mays* in summer; wheat - *Triticum aestivum*, barley - *Hordeum vulgare*, or rye - *Cecale cereale* in winter) under no-tillage, cropped with rye at physiological maturation at the time of sampling; secondary forest, regenerated after abandonment for 20 years of an avocado (*Persea americana*) orchard. All sampling sites are located within a 600-m radius and were sampled on the same day.

The soil was sampled at a depth of 0-0.1 m with a steel auger (0.05 m diameter). This soil depth was chosen because it is where the effects on microbiological and biochemical soil properties are more marked. In perennial crop areas, the samples were taken from between the rows. Four transects of 15 × 5 m were established at random in each site, from which 20 sub-samples were taken and pooled to form a composite sample for each transect. After sieving (<0.004 m), the samples were kept at 4 °C until analysis. For microbiological analyses, samples were processed within 72 h under field moisture, or with moisture adjusted to 70 % of field capacity (FC), if necessary. Moisture was determined gravimetrically after oven drying at 105 °C for 24 h. A sub-sample was air-dried for chemical analysis.

The microbial biomass C (MBC) was estimated by fumigation extraction (Vance et al., 1987). Basal respiration was assessed for 7 days by incubation at 28 °C in the dark, with moisture adjusted to 70 % of FC, in hermetically closed vials containing 0.5 mol $L^{-1}$ NaOH as a $CO_2$ trap, followed by titration with 0.5 mol $L^{-1}$ HCl (Alef, 1995). The ratio between basal respiration and the MBC provided the metabolic quotient ($qCO_2$) (Anderson & Domsch, 1993).

The following were determined in the air-dried samples: water-dispersible clay (WDC), pH in 0.01 mol $L^{-1}$ $CaCl_2$ (Embrapa, 1997), available P extracted with Mehlich-1 and determined by the ascorbic acid reduction method (Murphy & Riley, 1962) and soil organic C (SOC) (Yeomans & Bremner, 1988). The microbial quotient (*q*Mic) was calculated as the % of MBC in relation to SOC.

Activities of the enzymes amylase (E.C. 3.2.1), cellulase (E.C. 3.2.1.4) (Schinner & von Mersi, 1990), glutaminase (E.C. 3.5.1.2), asparaginase (E.C. 3.5.1.1) (Frankenberger & Tabatabai, 1991), dehydrogenase (Casida Jr. et al., 1964), acid phosphatase (EC 3.1.3.2) and alkaline phosphatase (EC 3.1.3.1) (Tabatabai & Bremner, 1969), urease (E.C. 3.5.1.5) (Tabatabai & Bremner, 1972) and the hot-water-soluble carbohydrate content (HWSC) (Ball et al., 1996) were assessed in the field-moist samples and results expressed on a dry soil basis.

The dataset was subjected to one-way ANOVA according to an entirely randomized design, followed by comparison of means by the Scott-Knott test at 5 %. Principal component analysis (PCA) was also performed by the software Canoco for Windows 4.5 (Ter Braak & Smilauer, 1998) to allow an integrated view of the behavior of the variables according to the type of soil use. A soil quality index (SQI) was calculated (Burger & Kelting, 1999; Jakelaitis et al., 2008; Nunes et al., 2009) for each soil use in relation to the reference site based on the microbiological and biochemical variables, in addition to soil moisture and

WDC. The value of each variable in the reference site was considered 1.0 and the values from the different soil uses were calculated in relation to the reference site. For most of the variables, the direct relationship (the more, the better) was obtained, whereas for $q\mathrm{CO}_2$ and WDC, the inverse relationship (the more, the worse) was obtained. An average SQI for each soil use was calculated based on each individual index.

## RESULTS AND DISCUSSION

### Soil moisture and chemical properties

Soil water content at the time of sampling varied among the sites and was highest in the native forest, followed by the peach-palm, secondary forest, cropped areas, and the recently reforested site (Table 1). The water content between the permanent wilting point and field capacity is critical for soil biological activities since adequate water availability supports microbial biomass and enzyme activities (Nogueira et al., 2006). Thus, management practices that contribute to maintaining water in the soil with fewer oscillations in its availability are also favorable to the microbial community (Nunes et al., 2009).

Higher concentrations of SOC were found in the sites of coffee intercropped with tree species, recent reforestation, and secondary forest regenerated after abandonment. These concentrations were higher than those found in the soil under native forest since the species used in reforestation, except for the recent reforestation, contribute to greater C inputs in the soil, resulting in the formation of stable SOC, as also observed in reforestations in the south-central region of Parana (Bini et al., 2013) and in the "Cerrado" region (Carneiro et al., 2009). In contrast, the site in which burning was used before sugarcane harvest, followed by harrowing for destruction of ratoons, showed the lowest SOC concentration. It is also important to stress that the sugarcane soil was the only one submitted to heavy harrowing. Sant'Anna et al. (2009) also found lower levels of SOC in sites cropped with sugarcane in comparison to the reference site with native forest, showing that soil management using conventional tillage favored SOC oxidation.

Available P contents were lowest in the native and secondary forests, whereas the cropped sites had higher contents owing to fertilizations of crops, corroborating results obtained by Carneiro et al. (2009), Nunes et al. (2009) and Lisboa et al. (2012). Thus, natural systems are more dependent on P cycling, which is partially intermediated by phosphomonoesterases, especially acid and alkaline phosphatases. Therefore, soils with lower inorganic P contents usually have higher phosphatase activity to recycle the soil organic P to be used by plants and microorganisms (Tarafdar & Jungk, 1987; Carneiro et al., 2009; Nunes et al., 2009).

Soil pH varied in a moderately acid range, from 4.5 to 5.7, with more acidity in the soils under native forest, and coffee and rye crops. The soils in this region are naturally acidic (Nogueira et al., 2006), requiring liming for improvement of chemical conditions for cropping where native vegetation was replaced by commercial crops.

### Water-dispersible clay (WDC)

From 6 to 12 % of total soil clay content (750 g kg$^{-1}$) was dispersed in the 0-0.1 m layer, where the highest levels were found in the soils under sugarcane cropping and secondary forest, differing significantly from the soil under native forest (Table 1). In general, the higher the soil pH is, the higher the clay dispersion (Leal et al., 2009), in accordance with a positive and significant correlation ($r = 0.59$; $p<0.05$) between WDC and soil pH (data not shown). Soil organic matter (SOM) has a prominent role as a cementing agent of soil particles since prior oxidation of SOM in samples results in an increase in clay dispersion (Tavares-Filho & Magalhães, 2008). Cropped sites may have more WDC because liming increases the diffuse electric

**Table 1. Water content (WC), soil organic carbon (SOC), available P (Mehlich-1), pH ($\mathrm{CaCl_2}$) and water-dispersible clay (WDC) in a clay soil under different types of management and plant cover**

| Soil | WC | SOC | P | pH ($\mathrm{CaCl_2}$) | WDC |
|---|---|---|---|---|---|
| | g kg$^{-1}$ | | mg kg$^{-1}$ | | g kg$^{-1}$ |
| Native forest | 380 a | 28.3 b | 8.3 d | 4.5 d | 45.0 b |
| Peach-palm | 344 b | 21.9 c | 76.3 a | 5.7 a | 73.7 ab |
| Sugarcane | 272 e | 19.3 d | 35.7 c | 5.6 a | 80.0 a |
| Coffee | 318 c | 31.7 a | 24.3 c | 4.7 d | 68.7 ab |
| Reforestation | 272 e | 30.5 a | 80.7 a | 5.0 c | 66.2 ab |
| Rye | 294 d | 27.8 b | 54.9 b | 4.7 d | 71.2 ab |
| Secondary forest | 345 b | 31.7 a | 16.6 d | 5.3 b | 90.0 a |
| CV (%) | 4.5 | 5.7 | 19.5 | 5.5 | 19.2 |

The same letters in the columns do not differ from each other by the Scott-Knott test at $p<0.05$.

double layer of colloids due to exchange of $Al^{3+}$ by $Ca^{2+}$ and $Mg^{2+}$ in the exchange complex. Liming also decreases the activity of $Al^{3+}$ and $H^+$, which act as flocculating agents in acid soils (Pedrotti et al., 2003). These ionic changes in the particle surfaces decrease the forces of attraction among colloids, making dispersion in water easier. Nevertheless, even with one of the highest concentrations of SOC, the levels of WDC in the soil under secondary forest were comparable to the cropped soils. This suggests that the effects of soil use on WDC before regeneration of the secondary forest still persist, even though the SOC have been recovered to levels even higher than in the native forest. Soil microorganisms play a critical role in the stability of soil aggregates, such as the exopolysaccharides produced by bacteria and the hyphae of filamentous fungi. Thus, in addition to low pH, the lower WDC in the native forest might have been a result of more microbial biomass in this soil (Table 2).

### Microbial biomass and metabolic activity

The highest MBC was found in the soil under native forest, followed by secondary forest, peach-palm and rye. All the other soils had lower MBC and were similar to one another (Table 2). The MBC represents the living fraction of the SOC and nutrients and is considered a sensitive indicator of soil quality because it is easily altered through anthropogenic action, like the conversion of forest to agricultural use, in addition to the impact of different strategies of soil use and management (Kaschuk et al., 2010). It is important to notice that, even after two decades with no anthropogenic interference in the secondary forest soil, the MBC was not reestablished to the levels found in the native forest. Carneiro et al. (2009) observed a reduction of MBC and *q*Mic in soils under different uses and management as compared to a site under native vegetation. The *q*Mic expresses how much of SOC is immobilized in the microbial biomass. Lower values of *q*Mic are usually found in cropped soils (Table 2), an indication of adverse conditions to the soil microbial community. The type of soil use leads to the selection of more adapted microbial groups (Anderson & Domsch, 1993), and ends up decreasing the overall MBC (Carneiro et al., 2009). However, the soil cropped with peach-palm showed higher *q*Mic in comparison to the other cropped soils, indicating more favorable conditions to the microbial community, which is confirmed by the third highest level of MBC.

Although the highest levels of $CO_2$ release occurred in the native forest soil, followed by the secondary forest and peach-palm crop, environments more favorable to biological soil functions, a similar value was observed in the soil with sugarcane. This probably occurred because the soil management in the sugarcane crop, based on heavy harrowing, caused a transient stimulus to microbial activity and, for that reason, these results must be carefully interpreted. This high $CO_2$ release in the sugarcane soil is in opposition to the decrease of indicators like water content, SOC, MBC, and the activity of some enzymes (Tables 2, 3 and 4). In contrast, high values of $qCO_2$ and high activity of dehydrogenase suggest unfavorable conditions to the microbial community at this site, despite the high respiration rate (Anderson & Domsch, 1993; Bini et al., 2013). Lisboa et al. (2012) observed a higher respiration rate of the microbial community in soil under native vegetation and under no-tillage as compared to conventional tillage. Higher respiration rates in the soil under no-tillage probably occurred because of more organic C accumulated in the topsoil, which is favorable to the microbial community, not only because of more availability of substrate, but also due to more homogeneous moisture and temperature conditions (Balota et al., 2003, 2004).

The lowest $qCO_2$ values were observed in native and secondary forest soils, differing from the other areas of cropped soils or under recent reforestation (Table 2). Lopes et al. (2010) and Jakelaitis et al. (2008) found similar results when comparing native forest with pasture, where the $qCO_2$ was significantly lower in the soil under native forest. The less stressful

**Table 2. Microbial biomass C (MBC), MBC in relation to the soil organic C ratio (*q*Mic) basal respiration (BR), and metabolic quotient ($qCO_2$) in a clay soil under different types of management and plant cover**

| Soil | MBC | *q*Mic | BR | $qCO_2$ |
|---|---|---|---|---|
| | µg g$^{-1}$ | % | µg $CO_2$ g$^{-1}$ d$^{-1}$ | mg C-$CO_2$ g$^{-1}$ MBC h$^{-1}$ |
| Native forest | 1264 a | 4.5 a | 114.7 a | 1.03 b |
| Peach-palm | 669 c | 3.0 b | 99.5 a | 1.70 a |
| Sugarcane | 496 d | 2.6 c | 98.8 a | 2.35 a |
| Coffee | 518 d | 1.6 d | 85.7 b | 1.88 a |
| Reforestation | 429 d | 1.4 d | 79.7 b | 2.18 a |
| Rye | 635 c | 2.3 c | 90.8 b | 1.75 a |
| Secondary forest | 959 b | 3.0 b | 110.6 a | 1.32 b |
| CV (%) | 16.4 | 16.6 | 10.8 | 21.5 |

The same letters in the columns do not differ from each other by the Scott-Knott test at $p<0.05$.

environment in the soil under native or regenerated forests results in a lower $qCO_2$ index, as a result of a more metabolically efficient microbial community (Anderson & Domsch, 1993; Pereira et al., 2013). Although not differing significantly from the other cropped sites, the soil with sugarcane showed the highest $qCO_2$ index, probably as a consequence of burning before harvest which decreases C inputs in the soil. Moreover, soil disturbance through heavy harrowing for renewal of the sugarcane plantation not only disturbs the microbial community by rupturing soil aggregates and microsites, but also by causing soil water loss. A similar result was found in the recently reforested soil because the recently transplanted tree species were still at an early developmental stage, insufficient for soil cover to protect the soil from sunlight and drying out, and with low inputs of C.

## Biochemical properties

In most cases, enzyme activities were higher in soils under native and secondary forests, and lower in the other soils, but enzyme activities varied according to soil use. Lower activities of cellulase and amylase were found in the recently reforested soil, not differing from the soil planted to coffee (Table 3). Enzymes like amylase and cellulase are more affected by the quality than the quantity of organic matter that enters the soil as plant residues (Andersson et al., 2004). Although both enzymes are involved in C cycling, cellulase was more sensitive in discriminating the types of soil use and did not follow the same tendency as amylase. For example, amylase activity in the peach-palm, sugarcane and rye soils was similar to the native and secondary forest soils, whereas cellulase activity decreased in these cropped soils compared to the forest soils. Conversely, in soils reforested with *Pinus*, *Araucaria* or mixed native vegetation in southern Brazil, amylase showed more sensibility than cellulase to the quality of residues that return to the soil, notably in the C/N ratio (Bini et al., 2013).

The N-cycling enzymes (asparaginase, glutaminase and urease) had higher activities in the native and secondary forest soils, and decreased in the other soils (Table 3). These results are in agreement with those of Fagotti et al. (2012) in which the soil under native forest and the soil reforested with *Araucaria* showed higher activities of glutaminase, whereas the cropped soil had the lowest activity. Glutaminase and urease proved to be more sensitive, resulting in more distinct levels of activity among the different types of soil use.

Dehydrogenase activity was highest in the sugarcane, secondary forest and peach-palm soils (Table 4). This high activity in the sugarcane soil, in contrast with the activity of the other enzymes, is probably a consequence of a transient stimulus of microbial activity due to soil harrowing. It is known that soil biological activity is stimulated after soil disturbance caused by harrowing because the rupture of soil aggregates exposes soluble C fractions to microbial action (Ball et al., 1996), but the resulting aeration also stimulates microbial activity. Moreover, high dehydrogenase activity may be a consequence of higher rates of microbial respiratory activity (Pereira et al., 2013) under stress conditions, which is in agreement with the higher $qCO_2$ in this soil. For its part, the high activity of dehydrogenase in the peach-palm soil is explained by the inputs of organic residues on the soil surface, comparatively higher than for the other crops. The input of organic matter via crop litter also stimulates the activity of dehydrogenase by making substrate available for the soil microbial community (Fagotti et al., 2012; Bini et al., 2013).

The activities of acid and alkaline phosphatases were more prominent in the soils under native and secondary forests, followed by the other soils (Table 4). These two soils showed lower concentrations of available P than the cropped soils, which explains the greater activity of phosphatases (Table 4). Higher availability of inorganic P in the soil reduces the dependency of the ecosystem on the cycling of organic forms of P via phosphatases, which results in lower activity of this enzyme (Tarafdar & Jungk, 1987;

**Table 3. Activity of enzymes related to C and N cycling in a clay soil under different types of management and plant cover**

| Soil | Amylase | Cellulase | Asparaginase | Glutaminase | Urease |
|---|---|---|---|---|---|
| | $\mu g$ glucose $g^{-1}$ $d^{-1}$ | | mg N $g^{-1}$ 2 $h^{-1}$ | | |
| Native forest | 751 a | 264 a | 1.02 b | 2.80 a | 3.15 a |
| Peach-palm | 721 a | 225 b | 0.60 c | 1.74 c | 1.06 c |
| Sugarcane | 666 a | 192 c | 0.58 c | 1.52 d | 1.11 c |
| Coffee | 636 b | 203 c | 0.61 c | 1.54 d | 0.84 d |
| Reforestation | 543 b | 182 c | 0.70 c | 1.41 e | 0.79 d |
| Rye | 690 a | 232 b | 0.61 c | 1.21 f | 0.84 d |
| Secondary forest | 750 a | 279 a | 1.35 a | 2.55 b | 1.44 b |
| CV % | 7.7 | 7.6 | 8.0 | 6.0 | 8.3 |

The same letters in the columns do not differ from each other by the Scott-Knott test at $p<0.05$.

Nunes et al., 2009). In natural ecosystems like forests, part of the labile P is cycled from organic P and the microbial community plays an essential role in this cycling (Balota & Chaves, 2010). Except for peach-palm and sugarcane soils, the activity of acid phosphatase was higher than that of alkaline phosphatase. Acid phosphatase has an optimum pH of 5.5 and was probably favored by acid conditions at most sites, whereas alkaline phosphatase has an optimum pH of 11 (Tabatabai & Bremner, 1969). As all soils were in an acid range, acid phosphatase showed greater sensitivity in discriminating the different types of soil use than alkaline phosphatase.

Higher contents of hot-water-soluble carbohydrates were also found in native and secondary forests, and the peach-palm crop. Carbohydrates in soil are important sources of energy for microorganisms (Insam, 1996) and represent the labile fraction of soil organic matter (Cambardella & Elliot, 1992). Thus, soils under plant cover, which results in more inputs of residues, have more soluble carbohydrates, contributing to the microbial community, which is in agreement with the greater microbial biomass and enzyme activities generally found in these three soils.

## Principal component analysis (PCA)

Considering the first axis of the factorial design, the soil under native and secondary forest showed more similarities to each other and held a position opposed to the other soils (Figure 1). The forest soils were associated with enzyme activities, except for dehydrogenase, in addition to greater microbial biomass and microbial activity, moisture and *q*Mic, suggesting more efficient cycling of C and nutrients. The association of soil moisture with microbial and biochemical properties are a consequence of greater water conservation in the sites that receive more inputs of organic C and that have a permanent plant cover (e.g., native and secondary forests) resulting in less water loss through evapotranspiration (Nogueira et al., 2006; Nunes et al., 2009; Pereira et al., 2013) and greater retention in the soil owing to higher levels of SOC.

The soils cropped with peach-palm and sugarcane, both of which are perennial crops producing residues with a higher C/N ratio, showed greater similarity, although the area with peach-palm held an intermediate position between the area of sugarcane and the areas under native and secondary forests. In spite of sugarcane management through burning, the roots contribute to inputs of residues with high C/N ratios. In these cases, the properties that most contributed to the similarity between sugarcane and peach-palm soils were WDC, pH and $q\text{CO}_2$. Likewise, soils under coffee, recent reforestation and annual crops also had more similarities to one another, especially in available P content, due to fertilization (Nunes et al., 2009), in contrast with the forest soils.

The factorial design also shows an inverse relationship between MBC and $q\text{CO}_2$, indicating that under unfavorable conditions, as in the sugarcane soil, the microbial community becomes less metabolically effective. Higher $q\text{CO}_2$ values in environments under stress indicate the predominance of *r*-strategist microorganisms, represented by few species, but with higher growth rates. In contrast, lower values of $q\text{CO}_2$ in balanced environments denote the prevalence of *K*-strategist microorganisms, represented by more diversity of species, but with lower growth rates (Odum, 1985; Anderson & Domsch, 1993). This alteration in the microbial community changes the way they act in cycling C and nutrients, as may be seen by the changes in the biological indicators according to the type of soil use.

## Soil quality index (SQI)

The available P and pH variables were not considered in ascertaining the SQI because they are directly affected by fertilizers and liming added to the

**Table 4. Activity of dehydrogenase, acid and alkaline phosphatases, and concentration of hot-water-soluble carbohydrates in a clay soil under different types of management and plant cover**

| Soil | Dehydrogenase[1] | Phosphatase | | Carbohydrate |
|---|---|---|---|---|
| | | Acid[2] | Alkaline | |
| | mg TFF $g^{-1}$ $d^{-1}$ | μg PNF $g^{-1}$ $h^{-1}$ | | μg glucose-eq. $g^{-1}$ |
| Native forest | 6.9 b | 589 a | 438 b | 732 a |
| Peach-palm | 9.4 a | 302 d | 321 c | 615 b |
| Sugarcane | 10.2 a | 242 e | 272 c | 340 c |
| Coffee | 4.2 c | 401 c | 290 c | 399 c |
| Reforestation | 3.9 c | 317 d | 262 c | 374 c |
| Rye | 3.5 c | 386 c | 263 c | 364 c |
| Secondary forest | 10.1 a | 493 b | 498 a | 691 a |
| CV % | 15.8 | 10.5 | 9.7 | 12.4 |

(1) TFF: triphenyl formazan; (2) PNF: *p*-nitrophenol. The same letters in the columns do not differ from each other by the Scott-Knott test at $p<0.05$.

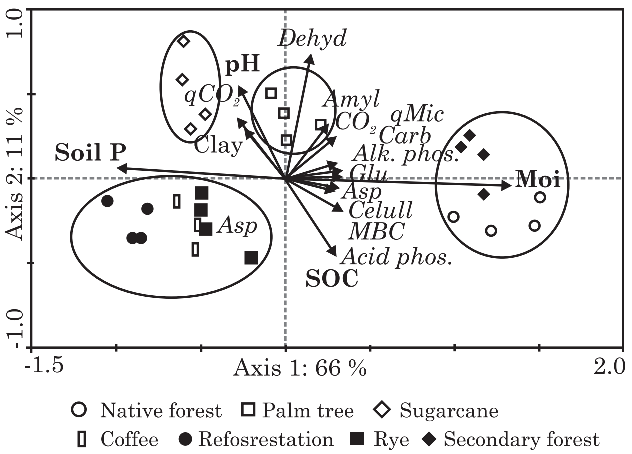

**Figure 1. Principal component analysis (PCA) based on chemical, microbiological and biochemical properties in a clay soil under different types of management and plant cover. Environmental, explanatory variables in bold print: Moi (soil moisture); pH (active acidity); Soil P (Mehlich-I available P); SOC (soil organic carbon); Clay (water-dispersible clay). Microbiological/ Biochemical variables: MBC (microbial biomass C); *q*$CO_2$ (metabolic quotient); *q*Mic (microbial quotient); $CO_2$ (basal respiration); Dehyd (dehydrogenase); Amyl (amylase); Glu (glutaminase); Alk. phos. (alkaline phosphatase); Acid phos. (acid phosphatase); Celull (cellulase); Asp (asparaginase); Carb (hot-water-soluble carbohydrates).**

cropped soils and are intrinsically associated with soil use and crop management. Dehydrogenase activity was also not considered because it may have a direct or inverse relationship to soil quality. For example, if the increase in activity is a consequence of greater microbial biomass, it has a direct relationship, but if the increase is due to metabolic stress imposed on the microbial community, resulting in increased *q*$CO_2$, it has an inverse relationship to soil quality (Bini et al., 2013). Thus, the SQI obtained from the 15 remaining properties showed that the secondary forest was the closest to the reference forest, followed by the peach-palm, coffee, and annual crop areas and, finally, the recent reforestation and sugarcane areas (Table 5). As previously discussed, these two soils have less favorable conditions for the microbial community, with limited organic residue inputs and soil turnover in the sugarcane area. It is important to highlight that the average SQI gives equal weight to all variables, which is not necessarily realistic (Burger & Kelting, 1999). However, the relatively high number of variables works as a "buffer" against any variable having a possible excessive effect on the index. Conversely, a variable that might be considered more important would be underestimated. Moreover, the indicators were not evaluated concerning their sensitivity in the face of a large range of environmental conditions (Velasquez et al., 2007). Despite these limitations, the average SQI allowed an overview of the quality of soils subjected to different types of farmland management. The same approach led to the

**Table 5. Relative values of physical, microbiological and biochemical soil quality indexes (SQI) in soils under different uses (2 to 7), based on the results obtained in the reference site (1), and the average SQI based on 15 indicators**

| Indicator | Soil use(1) | | | | | | | Relation to SQI |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| Moisture | 1.00 | 0.90 | 0.72 | 0.84 | 0.72 | 0.77 | 0.91 | Direct |
| SOC | 1.00 | 0.78 | 0.68 | 1.12 | 1.08 | 0.98 | 1.12 | Direct |
| MBC | 1.00 | 0.53 | 0.39 | 0.41 | 0.34 | 0.50 | 0.76 | Direct |
| *q*Mic | 1.00 | 0.68 | 0.58 | 0.37 | 0.32 | 0.51 | 0.68 | Direct |
| Basal respiration | 1.00 | 0.87 | 0.86 | 0.75 | 0.70 | 0.79 | 0.96 | Direct |
| Carbohydrate | 1.00 | 0.84 | 0.46 | 0.54 | 0.51 | 0.50 | 0.94 | Direct |
| *q*$CO_2$ | 1.00 | 0.60 | 0.44 | 0.54 | 0.47 | 0.59 | 0.78 | Inverse |
| Amylase | 1.00 | 0.96 | 0.89 | 0.85 | 0.72 | 0.92 | 1.00 | Direct |
| Asparaginase | 1.00 | 0.59 | 0.57 | 0.60 | 0.69 | 0.60 | 1.32 | Direct |
| Cellulase | 1.00 | 0.85 | 0.73 | 0.77 | 0.69 | 0.88 | 1.06 | Direct |
| Acid phosphatase | 1.00 | 0.51 | 0.41 | 0.68 | 0.54 | 0.65 | 0.84 | Direct |
| Alk. phosphatase | 1.00 | 0.73 | 0.62 | 0.66 | 0.60 | 0.60 | 1.14 | Direct |
| Glutaminase | 1.00 | 0.62 | 0.54 | 0.55 | 0.50 | 0.43 | 0.91 | Direct |
| Urease | 1.00 | 0.34 | 0.35 | 0.27 | 0.25 | 0.27 | 0.46 | Direct |
| Dispersible clay | 1.00 | 0.61 | 0.56 | 0.65 | 0.68 | 0.63 | 0.50 | Inverse |
| Average SQI | 1.00 | 0.69 | 0.59 | 0.64 | 0.59 | 0.64 | 0.89 | - |

(1) 1: native fragment of Atlantic Forest, reference site; 2: peach-palm (*Bactrys gasipaes*); 3: sugarcane (*Saccharum officinarum*) ratoon, recently harvested and harrowed; 4: coffee (*Coffea arabica*) intercropped with trees; 5: recent reforestation (1yr) with native tree species in a site previously under annual crops; 6: annual crops under no-tillage, under rye (*Cecale cereale*); 7: secondary forest, regenerated after 20 years of abandonment of an avocado orchard (*Persea americana*).

conclusion that pasture in integration with soybean or corn had an SQI with greater similarity to the reference site than continuous pasture (Jakelaitis et al., 2008). Similarly, the SQI obtained in a secondary forest approximated that of the reference site, while coffee cropping showed more divergent indexes (Nunes et al., 2009). Clearly, a cropped soil will never have the same properties as a soil under native vegetation, but a general overall index tending toward the index of a reference site indicates an increase in the sustainability of the type of soil use.

## CONCLUSIONS

1. Plant covers that allow for more inputs of residues and less intensive or more conservationist soil use favor an increase in soil organic carbon, and microbial and enzyme activities.

2. More intensive soil use results in a higher metabolic quotient, suggesting more stressful conditions for the microbial community, resulting in lower activity of key enzymes for C, N, and P cycling.

3. Even after regeneration of the secondary forest for more than 20 years, the patterns of microbial biomass, enzyme activities, and clay dispersion are still not at the same level as the native vegetation taken as a reference.

4. The soil quality index allows a global view of soil quality under different types of use in relation to the reference soil under native forest.

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## LITERATURE CITED

ALEF, K. Soil respiration. In: ALEF, K. & NANNIPIERI, P., eds. Methods in applied soil microbiology and biochemistry. London, Academic Press, 1995. p.214-219.

ANDERSSON, M.; KJØLLER. A. & STRUWE, S. Microbial enzyme activities in leaf litter, humus and mineral soil layers of European forests. Soil Biol. Biochem., 36:1527-1537, 2004.

ANDERSON, T.H. & DOMSCH, K.H. The metabolic quotient from $CO_2$ ($qCO_2$) as a specific activity parameter to assess the effects of environmental conditions, such as pH, on the microbial biomass of forest soils. Soil Biol. Biochem., 25:393-395, 1993.

BALL, B.C.; CHESHIRE, M.V.; ROBERTSON, E.A.G. & HUNTER, E.A. Carbohydrate composition in relation to structural stability, compactability and plasticity of two soils in a long-term experiment. Soil Till. Res., 39:1647-1653, 1996.

BALOTA, E.L.; COLOZZI, A.F.; ANDRADE, S.D. & DICK, P.R. Microbial biomass in soils under different tillage and crop rotation systems. Biol. Fert. Soils, 38:15-20, 2003.

BALOTA, E.L.; COLOZZI, A.F.; ANDRADE, S.D. & DICK, P.R. Long-term tillage and crop rotation effects on microbial biomass and C and N mineralization in a Brazilian Oxisol. Soil Till. Res., 77:137-145, 2004.

BALOTA, E.L. & CHAVES, J.C.D. Enzymatic activity and mineralization of carbon and nitrogen in soil cultivated with coffee and green manures. R. Bras. Ci. Solo 34:1573-1583, 2010.

BINI, D.; SANTOS, C.A.; CARMO, K.B.; KISHINO, N.; ANDRADE, G.; ZANGARO, W. & NOGUEIRA, M.A. Effects of land use on soil organic carbon and microbial processes associated with soil health in southern Brazil. Eur. J. Soil Biol., 55:117-123, 2013.

BURGER, J.A. & KELTING, D.L. Using soil quality indicators to assess forest stand management. For. Ecol. Manage., 122:155-166, 1999.

CAMBARDELLA, C.A. & ELLIOT, E.T. Particulate soil organic matter changes across a grassland cultivation sequence. Soil Sci. Soc. Am. J., 56:777-783, 1992.

CARDOSO, E.J.B.N.; VASCONCELLOS, R.L.F.; BINI, D.; MIYAUCHI, M.Y.H.; SANTOS, C.A.; ALVES, P.R.L.; PAULA, A.M.; NAKATANI, A.S.; PEREIRA, J.M. & NOGUEIRA, M.A. Soil health: looking for suitable indicators. What should be considered to assess the effects of use and management on soil health? Sci. Agric., 70:280-295, 2013.

CARNEIRO, M.A.C.; SOUZA, E.D.; REIS, E.F.; PEREIRA, H.S. & AZEVEDO, W.R. Atributos físicos, químicos e biológicos de solo de Cerrado sob diferentes sistemas de uso e manejo. R. Bras. Ci. Solo, 33:147-157, 2009.

CASIDA JR., L.E.; KLEIN, D.A. & SANTORO, T. Soil dehydrogenase activity. Soil Sci., 98:371-376, 1964.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. Centro Nacional de Pesquisa de Solos. Manual de métodos de análise de solo. 2.ed. Rio de Janeiro, 1997. 212p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. Centro Nacional de Pesquisa de Solos. Sistema brasileiro de classificação de solos. Brasília, Produção de Informações, 1999. 412p.

FAGOTTI, D.S.L.; MIYAUCHI, M.Y.H.; OLIVEIRA, A.G.; SANTINONI, I.A.; EBERHARDT, D.N.; NIMTZ, A.; RIBEIRO, R.A.; PAULA, A.M.; QUEIROZ, C.A.S.; ANDRADE, G.; ZANGARO, W. & NOGUEIRA, M.A. Gradients in N-cycling attributes along different land-use systems are indicative of soil capacity for N supply. Soil Use Manage., 28:292-298, 2012.

FRANKENBERGER, W.T. & TABATABAI, M.A. Asparaginase activity of soils. Biol. Fert. Soils, 11:6-12, 1991.

INSAM, H. Microorganism and humus in soils. In: PICCOLO, A., ed. Humic substances in terrestrial ecosystems. Amsterdam, Elsevier, 1996. p.265-292,

JAKELAITIS, A.; SILVA, A.A.; SANTOS, J.B. & VIVIAN, R. Qualidade da camada superficial de solo sob mata, pastagens e áreas cultivadas. Pesq. Agropec. Trop., 38:118-127, 2008.

KASCHUK, G.; ALBERTON, O. & HUNGRIA, M. Three decades of soil microbial biomass studies in Brazilian ecosystems: lessons learned about soil quality and indications for improving sustainability. Soil Biol. Biochem., 42:1-13, 2010.

LEAL, R.M.P.; HERPIN, U.; FONSECA, A.F.; FIRME, L.P.; MONTES, C.R. & MELFI, A.J. Sodicity and salinity in a Brazil Oxisol cultivated with sugarcane irrigated with wastewater. Agric. Water Manage., 96:307-316, 2009.

LISBOA, B.B.; VARGAS, L.K.; SILVEIRA, A.O.; MARTINS, A.F. & SELBACH, P.A. Indicadores microbianos de qualidade do solo em diferentes sistemas de manejo. R. Bras. Ci. Solo, 36:45-55, 2012.

LOPES, M.M.; SALVIANO, A.A.C.; ARAUJO, A.S.F.; NUNES, L.A.P.L. & OLIVEIRA, M.E. Changes in soil microbial biomass and activity in different Brazilian pastures. Spanish J. Agric. Res., 8:1253-1259, 2010.

MURPHY, J. & RILEY, J.P. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta, 27:31-36, 1962.

NAYAK, D.R.; BABU, Y.J. & ADHYA, T.K. Long-term application of compost influences microbial biomass and enzyme activities in a tropical Aeric Endoaquept planted to rice under flooded condition. Soil Biol. Biochem., 39:1897-1906, 2007.

NOGUEIRA, M.A.; ALBINO, U.B.; BRANDÃO-JÚDIOR, O.; BRAUN, G.; CRUZ, M.F.; DIAS, B.A.; DUARTE, R.T.D.; GIOPPO, N.M.R.; MENNA, P.; ORLANDI, J.M.; RAIMAN, M.; RAMPAZO, L.G.L.; SANTOS, M.A.; SILVA, M.E.Z.; VIEIRA, F.P.; TOREZAN, J.M.D.; HUNGRIA, M. & ANDRADE, G. Promising indicators for assessment of agroecosystems alteration among natural, reforested and agricultural land use in southern Brazil. Agric. Ecosyst. Environ., 115:237-247, 2006.

NUNES, L.A.P.L.; DIAS, L.E.; JUCKSCH, I.; BARROS, N.F.; KASUYA, M.C.M. & CORREIA, M.E.F. Impacto do monocultivo de café sobre os indicadores biológicos do solo na zona da mata mineira. Ci. Rural, 39:2.467-2.474, 2009.

ODUM, E.P. Trends expected in stressed ecosystems. BioSciences, 35:419-422, 1985.

PEDROTTI, A.; FERREIRA, M.M.; CURI, N.; SILVA, M.L.N.; LIMA, J.M. & CARVALHO, R. Relação entre atributos físicos, mineralogia da fração argila e formas de alumínio no solo. R. Bras. Ci. Solo, 27:1-9, 2003.

PEREIRA, J.M.; BARETTA, D.; BINI, D.; VASCONCELLOS, R.L.F. & CARDOSO. E.J.B.N. Relationships between microbial activity and soil physical and chemical properties in native and reforested *Araucaria angustifolia* forests in the State of São Paulo, Brazil. R. Bras. Ci. Solo, 37:572-586, 2013.

SANT'ANNA, S.A.C.; FERNANDES, M.F.; IVO, W.M.P.M. & COSTA, J.L.S. Evaluation of soil quality indicators in sugarcane management in sandy loam soil. Pedosphere, 19:312-322, 2009.

SCHINNER, F. & von MERSI, W. Xylanase-, CM-cellulase and invertase activity in soil: An improved method. Soil Biol. Biochem., 22:511-515, 1990.

SOIL SURVEY STAFF. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. Washington, USDA, 1999.

TABATABAI, M.A. Enzymes. In: WEAVER, R.W.; AUGLE, S.; BOTTOMLY, P.J.; BEZDICEK, D.; SMITH, S.; TABATABAI, A. & WOLLUM, A., eds. Methods of soil analysis. Part 2. Microbiological and biochemical properties. Madison, Soil Science Society of America, 1994. p.775-833.

TABATABAI, M.A. & BREMNER, J.M. Use of *p*-nitrofenol phosphate for assay of soil phosphatase activity. Soil Biol. Biochem., 1:301-307, 1969.

TABATABAI, M.A. & BREMNER, J.M. Assay of urease activity in soil. Soil Biol. Biochem., 4:479-487, 1972.

TARAFDAR, J.C. & JUNGK, A. Phosphatase activity in the rhizosphere and its relation to the depletion of soil organic phosphorus. Biol. Fert. Soils, 3:199-204, 1987.

TAVARES-FILHO, J. & MAGALHÃES, F.S. Dispersão de amostras de Latossolo Vermelho eutroférrico influenciadas por pré-tratamento para oxidação da matéria orgânica pelo tipo de agitação mecânica. R. Bras. Ci. Solo, 32:1429-1435, 2008.

TER BRAAK, C.J.F. & SMILAUER, P. CANOCO Reference manual and user´s guide to Canoco for Windows: Software for canonical community ordination (version 4). Microcomputer Power. New York, 1998.

VANCE, E.D.; BROOKES, P.C. & JENKINSON, D.S. An extraction method for measuring soil microbial biomass C. Soil Biol. Biochem., 19:703-707, 1987.

VELASQUEZ, E.; LAVELLE, P. & ANDRADE, M. GISQ, a multifunctional indicator of soil quality. Soil Biol. Biochem., 39:3066-3080, 2007.

YEOMANS, J.C. & BREMNER, J.M. A rapid and precise method for routine determination of organic carbon in soil. Commun. Soil Sci. Plant Anal., 19:1467-1476, 1988.