SILAS DE OLIVEIRA LAVARINI CALAZANS

NITROGÊNIO DO SOLO SOB VEGETAÇÃO NATIVA EM MINAS GERAIS: TEORES, ESTOQUES E MODELAGEM

LAVRAS – MG
2014

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Dissertação apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Ciência do Solo, área de concentração em Fertilidade do Solo e Nutrição de Plantas, para a obtenção do título de Mestre.

Orientador
Dr. Carlos Alberto Silva

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APROVADA em 22 de agosto de 2014.

Dr. Cleiton Antônio Nunes DCA/UFLA

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"A menos que modifiquemos a nossa maneira de pensar, não seremos capazes de resolver os problemas causados pela forma como nos acostumamos a ver o mundo."

Albert Einstein

RESUMO GERAL

Inventários florestais podem ser ferramentas importantes para o estudo dos ciclos de elementos como C e N, bem como para compreender os fatores ambientais que regulam seus níveis no sistema solo-planta. Quando os solos são amostrados também, esses inventários permitem identificar as áreas mais propensas ou frágeis em termos de armazenamento de N, que é fator chave para o sequestro de C na matriz solo. Este estudo foi realizado com o objetivo de inventariar os estoques de Ne seus fatores condicionantes em solos sob fragmentos florestais de Minas Gerais. Foram estudados os padrões de distribuição vertical de N nos perfis de solos e suas relações com os tipos de vegetação e fatores ambientais. Camadas superficiais (0-10, 10-20 e 20-40 cm) e subsuperficiais (40-60, 60-100 cm) foram amostradas em 319 parcelas experimentais alocadas em 36 fragmentos florestais, os quais incluíam Florestas Semideciduais, Deciduais e Ombrófilas, CampoCerrado, Cerradão e Cerrado *stricto sensu*. Os teores médios de N nos perfis do solo variaram de 0,12 a 7,54 g kg^{-1}. Os índices de estratificação (razão entre o teor médio de N na camada de 0-20 cm e o teor médio de N na camada de 20-100 cm) foram de 0,78 a 5,22 entre os solos amostrados, demonstrando grande variação entre os fragmentos florestais e em suas parcelas experimentais. O estoque total de N na camada de 0-100 cm de solo variou drasticamente (1,38 a 39,4 Mg ha^{-1}) entre os fragmentos investigados, com os maiores estoques sendo verificados em áreas de Floresta Ombrófila Montana. Altitude e teor de argila + silte correlacionaram-se positivamente com os estoques de N em solos florestais de Minas Gerais, apresentando melhores resultados que o teor de argila separadamente. Em áreas onde a altitude ultrapassa 1.500 m (florestas Ombrófilas Montanas), o efeito da temperatura em reduzir a taxa de decomposição da matéria orgânica do solo superou o efeito da argila + silte em proteger o N do solo. Finalmente, funções de pedotransferência, obtidas por regressão linear múltipla, permitiram estimar os teores de N para as diferentes camadas de solos florestais de Minas Gerais, com base em valores de altitude, profundidade média do solo, capacidade de troca de cátions a pH 7, teor de argila, argila + silte e matéria orgânica do solo.

Palavras-chave: Matéria orgânica do solo. Funções de Pedotransferência. Índice de estratificação. Solos florestais.

GENERAL ABSTRACT

Forest inventories can be important tools for the study of the cycles of elements such as C and N, as well as to understand the environmental factors that regulates their levels. When soils are also sampled, it allows the identification of more prone or fragile areas in terms of N storage, which is a key factor forsoil organic C sequestration. This study was carried out in order to inventory the stocks of N and its constraints in soils of forest fragments of Minas Gerais. It was studied the patterns of vertical distribution of N in soils profiles and their relationships with the vegetation types and the environmental factors. The upper(0-10, 10-20 e 20-40 cm) and subsoil layers(40-60, 60-100 cm), were sampled in 319 plots allocated into 36 forest fragments, that include Semideciduous, Deciduous and Rainforest forests, *CampoCerrado, Cerradão e Cerrado stricto sensu*. The average N contents in soil profiles are enclose in the range of0.12 and 7.54 g kg^{-1}.The stratification ratio (ratio between the mean N content at 0-20 cm and the mean N content at 20-100 cm) went from0.78 to 5.22 among the sampled soils, showing large vertical variation. Total N stock in the 0-100 cm soil layer varied dramatically (1.38 to 39.4 Mg ha^{-1}) among the fragments investigated, with the greatest stocks being verified at the montane rainforest areas. Altitude and clay + silt content correlated positively with the N stocks in forest soils of Minas Gerais, with better results than the clay content separately. In areas where altitude is higher than 1,500 m (under montane rainforest), the effect of low temperature in reducing soil organic matter decomposition rate overcome or minimize the effect of clay + silt on the retention of soil N. Finally, Pedotransfer functions, obtained by multi-linear regression, allowed estimating N levels in the different layers of the forest soils in Minas Gerais based on the values of altitude, soil depth, cation exchange capacity at pH 7, and clay, clay + silt and soil organic matter contents.

Keywords: Soil organic matter. Pedotransfer functions. Stratification ratio. Forest soils.

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1 INTRODUÇÃO

A substituição de ecossistemas naturais por áreas cultivadas tem se tornado cada vez mais frequente nas últimas décadas, acarretando alterações na dinâmica da matéria orgânica do solo (MOS) e, consequentemente, na qualidade do solo (RANGEL; SILVA, 2007). A MOS é parte importante dos ciclos de elementos como o C, N, P e S e seu conteúdo encontra-se estável em solos sob vegetação natural (BORTOLON et al., 2009). Com a decomposição biológica da MOS, o N é liberado na forma amoniacal em diferentes velocidades, cuja magnitude depende da composição química das frações orgânicas presentes e de sua resistência ao ataque microbiano (CAMARGO; GIANELLO; VIDOR, 1997). Cada solo possui, portanto, uma capacidade intrínseca de armazenar e fornecer N às plantas. Segundo Li, Han e Cai(2003), a predição da quantidade de N inorgânico liberada a partir da mineralização da MOS é essencial para o desenvolvimento de práticas que maximizem a eficiência no uso do N e minimizem eventuais impactos adversos do nutriente no ambiente, principalmente quando se considera a grande mobilidade e a dinâmica complexa do N no solo. Um dos preditores do N mineral disponível para as plantas é o N total armazenado no solo, que varia em função do clima, tipo de solo, vegetação, altitude e de outros fatores ambientais (GLENDINING et al., 2011; RASHIDI; SEILSEPOUR, 2009).

Diante da baixa eficiência do uso do N aportado artificialmente ao solo, muito se discute sobre estratégias de manejo do N aplicado em agroecossistemas, com vistas a aumentar a eficiência de utilização do N-fertilizante pelas plantas. Atualmente, mais da metade do N utilizado na agricultura é sintetizado industrialmente e menos de 10% do volume utilizado é retornado via alimentos produzidos, de modo que as rotas de perda são substanciais e podem contaminar diferentes matrizes ambientais (CAMERON;

DI; MOIR, 2013; FOLLET; FOLLET, 2001; TOWNSEND et al., 2003). Além da fixação por simbiontes ou organismos de vida livre, os teores de N retidos em solo são controlados também pelos processos de deposição atmosférica, lixiviação e volatilização (TIAN et al., 2010). Por se tratar de um elemento químico estreitamente associado à MOS, o armazenamento de N é controlado também por fatores similares àqueles responsáveis pela retenção de C no solo (BATJES, 1996; BAYER et al., 2000a, 2000b; NYBORG et al., 1997), de modo que há uma conexão estreita entre os ciclos, formas e dinâmica de C e N na maioria dos solos.

É sabido que os níveis de MOS presentes nos solos sob vegetação natural são condicionados pela rocha de origem, organismos, relevo, tempo de formação do solo e tipo de vegetação (QUIDEAU et al., 2002; STEVENSON, 1994), de modo que esses fatores, muito possivelmente, são reguladores também dos estoques de N presentes em solos. Segundo Bardgettet al. (2007), o N associado às plantas e microrganismos e aquele dissolvido na solução do solo sofrem baixas variações temporais, que são reguladas pela temperatura e umidade ao longo das estações de crescimento vegetal. Em condições naturais, os fatores que regulam o N-solo agem simultaneamente, em combinações complexas dos fatores que se desdobram em subfatores, de modo que é grande a chance de haver, em escala regional, solos com teores muito variados de N, tanto ao longo dos perfis de solo de Minas Gerais, quanto entre as diferentes fitofisionomias. Além dessas combinações, outros subfatores de formação dos solos e condicionantes dos estoques de MOS e N podem interagir, complicando em muito o entendimento dos mecanismos de retenção e distribuição do N no perfil do solo, fazendo com que seu estudo em solos de fragmentos florestais seja um desafio ainda maior.

Estudos de avaliação de estoques de C e N em solos têm sido feitos visando conhecer a magnitude de variação da capacidade de os ecossistemas terrestres armazenarem tais elementos (LORENZ et al., 2007). Recentemente, tem se tornado claro que modelos que consideram apenas o ciclo do C para estimar os efeitos das mudanças climáticas ao longo dos anos são inadequados, sendo necessários modelos que considerem um ciclo conjunto entre C e N, para que seja possível compreender corretamente a dinâmica do C no sistema solo/planta/atmosfera (OSTLE et al., 2009; XU; PRENTICE, 2008). Deste modo, a avaliação conjunta destes elementos tem recebido atenção crescente devido à aparente ação limitante do N para o sequestro de C no solo (HUNGATE et al., 2003; JANSSENS et al., 2010; LUO et al., 2004; REICH et al., 2006).

Como indicado por Batjes (2011), é importante que se forneçam dados para o estudo da emissão de gases do solo, sequestro de C, vulnerabilidade do solo a processos de degradação ambiental, e possíveis impactos dessa degradação na produção mundial de alimentos. Desde a década de 1980, diversos países vêm estimando reservas de C em escala regional, nacional, continental e global (BATJES, 1996; BOHN, 1976, 1982; ESWARAN; BERG; REICH, 1993; KERN, 1994; POST et al., 1982; WANG et al., 2001). Entretanto, devido às diferenças entre amostragem, técnicas analíticas e métodos de cálculo dos estoques de C, existe um erro considerável relacionado aos estoques estimados em escalas continentais e globais (WANG et al., 2004), sendo o mesmo válido para o N. Em geral, equações exponenciais explicam razoavelmente a retenção de matéria orgânica em razão da profundidade de solo (JOBBÁGY;JACKSON, 2000; ZINN; LAL; RESCK, 2007), mas pouco se sabe sobre a adequabilidade desses modelos matemáticos para a modelagem dos teores de N. Além disso, um maior conhecimento dos padrões de distribuição e de suas determinantes pode ser essencial para se avaliar como o C em horizontes mais profundos exercerá influência sob o fluxo de CO_2 do solo (FONTAINE et al., 2007; MEERSMANS et al., 2009). Em função da estreita relação com a

MOS, os compartimentos de N podem ser indicadores do potencial de sequestro e preservação do Cem solo (AKSELSSON et al., 2005).

Se já existem dados que explicam os padrões de distribuição do C e de seus fatores condicionantes em solos tropicais, são escassos os estudos que buscam investigar os padrões de retenção de N em solos brasileiros – o que não se justifica, tendo em vista o papel central desempenhado pelo N em ambientes naturais e cultivados. Devido à grande variação dos teores de N de um solo para outro, em função dos fatores discutidos anteriormente, qualquer estudo que vise à modelagem dessas condicionantes deve abarcar uma abrangência geográfica que contemple ampla variação desses fatores. O Estado de Minas Gerais engloba uma área de cerca de 586 mil km^2 e abriga uma diversidade enorme de biomas, classes de solos, fauna e flora. Assim, existem no Estado paisagens muito variadas que nos dá uma ideia da diversidade de solos e condições climáticas verificadas nos ambientes brasileiros, fruto das diferenças em vegetação e regimes climáticos, peculiares às diferentes sub-regiões do estado de Minas Gerais. Desse modo, são facilmente encontrados em MG grandes faixas de terra dominadas por cerrado, campo cerrado, cerradão, florestas deciduais, semideciduais e ombrófilas, bem como campos com gramíneas rupestres e campos limpos – na maioria das vezes compostos por gramíneas de baixo valor nutricional e adaptadas a solos de reduzida fertilidade.

Simultaneamente, em Minas Gerais, as temperaturas médias anuais podem variar de 18 ºC a 24,6 ºC e a precipitação média anual engloba valores na faixa de 750 a 1.647 mm (BRASIL, 1992), amplitudes de variação que antecipam efeitos marcantes nos estoques de N em solo.A altitude dos municípios varia de 74 a mais de 2.800 m, o que implica em forte variação direta na temperatura e regime pluviométrico. A parte norte, mais seca do Estado, abriga paisagens típicas e características de regiões semiáridas, devido às altas temperaturas e ao regime escasso de chuva, que se concentra em poucos meses do ano. Na região de cerrado, as chuvas são mais bem distribuídas do que na região norte, mas são comuns períodos de escassez de chuva de abril a outubro, e de veranicos, em plena estação chuvosa. No sul e na Zona da Mata do estado, chove mais e as chuvas são distribuídas ao longo de seis meses do ano, não sendo tão comum a incidência de veranicos, como no cerrado. Essas variações amplas nas condicionantes da produção primária líquida da vegetação afetam sobremaneira os estoques de N e sugerem o potencial de Minas Gerais como paisagem-modelo para inventariar o N do solo e suas condicionantes ambientais, com possibilidade de que os dados gerados no Estado sejam utilizados na modelagem do N de solos de outras regiões do Brasil.

Neste estudo, foram utilizadas amostras de solo do Inventário Florestal de Minas Gerais (SCOLFORO; CARVALHO, 2008), representativas de 36 fragmentos de florestas nativas localizadas em 31 municípios. Foram coletadas amostras de solo em cinco camadas, até um metro de profundidade (0-10, 10-20, 20-40, 40-60 e 60-100 cm), resultando em um total de 1.582 amostras de solos sob Cerrado (*stricto sensu*), Cerradão, Campo Cerrado, Floresta Estacional Semidecidual, Floresta Estacional Decidual e Floresta Ombrófila. O presente estudo objetivou: a) construir um banco de dados dos teores e estoques de N em solos de fragmentos florestais do Estado de Minas Gerais; b) estudar os padrões de distribuição vertical de N no perfil dos solos e sua relação com os cinco tipos de vegetação aqui avaliados; c) calcular o índice de estratificação de N, i.e. relação entre teores de N em camadas superficiais e subsuperficiais do solo; d) investigar os efeitos dos fatores ambientais sobre os teores e estoques de N e e) disponibilizar funções de pedotransferência para estimar teores de N no solo a partir de dados de análise de rotina de solos e de outras informações pertinentes ao solo, às condições climáticas e à localização geográfica do fragmento florestal.

2 CONSIDERAÇÕES FINAIS

Neste estudo, foram examinados os teores, estoques de nitrogênio total do solo e os efeitos de alguns fatores ambientais sobre os estoques de N em fragmentos florestais de Minas Gerais. Os teores de N total nos perfis de solo variam entre 0,009 e 15,8 g kg^{-1}. A distribuição vertical de N no perfil de solos de MG variou ainda com a fitofisionomia investigada e entre e dentro dos fragmentos, sendo o modelo exponencial o que melhor se ajustou aos teores de N em função da profundidade média da camada de solo avaliada.

O índice de estratificação médio para N no solo variou de 1,05 a 2,33. Tal amplitude de variação sugere que, em um cenário de aquecimento global intensificado, solos com maiores teores de N nas camadas superficiais são mais susceptíveis a perda de formas gasosas de N para a atmosfera, se houver aumento da taxa de decomposição da MOS com a elevação da temperatura média do planeta. Teores e estoques de N são maiores nas camadas superficiais em relação às de subsolo e a distribuição vertical de N é influenciada pela fitofisionomia. Considerando-se as fitofisionomias estudadas, o índice de estratificação para o N do solo seguiu a seguinte ordem crescente: Campo Cerrado < Cerrado = Cerradão = Floresta Estacional Semidecidual = Floresta Estacional Decidual < Floresta Ombrófila.

Os estoques de N variaram entre os fragmentos florestais estudados, na faixa de 1,38 a 39,4Mg ha^{-1}, quando a camada de 0-100 cm de profundidade foi considerada. Tais estoques correlacionaram-se positivamente com longitude, altitude, precipitação e teor de argila, silte e argila + silte e, negativamente, com latitude e temperatura média. Nos fragmentos situados em Camanducaia e Baependi (Floresta Ombrófila), onde a altitude ultrapassa os 1.500 m, a baixa temperatura média (aproximadamente 14 ºC) é o principal fator condicionante do N no solo, anulando e, ou, minimizando o efeito de proteção física e química que a textura confere ao N em termos de exposição aos organismos decompositores. Entre os fatores ambientais testados, para a maioria dos fragmentos florestais investigados, temperatura e argila + silte são preditores eficazes das quantidades de N armazenadas nos perfis de solos (0-100 cm) dos fragmentos florestais estudados.

Este estudo disponibiliza dados relativos aos fatores que condicionam os estoques de N em solos de paisagens florestais mineiras. A modelagem dos fatores que condicionam os teores de N pode ser calibrada para solos de outras regiões brasileiras, o que pode ser útil, pois a ampla variação nos teores de N e a elucidação dos fatores que a condicionam permite uma melhor seleção de áreas mais frágeis para proteção ambiental ou otimizar o uso do nutriente quando esses solos são convertidos para o uso agrícola. Os baixos estoques de N verificados em muitos dos solos florestais investigados causam preocupação, já que podem limitar o sequestro de C, uma vez que o maior armazenamento de MOS é também dependente do N armazenado no solo. Por exemplo, uma baixa capacidade de alguns solos florestais mineiros em estocar N sinaliza para uma provável baixa capacidade natural de fornecer o nutriente às plantas, daí a necessidade de uso intensivo e eficiente de N-fertilizante quando esses solos forem destinados à implantação de lavouras.

Em função dos dados levantados neste estudo, sugerem-se ações de pesquisa ampliadas no Estado de Minas Gerais e em outros Estados do Brasil, com a perspectiva de investigação dos reservatórios naturais de N em nossos solos, da relação entre o C e o N estocados no solo e de outros componentes dos ecossistemas e de sua participação nos ciclos globais desses elementos. Os dados de N medidos em condições naturais sinalizam para a fragilidade de alguns solos do Estado em armazenar N. Certamente, isso contribui para a baixa eficiência de uso de N notada em alguns agroecossistemas mineiros e do Brasil. Com essa perspectiva, as ações de pesquisa aqui listadas devem ser estendidas para outras paisagens minerais e do Brasil, com vistas ao estudo da dinâmica, armazenamento, formas, ciclo e fluxos de N em solos já cultivados.

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SEGUNDA PARTE – ARTIGO

ARTIGO

(Este artigo será submetido à revista Forest Ecology and Management)

Environmental factors controlling N contents and stocks in soils under native forest fragments in Minas Gerais, Brazil

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Abstract

Nitrogen is a major factor limiting plant growth in forests and its retention in soils controls not only plant uptake but losses to groundwater and the atmosphere. Although it is known that N is chiefly retained in soil organic matter, little is known about what environmental factors also regulates N levels in tropical soils. This study was based on a comprehensive database on soil N pools under native vegetation in a large tropical humid area, and aimed to study patterns of vertical distribution of N in soil profiles, their relationships with the vegetation types and conditioning factors. Soils from different forest and savanna types were sampled in 319 native forest fragments along the state of Minas Gerais, Brazil, in five soil depths (0-

10, 10-20, 20-40, 40-60 and 60-100 cm). Soil samples were characterized by routine textural and fertility analyses, and total N was determined by the micro-Kjeldahl method. The average N contents in soil profiles (0-100 cm) ranged between 0.12and7.54 g kg^{-1}. The stratification ratios (ratio between the mean N content at 0-20 cm and the mean N content at 20-100 cm) varied from 0.78 to 5.22 among the forest soils sampled, suggesting a widely different vertical N distribution. Total N stock in the 0-100 cm soil layer varied dramatically (1.38to 39.4 Mg ha^{-1}) among the forest fragments investigated, with the greatest stocks at montane rainforest. Latitude correlated poorly with soil N stocks, and no correlation was found with longitude, whereas altitude correlated positively. Clay and silt contents were also well correlated with N stocks, and the combined clay + silt contents showed even better correlation coefficients. In areas where altitude is higher than 1,500 m (montane rainforests), the effect of lower temperatures seems to overcome the protective effect of texture, as soils with lower clay + silt contents can contain the highest N stocks.

Keywords: soil organic matter, altitude, stratification ratio, tropical soils, phytophysiognomy.

1. Introduction

Soils are the largest N reservoir on the terrestrial biosphere, storing more N than plant biomass (SCHLESINGER, 1997), and N_2O emissions from soils are controlled by how N is released from soil organic matter (SOM) decomposition and management (DICK; GREGORICH, 2004; SÁ et al., 2014). N availability in soils can also affect other element cycles

(LUO et al., 2004), notably that of carbon (C), with consequences on the amounts of C stored as SOM (BATJES, 1996; LAL, 2004). Since N and C cycles are closely linked in SOM, the vertical distribution of N in soil profiles is generally similar to that of organic C, with higher levels in soil surface and decreasing in subsoil layers (JOBBÁGY; JACKSON, 2000; YANG et al., 2010). In natural ecosystems, the mobility of inorganic N, the diversity and activity of free-living and symbiotic N-fixing organisms and the soil food web can also affect the amounts of N stored in soil profiles (CALLESEN et al., 2007; VITOUSEK et al., 2002). In tropical regions, there are limited data on N retention on soils, especially in subsurface layers. Such a paucity of information is detrimental since N plays a central role in the productivity of natural and cultivated ecosystems. As proposed by Liu, Shao and Wang (2011) for soil C, knowledge of soil N and its controlling factors is essential in order to estimate N budgets, to understand N retention in soils and to choose the best management practices for N fertilizers, N-fixation and use of SOM-bound N stored in cultivated lands.

In soils, N is so dependent on SOM levels that H. Jenny (1941) often used total N as an indicator of SOM in his seminal work. SOM levels are controlled by soil texture, time, relief, climate and vegetation (JENNY, 1941; QUIDEAU et al., 2001; STEVENSON, 1994). In natural environments, predicting N and SOM contents is difficult since these factors act simultaneously, and probably in complex combinations, since each one can be subdivided into sub-factors. In such a complex net of possible combinations, there is always a site-specific asymmetry in the role that each factor exerts in controlling soil N, so there is large variability in SOM and N levels among soil types, biomes, climatic zones, and within the soil vertical profile (CAMERON; DI; MOIR, 2013; CARDOSO et al., 2010; RANGEL et al., 2008; SILVA et al., 2004). Climate and vegetation significantly affect soil N by determining a balance between organic inputs derived from plant production and SOM losses associated to microbial decomposition (BRADY; WEIL, 2004; POST et al., 1985). The distribution of root biomass within the soil profile is another factor related to vegetation type that also regulates N contents and its vertical distribution in soils (JOBBÁGY; JACKSON, 2000).

Altitude is usually considered an important environmental factor indirectly regulating SOM dynamics (GARTENJUNIOR et al., 1999; LEMENIH; ITANNA, 2004). Barry and Chorley (2003) stated that an increase in altitude generally promotes a decrease in temperature and increase in precipitation. Thus, altitude also influences plant communities and their net primary productivity and, consequently, the amount, turnover and distribution of SOM (GARTEN JUNIOR et al., 1999; QUIDEAU et al., 2001; STEVENSON, 1994). Altitude also influences SOM due to its influence on soil water balance, erosion processes and sediment deposition (TAN et al., 2004). SOM contents typically decrease with increasing mean annual temperature (COLE et al., 1993; KIRSCHBAUM, 1995), since decomposition rates double for each 10 °C increase in the local average temperature (SCHLESINGER, 1997). This inverse relationship implies that a temperature increase also results in lower soil N (ALVAREZ; LAVADO, 1998; JENNY, 1941; STEVENSON, 1994). Precipitation also has a clear effect on regional and local C and N stocks (STEVENSON, 1994; WANG et al., 2004), since organic inputs to the soil are regulated by the net primary production, which chiefly depends on water availability to plants (FORNARA; TILMAN, 2008; WANG et al., 2005; WU; GUO; PENG, 2003).

Soil texture is a property often associated to soil N contents (CALLESEN et al., 2003; JOBBÁGY; JACKSON, 2000), and its mineralization rates (CÔTÉ et al., 2000; GIARDINA et al., 2001; REICH et al., 1997). In a homogeneous climatic zone, SOM concentration generally increases as soil clay content increases, because of the protective effect of SOM sorption by clay minerals, resulting in lower availability of organic substrates to soil microbiota (CAMARGO; GIANELLO; VIDOR, 1997). According to Maia et al. (2009) and Vejre et al. (2003), in soils with higher contents of fine particles, soil N is also greater, and Gami, Lauren and Duxbury (2009) found a positive correlation between N and clay + silt contents in soils of the eastern Indo-Gangetic Plains. Since C and N cycles are coupled, effects of soil texture on SOM also work for N, and besides, texture regulates water holding capacity, plant productivity and SOM mineralization rate (BERHONGARAY et al., 2013). Nevertheless, the number of studies on soil N pools and their affecting factors is much lower than for SOM, especially for tropical humid regions.

Pedotransfer functions (PTFs) are often used to predict variables which are time-consuming and expensive to determine, such as soil N. The term was first presented by Bouma (1989) as “translating data we have into what we need”, although this concept was already being used widely to estimate soil water holding capacity. Glendining et al. (2011)

developed PTFs to estimate soil N contents in a global scale using a dataset (BATJES, 2002) with 4,382 soil profiles. Despite the quality of the results obtained, it is known that studies that aim to estimate C and N contents in global scale are subjected to significant errors due to differences in sampling, analytical and calculation methods (WANG et al., 2004). These errors can be minimized once the study area is restricted and the methods are standardized.

Therefore, this study was carried out in order to: a) build a comprehensive database on soil N pools under native vegetation in a large tropical humid area; b) study the patterns of vertical distribution of N in soil profiles and their relationships with the vegetation types; c) investigate the stratification ratio of N in soil and subsoil layers; d) assay the effects of environmental factors on N stocks and e) generate pedotransfer functions for soil N contents under native vegetation in the State of Minas Gerais, Brazil.

2. Material and Methods

2.1. Study area

The State of Minas Gerais covers an area of about 585,000 km², located between the latitudes of -14.2327 and -22.9000 S, and the longitudes of -39.8588 and -51.0430 W. Mean annual temperatures in Minas Gerais range from 18 to 24.6 ºC, whereas mean annual precipitations vary between 750 to 1,647 mm (BRASIL, 1992). Altitude ranges between 74 to >2,800 m, which implies a considerable variation in mean annual temperature and precipitation even at similar latitudes. The northern part of the Minas Gerais has a distinctive semi-arid climate marked by high temperatures and scarce rainfall (around 600 mm/year), which is concentrated in only a few months. In the central and west region, rainfall is better distributed, but with a marked period of low rainfall from April to October, and frequent dry spells during the rainy season. Such conditions favor the occurrence of savannic formations (Cerrado *stricto sensu*, woodland and prairie), whereas deciduous forests are common in the north region (Figure 1). In the southern and eastern areas, rainfall is more equally distributed throughout the year and summer dry spells are not common, favoring the predominance of semi-deciduous forests and rainforests.

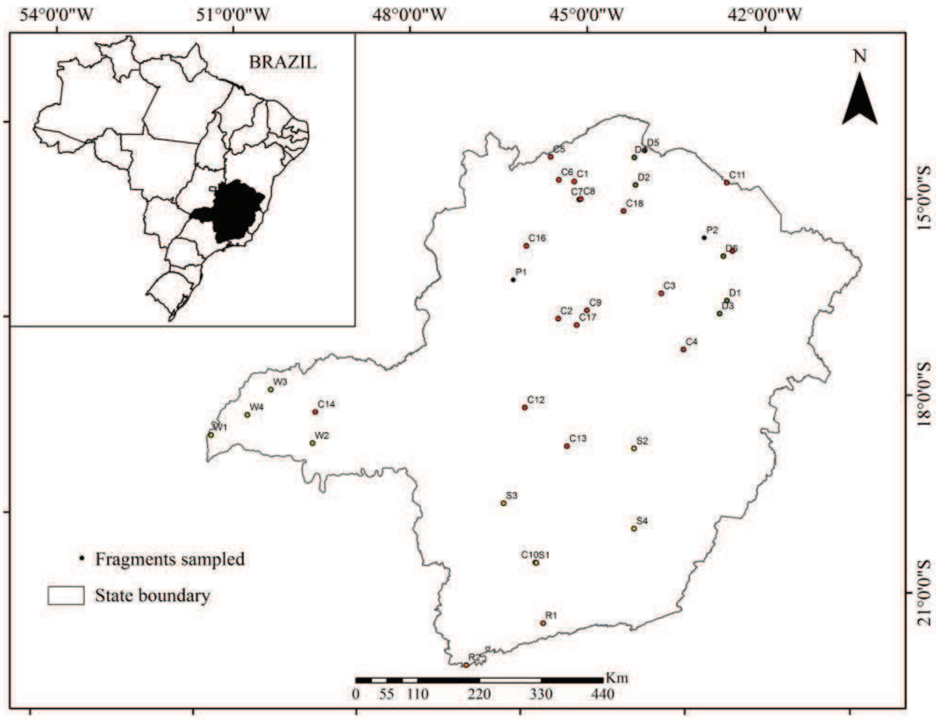

Figure 1: Locations of the fragments sampled and the boundary of the State of Minas Gerais, Brazil.

2.2. Soil sampling

Soil sampling for this study was based on the network of forest fragments established for the Minas Gerais Forest Survey initiative (SCOLFORO; CARVALHO, 2008). Such network aimed to sample the landscape and biological diversity within the remnants of native vegetation types in the state, and the forest fragments used in this study are shown in Figure 1. In each fragment, a variable number of rectangular plots with an area of 0.1 ha (10 x 100 m) were marked, as a grid, depending on the total area of the remnant (SCOLFORO et al., 2008). In each plot, three pits of 1.0x0.5x1.0 m were dug and five soil layers (0-10, 10-20, 20-40, 40-60 and 60-100 cm) were sampled. In some shallow soils, it was impossible to collect samples up to 1 m depth, thus sampling was performed to the deepest soil layer accessible. A total of 1,582 soil samples were collected in 36 forest fragments, comprising 319 sampling plots (Table 1). Soil samples were dried at 35 °C in an oven with air circulation, sieved < 2 mm and stored.

Table 1 – Main characteristics of the forest fragments investigated across the Minas Gerais state.

Fragment legend	Phytophysionomy	Mean longitude	Mean latitude	Mean altitude (m)	Number of samples
C1	Cerrado *stricto sensu*	-44,968	-15,3383	588	60
C2	Cerrado *stricto sensu*	-45,0117	-17,4671	551	30
C3	Cerrado *stricto sensu*	-43,2653	-16,9165	915	35
C4	Cerrado *stricto sensu*	-42,7679	-17,7379	944	55
C5	Cerrado *stricto sensu*	-45,4151	-14,9963	758	70
C6	Cerrado *stricto sensu*	-45,237	-15,3353	620	100
C7	Cerrado *stricto sensu*	-44,8487	-15,6086	508	30
C8	Cerrado *stricto sensu*	-44,8267	-15,5974	512	60
C9	Cerrado *stricto sensu*	-44,5235	-17,2982	560	30
C10	Cerrado *stricto sensu*	-44,9839	-21,2262	890	20
C11	Cerrado *stricto sensu*	-42,3512	-15,1029	985	40
C12	Cerrado *stricto sensu*	-45,444	-18,8793	620	25
C13	Cerrado *stricto sensu*	-44,6332	-19,4051	717	50
C14	Cerrado *stricto sensu*	-49,1434	-19,2151	619	30
C15	Cerrado *stricto sensu*	-42,1179	-16,1423	845	50
C16	Cerrado *stricto sensu*	-45,6895	-16,3992	515	25
C17	Cerrado *stricto sensu*	-44,6773	-17,5376	512	30
C18	Cerrado *stricto sensu*	-44,0701	-15,7154	823	25

Frag ment legend	Phytophysionomy	Mean longitude	Mean latitude	Mean altitude (m)	Number of samples
W1	Woodland	-50,9663	-19,6739	398	30
W2	Woodland	-49,1524	-19,6961	585	25
W3	Woodland	-49,958	-18,9185	486	25
W4	Woodland	-50,3438	-19,3308	428	45
P1	Prarie	-45,8606	-16,9429	578	60
P2	Prarie	-42,6308	-15,9888	890	90
S1	Semideciduous forest	-44,9708	-21,2283	923	25
S2	Semideciduous forest	-43,4408	-19,3318	718	14
S3	Semideciduous forest	-45,6571	-20,3703	693	30
S4	Semideciduous forest	-43,285	-20,552	844	30
D1	Deciduous forest	-42,1101	-16,9108	354	50
D2	Deciduous forest	-43,9126	-15,2936	509	60
D3	Deciduous forest	-42,2122	-17,1226	615	28
D4	Deciduous forest	-43,982	-14,8719	471	85
D5	Deciduous forest	-43,8185	-14,7466	464	85
D6	Deciduous forest	-42,2641	-16,2365	467	60
R1	Montane rainforest	-44,7365	-22,1362	1774	35
R2	Montane rainforest	-46,0583	-22,8871	1890	40

2.3. Analytical procedures for soil characterization

Soil samples were analyzed for particle size distribution by the hydrometer method (BOUYOUCOS, 1962). Bulk density was determined by the core method (GROSSMAN; REINSCH, 2002). SOM, cation exchange capacity (CEC at pH 7) and pH in water 1:2.5 were determined according to the methodologies described at Sparks et al. (1996). Total N concentration was determined according to the methodology described by Bremner (1996), with the modifications described below. In 100 mL tubes, 0.3 g of soil samples was mixed with 0.1 g of a mixture containing potassium sulfate, copper sulfate and selenium at the proportion of 100:10:1, respectively, and 3 mL of concentrated sulfuric acid. The mixture inside the glass tubes was digested in sealed vials using the following heating rate: gradual 50 ºC increase every 20 minutes until the temperature of 250 °C was reached; after an hour, the block temperature was increased to 350 °C and kept until the desired white coloration of the digested mixture in the tubes was reached (approximately 40 minutes after). At the end of the digestion, 10 mL of distilled water were added to each tube. The extract was distilled in presence of sodium hydroxide (13 mol L^{-1}) in a *Kjeldahl* distiller and the extract collected in a boric acid solution, until obtaining 50 mL of condensate in the flasks. The distilled samples were titrated with hydrochloric acid (0.07143 mol L^{-1}), as recommended by Bremner (1996), and vials with blank samples and with elementar certified samples with known N contents were used in each 40 samples batch. Since this method to measure soil N was developed for soils from temperate regions with higher N contents, in this study, we used 0.3 g of soil, instead of 0.1 g.

2.3.1 Nitrogen stocks

Nitrogen stocks were calculated for three standard soil layers (0-20, 0-40 and 0-100 cm depths) using the following equation:

$$N\ stock = \frac{N\ content \times bulk\ density \times soil\ layer}{10}$$

in which the stock is given in Mg ha-1, the N content in g kg-1, bulk density in g cm-3, and the soil layer thickness in cm. In order to verify the influence of soil texture on N stocks in the whole soil (0-100 cm), the mean weighted average of clay + silt (<50 µm) contents were calculated considering the thickness of the five soil layers sampled.

In order to evaluate the proportions of N in the soil surface (0-20 cm) in relation to those found in subsoil layers (20-100 cm), the stratification ratio proposed by Franzluebbers (2002) was calculated, with some modifications, according to the equation presented below:

$$SR = \frac{N\ (0 - 20\ \text{cm})}{N\ (20 - 100\ \text{cm})}$$

where $N\ (0 - 20\ cm)$is the average N concentration in the 0-20 cm layer; and$N\ (20 - 100\ cm)$ is the weighted average for N content in the 20-100 cm layer, considering the thickness of each soil layer and its respective soil N content.

2.4. N pedotransfer functions and statistical analysis

Before starting the statistical analysis, data were analyzed separately, using the boxplot feature from R 3.0.2 statistical program (R CORE TEAM, 2013), in order to remove outliers at the soil database. Data were collated by phytophysiognomy and soil depth, and analyzed by descriptive statistics and linear regression. The Shapiro-Wilk test was used to test the normality of frequency distributions of soil N and other input data. The Scott-Knott test was used to test the means. Multi-linear regressions with stepwise procedures were used to predict soil N based on geographical database (latitude, longitude and elevation) and the key soil properties (texture, bulk density, SOM, pH and CEC), either separately for each sampled depth or as a whole (0-100 cm), were also use to predict N soil contents in the forest fragments investigated. The statistics of the input data used to provide N pedotransfer functions (PTFs) are presented in Table 2.

Table 2 – Descriptive statistics of the input data

Input data										
Phytophysiognomies	Cerrado *sensu stricto*, woodland, prairie, semideciduous, deciduous and montane rainforest									
Soil depth intervals	0-10, 10-20, 20-40, 40-60, 60-100 and 0-100 cm									
No. samples	1,297									

Input parameters	Latitude	Longitude	Altitude	Clay (<2µm)	Silt (2-50µm)	Sand (>50µm)	Bulk density	pH	CEC*	SOM*
Units			m	%	%	%	g/cm^3		$cmol_c/dm^3$	%
Minimum	-22.89	-50.98	350	0	0	1	0.31	3.3	1.06	0.04
Maximum	-14.66	-42.10	1,988	86	79	97	1.69	7.8	58.8	15
Median	-16.23	-44.64	635	27	9	46	1.34	5	5.4	1.41
Mean	-17.16	-44.53	721.2	32.4	13.8	51.8	1.28	5	7.2	1.92
Standard deviation	2.2	1.9	320.3	22.5	15.3	29	0.24	0.6	6.02	1.8

***CEC, cation exchange capacity at pH 7; SOM, soil organic matter.**

3. Results

3.1. N concentrations, variation with depth and modelling

Soil N contents varied widely and decreased with sampling depth. When sorted by Forest fragment (Figure 2), there was also wide variation between and within fragments, which seem to be comparable along the different sampling depths. At the 0-10 cm, N contents varied from 0.19 to 15.8 g kg^{-1}. The amplitude of variation was narrower for the deepest soil layers, between 0.009 g kg^{-1} and 8.36 g kg^{-1}. Considering the average N content in the whole soil profile (0-100 cm), 87% of the N contents are in the range of 0.1 to 1.5 g kg^{-1}. The rainforest fragments located in the southernmost area of Minas Gerais showed the highest N contents, in some cases up to 7 g kg^{-1}, reflecting very high SOM levels. In these soils, the average N concentrations (0-100 cm) ranged from 1.1 to 7.54 g kg^{-1}. For all phytophysiognomies investigated, the average soil N content declines with increasing depth, following an exponential function, according to the equations presented in Table 3.

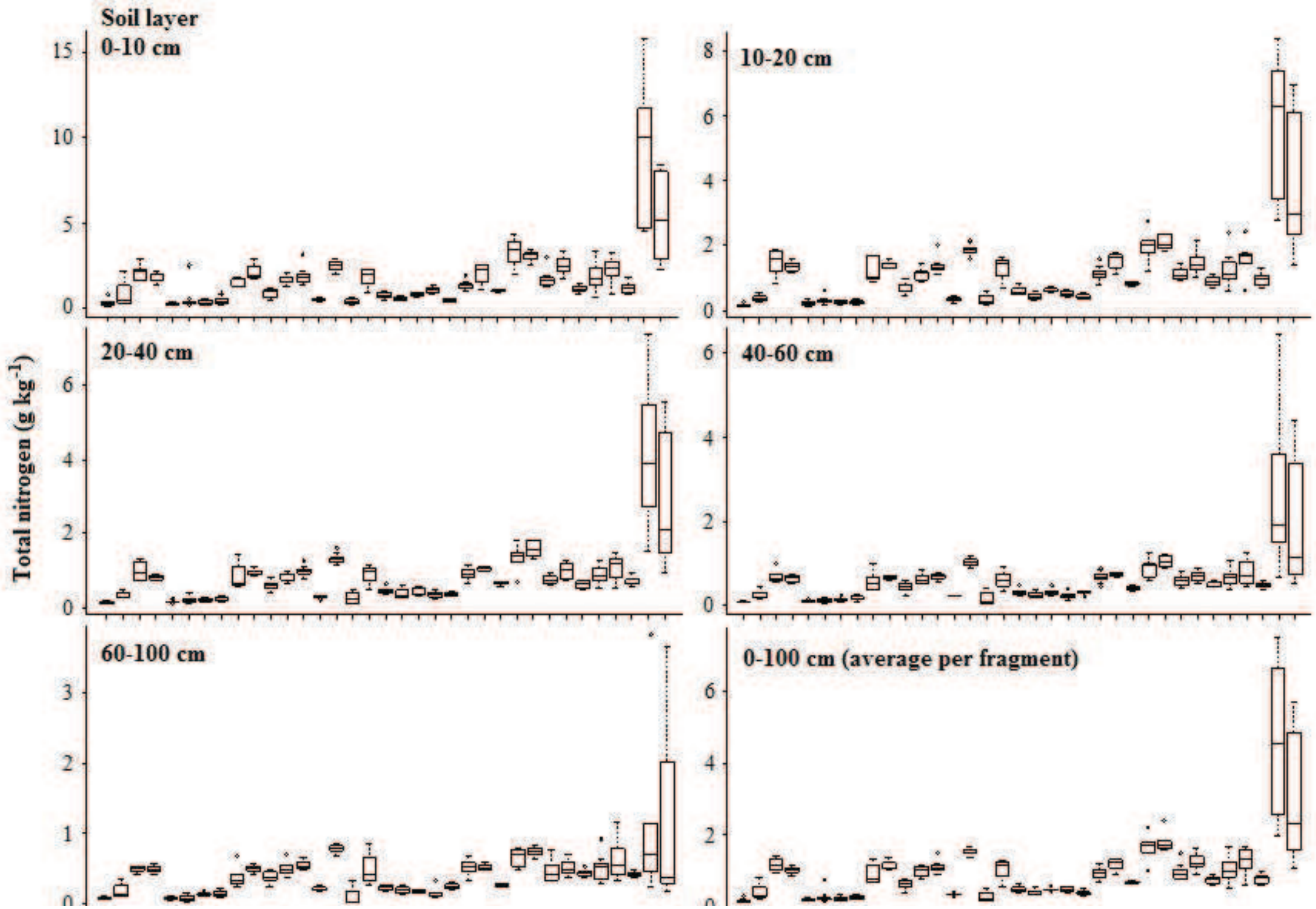

Figure 2 – Boxplots (5, 25, 50, 75 and 95% percentiles) of total nitrogen content as a function of sampled fragments for each soil layer

Table 3 – Exponential matemathical equations for mean total nitrogen content at each phytophysiognomy studied.

Phytophysiognomy	**Equation**	**R²**
Cerrado	$N = 0.20e^{0.32d}$	0.99
Woodland	$N= 0.13e^{0.37d}$	0.99
Prairie	$N = 0.36e^{0.23d}$	0.99
Semideciduous forest	$N = 0.41e^{0.37d}$	0.99
Deciduous forest	$N = 0.33e^{0.33d}$	0.99
Montane rainforest	$N = 0.84e^{0.44d}$	0.98

N: mean total nitrogen content (g kg^{-1}); d: average depth of the soil layer.

A broad range of variation (means of 1.05 to 2.33) was observed in the stratification ratio (SR) values among the forest soils sampled (Figure 3a), suggesting a strong effect of the site. A prairie soil (P1) in the northwest region of the state showed the lowest ratio (1.05), whereas values >1.5 occurred in fragments under different phytophysiognomies throughout the study area, and were especially high for the montane rainforests. When sorted by phytophysiognomies, soil N stratification ratio showed the following increasing order: Prairie < Cerrado = Woodland = Semideciduous = Deciduous < Rainforest (Figure 3b). Table 4 shows the best regression equations to predict soil N content in each depth or in all soil depths combined, while Figure 4 shows the respective observed versus estimated values plots. All equations were able to describe soil N either as in low or in high concentrations, and in all cases SOM was the variable with higher predictive power, as expected.

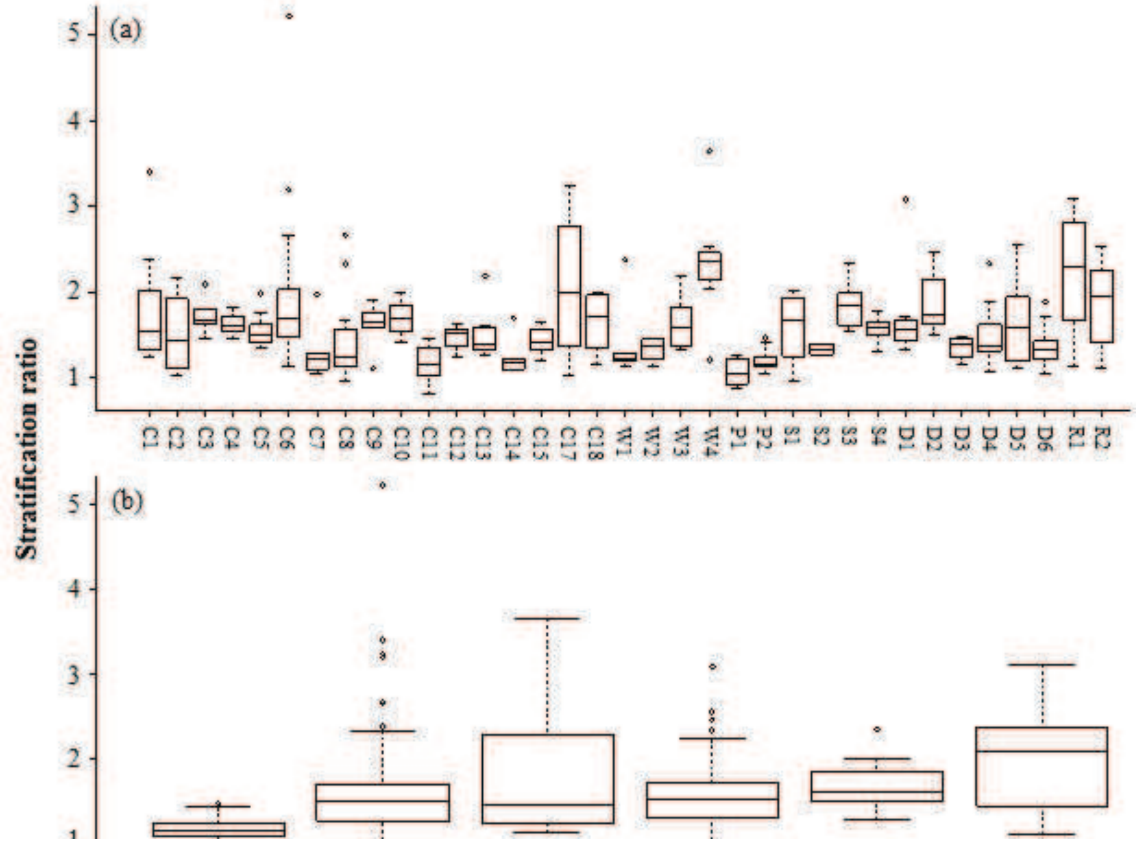

Figure 3 – Stratification ratio of soil N as a function of (a) forest fragments and (b) phytophysiognomies.

Table 4 – Multivariate equation to estimate total N content per soil layer or for all soil depths.

Soil depth (cm)	Equation
0 – 10	N (g kg^{-1}) = -1.05*** + 0.00081***(altitude) – 0.0059**(clay) + 0.105***(cec) + 0.37***(som)
10 – 20	N (g kg^{-1}) = -0.432 + 0.00023*(altitude) – 0.0022*(clay + silt) + 0.049***(cec) + 0.47***(som)
20 – 40	N (g kg^{-1}) = -0.219*** – 0.0037***(clay) + 0.041***(cec) + 0.51(som)***
40 – 60	N (g kg^{-1}) = -0.129*** –0.0018**(clay) + 0.038***(cec) + 0.46***(som)
60 – 100	N (g kg^{-1}) = -0.168*** + 0.00026***(altitude) + 0.031***(cec) + 0.25***(som)
0 – 100	N (g kg^{-1}) = -0.534*** + 0.0025***(depth) + 0.00024***(altitude) – 0.0039***(clay) + 0.062***(cec) + 0.46***(som)

***: P<0.001; **: P<0.01; * P<0.05; som, soil organic matter; cec, cation exchange capacity at pH 7.

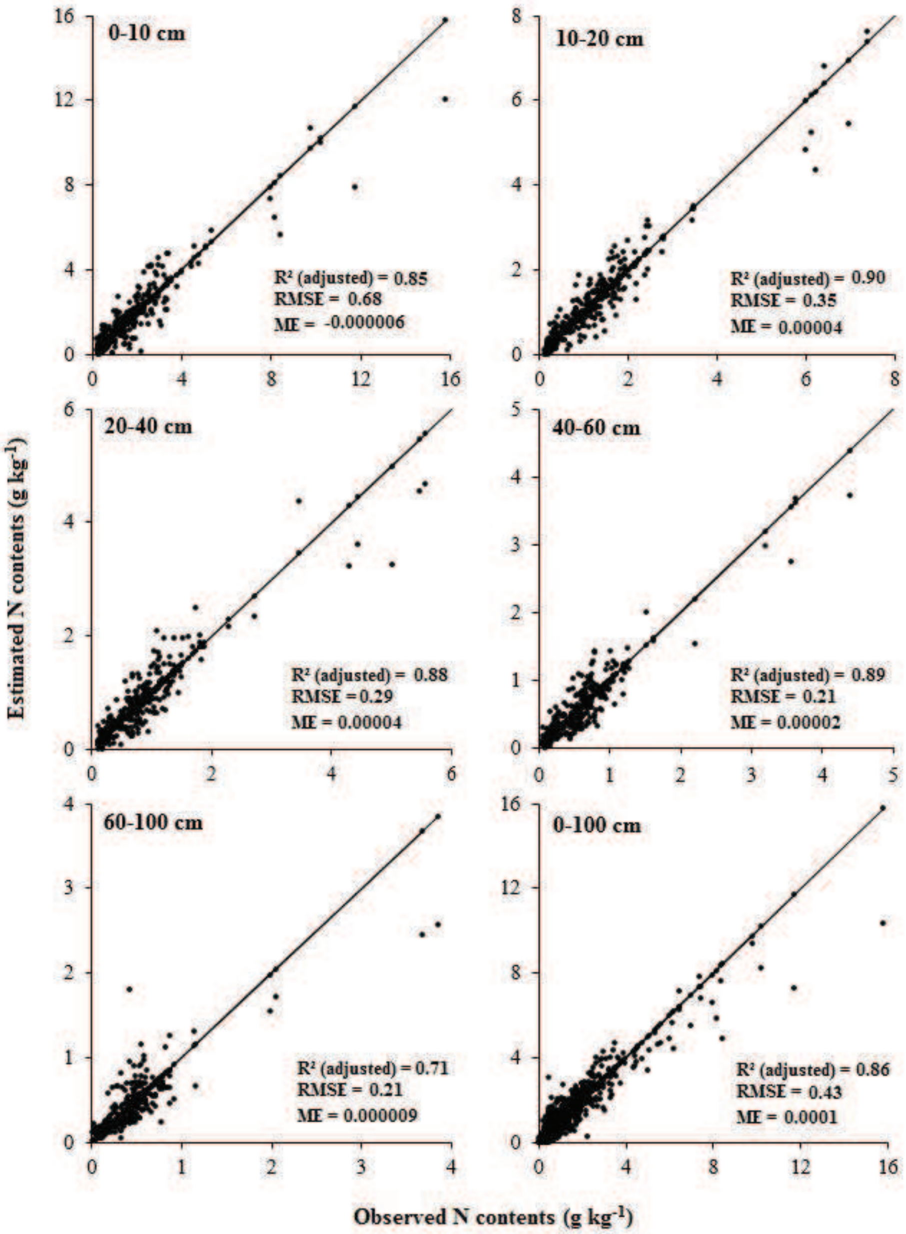

Figure 4 – Estimated versus observed total nitrogen contents per soil layer or with all combined depths

3.2. N stocks, vertical distribution and affecting factors

The total (0-100 cm depth) N stock within forest fragments varied from 1.38 to 39.4 Mg ha-1 (Figure 5). In all depths, montane rainforests contained the greatest N stocks. For the upper 0.2 m, the amplitude of variation is high, within a range of 0.48 to 10.7 Mg ha-1, although 58 % of the forest fragments contain N stocks < 3 Mg ha-1. As N stocks increase across the different sites, the amplitudes become also higher, although, in the deeper soil layers, the variation tends to be lower. When the mean N stock per fragment were calculated, the two rainforest fragments again showed the highest stocks, with R1 presenting an average of 24.8 Mg ha-1 followed by R2 (19.3 Mg ha-1). Two fragments of Cerrado *stricto sensu*, C1 (1.92 Mg ha-1) and C5 (2.02 Mg ha-1) showed the lowest N mean stocks.

The percentage of N stocks in the top 20 cm (relative to the first meter) in prairie soils was significantly lower ($P<0.05$) than those verified in other phytophysiognomies. The vertical distribution of N stocks could be fitted adequately to exponential equations (Table 5), although its distribution in prairie soils is not so sharp as those verified in the other vegetation types. There was little difference in the N stocks throughout soil profile between the other physiognomies, in which tree components predominate.

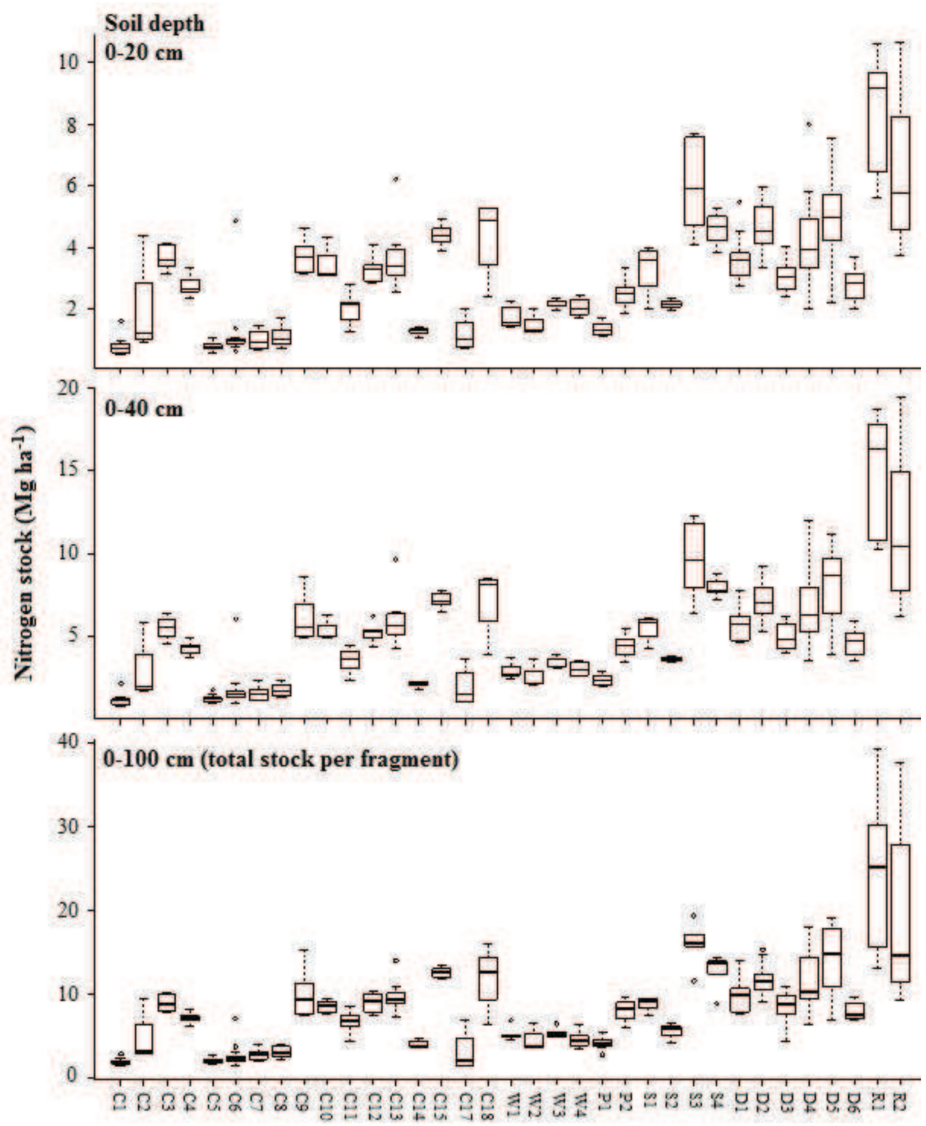

Figure 5 – Boxplots (5, 25, 50, 75 e 95% percentiles) of nitrogen stocksper forest fragment, for the standardized depths ofat 0-20, 0-40 and 0-100 cm.

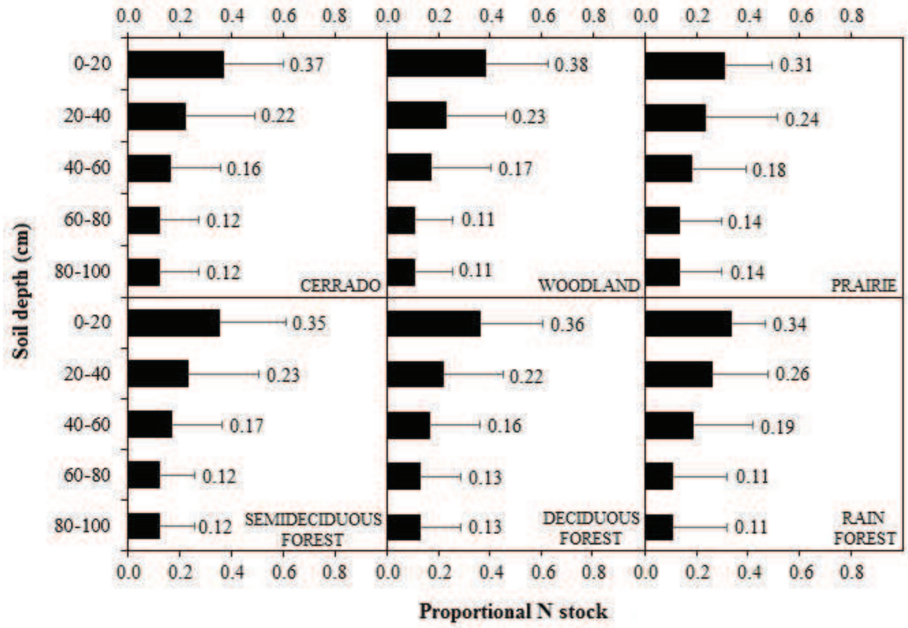

Figure 6 – Vertical distribution of percent N stocks for the studied phytophysiognomies. Black bars (and associated numbers) indicate the proportional distribution of N stocks in the first meter of soil divided in 20 cm intervals. Error bars express the standard error of the mean.

Table 5–Exponentialmatemathical equations for percent N stocks in each phytophysiognomy studied.

Phytophysiognomy	Equation	R²
Cerrado	$NS = 0.08e^{0.28d}$	0.91
Woodland	$NS= 0.07e^{0.32d}$	0.93
Prairie	$NS = 0.10e^{0.22d}$	0.95
Semideciduous forest	$NS = 0.08e^{0.28d}$	0.93
Deciduous forest	$NS = 0.08e^{0.27d}$	0.90
Montane rainforest	$NS = 0.07e^{0.32d}$	0.94

NS: percent nitrogen stock (Mg ha^{-1}); d: average depth of the soil layer.

Figure 7illustrates the relationships of mean N stocks on the whole soil profile (0-100 cm) with latitude, longitude, altitude and weighted mean clay, silt and clay + silt. Latitude and especially longitude did not seem to consistently affect N stocks within the statewide limits. Altitude did show a positive effect, although it is evident that the effect was mostly due to the two montane rainforests. The separate clay and silt contents were also correlated with N stocks, and even more the combined soil clay + silt weighted means (R = 0.65). Thus, soil texture, in particular, clay + silt contents, were strongly correlated with the amounts of N stored in soil, and this relationship could be improved further when data of the two montane rainforests are excluded (Figure 7b).

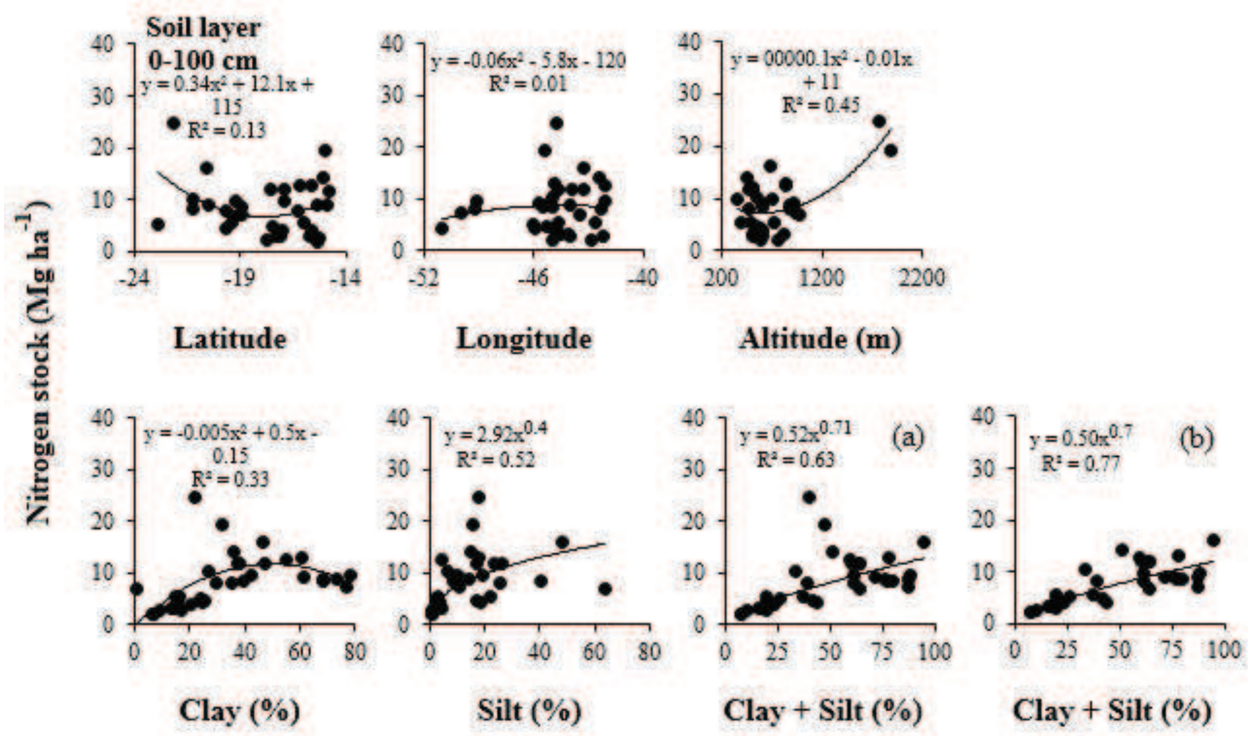

Figure 7 – Relationship of soil latitude, longitude, altitude, clay, silt, (a) clay + silt and (b) clay + silt excluding the dataset of R1 and R2, with N stocks for the whole soil profile.

4. Discussion

4.1. Soil N contents and distribution in soil profile

Regardless of the site sampled, the mean N content decreased with depth(Figure 8), following the same distribution pattern verified for organic C in other studies (ANDRÉA et al., 2004; ARROUAYS; PELISSIER, 1994; XU; PRENTICE, 2008; YANG et al., 2010), which was already expected since N is closely related to SOM (KNOPS; BRADLEY, 2009).

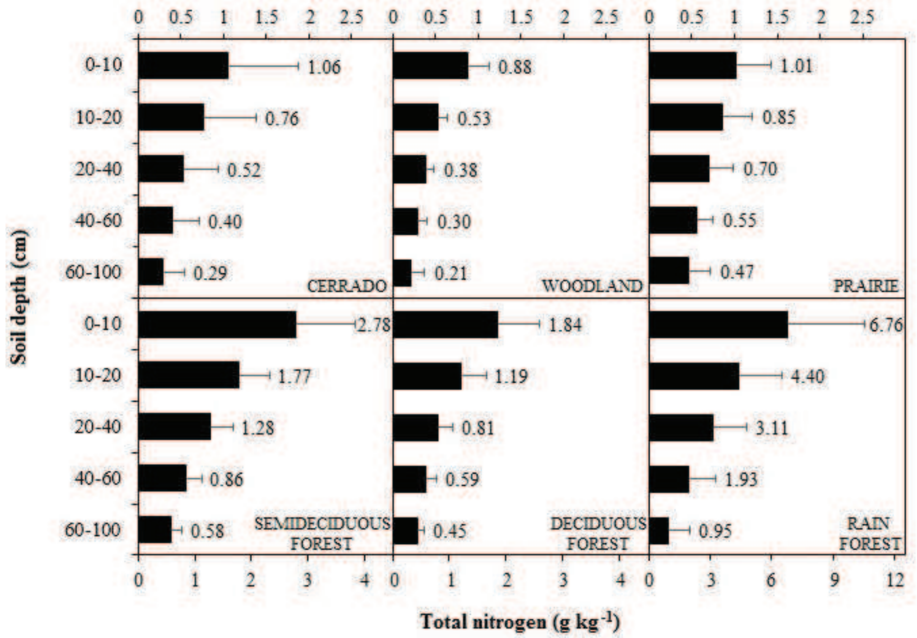

Figure 8 – Vertical distribution of N contents for the studied phytophysiognomies. Black bars indicate the average N/soil layer/phytophysionomy (0-100 cm). Error bars express the standard error of the mean.

It is likely that the equations found in this study (Table 3) are specific for the region and phytophysiognomies investigated. In natural ecosystems, higher SOM levels in surface can be explained by high litter inputs in soil surface and low N solubility of organic residues, in which is common the prevalence of hydrophobic instead of hydrophilic substances. Our results for total N contents agree with previous soil N contents reported for Minas Gerais soils (SILVA; VALE; FERNANDES, 1999; SILVA; VALE; GUILHERME, 1994), although soil N contents usually varies greatly among the soils of other geographic regions in Brazil (CAMARGO; GIANELLO; VIDOR, 1997; RHODEN et al., 2006; YAGI et al., 2009). The wide variation of the standard errors can be explained by the great variability in soil texture of plots sampled at Cerrado and deciduous forest areas (Figure 9), the high number of plots sampled at these very same phytophysiognomies and the great variation of N content between the two montane rainforests.

Vertical distribution of soil N under Cerrado, woodland, and prairie are similar (Figure 8). Soils under semideciduous and deciduous forest fragments are enriched in N compared to the soils from the Cerrado phytophysiognomies, probably due to higher organic carbon concentrations. As observed by Skorupa et al. (2012) for Minas Gerais, soils under deciduous forest generally occur on outcrops of different rocks, resulting in shallow and high fertility soils (SCHAEFER et al., 2009). Semideciduous forest fragments, on average, have higher soil N contents than deciduous forest soil profiles, which can be justified by a typically higher clay content (SKORUPA et al., 2012), and probably also higher biomass. The two montane rainforests in the southernmost fragments comprise the richest soils in terms of soil N contents, again reflecting higher SOM levels. Compared to the Savannic phytophysiognomies (Cerrado, woodland and prairie), N contents for a 0-100 cm depth are approximately 6 times higher in the montane rainforests.

Nevertheless, it must be highlighted that the rainforest fragments are located in altitudes above 1,500 m. The effect of altitude is most likely due to lower temperatures decreasing SOM decomposition rates, as well as probably higher mean annual precipitation. These are probably the most likely areas to become sources of N2O or dissolved N upon SOM decomposition due to global warming or land use change.

4.1.1. Factors controlling total N

Apparently, the main environmental factor to influence soil N contents across the steady region was soil texture. Generally, fragments with high N contents also showed high clay contents (Figures 5, 7, 9) and vice versa.

However, soil texture was not the only factor to influence soil N, since rainforests soils did not follow the same pattern. In fact, when these two soils are compared, the higher average N levels in all depths occurred in the soil with lower clay contents (Figure 2). This exception clearly shows that the montane climate plays an important role on soil N, although small variations in elevation appear to have no expressive effect on the regional scale. By comparing data in Table 1, it is possible to note that the rainforest plots sampled at R2 are located about a 100 m above those sampled at R1, which also is approximately 160 km north. It is likely that these trends are due to differences in plant biomass, temperature and/or precipitation, not measured in this work.

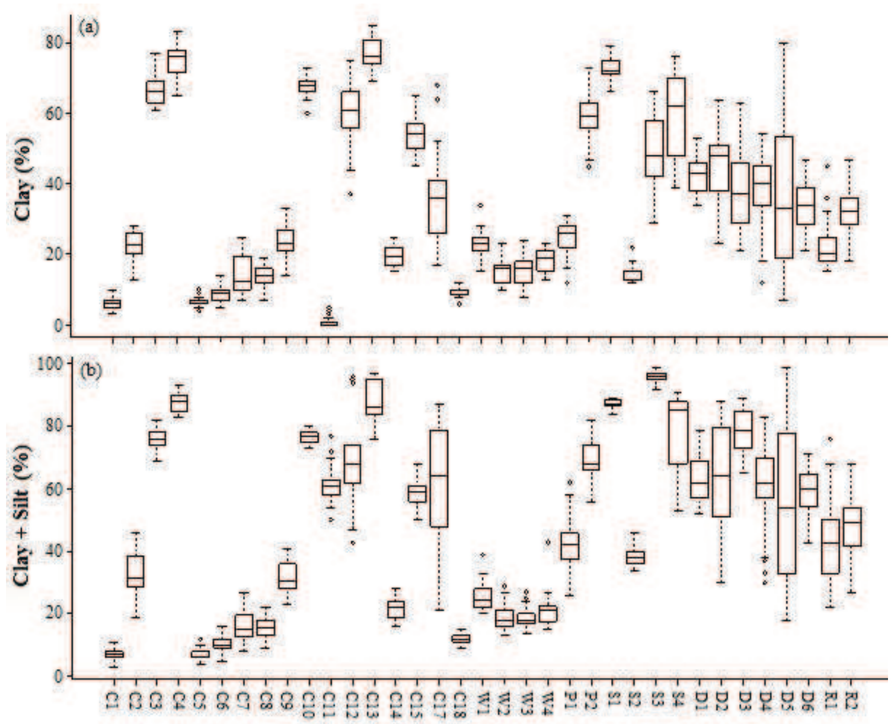

Figure 9 – Observed (a) clay and (b) clay + silt content (%) at the studied forest fragments, averaged for the 0-100 cm depth.

4.1.2. N stratification ratio

When N stratification ratio (SR) data were grouped by phytophysiognomies (Figure 3b), the average difference of SR increased in the following order: Prairie < Cerrado *sensu stricto* = Woodland = Semideciduous = Deciduous < Rainforest. Thus, three different groups were basically formed: the prairies, presenting the lowest SR; the rainforests group, with the highest SR; and an intermediary group comprising the other vegetation types with similar means among them.

According to De Deyn et al. (2009), differences in plant species richness and functional groups influence the storage and loss of C and N, but these processes are also related to biomass and the presence of some species, notably those in symbiosis with N-fixing organisms. The Brazilian Cerrado prairie is the phytophysiognomy with the lower aboveground vegetation biomass in comparison to the other vegetation types, and is basically a grassland known as 'open savanna formation' by some authors (MÜLLER, 1979). As a result, less SOM is expected to be found on soil surface in comparison to deeper layers, what justifies the low SR found. Indeed, Skorupa et al. (2012) noted that prairies show the lowest SOM levels for the 0-20 cm layer, in accord with data presented here. The opposite takes place with rainforest areas, where rich and dense vegetation can be found and intense litter fall occurs. Additionally, the rainforest fragments are located at higher altitudes with more steep slopes, resulting in shallower soils with lower permeability that tends to concentrate SOM in the surface layers.

As proposed by Jobbágy and Jackson (2000) for soil C, this study showed that vegetation – through patterns of biomass allocation and root distribution – can be the main factor affecting the relative vertical distribution of N in soil profiles. According to Franzluebbers (2002), higher organic matter levels at the soil surface, and consequently of soil N, are critical because most of the exchanges in energy, water, gases and nutrients occur at the soil surface, strongly affecting soil productivity and quality. On the other hand, in a scenario of anthropogenic climate change, storage of SOM and N in deeper soil layers can represent a more stable and protected nitrogen pool (JOBBÁGY; JACKSON, 2000).

4.2. Predicting soil N under native vegetation in Minas Gerais

The equations presented at Table 4 suggest that altitude has a determinant, positive effect on N contents in superficial soil layers (0-10 and 10-20 cm depth). These results were already expected considering the effect of altitude as decreasing mean annual temperature and increasing precipitation (BARRY; CHORLEY, 2003), which simultaneously favors plant growth and slows down microbial decomposition (GARTENJUNIOR et al., 1999; QUIDEAU et al., 2001; STEVENSON, 1994). The lack of any apparent effect at depths <20 cm is in agreement with the proposed by Jobbágy and Jackson (2000) that SOM and N retention in surface layers is determined more by soil properties than plant biomass.

Values for SOM and CEC were significant in all cases, demonstrating in the first case the direct relation of SOM and soil N contents, and its intrinsic but not causal relationship with CEC. In highly weathered soils of the humid tropics common in Minas Gerais, CEC depends greatly on SOM levels (MENDONÇA; ROWELL, 1996). Indeed, SOM is given much more weight in the predictive equation than the other factors.

Soil texture was also an important parameter to estimate total N. However, despite the positive correlation with clay + silt contents and 0-100 cm N stocks (Figure 7), in the predictive equation of Table 4, clay content is associated with a negative effect on N concentrations. Although this may seem contradictory, in fact it must be interpreted as a corrective factor for the positive, much stronger effect of SOM concentrations, similarly to the positive effect of depth in the equation for the 0-100 cm depth.

4.3. Nitrogen stocks and affecting factors

The results obtained for N stocks can be related to differences in altitude and phytophysiognomies sampled, since the highest values occur in montane rainforests, whereas the lowest values occur under Cerrado *stricto sensu*. The higher N stocks in the rainforests, in relation to other fragments, may also be due to dense canopy and higher input of litter and root exudates, which results in maximum amounts of N stored in the whole profile. Also, optimal conditions for soil N-fixing organisms in the rainforests could not be discharged as the main determining factor of the high N stocks found in such soils, as stated by Silva et al. (2012) for soil carbon.

There was apparently no direct effect of latitude and longitude (Figure 7) over the N stocks of Minas Gerais. Altitude showed a good positive correlation with the N stocks, what was also found by Dai and Huang (2006). In general, for each increment of 170 m in altitude, there is a decrease of 1 °C in the temperature, so the effect of altitude on the soil N content, in fact, might be due to the control that temperature exerts on SOM decomposition rate (ALVAREZ; LAVADO, 1998; BARRY; CHORLEY, 2003; LIU; SHAO; WANG, 2011; QUIDEAU et al., 2001).

The particle size distribution correlated strongly with N stocks at Minas Gerais (Figure 7). Soil texture is a determinant factor on soil N and it is often used to explain soil its content (CALLESEN et al., 2003; JOBBÁGY; JACKSON, 2000; MAIA et al., 2008; VEJRE et al., 2003) as well as its mineralization rate (CÔTÉ et al., 2000; GIARDINA et al., 2001). The influence of soil parent material is linked to its role in texture, mineralogy, and soil fertility. According to Baldock and Nelson (2000), rocks that give origin to sandy soils, especially in the tropics, cause low levels of SOM and N in soil. Furthermore, there is a direct correlation with clay contents and good conditions for plant growth and the subsequent increase in SOM (BALDOCK; NELSON, 2000; FELLER; ALBRECHT; TESSIER, 1996; OADES, 1988,). It is known that SOM usually becomes protected in the interior of soil aggregates and, when adsorbed by soil clays (CAMARGO; GIANELLO; VIDOR, 1997; SIX et al., 2002; ZINN; LAL; RESCK, 2005), soil decomposers have limited access to SOM. Oades (1988) stated that in clayey soils there are more cationic bridges able to retain organic molecules, what may be an important mechanism of SOM protection in the Brazilian acid soils that are rich in Al and Fe oxides.

N stocks in the whole soil profile is intimately associated to the soil clay + silt weighted means ($R^2 = 0.63$) as presented in Figure 7a. This relationship could be improved ($R^2 = 0.77$) if data of the two montane rainforests are excluded (Figure 7b). This suggests that in soils located in altitudes > 1,500 m and, in consequence, with lower temperatures, the effect of soil texture in protecting SOM against decomposers is superseded by the lower SOM decomposition rate.

5. Conclusions

In this study, it was examined soil total nitrogen contents and stocks and the effects of environmental factors on the N stocks across Minas Gerais forest fragments. The average N contents in soil profiles are enclosed in the range of 0.12and7.54 g kg^{-1}. Vertical distribution of total N depends on the phytophysiognomy investigated and, as a function of soil depth, it is best fitted to a specific exponential equation for each phytophysiognomy studied. The mean stratification ratio for soil N varied from0.78 to 5.22, and such intense amplitude of variation brings some concerns bearing in mind that, in a scenario of intensified global warming, the soils with higher N contents in surface are prone to lose N gaseous forms to the atmosphere. N contents and stocks are higher in surface layers in relation to subsoil, and the vertical distribution of N is regulated by vegetation types. Vegetation explains part of the variance in soil N contents and its distribution in soil profiles. As a function of the studied phytophysiognomies, soil N stratification ratio showed the following increasing order: Prairie < Cerrado *stricto sensu* = Woodland = Semideciduous = Deciduous < Rainforest. N stocks varied dramatically among the forest fragments, in the range of 1.38 to 39.4 Mg ha^{-1}, considering the 0-100 cm soil layer. The stocks are significantly and positively correlated with altitude, clay, silt and clay + silt, while latitude and longitude seem not to be good predictors for soil N in Minas Gerais. At the R1 and R2 (montane rainforest fragments), where altitude is higher than 1,500 m, its effect overcome part of the protection of N assured by clay + silt against decomposers. Amongst the factors tested, SOM, CEC, clay content and altitude are reliable predictors of soil N, being used in most of the PTFs generated in this work. These functions allow estimating N contents, with a small uncertainty, in the different soil layers of Minas Gerais.

(Preliminary version of the article)

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