ALTERATIONS IN SOIL PROPERTIES INDUCED BY PASSIVE RESTORATION BY *Clidemia urceolata* DC IN THE ATLANTIC RAINFOREST OF BRAZIL

Felipe Araujo Mateus[1*], Ricardo Valcarcel[1], Mateus Marques Bueno[2], Kenedy Donizete Ribeiro da Mota[1]

[1*] Federal Rural University of Rio de Janeiro, Seropédica, Rio de Janeiro, Brazil – felipearaujomateus@gmail.com*; ricval@ufrrj.br; kenedymota@gmail.com
[2] Federal Institute of Education of Minas Gerais, São João Evangelista, Minas Gerais, Brazil – mateus.bueno@ifmg.edu.br

Received for publication: 17/01/2018 - Accepted for publication: 16/05/2018

Abstract

The passive restoration induced by nuclei of *Clidemia urceolata* affects the successional dynamics of ecosystems, and these in turn influence the physical and chemical characteristics of soils depleted by disturbed pastures, creating a positive synergy between the soil and the vegetation. This study evaluated the physical and chemical properties of the top 30 cm of the soil. This was carried out at the Federal Institute of Rio de Janeiro (IFRJ), Pinheiral Center, in the municipality of Pinheiral, state of Rio de Janeiro, Brazil, at five sampling sites with similar soil and physical environments. All the sites were pastures abandoned for different periods: 3 years of passive restoration (Site 1), 8 years (i.e., in an initial stage of colonization by plants; Site 2), 14 years (i.e., in an intermediate stage of colonization by plants; Site 3), 19 years (i.e., in an advanced stage of colonization by plants; Site 4), and 34 years (i.e., covered by fragments of secondary forest; Site 5). The following parameters were measured in the center of each site: a) mechanical resistance of the soil to penetration, b) apparent density, c) total porosity, d) macroporosity, e) microporosity, f) hydraulic conductivity, and g) nutrient content. The greatest contrasts in soil data were registered between 0 and 10 cm of depth, demonstrating the soil restoration done by the vegetation during passive restoration over 34 years. The development of *Clidemia urceolata* after 14 years is a key determinant of soil recovery, which modified its physical and chemical properties and created conditions for the environment to permit the growth and development of tree species, and the formation of forest fragments in less than 34 years of passive restoration, with no need of any additional efforts for the restoration of the disturbed areas.
Keywords: Ecological succession, soil restoration, forest fragments.

Resumo

Alterações edáficas promovidas pela restauração passiva em núcleos de Clidemia urceolata *DC na Mata Atlântica*. A restauração passiva promovida pelos núcleos de *Clidemia urceolata* influencia na dinâmica sucessional dos ecossistemas e estes, nas características físicas e químicas dos solos empobrecidos pelas pastagens perturbadas, criando sinergia positiva entre solo e vegetação. Este estudo avaliou as propriedades físicas e químicas do solo nos primeiros 30 cm de profundidade. Ele foi feito no Instituto Federal do Rio de Janeiro (IFRJ - Núcleo Pinheiral) em cinco sítios amostrais com solos e atributos do meio físico similares, sendo todos derivados de pastagens abandonadas em diferentes períodos: Sítio 1 (3 anos de restauração passiva, pastagem abandonada); Sítio 2 (8 anos, estádio inicial de colonização); Sítio 3 (14 anos, estádio intermediário de colonização), Sítio 4 (19 anos, estádio avançado de colonização); e Sítio 5 (34 anos, fragmento de floresta secundária). Os seguintes parâmetros foram mensurados no centro dos núcleos: a) Resistência mecânica do solo à penetração; b) Densidade aparente; c) Porosidade total; d) Macroporosidade; e) Microporosidade; f) Condutividade Hidráulica; e g) Nutrientes. Os maiores contrastes de dados do solo foram registrados entre 0 e 10 cm de profundidade, evidenciando os trabalhos edafogênicos da vegetação na restauração passiva ao longo de 34 anos. O desenvolvimento de *Clidemia urceolata* após os 14 anos constituiu um fator diferencial na recuperação do solo, modificando suas propriedades físicas e químicas. Além disso, criou condições para que o meio permitisse abrigar e desenvolver espécies arbóreas e formar fragmento florestal em menos de 34 anos de restauração passiva, sem necessidade de adição de energia para restaurar áreas perturbadas.
Palavras-chave: Sucessão ecológica, restauração do solo, fragmento florestal.

INTRODUCTION

Abandoned areas in the Brazilian Atlantic Rainforest involving inadequate management, the effect of economic infeasibility which could not sustain rural populations and which was unable to utilize sustainable and productive technology, occupy a substantial part of its hydrographic basins (TURCHIN; NEFEDOV, 2009).

These areas were intensively used in the recent past for growing coffee and grazing cattle, which were considered to be highly potential agricultural activities.

In these areas, low productivity restricts the options for intensive land use and extensive cattle grazing become customary, thereby intensifying both the degradation processes and impoverishment of the soil, thus impairing the socioeconomic activities of the rural properties within the hydrographic basins.

In locations where these economic cycles occurred, there are damages to nutrient cycling, physicochemical properties, and collection and retention of humidity in the soil, which gradually reduce the capacity for supporting the ecosystems (DALY; FARLEY, 2003; SOUZA *et al*., 2005) and, consequently, economic activities. Thus, they function as negative feedback mechanisms for controlling the rate of resource depletion and sustain the supply of ecosystem services in different parts of these areas, such as the floodplains (BAPTISTA *et al*., 2017).

However, in those areas, which still maintain a minimum supply of environmental attributes related to ecological factors, such as exposure, toposequence, and proximity to forest fragments, it is possible to observe the process of passive restoration by tree and shrub species (REZENDE *et al*., 2015) by means of induced ecological succession (MARTINS *et al*., 2017). Passive restoration occurs spontaneously through the colonization of facilitating species, which promote positive and synergistic interactions between individual trees and accelerate the ecological succession (BECHARA *et al*., 2016; AERTS *et al*., 2007).

In abandoned pastures, colonization by *Clidemia urceolata,* which occurs from Central America to the Southern Brazil (MICHELANGELI; REGINATO, 2015), contributes to the reestablishment of the water balance and nutrient cycling within the ecosystems (MATEUS *et al*., 2013; DINIZ *et al*., 2013). *Clidemia urceolata* is a rustic species, which provides facilitation mechanisms and forms restoration nuclei in full sunlight. It has specific ecological preferences (MIRANDA *et al*., 2015), gregarious tendencies, propagates vegetatively by its roots, and produces edible fruits for the birds that disperse propagules. As it develops, it modifies its physical environment and alters the humidity by adding leaf litter to the surface (MATEUS *et al*., 2013), in addition to adjusting the distribution of water in the soil through its root system. This species facilitates the restoration of forest ecosystems of the Atlantic Rainforest and promotes the synergy for enriching forest fragments in the process of ecological succession (MIRANDA *et al*., 2015).

The restoration of ecosystems with chemically and physically exhausted soil, produced by inappropriate agricultural practices in the past, can happen partly owing to the altered pedogenetic processes (CORREA, 2002; MORRIEN *et al*., 2017), because the availability of air and water supplies for plant roots depends on the horizontal surfaces of the soil, which are altered during these processes (SILVA *et al*., 2006). Forest regeneration through plant/soil interaction fosters improvements in soil attributes, which contributes to increasing the organic carbon content and macroporosity and reducing the density of the soil (COUTINHO *et al*., 2017).

The aim of the present study was to conduct a survey and characterize the effects of the passive restoration process, driven by the effects of colonization by the facilitator species *Clidemia urceolata* DC, on the physical and chemical properties of the top 30 cm of the soil. It was expected that this would provide information on the physicochemical properties of the soil during the restoration process in order to contribute towards the perfection of nucleation techniques in forest restoration of abandoned pastures.

MATERIAL AND METHODS

Sampling

The characterization of the physical and chemical properties of the soil colonized by *Clidemia urceolata* was performed in five sampling sites at different ages and stages of development of their ecosystems. However, all originating from the same land use matrix consisting of abandoned pastures with the history of their use known to the Pinheiral campus of the Federal Institute of Rio de Janeiro (IFRJ). These areas have similar declivity, features, altitude, exposure, relative position in the toposequence, water-collecting area uphill, and distance from a source of propagules. The soil was described as Dystrophic Yellow Oxisoil with a loamy texture according to the "Manual for Describing and Collecting Soil in the Field" (SANTOS *et al*., 2015), which allows us to assume that the environmental attributes resulting from the combination of these effects on the physical environment are similar.

These sites were defined as follows: Site 1 (S1) – 3 years in the process of abandoned pasture restoration; Site 2 (S2) – 8 years in the process of passive restoration, with a nucleus of *Clidemia urceolata* in the initial stages of colonization; Site 3 (S3) – 14 years in the process of passive restoration, with a nucleus of *Clidemia urceolata* in the intermediate stages of colonization and seven individual trees); Site 4 (S4) – 19 years in the process of passive restoration, with a nucleus of *Clidemia urceolata* in the advanced stage of colonization, consisting of 20 individual trees; Site 5 (S5) – 34 years in the process of passive restoration based on colonization by

.ISSN eletrônico 1982-4688
DOI: 10.5380/rf.v48i4.57472

Clidemia urceolata, which has become a fragment of a secondary forest, consisting of 62 individual trees, without *Clidemia urceolata*, in shrub form but only in the seed bank (Table 1).

Table 1. Floristic characteristics of the stages of passive restoration based on colonization and facilitation using *Clidemia urceolata*: soil texture and species of the arboreal strata.
Tabela 1. Características florísticas dos estádios de restauração passiva a partir da colonização e facilitação de *Clidemia urceolata*: textura e espécies do estrato arbóreo.

Treatment	Soil texture	Species in the arboreal strata (no. of individuals)
3 years	Loamy	0
8 years	Loamy	0
14 years	Loamy	*Cecropia pachystachya* Trécul (3); *Handroanthus ochraceus* (Cham.) Mattos (1); *Machaerium hirtum* (Vell.) Stellfeld (1); *Psidium guineense* Sw. (1); *Rapanea ferruginea* (Ruiz & Pav.) Mez (1)
19 years	Loamy	*Cecropia pachystachya* Trécul (17); *Casearia sylvestris Sw.* (3)
34 years	Loamy	*Siparuna guianensis* Aubl. (25); *Cecropia pachystachya* Trécul (16); *Sparattosperma leucanthum* (Vel.) K. Schum (6); *Schinus terebinthifolius* Raddi (5); *Casearia sylvestris* Sw. (3); *Eugenia florida* DC. (2); *Astrocaryum aculeatissimum*(Schott) Burret (2); *Casearia sp.* (1); *Guarea guidonia* (L.) Sleumer (1); *Miconia prasina (Sw.) DC.* (1)

Physical attributes of the soil

Mechanical resistance to soil penetration (MRP)

The mechanical resistance of the soil to penetration (MRP) was determined using an impact penetrometer (IAA/Planalsucar-Stolf). The measurements were done at a depth of 30 cm, totaling 10 sample points per site. The choice of the sample points was random, in the center of each site, within a grid of 50 chosen points. The collection was performed during the dry season (July 2016), after a period of 20 days without rain.

In the literature consulted, there was no consensus in relation to the values or ranges of values of MRP, which limit the development of root systems of either forest species or agricultural crops. In the present study, we adopted the values used by Couto *et al*. (2016) in a study on pastures, forests, and agro-forestry systems. The author divided his observations into three classes: no restriction to root penetration, with MRP values less than 2 MPa; restrictive to root penetration, with MRP values of between 2 and 3.5 MPa; impeditive to root penetration, with MRP values greater than 3.5 MPa.

Apparent density and soil porosity

Three parcels were selected for the removal of intact samples at a depth of 5 cm (for the layer of soil located between 0 and 10 cm) and 20 cm (for the layer between 10 and 30 cm). This procedure was performed for all the five phases of restoration, with the information being collected in August 2016. An Uhland auger with a ring with volume of 104.08 cm^3 was used. The undeformed samples were taken to the laboratory in order to determine the apparent density, microporosity, macroporosity, and total porosity. The tests were performed according to the methodology proposed by Donagema *et al*. (2011).

Hydraulic conductivity of saturated soil

The hydraulic conductivity of saturated soil is comparable to the infiltration rate of water in the soil, which interferes in water drainage through the soil (MESQUITA *et al*., 2007). Three parcels were randomly selected at each sampling site, where the collection was performed at a depth of 5 cm (for the layer of soil located between 0 and 10 cm) and again at 20 cm (for the layer between 10 and 30 cm). This analysis was performed at all five phases of restoration, totaling 30 samples in August 2016. The undeformed samples were collected using an Uhland auger with a ring with volume of 104.08 cm^3, sealed with gauze at both extremities and carried to the laboratories. In the laboratory, a test of the rate of water flow (in millimeters per hour) was performed. In addition, this flow was transformed into hydraulic conductivity according to the methodology proposed by Donagema *et al*. (2011).

Chemical attributes of the soil

The soil samples for this test were collected at a depth of 0 – 10 cm, in the center of the sampling sites, because this layer is considered to be organic and contains the highest quantity of nutrients. At each sampling site, five composite samples were collected in July 2016, with each composite sample composed of a mixture of five individual samples, collected at random within the sampling areas, and homogenized in a clean plastic tray. The chemical attributes of the soil, including pH, phosphorus (P) content, potassium (K) content, calcium (Ca) content, magnesium (Mg) content, aluminum (Al) content, and organic carbon (C org.) content, were studied. The soil analyses were performed according to the methodology proposed by Donagema *et al*. (2011).

Statistical analysis

The MRP was described according to the IAA/Planalsucar-Stolf user's manual and separated into three classes, according to the values utilized by Couto *et al*. (2016).

The apparent density, total porosity, microporosity, macroporosity, hydraulic conductivity, and chemical attributes were evaluated using the ANOVA test. This was performed after the normality and homogeneity tests, and with a post-hoc Tukey's test of significance at the 5% level, in cases with a significant difference. These analyses were performed using the R 3.3.1 (R Core Team, 2016).

In the case of apparent density, total porosity, microporosity, macroporosity, and hydraulic conductivity, the difference between the five sites at two distinct depths was evaluated, whereas the chemical attributes were evaluated at a single depth. The parameters attended the prerequisites of ANOVA test, and data transformation was not necessary.

RESULTS

Mechanical Resistance to Soil Penetration (MRP)

The chronology of the census of arboreal species in the passive restoration process (Table 1) shows an absence of individual trees until 8 years after introducing *Clidemia urceolata*, representing maintenance of overgrown pasture, with all the resulting risks and consequences in areas where extensive cattle grazing prevailed, and burning underbrush to clear the land is a cultural tradition. Moreover, the introduction of new species and individual trees consolidates the ecological succession in ecosystems, which grew to five species (seven individuals) after 14 years. Accordingly, there was a change in the environment, with a reduction in the initial colonizing species and an increase in the number of individual trees (20), with the numbers reaching to ten species and 62 individuals after 34 years, which confirms a dynamic process of colonization in these ecosystems during the restoration process. This factor indicates sustainability in the tendency towards restoration, due to the acquired resilience and forest growth with its ecosystem services.

The MRP interferes from the introduction of seeds and propagating material to the colonization of new species in the ecosystem, especially in the top few centimeters of the soil, because it inhibits the development of the root system. The MRP value after 3 years shows the difficulty in the establishment of new species in abandoned pastures. Because of this difficulty, *Clidemia urceolata* plays an important role in the restoration process, in which it forms clustered groups capable of reducing the MRP in the top 5 cm of soil to 2.5 MPa over 11 years of development (Figure 1). During the passive restoration process, 34 years of intervention were sufficient for reducing the MRP in the top 5 cm of soil to 1.75 MPa, as compared with that in the 3 years abandonment treatment, which is an essential factor for the colonization of new species (Figure 1).

In the layer from 5 to 15 cm, the values of MRP moved away from the improvements achieved in the layer from 0 to 5 cm and approached those of the deeper layers, in which the effects of the restoration process are not observed (Figure 1). From the depth of 15 cm onwards, soil resistance values remained in the class, which impedes root penetration, and alternated between 4 and 5.5 MPa. Moreover, the soil conditions in layers shallower than 20 cm in the area subjected to 3 years of passive restoration (disturbed pastures) improved (Figure 1), which may be related to bunched root systems in grasses, which develop in the upper layers of the soil.

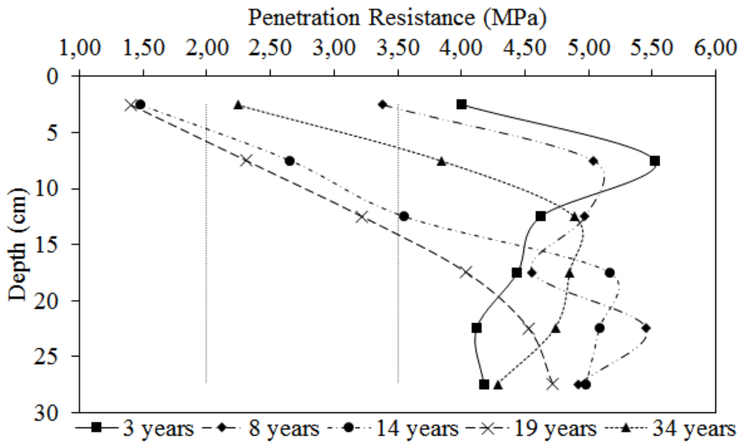


Figure 1. Penetration resistance in the center of passive restoration nuclei in five distinct evolutionary periods based on abandoned pastures in the middle stretch of the Paraíba do Sul River, IFRJ, Brazil.

Figura 1. Resistência à penetração no centro dos núcleos de restauração passiva em cinco fases distintas de evolução, a partir de pastagens abandonadas na região do médio Paraíba, IFRJ.

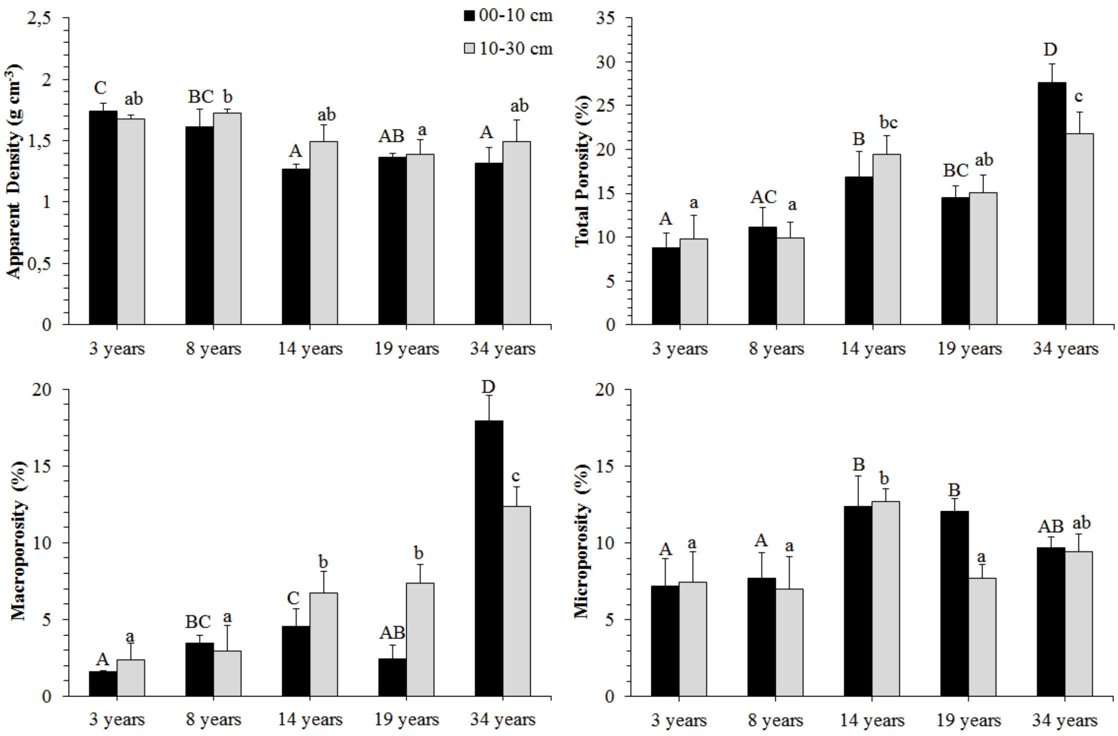
Apparent density and soil porosity

The apparent density reached 1.27 $g \cdot cm^{-3}$ after 14 years of the passive restoration process in the layer at a depth of 0 – 10 cm, confirming the edaphogenic effects resulting from the passive plant restoration promoted by *Clidemia urceolata* in the center of its nuclei. In the layer of soil between depths of 10 and 30 cm, the effects were perceived only after 19 years (1.39 $g\ cm^{-3}$) (Figure 2).

Total porosity at a depth of 0 – 10 cm after 14 years of the passive restoration process (17%) doubled as compared with that after 3 years of abandonment (9%), and it reached 28% after 34 years of restoration. At a depth of 10 – 30 cm, total porosity reached 22% after 34 years of the restoration process, which differed significantly from that of the other areas, except for the area with 14 years of restoration (20%) (Figure 2).

Macroporosity showed gradual recuperation after 14 years of restoration (5%) in the layer at a depth of 0 – 10 cm. However, it decreased after 19 years (3%), and subsequently increased six-fold after 34 years (18%). The restoration of the macropore network at a depth of 10 – 30 cm occurred gradual, presenting a significant difference after 14 years (7%) and reaching its highest value (12%) after 34 years of the passive restoration process (Figure 2).

Microporosity in the layer at a depth of 0 – 10 cm remained stable during the first 8 years of the restoration process (7 – 8%), but increased at 14 and 19 years (12%). In the layer at a depth of 10 – 30 cm, microporosity remained practically stable during the entire time interval evaluated for the restoration process, except at 14 years (13%), when it presented growth during the intermediate stage of development of *Clidemia urceolata* (Figure 2).



The same upper-case letters for the layer of soil at a depth of 0 – 10 cm and the same lowercase letters for the layer of soil at a depth of 10 – 30 cm do not differ significantly from each other in Tukey's test at a level of 5% probability.

Figure 2. Apparent density, total porosity, macroporosity, and microporosity in five phases of the passive restoration process driven by the colonization of abandoned pastures by *Clidemia urceolata*.

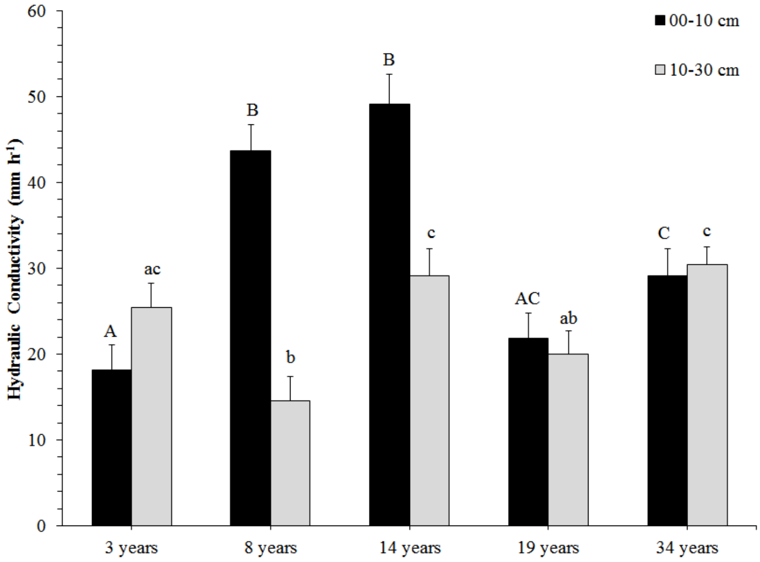
Figura 2. Densidade aparente, porosidade total, macroporosidade e microporosidade em cinco fases distintas do processo de restauração passiva a partir da colonização de pastagens abandonadas pela espécie *Clidemia urceolata*.

Hydraulic conductivity of saturated soil

The level of hydraulic conductivity in the layer at a depth of 0 – 10 cm after 3 years (18 mm·h^{-1}) increased significantly after five more years had elapsed (44 mm·h^{-1} at 8 years) (Figure 3), which favored the infiltration of water in the soil and the processes leading to this infiltration substantially. Moreover, it tended to reduce surface runoff, which is the principal degrading agent and key element in creating erosive processes in abandoned pastures in this hydrographic basin.

Hydraulic conductivity in the soil reached its highest value after 14 years of the restoration process (49 mm h^{-1}) (Figure 3); however, after 19 years, the hydraulic conductivity of the soil returned to the same level as it had after 3 years (18 mm·h^{-1}), thereby elucidating the predominant role of *Clidemia urceolata* after 8 and 14 years.

In the layer between 10 and 30 cm of depth, alternations were observed in the values of hydraulic conductivity with the advancement of the restoration process, which were not significantly different after 3 years (26 mm·h^{-1}), 14 years (29 mm·h^{-1}), and 34 years (31 mm·h^{-1}) (Figure 3).



The same upper-case letters for the layer of soil at a depth of 0 – 10 cm, and the same lowercase letters for the layer of soil at a depth of 10 – 30 cm, do not differ significantly from each other in Tukey's test at a level of 5% of probability.

Figure 3. Hydraulic conductivity of the soil in different phases of evolution of the passive restoration process driven by the colonization of abandoned pastures by *Clidemia urceolata*.

Figura 3. Condutividade hidráulica do solo nas diferentes fases de evolução do processo de restauração passiva a partir da colonização de pastagens abandonadas pela espécie *Clidemia urceolata*.

Chemical attributes of the soil

The introduction of ecological restoration and nutrient cycling favors the recovery of the chemical attributes of the soil. The concentration of Ca after 3 years (1.6 $Cmol_c \cdot dm^{-3}$) was reduced to half after 8 years (0.7 $Cmol_c \cdot dm^{-3}$); however, it nearly tripled after 14 years (2.5 $Cmol_c \cdot dm^{-3}$) and reached its highest concentration after 34 years of passive restoration (4.3 $Cmol_c \cdot dm^{-3}$; Table 2).

Magnesium (Mg), concentration reduced when in the first 8 years, but increased in accordance with the colonization by *Clidemia urceolata* nuclei. These differences reached statistically significant levels after 19 years (2.3 $Cmol_c \cdot dm^{-3}$) as compared with that after 3 years (0.9 $Cmol_c \cdot dm^{-3}$) and 8 years (0.5 $Cmol_c \cdot dm^{-3}$). The concentration of potassium (K) tripled after 14 years of the passive restoration process (0.4 $Cmol_c \cdot dm^{-3}$) as compared with the values after 3 years (0.1 $Cmol_c \cdot dm^{-3}$) and 8 years (0.1 $Cmol_c \cdot dm^{-3}$; Table 2).

Aluminum (Al) concentration reached 1.6 $Cmol_c \cdot dm^{-3}$ after 8 years, its concentration reduced to one-fifth of that value after 14 years (0.3 $Cmol_c \cdot dm^{-3}$), and it dropped to a lower level after 19 years (0.1 $Cmol_c \cdot dm^{-3}$). The soil pH level was altered with the advancement of ecological succession; however, the concentration of organic carbon (C org) and phosphorous (P) did not change appreciably during the 34 years of the passive restoration process (Table 2).

Table 2. Chemical analysis of the soil at a depth of 0 – 10 cm in different stages of passive restoration driven by the colonization of abandoned pastures by *Clidemia urceolata*.

Tabela 2. Análise química do solo nos diferentes estágios de restauração passiva a partir da colonização de pastagens abandonadas pela espécie *Clidemia urceolata* na profundidade de 0 a 10 cm.

Treatment	pH	P	C org.	Ca	Mg	K	Al
	H_2O	mg/L	%	------------- $Cmol_c/dm^3$ ----------			
	------------------------------- 0-10 cm -----------------------------------						
3 years	4,7 b	17,4 a	1,6 a	1,6 ab	0,9 a	0,1 a	0,6 b
8 years	4,2 a	18,0 a	2,0 a	0,7 a	0,5 a	0,1 a	1,6 c
14 years	4,9 c	18,2 a	1,6 a	2,5 b	1,4 ab	0,4 b	0,3 ab
19 years	5,1 cd	17,2 a	1,8 a	3,7 c	2,3 b	0,2 ab	0,1 a
34 years	5,2 d	18,2 a	1,5 a	4,3 c	2,0 b	0,4 b	0,2 a

The same letters in a given column indicate non-significant differences, according to Tukey's test at a level of 5% of probability.

DISCUSSION

Areas of abandoned pastures with few trees having short life cycles, scarce plant coverage, and a low density of roots in the porous soil, subjected to brush fires and grazing by herbivores have soil exposed to climatic adversities. Furthermore, they have at a high risk of suffering erosion, exposing the subsurface layers to torrential rains, and a high risk of suffering continual processes of degradation.

The soils in Southeast Brazil have a low potential for intensive use as arable land or pasture, leading to the abandonment of the fields after 20 – 30 years of use (MARTINS *et al*. 2015). The following characteristics impede root development, affecting edaphization processes, which involve both chemical and physical factors, such as apparent density, total porosity, microporosity and macroporosity. Furthermore, they impede water infiltration and increase superficial flows, which lead to superficial runoff and soil loss, thus degrading both slopes and lowlands, as well as water quality.

The pedogenetic processes undergo qualitative and quantitative alterations in the soil at a depth of 0 – 10 cm after 8 years of the introduction of *Clidemia urceolata* (Site 2). The nuclei formed owing to its influence, in both the plant canopy and the accumulated leaf litter, provide protection to the soil and facilitate water infiltration, in addition to serving as a source of forming nutrients and humic substances (MATEUS *et al*., 2013). The action of these agents improved the soil conditions and structure, and reduced the resistance of the soil, thereby facilitating germination and the establishment of new trees in the developing ecosystems. In addition, it increased macroporosity, which interferes directly in the improvement of hydraulic conductivity. This greater infiltration homogenized the distribution of water within the soil profile. In this area, the highest concentration of aluminum was detected, which was formed by the deterioration of leaf litter and the infiltration of precipitated water-bearing nutrients absorbed from the plant cover. In addition, these values, based on studies on abandoned pastures, are lower than those in the Atlantic Rainforest ecosystem, which is in the process of passive restoration for 9 – 11 years (MARTINS *et al*., 2015).

The dynamics of the number of species and individual trees after 14 years (Site 3) indicate the synergistic effects on the ecosystem, which are reflected in other variables, as in the case of advancement in pedogenetic processes. The MRP was modified after an interval of 6 years, and it improved from the class of “restrictive” to that of “not restrictive” in the layer at a depth of 0 – 5 cm. According to Couto *et al*. (2016), this change is a reflection of better management of this area, which provides protection to the soil owing to increased plant coverage. Such factors enable the germination and development of new species belonging to advanced levels of succession. In this phase of the passive restoration process at a depth of 0 – 10 cm, the apparent density, total porosity, macroporosity, and microporosity were positively and significantly affected, as compared with the stage equivalent to 8 years of growth. The development of these physical attributes of the soil is considered to constitute an ecosystem service provided by the development of nuclei of *Clidemia urceolata*, which endows the soil with the means to sustain the advancement of ecological succession.

The introduction of new shrub and tree species after 19 years of the process of passive restoration (Site 4) maintained the MRP, apparent density, microporosity, and total porosity as compared with those after 14 years of this treatment. The advanced development of *Clidemia urceolata* and the new species composition in the ecosystem present a greater demand for resources, generating an increase in the absorption of nutrients from the soil. This is sustained by the new physical and chemical conditions of the soil, which make greater quantities of C and Mg available. According to Cardoso *et al*. (2012), the quantity of N, P, K, and Ca available in the soil is positively related to root growth of the plant species and to their correct phenological activity.

In the forest fragment with 34 years (Site 5), the occurrence of 18% macropores was double of that reported by Ortiz *et al.* (2017) in the ultisoil in a forest fragment in the Atlantic Rainforest of the Brazilian state of Pernambuco. Coutinho *et al*. (2017) found 17% macropores in inceptisol in a forest fragment in the same basin. The increase in macropore occurrence causes an increase in water infiltration, and the micropores retain this water for utilization by the plants (ORTIZ *et al*., 2017). The presence of trees of larger size (6 m) caused a change in the class of MRP in the soil layer at a depth of 0 – 5 cm, which is a consequence of the interlacing of their roots.

The difference in the physical attributes in soils at different depths is a result of the restoration process using the plant/soil interaction in the surface layer (0 – 10 cm), which undergoes the initial effects of the process of ecological restoration. This surface layer is a source of resources for the species of the ecosystem during their entire life cycle, which makes its recovery indispensable for the success of the restoration process.

.ISSN eletrônico 1982-4688
DOI: 10.5380/rf.v48i4.57472

CONCLUSION

- The advancement of the passive restoration process by using *Clidemia urceolata* modifies the pedogenetic processes, thereby altering the chemical and physical attributes of the soil.
- *Clidemia urceolata* acted directly over 14 years, creating the means for the other species to interact and continue the process of improving the physical and chemical conditions of the soil. This occurred over 34 years of forest restoration, when the tree species performed their ecological functions as forest fragments.
- After 34 years of the passive restoration process, it was observed that the macropore values increased nine times as compared with the values for the abandoned pastures, whereas hydraulic conductivity continued to increase. Together, these variables were responsible for the increase in water infiltration in the soil, which tends to recharge the reserves in the soil.
- This evidence suggests that the passive restoration process can be improved by using *Clidemia urceolata* for inducing regeneration in the locations preferred by it during the first 8 years; thereafter, the ecosystem determines its own subsequent growth.

ACKNOWLEDGMENTS

We thank the Post-Graduate Program in Environmental and Forest Sciences of the Federal Rural University of the state of Rio de Janeiro (PPGCAF/UFRRJ) for the opportunity to refine the studies of the first author. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. We also wish to thank the Federal Institute of Rio de Janeiro, in Pinheiral, state of Rio de Janeiro (IFRJ) for the logistic support they offered, and the Brazilian Institute of the Environment and Renewable Natural Resources (ISOLUX CORSÁN/IBAMA) for their support in our field work for this study.

REFERENCES

AERTS, R.; NEGUSSIE, A.; MAES, W.; NOVEMBER, E.; HERMY, M.; MUYS, B. Restoration of dry Afromontane forest using pioneer shrubs as nurse-plants for Olea europea ssp. cuspidata. **Restoration Ecology**, v. 15, n. 1, p. 129 – 138, 2007.

BAPTISTA, M. N; VALCARCEL, R.; MATEUS, F. A.; MEDEIROS, W. S.; ANDRADE, F. C. Impact of Urbanization on the Hydrodynamics Water Table in a Floodplain with High Potential for Renaturation. **Water Resources Management,** V. 31, n. 13, p. 4091 - 4102, 2017.

BECHARA, F. C.; DICKENS, S. J.; FARRER, E. C.; LARIOS, L.; SPOTSWOOD, E. N.; MARIOTTE, P.; SUDING, K. N. Neotropical rainforest restoration: comparing passive, plantation and nucleation approaches. **Biodiversity and Conservation**, v. 25, n. 11, p. 2021 – 2034, 2016.

CARDOSO, F. C. G.; MARQUES, R.; BOTOSSO, P. C.; MARQUES, M. C. M. Stem growth and phenology of two tropical trees in contrasting soil conditions. **Plant Soil,** v. 354, p. 269 – 281, 2012.

CORRÊA, J. C. Efeito de sistemas de cultivo na estabilidade de agregados de um Latossolo Vermelho-Amarelo em Querência, MT. **Pesquisa Agropecuária Brasileira**, v. 37, p. 203 - 209, 2002.

COUTINHO, F. S.; PEREIRA, M. G.; MENEZES, C. E. G.; GUARESCHI, R. F.; ASSUNÇÃO, S. A. Atributos Edáficos em Áreas de Agricultura, Pastagem e Três Estágios Sucessionais de Floresta. **Floresta e Ambiente**, v. 24, p. 1 - 11, 2017.

COUTO, W. H.; ANJOS, L. H. C.; WADT, P. G. S.; PEREIRA, M. G. Atributos edáficos e resistência a penetração em áreas de sistemas agroflorestais no sudoeste amazônico. **Ciência Florestal**, v. 26, n. 3, p. 811 - 823, 2016.

DALY, H. E.; FARLEY, J. **Economia Ecológica:** Princípios e Aplicações. Island Press. 2003.

DINIZ, A. R.; PEREIRA, M. G.; BALIEIRO, F. C.; MACHADO, D. L.; MENEZES, C. E. G. Precipitação e aporte de nutrientes em diferentes estágios sucessionais de floresta Atlântica, Pinheiral – RJ. **Ciência Florestal**, v. 23, n. 3, p. 389 - 399, 2013.

DONAGEMA, G. K.; CAMPOS, D. D.; CALDERANO, S. B.; TEIXEIRA, W. G.; VIANA, J. H. M. **Manual de métodos de análise de solos**. Rio de Janeiro: Embrapa Solos. 2011, 230 p.

MARTINS, D. A. P.; LANZARINI, A. C.; HEINZ, C. F.; VIEIRA, F. S.; BONATTO, R. A.; KANIESKI, M. R. Avaliação da transposição de serapilheira e do banco de sementes do solo em uma área degradada no planalto catarinense. **Floresta**, v. 47, n. 3, p. 237 - 246, 2017.

MARTINS, K. G.; MARQUES, M. C. M.; SANTOS, E.; MARQUES, R. Effects of soil conditions on the diversity of tropical forests across a successional gradient. **Forest Ecology and Management**, v. 349. p. 4 – 11, 2015.

MATEUS, F. A.; MIRANDA, C. C.; VALCARCEL, R.; FIGUEIREDO, P. H. A. Estoque e capacidade de retenção hídrica da serrapilheira acumulada na restauração florestal de áreas perturbadas na Mata Atlântica. **Floresta e Ambiente**, v. 20, p. 336 - 343, 2013.

MESQUITA, M. G. B. F; MORAES, S. O.; PERUCHI, F.; TEREZA, M. C. Alternativa para caracterização da condutividade hidráulica saturada do solo utilizando probabilidade de ocorrência. **Ciência e agrotecnologia**, v. 31, n. 6, p. 1605 - 1609, 2007.

MICHELANGELI, F. A.; REGINATO, M. 2015. *Clidemia* in **Lista de Espécies da Flora do Brasil.** Jardim Botânico do Rio Janeiro. Disponível em: <http://floradobrasil.jbrj.gov.br/jabot/floradobrasil/FB9452/> Acesso em: 26/05/2015.

MIRANDA, C. C.; VALCARCEL, R.; FIGUEIREDO, P. H.; MATEUS, F. A.; ROPPA, C.; NUNES-FREITAS, A. F. Caracterização de núcleos espontâneos de *Clidemia urceolata* DC. em áreas perturbadas da Mata Atlântica. **Ciência Florestal**, v. 25, n. 1, p. 199 - 209, 2015.

MORRIËN, E.; HANNULA, S. E.; SNOEK, L. B.; HELMSING, N. R.; ZWEERS, H.; HOLLANDER, M.; SOTO, R. L.; BOUFFAUD, M. L.; BUÉE, M.; et al. Soil networks become more connected and take up more carbon as nature restoration progresses. **Nature Communications**, v. 8, n. 14349, p. 1 – 10, 2017.

ORTIZ, P. F. S.; ROLIM, M. M.; LIMA, J. L. P.; PEDROSA, E. M. R.; DANTAS, M. S. M.; TAVARES, U. E. Physical qualities of an Ultisol under sugarcane and Atlantic forest in Brazil. **Geoderma Regional**, v. 11, p. 62 – 70, 2017.

R CORE TEAM (2016) **R: a language and environment for statistical computing**. R Foundation for Statistical Computing, Vienna, Austria. Disponível em: <https://www.R-project.org/> Acesso em: 15/10/2017.

REZENDE, C. L.; UEZU, A.; SCARANO, F. R.; ARAUJO, D. S. D. Atlantic Forest spontaneous regeneration at landscape scale. **Biodiversity and Conservation**, v. 24, n. 9, p. 2255 – 2272, 2015.

SANTOS, R. D.; SANTOS, H. G.; KER, J. C.; ANJOS, L. H. C.; SHIMIZU, S. H. **Manual de descrição e coleta de solo no campo**. Viçosa: Sociedade Brasileira de Ciência do Solo, 7ed. 2015, 102 p.

SILVA, A. J. N.; RIBEIRO, M. R.; CARVALHO, F. G.; SILVA, V. N.; SILVA, L. E. S. F. Impact of sugarcane cultivation on soil carbon fractions, consistence limits and aggregate stability of a Yellow Latosol in Northeast Brazil. **Soil & Tillage Research**, v. 19, p. 420 - 424, 2006.

SOUZA, E. D.; CARNEIRO, M. A. C.; PAULINO, H. B. Atributos físicos de um Neossolo Quartzarênico e um Latossolo Vermelho sob diferentes sistemas de manejo. **Pesquisa Agropecuária Brasileira**, v. 40, p. 1135 - 1139, 2005.

TURCHIN, P.; NEFEDOV, S. A. **Ciclos Seculares**. Princeton University Press. 2009.