SOIL CARBON AND NITROGEN MINERALIZATION UNDER DIFFERENT TILLAGE SYSTEMS AND PERMANENT GROUNDCOVER CULTIVATION BETWEEN ORANGE TREES[1]

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ABSTRACT - The objective of this work was to evaluate the alterations in carbon and nitrogen mineralization due to different soil tillage systems and groundcover species for intercropped orange trees. The experiment was established in an Ultisol soil (Typic Paleudults) originated from Caiuá sandstone in northwestern of the state of Paraná, Brazil, in an area previously cultivated with pasture (*Brachiaria humidicola*). Two soil tillage systems were evaluated: conventional tillage (CT) in the entire area and strip tillage (ST) with a 2-m width, each with different groundcover vegetation management systems. The citrus cultivar utilized was the 'Pera' orange (*Citrus sinensis*) grafted onto a 'Rangpur' lime rootstock. The soil samples were collected at a 0-15-cm depth after five years of experiment development. Samples were collected from under the tree canopy and from the inter-row space after the following treatments: (1) CT and annual cover crop with the leguminous *Calopogonium mucunoides*; (2) CT and perennial cover crop with the leguminous peanut *Arachis pintoi*; (3) CT and evergreen cover crop with Bahiagrass *Paspalum notatum*; (4) CT and cover crop with spontaneous *B. humidicola* grass vegetation; and (5) ST and maintenance of the remaining grass (pasture) of *B. humidicola*. The soil tillage systems and different groundcover vegetation influenced the C and N mineralization, both under the tree canopy and in the inter-row space. The cultivation of *B. humidicola* under strip tillage provided higher potential mineralization than the other treatments in the inter-row space. Strip tillage increased the C and N mineralization compared to conventional tillage. The grass cultivation increased the C and N mineralization when compared to the others treatments cultivated in the inter-row space.

Index terms: Potential mineralization, soil management, vegetable cover, nutrient cycling.

MINERALIZAÇÃO DO CARBONO E NITROGÊNIO SOB DIFERENTES PREPAROS DE SOLO E COBERTURAS PERMANENTES INTERCALARES EM POMAR DE LARANJEIRA

RESUMO - No presente trabalho, foi avaliada a mineralização do Carbono e Nitrogênio devido ao cultivo intercalar de diferentes coberturas permanentes em pomar de laranjeira. O experimento foi conduzido no noroeste do Paraná, em um Argissolo Vermelho distrófico latossólico de textura arenosa/média originado do arenito Caiuá, em área previamente ocupada por pastagem (*Brachiaria humidicola*). Foram estudados dois sistemas de preparo do solo (preparo convencional [PC] e preparo em faixa [PF]) e diferentes coberturas intercalares em plantas de citros. Foi utilizada a laranja 'Pera' (*Citrus sinensis*) enxertada em limoeiro 'Cravo' (*Citrus limonia*). As amostras de solos foram coletadas cinco anos após a instalação do experimento, na profundidade de 0-15 cm, sob a projeção da copa e na entrelinha, nos seguintes tratamentos: (1) PC e cobertura vegetal com a leguminosa anual *Calopogonium mucunoides*; (2) PC e cobertura vegetal com a leguminosa perene amendoim-forrageiro *Arachis pintoi;* (3) PC e cobertura vegetal com gramínea mato-grosso ou batatais *Paspalum notatum*; (4) PC e cobertura com vegetação espontânea da gramínea *Brachiaria humidicola*; (5) PF e manutenção da gramínea remanescente da pastagem, *Brachiaria humidicola*. O preparo do solo e as diferentes coberturas vegetais influenciaram na mineralização do C e N tanto na projeção da copa como na entrelinha. O cultivo de *Brachiaria* sob preparo em faixa proporcionou aumento na mineralização do C e N na entrelinha, comparado aos outros tratamentos. O preparo em faixa aumentou a mineralização de C e N quando comparado ao preparo convencional. O cultivo de gramíneas aumentou a mineralização de C e N na entrelinha.

Termos para indexação: Mineralização potencial, manejo do solo, plantas de coberturas, ciclagem de nutrientes.

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INTRODUCTION

A great part of the orange orchards in the state of Paraná (about 50%) has been cultivated in soil originating from geological Caiuá sandstone, which has low clay content, low natural fertility and high water erosion potential. Because of these native soil characteristics, a common technical recommendation is to maintain the soil of the orange orchards using protection by groundcover vegetation, which can minimize soil erosion and enhance soil fertility (FIDALSKI et al., 2007; AULER et al., 2008). However, a large amount of Brazilian orange orchards have been planted using conventional tillage for limestone incorporation and for subsequent maintenance of a clean soil surface. This is often done because permanent intercropped vegetable cover could compete with the orange trees for soil water (CAETANO, 1980). However, the soil management systems of orange orchards that use the conventional systems that disturb the soil over the entire area (one disc plowing at a 20-cm depth and two light harrowing) before planting orange seedlings can favor the occurrence of erosive processes, particularly during the initial period of orchards formation (POLITANO; PISSARRA, 2005).

Several studies conducted in the same area of this experiment have shown the efficiency of superficial limestone used in undisturbed soil (FIDALSKI; TORMENA, 2005, AULER et al., 2008, FIDALSKI et al., 2008). These results have demonstrated that strip tillage treatment, in which the limestone is applied on the soil surface without incorporation, does not have negative effects on the soil's chemical properties (0-40 cm) or on the orchard's orange production (AULER et al., 2008).

The use of plants for covering inter-row space between perennial crops is one of the most efficient isolated practices for reducing soil erosion because it acts at the origin of erosive process. The crops reduce the energy of raindrops against the soil surface and help to avoid the soil particles' disaggregation, which in turn prevents greater water infiltration. Such crops also act to improve the soil's chemical, physical and biological characteristics (CHAVES et al., 1997; CORÁ et al., 2005). It is advisable then that plants used in this practice have rapid development capacity, have high biomass production per unit area, have high nutrient content, be ramified, generate a robust and deep root system, exhibit a high capacity to mobilize soil nutrients and have the capacity for biological fixation of N_2. These characteristics allow for the important protection of the superficial soil layer and provide for extraction and mobilization of nutrients from deep soil layers.

Different plant species can affect soil properties in different ways due to variation in their quantity and quality (e.g., C/N ratio and other compounds), which may affect soil organic matter content, microbial activity and nutrient turnover. These changes alter the potential for the soil to supply or to sequester nutrients due to changes in mineralization and immobilization (FRANZLUEBBERS et al., 1995). Therefore, residue decomposition is an important driving variable in the nutrient cycling processes.

Soil microbiota is responsible for nutrient mineralization through organic matter decomposition. Microbial biomass represents only 5% of soil organic matter, but it is an important reservoir of soil nutrients because many transformations of these nutrients occur in the microbial biomass (DICK, 1992). Additionally, the nutrients released from microbial cells turn over five times faster than those from soil vegetable residue decomposition (PAUL; CLARK, 1996).

Therefore, soil management (tillage and groundcover species cultivation) has great effects on a soil's chemical, physical and biological properties and on an orange plant's growth and nutrition patterns. Better knowledge of the dynamics of microbial activity and soil nutrient mineralization from plant residues cultivated between orange trees is essential for quantification of the potential benefits for soil quality and crop production.

The objective of this work was to evaluate soil C and N mineralization due to different soil tillage systems and species of groundcover cultivated between rows of orange trees.

MATERIAL AND METHODS

Experimental characteristics and soil sampling

The experiment was established in 1993 at Alto Paraná in the northwestern of the state of Paraná (23° 05' S, 52° 26' W) under sandy Ultisol soil classified as Typic Paleudults or Argissolo Vermelho distrófico latossólico, according to Brazilian soil classification (BHERING; SANTOS, 2008) that originated from Caiuá sandstone. The soil consisted of 90% sand, 2% silt and 8% clay, with pH = 3.9 ($CaCl_2$), 1.9 mg kg^{-1} of P (Mehlich-1) and 3.7 g kg^{-1} of organic carbon (WALKLEY; BLACK) in the surface layer (0-15 cm). The chemical analyses were conducted according to Pavan et al. (1992). The experiment utilized a randomized complete block as the experimental design, consisted of three replicates and was installed in an area previously cultivated with pasture (*Brachiaria humidicola)*. Each parcel was composed of 15 orange plants, arrayed in three planting lines with five plants. The plants to be studied were the three trees located at the center of each parcel.

Two soil tillage systems were evaluated, conventional tillage (CT) in the entire area and strip tillage (ST) with a 2 m width, in combination with different groundcover vegetation management systems. The citrus cultivar utilized was the ‘Pera’ orange (*Citrus sinensis*) grafted onto the ‘Rangpur’ lime rootstock. The soil CT systems were prepared through one disc plowing at a 20 cm depth followed by two light harrowing steps for the planting of the orange seedlings. The ST system consisted of soil preparation in a 2 m strip without disturbing the remaining area (5 m). The orange tree line was placed in the center of the strip tillage. In ST system, just 30% of the soil was disturbed, leaving 70% of the area without disturbance and with natural vegetation covering. Before the soil preparation, two tons of dolomitic limestone per hectare was applied over the total area. From 1996 to 1998 3.0 tons of a mix of dolomitic and calcitic (1:1) limestone were added to the area without incorporation each year under the tree canopy. Similarly, 1.5 tons were added in the inter-row space. Annually, from September to March, mineral fertilizers (NPK) were applied under the tree canopy of the orange plants. The fertilizer was applied at a rate of 140 kg ha^{-1} of N, 50 kg ha^{-1} of P_2O_5 and 110 kg ha^{-1} of K_2O, as ammonium sulfate, simple superphosphate and potassium chloride were used, respectively. The N was parceled out four times, the K was applied twice and the P was applied in one dose.

This experiment examined several treatments including (1) CT and annual cover crop with the leguminous *Calopogonium mucunoides*, (2) CT and perennial cover crop with the leguminous peanut *Arachis pintoi* (Krap & Greg), (3) CT and evergreen cover crop with Bahiagrass *Paspalum notatum* (Flügge), (4) CT and cover crop with spontaneous *Brachiaria humidicola* grass vegetation and (5) ST and maintenance of the remaining grass (pasture) of *Brachiaria humidicola*. The groundcover vegetation was controlled using a mower whenever necessary. Additional information about the experimental procedures can be found in Fidalski et al. (2007) and Auler et al. (2008).

Five sub-samples of soil were taken from 0-15 cm depth within each replicate from the area under the tree canopy and from the center of the inter-row space. Samples were taken in two seasons, in the summer (March) and in the spring (October) from 1997 to 1998, fourth and fifth year from the beginning of the experiment. The fresh soil samples were sieved through a 4 mm screen with the large plant material removed and then stored at 4°C until analysis for microbial and chemical characteristics.

C and N mineralization

Mineralization of C was determined in each soil sample through incubation of 30 g moist soil in a 350 mL sealed jar in the presence of an NaOH trap, with water in a separate vessel to maintain high humidity, for 3, 6, 10, 17 and 24 days at 30°C in a dark chamber. At each sampling period, NaOH was collected and replaced. The concentration of CO_2 released in each period was determined by Flow Injection Analysis (KAWAZAKI et al., 2000) and the result was presented as the total of C mineralized in the period of 24 days of incubation.

Nitrogen mineralization was determined from 24-day incubation at 30°C of 5 g of moist soil. An initial 5 g sample, before the incubation, and the incubated soil were extracted with 20 mL of K_2SO_4 solution (0.25 M) by shaking for 50 minutes at 220 rpm, followed by centrifuging and filtering. The concentration of nitrate was determined by the procedure as described in Balota et al. (2004). The mineralized N was calculated from the difference between nitrate concentration before and after the incubation.

The ratio of C mineralization (C_{MIN}) to organic C (C_{org}) or to microbial biomass C (MBC) and the ratio of N mineralization (N_{MIN}) to microbial biomass N (MBN) were calculated. The microbial biomass was determined using a fumigation-extraction method for C (VANCE et al., 1987) and for N (BROOKES et al., 1985).

All determinations were made in triplicate and expressed on a dry weight basis. Within each treatment, data were averaged over the four seasons before statistical analysis by ANOVA to determine effects of groundcover cultivation and sample position on soil properties. Treatment effects were statistically evaluated by analysis of variance using Tukey’s test for mean comparison at $P \leq 0.05$. The relationships between soil microbial biomass and chemical properties were analyzed by the Pearson correlation coefficient (r). All statistical analyses were performed using the SAS statistical package version 9th (SAS, 2002).

RESULTS AND DISCUSSION

Chemical Properties

The chemical properties of the soils after five years of experimentation due to different groundcover and soil tillage systems are shown in Table 1. The pH under the tree canopy was lower than in the inter-row space. The higher acidification under the orange tree canopy is due to various factors, including the high quantity of fertilizer applied, nutrient leaching, and the orange tree capacity to uptake high amount of nutrients. Besides the soil samples were taken near the edge of the tree canopy, at the site of the fertilizers application, where the acidification processes is greater. The cultivation of groundcover between the orange trees influenced in a differentiated way the soil acidification, as was previously observed with other cover crops (MIYAZAWA et al., 1992; MEDA et al., 2001). The organic matter addition to the soil may contribute to the reduction of organic anion losses in the system and to an increase in the H^+ consumption. The low Al saturation in the inter-row area can be attributed to the pH increase, which reduces the Al solubility through Al complexation with organic compounds (MIYAZAWA et al., 1992; MEDA et al., 2001). Several plants have the capacity to alleviate the soil acidity through water-soluble plant organic compounds (MEDA et al., 2001). This chemical change is associated with the concentrations of basic cations in the plant extract: the higher the concentration the greater the effects in alleviating soil acidity.

The soil P concentration was higher under the tree canopy than in the inter-row space. The P available accumulated over time under the tree canopy because the P fertilizer is applied in the soil surface in this site without mechanical incorporation. However, in the center of inter-row space there was also an alteration in the available P content compared to initial content (1.9 mg kg^{-1}). This P content change over time in the inter-row space may have occurred due to the P cycle through P redistribution into the undisturbed soil by different permanent groundcovers, as observed by using green manure.

Carbon and Nitrogen Mineralization

The carbon mineralization (C_{MIN}) during the 24 days of incubation varied from 53 to 172 μg CO_2-C g^{-1} under the tree canopy and from 100 to 208 μg CO_2-C g^{-1} in the inter-row space (Table 2). ST-*Brachiaria* provided higher C_{MIN} than other groundcover species, both under tree canopy and inter-row space. The increase compared to CT-*Arachis* was up to 225% and 108%, respectively under tree canopy and inter-row space.

The C_{MIN} varied widely from 10 μg C g^{-1} d^{-1} (FRANZLUEBBERS et al., 1995) to 222 μg C g^{-1} d^{-1} (CARTER; RENNIE, 1982) in temperate climates and from 0.75 to 7.1 μg C g^{-1} d^{-1} in subtropical Brazilian conditions (BALOTA et al., 2004; BALOTA; CHAVES, 2009). The C_{MIN} obtained in this study was similar to that observed in another region of the state of Paraná under different soil tillage systems in clayey soil with high natural fertility (BALOTA et al., 2004) and it is also around 4.0 times higher than that observed when using different leguminous plants as green manure for a coffee crop in sandy soil with low natural fertility (BALOTA; CHAVES, 2009). This wide variation may be due to various factors including soils, plants, climate, and experimental conditions. Soil factors include soil temperature, soil aeration, and available nutrients. Plant factors include age, quantity of biomass, C/N ratio and other compounds in plant residues. The decomposition rate is slower with higher C/N ratios and greater lignin content. Using decomposition rate, the crops can group into two classes, the leguminous plants with fast decomposition (C/N below 25) and the grasses with slow decomposition (C/N above 25). However the higher C_{MIN} and N_{MIN} under ST-*Brachiaria* may be due to greater amount of plant residues produced and other compounds as exudates which stimulated the microbial activity.

Another important fact is that mineralization studies conducted under laboratory conditions do not reflect orange crop field conditions, which have minimal soil disturbance. The disturbance of sampling and processing has exposed the protected soil organic matter pool, stimulating C mineralization. While under field conditions, the groundcover residues remain on the soil surface, which may have slowed their decomposition rates.

The large variation in C_{MIN} due to various treatments demonstrates that groundcover species cultivation changes the soil's levels of accumulated labile organic C. Our results agree with previous studies (CARTER; RENNIE, 1982; FRANZLUEBBERS et al. 1995; BALOTA et al., 2004) that demonstrate the responsiveness of soil organic matter quality (potential C mineralization) to changes in soil management practices.

The nitrogen mineralization (N_{MIN}) over 24 days varied from 7.1 to 11.6 μg NO_3^--N g^{-1} in the soil under the tree canopy and from 8.3 to 18.3 μg NO_3^--N g^{-1} in the inter-row space (Table 2). ST-*Brachiaria* provided higher N_{MIN} compared to CT-*Arachis*, representing an increase of 68% under tree canopy and an increase around 110% in the inter-row space. Greater N_{MIN} variation due to soil management has been observed by various authors. FRANZLUEBBERS et al. (1995) observed values ranging from 4.8 to 24.0 μg g^{-1} of N ($NH_4^+ + NO_3^-$) in temperate climates, while under subtropical conditions Balota et al. (2004) observed values from 1.2 to 5.2 μg N-NO_3^- g^{-1} in clayey soil with high natural fertility under different soil tillage systems. Balota e Chaves (2009) observed N_{MIN} from 1.8 to 18.3 μg N-NO_3^- g^{-1} under different leguminous plants used as green manure for coffee crops in sandy soil with low natural fertility. All of these studies used 24-day incubation.

Therefore, greater potential N_{MIN} under *Brachiaria* cultivation was probably due to the larger organic N pool. However, the groundcover residues were left on the soil surface after cutting. It has been suggested that when residue is left on the soil surface, the nitrification can be inhibited due to the presence of the organic matter. Additionally, N may accumulate at or near the soil surface and restrict N-mineralization (BLEVINS; FRYE, 1993).

It has been suggested that a considerable portion of the N available for plant uptake comes from soil microbial biomass turnover (SMITH; PAUL, 1990). This process can supply of nutrients the plants during critical periods. Nitrogen flux through soil microbial biomass can be sufficient to supply at least part of a crop's demand. However, the uptake of the nutrients released for orange plants through groundcover residue decomposition depends on the synchrony between the nutrient release and the orange tree requirements.

Mineralization of N from soil organic matter can provide a useful integration of chemical, physical and biological aspects of soil health because it combines the accumulation of N through previous biological activity, the present organic matter status of the soil and the current N mineralization activity of soil microorganisms (SPARLING, 1997).

On average in the inter-row space, the *Brachiaria* presented 64% larger N_{MIN} than legumes (*Calopogonium* and *Arachis*) despite evidence that *B. humidicola* root exudates reduce nitrification in soils (IPINMOROTI et al., 2008). This effect is denoted as biological nitrification inhibition (BNI) and occurs due to Brachiaria exudates' ability to block both the Ammonia Monoxygenase (AMO) and the Hydroxylamino Oxidoreductase (HAO) enzymatic pathways of *Nitrossomonas* during the nitrification process. The *B. humidicola* root system is very active and releases root exudates with high BNI, which may be affected by soil biotic and abiotic factors. This suppressive effect on nitrification (BNI) would enhance N use efficiency of applied N fertilizers, thereby reducing environmental pollution by leaching and erosion losses into underground water. However, as discussed previously, the disturbance of sampling and the methodology process for determining soil mineralization may alter the soil equilibrium, which may hide BNI effects.

The increase of soil C and N mineralization can be due to the large amount of plant residue produced by groundcover species. In general the production of total biomass by different groundcovers is about 4 ton ha^{-1} $year^{-1}$ for *Arachis pintoi* and *Calopogonium mucunoides*, 7 ton ha^{-1} $year^{-1}$ for Bahiagrass and 15 ton ha^{-1} $year^{-1}$ for *B. humidicola* (VILELA, 2010). However, the biomass production by these groundcovers has great variation due to biotic and abiotic conditions. For example, the *Arachis pintoi* can produces up to 10 ton ha^{-1} $year^{-1}$ (PERIN et al., 2003), while the *B. humidicola* has the capacity to produce more than 35 ton ha^{-1} of dry matter biomass with application of 120 kg ha^{-1} of N (ORIOLI, 2008).

Another fact is that a large amount of the roots produced recycles annually. The total root biomass of *Arachis pintoi* at the 30 cm layer is more than 17 t ha^{-1} of dry matter (VALENTIN et al., 2001). For *B. humidicola,* it has been observed that 60% of the root system is concentrated in the first 20 cm depth, which represented 2.8 ton ha^{-1} and 5.4 ton ha^{-1} of root dry matter, respectively, in sites with one and seven years of cultivation (SÉRGIO et al., 2007). On average the grass cultivation increased the potential mineralization compared to leguminous cultivation, with 28% for C_{MIN} and 79% for N_{MIN} under the inter-row space.

Soil is an important sink for the carbon storage as soil organic matter because soil contains three times more C than the vegetation and twice as much as the atmosphere (KUMAR et al., 2006). Additionally, organic matter is fundamental for improving the quality of the soil. The majority of studies have considered only the contribution of above-ground biomass for carbon input into the soil. However, the root systems contribute to input of several kinds of carbon into the soil: alive and dead roots, roots exudates and carbon dioxide (both from root respiration and from symbiotic microorganisms with roots). In general, from 30 to 80% of net fixed carbon is transferred to roots. Of the total C transferred to root, between 23 and 80% is lost to respiration and rhizodeposition in the soil (WHIPPS, 1990).

The exudates released by roots have almost all of the chemical components of the plant and can be classified into four different groups: water-soluble exudates (sugar, amino acids, organic acids, hormones and vitamins), secretions (polymeric carbohydrates and enzymes), lysates (cell autolyse, cell walls) and gases (ethylene and CO_2) (WHIPPS, 1990). More than 200 carbon compounds are released from plants roots as exudates (KUMAR et al., 2006), which may vary due to plant species, physiological conditions (age, nutrient status) and abiotic conditions (temperature, soil structure, aeration, water content). Exudates can also be a major source of substrate for soil microorganisms. These compounds can be utilized by microorganisms immediately, increasing significantly the diversity, number and activity of microorganisms in the rhizosphere. It has been accounted that nearly 5 to 21% of all photosynthetically fixed carbon is transferred to the rhizosphere through root exudates, which range from 20 to 50% of plant biomass (KUMAR et al., 2006).

The ratio of C mineralized to organic C (C_{MIN}/C_{org}) ranged from 1.9% to 3.3% (Table 3). In the literature, the C_{MIN}/C_{org} ratio varies widely, from 0.2% (FRANZLUEBBERS et al. 1995) to 3.6% (CARTER; RENNIE, 1982). The ratio of C mineralized to microbial biomass C (C_{MIN}/MBC) was from 41% to 64% under the tree canopy and from 36 to 51% in the inter-row space, while the C_{MIN}/MBC ratio in the literature ranges from 48% (FRANZLUEBBERS et al., 1995) to 74% (CARTER; RENNIE, 1982) if considered 24 days of incubation. The ratio of N mineralized to microbial biomass N (N_{MIN}/MBN) was from 31% to 43% under the tree canopy and from 41 to 71% in the inter-row space, while the N_{MIN}/MBN ratio in the literature ranges from 6.9% (BALOTA et al., 2004) to 36.0% (SING; SINGH, 1995).

The results obtained in this study with the large variation of C and N mineralization show clearly that soil management causes different decomposition rates of organic matter, probably due to effects on microbial biomass and its activity. Therefore, determination of the dynamic of C and N mineralization of different groundcover residues is important to adopt appropriate strategies for soil sustainability.

The ST-*Brachiaria* treatment presented an increase of 52% for C_{MIN} and 22% for N_{MIN} compared to CT-*Brachiaria* in the inter-row space, which is evidence that the decrease soil disturbance (strip tillage) can improve microbial activity (Table 2). Conventional tillage (CT), which disturbs the soil to prepare the land, increase soil organic matter oxidation and reduce the soil structure with consequent reduction of soil organic matter. Additionally, the modifications in soil habitat due to soil disturbance provide for a significant decrease in the microbial community (SPARLING, 1997). On the other hand, the lack of soil disturbance (Strip Tillage - ST) can provide a steady source of organic C to support higher microbial activity than CT system (Tabela 1). Smaller soil disturbance also favors formation and stabilization of macroaggregates to improve and protect habitat for microbiota (POWLSON; JENKINSON, 1981; BEARE et al., 1994), thus improving soil quality.

The results obtained in this study are in agreement with other observations of the efficiency of strip tillage systems in orange orchards. The great part of soil in orange orchards has been managed with soil disturbance (conventional tillage) during orchard establishment and with subsequent maintenance of a clean soil surface. Traditionally, soil disturbance methods have been employed because of the incorrect idea that soil disturbance is indispensable for limestone incorporation at the orchard's establishment and that the orange orchard must have a clean soil surface because permanent intercropped vegetable cover compete with the orange tree for soil water. However, results obtained in the same area (FIDALSKI; TORMENA, 2005; AULER et al., 2008; FIDALSKI et al., 2008) have shown the efficiency of superficial limestone use on undisturbed soil (without incorporation). Strip tillage does not have negative effects on soil chemical properties at 0-40 cm depth (FIDALSKI ; TORMENA, 2005) nor on orange production (AULER et al., 2008). The results also indicated that the permanent vegetable cover crop between orange trees does not compete for soil water (FIDALSKI et al., 2008) nor decrease the fruit production (AULER et al., 2008). These results correct some wrong concepts held regarding to soil management for orange crops, and they reinforce previous suggestions that the soil management system which uses vegetable cover between orange trees may provide a positive influence on orchard productivity and longevity (NEVES; DECHEN, 2001).

C/N mineralization ratio

The C/N mineralization ratio varied from 7.5 to 14.9 under the tree canopy and from 9.2 to 16.4 in the inter-row space (Table 2). Changes in the C/N mineralization ratio demonstrate the effects due to soil management. ST-*Brachiaria* and CT-*Calopogonium* presented almost 90% higher C/N mineralization than CT-*Arachis* under the tree canopy, while in the inter-row space, CT-*Calopogonium* increased C/N mineralization around 78% compared to CT-*Brachiaria*.

Wider C/N mineralization ratios may suggest that microbial populations are using organic matter with wide C/N ratios, while lower C/N mineralization ratios can suggest that the flow of C and N through the mineralizable fraction has become less stable, which may decrease conservation of C and N in the long term (FRANZLUEBBERS; ARSHAD, 1996).

However, our results showed that the cultivation of CT-*Brachiaria* provided a lower C/N mineralization ratio compared with other treatments, while organic C increased up to 27% under the tree canopy and 43% in the inter-row space when compared to the initial content (3.7 g kg^{-1}). Under other treatments, organic C increased up to 46% under the tree canopy and 70% in the inter-row space after five years of groundcover cultivation between orange trees.

The C/N mineralization ratio can be used as an index of labile substrate availability. C/N mineralization ratios greater than 25 may indicate that the crop residues and the resulting soil organic matter fractions are low in concentrations of N (FRANZLUEBBERS; ARSHAD, 1996). Wider C/N mineralization ratios may indicate a N limitation for heterotrophic microbes, with greater potential for N immobilization. The variation of C/N mineralization ratios obtained in this study is narrow, from 7.5 to 16.4, reflecting the low variation of the C/N content of the groundcover species, ranging from 19.3 in *Arachis pintoi*, to 21.6 in *Calopogonium* and to 34.0 in *Brachiaria*. In general, C/N ratios below 30 do not affect microbial activity. Furthermore, the mineralization ratio is highly influenced by other residues characteristics, such as polyphenolics, lignin and cellulose, as well the relationship between them (TIAN et al., 1992).

The groundcover species used in this experiment have a range of lignin contents. According to the literature, lignin content is 13.9% for *Arachis pintoi*, 13.3% for *Calopogonium* and 11.5% for *B. humidicola* (MONTEIRO et al., 2002). However, the lignin content may vary considerably with plant maturity. In the flowering period, leguminous plants present higher nutrient content and lower lignin content. For example, N content in *Crotalaria* (sunnhemp) plants can decrease from around 3% at flowering to 1% in the mature plant, while lignin increases from 6 to 18% (GILLER, 2001) during the same period.

The plant's polyphenol content can also affect the residue decomposition because polyphenols may form a complex with proteins, thus reducing N availability to microorganisms (MONTEIRO et al., 2002). Although they belong to different groups (leguminous or grass) the polyphenol content is 2.1% for *Arachis pintoi* and 1.2% for *B. humidicola* (MONTEIRO et al., 2002). However, the polyphenol content can present wider variation within the same group, as observed in several legumes. Polyphenol content varied from 1.8 - 4.0% in several legumes (*Desmodium ovalifolium*, *Cajanus cajan*, *Calopogonium mucunoides*, *Centrosema pubescens*, *Mucuna sativa*) to 7.1% in *Leucaena leucocephala* (MONTEIRO et al., 2002). Additionally, the polyphenol content can vary widely with the season, as observed in *Arachis pintoi* which has a polyphenol content of 15.5% in the dry season (April 1997) and 32.5% in the rainy season (January) (ESPINDOLA, 2001).

Correlation

Simple correlations across all treatments and sample positions showed that there was high correlation between C_{MIN} and N_{MIN} (r=0.78*) as well both with organic C (r=0.78* and r=0.87*, respectively) and microbial biomass carbon (MBC) (r=0.84* and r=0.91*, respectively) (Table 4). The higher correlation between C_{MIN} with MBC and C_{MIN} with C_{mic}/C_{org} ratio (r=0.82*) is evidence that microbial biomass and the C_{mic}:C_{org} ratio play a more important role in C_{MIN} than simply organic C content. This result also evidence that soil C and N cycles are intimately related through the processes of mineralization and immobilization, suggesting a strong relationship that may exist between soil N transformations and soil C-CO_2 flux. The C_{MIN} and N_{MIN} also presented high correlations with soil enzyme activities, pH and base saturation. There was a high correlation between C_{MIN} and N_{MIN} with soil enzyme activity, which is evident the importance and the direct role of the microbial activity in the mineralization process.

The results demonstrate that utilization of groundcover species intercropped with orange trees can contribute to enhance soil quality. This contribution occurs due to a high amount of biomass produced, which promotes the recycling of soil nutrients. Benefits are also due to the groundcover's capacity to add N to the soil system through biological N_2-fixation (by symbioses or no-symbioses), which contribute an expressive amount of nitrogen to the soil-plant system (GILLER, 2001). Under tropical conditions in the state of Rio de Janeiro, the leguminous *Arachis pintoi* produced up to 10 ton ha per year of dry biomass with around 286 kg ha^{-1} $year^{-1}$ of N and 19 kg ha^{-1} $year^{-1}$ of P over a two-year experiment period (PERIN et al., 2003). When this leguminous plant is cultivated alone, 91% of the total N is from biological N_2-fixation (BNF), but when cultivated in association with a banana tree, the BNF contributed around 61% (ESPINDOLA, 2001). So the contribution of BNF with *A. pintoi* cultivation may vary from 150 to 260 kg ha^{-1} $year^{-1}$ of N. These results are evidence that the use of *A. pintoi* as groundcover has high potential to supply a great part of the N need by the system. *Calopogonium* produced around 5.6 ton ha^{-1} of dry matter at 145 days after sowing (GUERRA; TEIXEIRA, 1997), which can add about

121 kg ha^{-1} of N and 6.7 kg ha^{-1} of P. Around 70% of the N accumulated in *Calopogonium* is from BNF (GILLER, 2001), contributing roughly 85 kg ha^{-1}. The Bahiagrass (*Paspalum notatum*), which has *Azobacter paspali* a BNF bacteria in its rhizosphere, was estimated to gain up to 25% of its N from biological N_2-fixation, which translates to around 20 kg ha^{-1} (BODDEY et al., 1983; GILLER, 2001). While it has also been observed that considerable amount of accumulated N in plant of *B. humidicola* (39%) was from biological N_2-fixation (SILVA et al., 2010; GILLER, 2001).

The improvement of N content in the soil through biological N_2-fixation by groundcover species is particularly important in tropical soils, which have low natural fertility and high organic matter decomposition ratios. When the soil-plant system is considered, groundcover cultivation between orange rows may introduce a significant amount of N derived from biological N_2-fixation. This amount would be enough to balance the N exported by the orange fruit. This practice may contribute to the increase of N in the soil, allowing for reductions in mineral fertilization. The usefulness of legumes or grasses in maintaining or in building up soil fertility has been recognized by several authors. The intercropping of groundcover can benefit the orange crop via a large amount of shoot and root residue, which can release a high amounts of nutrients through excretion of roots exudates and through biological N_2 fixing.

The results obtained in this study confirm previous observations that demonstrate the responsiveness of soil mineralization potential to changes in soil management practices (CARTER; RENNIE, 1982; FRANZLUEBBERS et al., 1995; FRANZLUEBBERS; ARSHAD, 1996; BALOTA et al., 2004). Therefore, the long-term groundcover species cultivation, which has different rooting abilities and plant biomass productivities, may provide slight but progressive increases in soil quality.

TABLE 1 - Soil chemical properties (0-15 cm depth) after a five year period of cropping with permanent groundcover species between the orange trees. Average of twelve replications[1].

Treatment	pH	Al saturation (%)	P mg kg^{-1}	C_{org} g kg^{-1}
Tree Canopy				
CT - *Calopogonium*	3.9 a	36.5 bc	28.6 b	5.4 a
CT - *Arachis pintoi*	3.9 a	46.0 a	35.2 b	4.5 a
CT - Bahiagrass	3.8 a	39.2 b	68.7 a	4.7 a
CT - Brachiaria	3.8 a	40.8 b	69.6 a	4.7 a
ST - Brachiaria	4.0 a	34.0 c	66.9 a	5.3 a
Inter-Row Space				
CT - *Calopogonium*	4.7 ab	2.7	3.1 a	4.8 b
CT - *Arachis pintoi*	4.6 b	3.6	3.1 a	5.1 b
CT - Bahiagrass	4.8 ab	1.8	4.6 a	5.6 ab
CT - Brachiaria	4.7 ab	3.9	2.6 a	5.3 b
ST - Brachiaria	5.1 a	0.0	2.6 a	6.3 a

[1] pH: $CaCl_2$ 0.01 M; P: Mehlich. CT: Conventional tillage; ST: Strip tillage. Means followed by a different lower case letter within a column of the same sample position are significantly different by the Tukey test ($P \leq 0.05$).

TABLE 2 - C and N mineralization during 24 days and the C/N mineralization ratio under the tree canopy and in the inter-row space, as affected by different permanent groundcover crops.

Treatment[1]	C_{MIN} µg C-CO_2 g^{-1}	N_{MIN} µg N-NO_3 g^{-1}	C_{MIN}/N_{MIN}
Tree Canopy			
CT - *Calopogonium*	137 b	10.5 ab	13.0 ab
CT - *Arachis pintoi*	53 c	7.1 c	7.5 c
CT - Bahiagrass	118 b	9.0 bc	13.1 ab
CT - Brachiaria	121 b	11.1 a	10.9 b
ST - Brachiaria	172 a	11.6 a	14.9 a
Inter-Row Space			
CT - *Calopogonium*	159 b	9.7 c	16.4 a
CT - *Arachis pintoi*	100 c	8.3 c	12.0 b
CT - Bahiagrass	153 b	14.9 b	10.3 bc
CT - Brachiaria	137 b	15.0 b	9.2 c
ST - Brachiaria	208 a	18.3 a	11.3 bc

[1] CT: Conventional tillage; ST: Strip tillage. Means followed by a different lower case letter within a column of the same sample position are significantly different by the Tukey test ($P \leq 0.05$).

TABLE 3 - The ratio of C mineralization (C_{MIN}) to organic C (C_{org}) or to microbial biomass C (MBC) and the ratio of N mineralization (N_{MIN}) to microbial biomass N (MBN) under the tree canopy and the inter-row space, as affected by different permanent groundcover crop.

Treatment[1]	C_{MIN}/C_{org}	C_{MIN}/MBC	N_{MIN}/MBN
	%		
Tree Canopy			
CT - *Calopogonium*	2.5 b	45.9 bc	30.9 b
CT - *Arachis pintoi*	1.9 c	40.7 c	39.3 ab
CT - Bahiagrass	2.5 b	53.7 b	42.7 a
CT - Brachiaria	2.9 ab	48.5 bc	32.6 b
ST - Brachiaria	3.3 a	64.4 a	40.0 ab
Inter-Row Space			
CT - *Calopogonium*	3.3 a	50.5 a	41.0 c
CT - *Arachis pintoi*	2.0 c	35.8 b	46.9 c
CT - Bahiagrass	2.7 b	39.8 b	70.6 a
CT - Brachiaria	2.6 b	38.1 b	56.9 b
ST - Brachiaria	3.3 a	42.3 b	63.2 ab

[1] CT: Conventional tillage; ST: Strip tillage. Means followed by a different lower case letter within a column of the same sample position are significantly different by the Tukey test ($P \leq 0.05$).

TABLE 4 - Simple correlations (r) between C and N mineralization, microbial and chemical properties across all treatments and sampling position.

Variables[1]	C_{MIN}	N_{MIN}
N_{MIN}	0.78*	
MBC	0.84*	0.91*
MBN	0.49	0.38
C_{mic}:C_{org}	0.82*	0.84*
Organic C	0.78*	0.87*
pH	0.55	0.67*
Al saturation	-0.50	-0.55
Ca	0.73*	0.56
Mg	0.57	0.67*
Base saturation	0.60	0.65
P Available	-0.22	-0.39

[1] pH: $CaCl_2$ 0.01M; Ca, Mg and Al: KCl M; Base saturation: Ca + Mg + K; P and K: Mehlich.

CONCLUSION

The groundcover species intercropped with orange trees influenced C and N mineralization, both under the tree canopy and in the inter-row space. The cultivation of *B. humidicola* under strip tillage provided higher mineralization than other treatments in the inter-row space. Strip tillage increased C and N mineralization compared to conventional tillage. Finally, the grass cultivation increased the C and N mineralization compared to legume cultivation in the inter-row space.

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