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Soil remineralization and recovery of degraded areas: An experience in the tropical region

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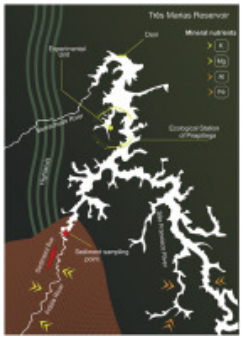
Abstract

Many activities related to the expansion of food supply, energy and infrastructure result in great environmental impacts, whose most visible features are observed in the degradation of large areas. The present study demonstrates how the combined use of stonemeal technology and agroforestry systems can help to reverse such impacts, allying the recovery of degraded areas with agricultural and forest production. The study area is located in a hydroelectric reservoir affected by the siltation process and soil erosion in the hydrographic basin of the San Francisco River, Brazil. An Experimental Unit (EU) was set up in the Ecological Station of Pirapitinga (Três Marias reservoir). The design of the EU was based on a factorial design, with seven treatments applied on six native tree species, with three replications (21 blocks). The germination and establishment data of each species were considered in the different treatments. The oxides concentration and fertility level of sediments were analyzed for the determination of the sampling points in the reservoir. The experiment and evaluation were conducted over six years, and the sediments analysis presented high levels of the essential macronutrients K_2O, MgO and TiO_2, while CaO and Na_2O levels were significantly low, due to their high solubility and mobility. The P_2O_5 also showed equally low values. After two years, soil pH was balanced, especially in the blocks with mineral inputs. P, K, Ca and Mg concentrations were increased up to 5 times more than those of original soil of the EU, and the highest values were found in the remineralizer+sediment treatment. The use of geological material (e.g. mining waste) and organic compost was proved to be an adequate and sustainable technology to mitigate degradation processes. Besides, locally available sources of organic matter enhanced.

Graphical abstract



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Introduction

Throughout planet Earth's evolution, the dynamics of the tectonic and weathering processes have stoned the ecosystems, providing the formation and diversification of the most varied features and environments. More recently, the anthropic actions have interfered with the Planet's superficial dynamics, modifying the processes that occur in the pedosphere and biosphere, being soil erosion a direct consequence of the impact of changing land use that causes soil degradation and mobilization (e.g. Syvitski and Kettner, 2011).

According to Lal et al. (1989), soil degradation can occur due to deforestation, inappropriate land use, high population density, urbanization, industrial activity and land tenure management which may cause alterations of soil's physical, chemical and biological properties and processes, such as: accelerated erosion, increasing wetness and poor drainage, laterization, salinization, nutrient imbalance, the decline in soil organic matter, and reduction in activity and species diversity of soil fauna and flora. Such processes are especially intense in tropical developing countries, where a significant challenge is posed by the need to achieve food security while minimizing environmental impact (Scherr, 1999; Lal, 2001).

Besides increased soil erosion, human action has also modified sediment pathways and storage by damming rivers for the construction of water or hydroelectric reservoirs, which retain part of the sediment load carried by the rivers with outstanding impact on floodplains or coastal areas (e.g. Walling, 2006; Latrubesse et al., 2017). The sediment trapping efficiency of large reservoirs can be in excess of 80% (Vörösmarty et al., 2003), although it could be reduced for hydrographic basins characterized by high intra-annual flow variability (Lewis et al., 2013), causing intense siltation and reduction of the water storage capacity.

The degradation processes of vast portions of the Brazilian territory is a long-lasting reality which is closely linked to development model of the country, based on intensive, and frequently unplanned, land use to accommodate growing agricultural and mining activities, as well as urban settlements, which leads to significantly higher rates of soil erosion as compared to natural processes (Nearing et al., 2017). Due to environmental concerns, the imposition of legal norms and the economic costs of recovery, the search for a more balanced approach to land use has been encouraged in order to minimize or reverse the degradation processes, leading to new production practices or application of new technologies.

In this aspect, the combined use of the principles related to the Stonemeal technology (that provides for the use of rock dust to remineralizer the soil), and practices related to Agroforestry Systems - AS (that facilitates the recoating of the soil in a successional way), has shown very positive results in Brazil, as described in the pioneering studies (e.g. Rocha, 2006; Theodoro et al., 2013; Theodoro and Leonardos, 2015; Soares, 2018). The use of Stonemeal technology, which involves the use of rock dust to remineralize the soil, has become an alternative to classic fertilization techniques that may represent a more sustainable option for degraded

soils in tropical regions. In particular, attention has been paid to the possibility of using rocks of volcanic origin, such as basalts, due to the ability to release macro and micronutrients important for plant growth (Ramos et al., 2019). Furthermore, the combined use of this technique with practices related to Agroforestry Systems, that facilitate the recoating of the soil in a successional way, has shown very positive results as it facilitates the soil-plant synergy, enhanced by the increase of the fertility and fast recoating of the soil with several types of plants (agricultural, leguminous and forestry) inserted simultaneously in the system, but with different growth timing (Theodoro et al., 2009).

The objective of this study is to prove the effectiveness and the synergy between these two technologies to recover a degraded area, and to this purpose, an Agroforestry System (AFS) was installed in an Experimental Unit (EU) in the Ecological Station of Pirapitinga (ESP), located in the Três Marias Reservoir, in the hydrographic basin of the San Francisco River (Fig. 1).

To achieve this objective, seven treatments were used to investigate the potential of individual and mixed inputs in modifying soil fertility, as well as to enhance the development of native plants. In particular, we emphasize that the remineralizer used derived from a rock denominated Kamafugite, which belongs to the Mata da Corda formation (upper Cretaceous). The sediment was removed from a location in the reservoir where there is contribution of materials from surrounding areas (Três Marias formation – upper Proterozoic, as well Mata da Corda formation). Organic compost from bovine manure was also applied. The use of these materials suggests a virtuous cycle that, while contributing to nourish depleted tropical soils, also offers the possibility of restoring the storage capacity of the reservoir.

Section snippets

Characterization of the ecological station of pirapitinga

The construction of the Hydroelectric Power Plant (HPP) of Três Marias started in 1957 and was completed in 1961. The dam has 2700 m of extension, a height of 75 m and its power plant has the capacity to generate 396 MW. The lake formed by the damming of the São Francisco River has a volume of 21 billion m^3, a surface of 1040 km^2 and extends across eight municipalities. In addition to the São Francisco River, the Paraopeba, on the right margin, and Indaiá and Borrachudo Rivers, on the left…

Remineralization and agroforestry: the reverse of degradation

Finding methods to abbreviate and/or facilitate the recovery of degraded areas is one of the most important challenges for sustainable development worldwide. In order to stop erosive processes, mechanical, ecological, structural, agricultural and bio-energy techniques have been used (Rotta, 2012). Such techniques could be used synergically to achieve the restoration of the original conditions, or get as close as possible to them.

The use of remineralizers, according to the assumptions of the…

Methodology

The above-mentioned concepts were put into practice in a synergistic way to set up the Experimental Unit (EU) in the ESP. The following steps were carried out: (a) study of geospatial conformation of the reservoir - geology, pedology and land use; (b) definition of the sediment and soil sampling point in the reservoir and

its banks (based on the results of Fonseca et al., 2007), including a sample from the ESP; (c) sampling of the bottom sediment of the reservoir using a simple “Shipeck” grab…

Results and discussion

The results of the research can be divided in two groups: 1) geochemical and fertility analyses of the reservoir sediments, remineralizers, treated and untreated soils; 2) monitoring of the evolution of the agroforestry system. For each group, a protocol was defined in order to establish a procedure that could provide easily understandable indicators.…

Conclusions

The results presented in this study reinforce the need for interdisciplinary studies and transversal actions to solve or seek tools for tackling problems of soil degradation and/or for ensuring agricultural/forestry production. The data indicate that the incorporation of low solubility "smart" fertilizers with Agroforestry System provides fast, efficient and low-cost responses. In addition to environmental issues (loss of fertile soil, erosion, silting etc.), the socio-economic costs of…

Authors statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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References (49)

B.B. Basak *et al.*

Waste mineral powder supplies plant available potassium: evaluation of chemical and biological interventions
Journal of Geochemical Exploration n (2018)

A.C. Dalmora *et al.*
Chemical characterization, nano-particle mineralogy and particle size distribution of basalt dust wastes
Sci. Total Environ. (2016)

W. Fyfe *et al.*
Global tectonics and agriculture: a geochemical perspective
Agric. Ecosyst. Environ. (1983)

D. Lefebvre *et al.*
Assessing the potential of soil carbonation and enhanced weathering through Life Cycle Assessment: a case study for Sao Paulo State, Brazil
J. Clean. Prod. (2019)

D.A.C. Manning *et al.*
Enabling food security through use of local rocks and minerals
The Extractive Industries and Society (2020)

M.A. Nearing *et al.*
Natural and anthropogenic rates of soil erosion
International Soil and Water Conservation Research (2017)

C.J. Vorosmarty *et al.*
Anthropogenic sediment retention: major global impact from registered river impoundments
Global Planet. Change (2003)

D.E. Walling
Human impact on land – ocean sediment transfer by the world's rivers
Geomorphology (2006)

E. Almeida *et al.*
Powdered rock to revitalize soils
LEISA Magazine (2006)

L.G. Azevedo *et al.*
Ensaio metodológico de identificação e avaliação de unidades ambientais: Estação Ecológica de Pirapitinga/MG
(1987)

J.E.G. Campos *et al.*
A glaciação neoproterozóica na porção meridional da Bacia Sanfranciscana
Rev. Bras. Geociencias (1994)

A.M.X. Carvalho *et al.*
Rochagem: o que se sabe sobre essa técnica?

P.T.A. Castro *et al.*

The sediment stratigraphy and tectonic context of the São Francisco Super group at the Southern domain of the São Francisco Craton, Brazil
Rev. Bras. Geociencias (2000)

C.D. Cruz
Programa Genes, estatística experimental e matrizes
(2006)

A.R. Dechen *et al.*
Fertilidade do solo. Cap. III. Elementos requeridos à nutrição de plantas
(2007)

J.G. Farrell *et al.*
Agroecologia: bases científicas para uma agricultura sustentável
(2002)

W.S. Fyfe *et al.*
Global tectonics and resources for man: minerals and agriculture
Jornal de mineralogia. Volume Djalma Guimarães, Recife (1978)

R. Fonseca *et al.*
The Três Marias reservoir, a sink for sediments outcoming from over-erosion of soils in Minas Gerais (Brazil)

S.R. Gliessman
Agroecologia: Processos Ecológicos Em Agricultura Sustentável. Porto Alegre
(2000)

D. Guimarães
Contribuição ao estudo dos Tufos da Mata da Corda
Inst. Tecnol. Industrial, Minas Gerais. (1955)

A.D. Harley *et al.*
Factors influencing the release of plant nutrient elements from silicate rock powders: a geochemical overview
Nutrient Cycl. Agroecosyst. (2000)

ICMBio
Management plan of the ecological station of Pirapitinga

W. Ilchenko
Os tufos da Mata da Corda e seu emprego na Agricultura
Dep. Prod. Vegetal. Belo Horizonte, Boletim Agricultura (1955)

B.I. Kronberg *et al.*
The chemistry of some Brazilian soils element mobility during intense weathering
Chem. Geol. (1987)

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Cited by (10)

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2024, Chemosphere

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2022, Geoscience Frontiers

> *Citation Excerpt :*
>
> ...According to Theodoro and Leonardos (2006), soluble fertilizers would supply the initial need for macronutrients for plants, which would later be supplied by the wide diversity of macro and micronutrients available in the minerals that form silicate rocks (Fig. 1). Burbano and Theodoro et al. (2020) compared the development of quinoa plants according to five types of treatments (basaltic rocks (R), NPK, organic compound (OC), the mixture of basaltic rocks + organic compound (R + OC), and the control plots). They used the same type of soil (oxisoles) and a basaltic rock of similar composition to that used by Leonardos and Theodoro (1999), however the most recent study was conducted for crops of short cycle (beans, arugula, and quinoa) in rotation system....

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Nanoparticles generated during volcanic rock exploitation: An overview

2021, Journal of Environmental Chemical Engineering

> *Citation Excerpt :*
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> ...In this context, the high geodiversity of silicate rocks distributed in quantities may aid to reduce the dependence on soluble fertilizers or make viable agriculture in unfavorable areas [12,13, 16,37,65–68]. In the case of Brazil, national policy in favor of multinutrient rock uses following the Remineralizer's law has been approved [67,69]. Remineralizers, a in nature rock powder, consist of a minimum multi-nutrient rock composition, which after application in soils, generates positive effects on soil attributes....

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