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# Topsoil for restoration: Resprouting of root fragments and germination of pioneers trigger tropical dry forest regeneration

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ABSTRACT

Topsoil translocation has been effective for the restoration of plant communities, but until recently this method had not been used for tropical dry forest restoration. We tested different methods of topsoil deposition for restoring a dry forest on an abandoned limestone quarry. We also tested the effects of irrigation during the first dry season after topsoil deposition. The study was conducted in the Federal District of Brazil. A 2.1-ha area was cleared of vegetation, and the topsoil from that site was deposited on an exotic pasture field 1.4 km away. First, a secondary forest was clear-cut, and the first 30 cm of topsoil were removed and translocated. The soil was transported in dump trucks to the deposition site, which had been scarified in advance, and deposited by either forming 1.25-m-tall mounds or by leveling the soil into a 40-cm or 20-cm deep layer using a hydraulic excavator. The seed bank and the availability of root and stem fragments in the soil were both surveyed. The origin of the regenerants was categorized as either from seed or resprouting. We estimated vegetation cover for each life form, and measured all trees and lianas. After six months, 74% of the tree individuals and 60% of the liana individuals came from resprouting. Ruderal herbs and shrubs germinated from seeds. After 28 months, there were 51 species of trees, 8 species of lianas, 12 species of shrubs, and 34 species of herbs in the deposition treatments. The three deposition treatments were thickly covered with herbaceous/shrubby species, and had nine times the number of species (44 *vs.* 5) and five times the tree density (1.17 ind./m$^2$ *vs.* 0.25 ind./m$^2$) as the non-deposition control. Tree survival was relatively high in both the non-irrigated and irrigated treatments. The total cost of topsoil translocation was 9604 USD, and the output was 0.43 ha deposited/ha excavated when forming mounds of soil, 5951 USD and output of 0.75 when leveling to a 40-cm layer, and 3551 USD and 1.5 for a 20-cm layer of deposited material. However, deposition and transportation costs are fixed costs of establishing a new quarry that can be deducted from the total cost of restoration. Topsoil translocation was effective in kick-starting the succession process of a tropical dry forest.



## 1. Introduction

Restoration ecology aims to understand natural ecosystem regeneration and to use this information to solve bottlenecks that hinder the reestablishment of their structure and function. Methods that tap into the potential for natural regeneration are appealing, because they are usually more efficient, cheaper, and better adapted to the ecosystem (Holl and Aide, 2011). Some examples are shrub seeding to cover the soil and attract dispersers (Holl et al., 2000), trees established from cuttings that subsequently serve as perches (Zahawi, 2005), the use of resprouting in abandoned pastures (Vieira et al., 2006; Sampaio et al., 2007a), transference of the transient seed bank accumulated on the surface of the soil (Sampaio et al., 2007b) and translocation of topsoil from areas affected by mining or infrastructure construction to restoration areas (Rokich et al., 2000; Ferreira et al., 2015). Topsoil translocation transfers substrate, organic matter, soil microorganisms, soil mesofauna, plant fragments, and seeds to a degraded site, increasing the potential for successful vegetation restoration (Rokich et al., 2000; Vécrin and Muller, 2003; Hall et al., 2010; Vergílio et al., 2013). Seedling recruitment from seeds in the topsoil is considered the main pathway for vegetation regeneration, but resprouting from root fragments, bulbs, xylopodia, rhizomes, corms, and tubers also contributes to the pool of regenerants (Tozer et al., 2012; Ferreira et al., 2015).

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Although nothing is known about the use of topsoil to restore tropical dry forests, this method has the potential to be very successful for vegetation types with high resprouting ability and a seed bank of ruderal species (Ferreira et al., 2015). In tropical dry forests, resprouting is the main form of regeneration following disturbances such as fire events (Kennard et al., 2002), selective logging (Griscom and Ashton, 2010), conversion into pasture (Vieira et al., 2006), conversion into cultivated field without stump removal (Lévesque et al., 2011) and removal of the topsoil (Ferreira et al., unpublished data). Seed regeneration of trees and lianas is lower in deforested areas due to a decreased seed rain (Kennard et al., 2002; Ceccon and Hernández, 2008; Martínez-garza et al., 2011) and lack of favorable conditions for seed germination and seedling establishment (Kennard et al., 2002; Vieira and Scariot, 2006). In contrast, ruderal herbs and shrubs are recruited from the seed bank that persists in the soil (Ewel, 1980; Guariguata, 2000), and are responsible for the herbaceous/shrubby stage of forest succession, the first stage of regeneration of large gaps and deforested areas (Finegan 1996).

Seasonal forests are one of the most threatened terrestrial ecosystems on the planet (Murphy and Lugo, 1986; Vieira and Scariot, 2006), justifying the current efforts for their ecological restoration. They are estimated to represent 42% and 22% of the tropical forests in the world and in South America, respectively (Murphy and Lugo, 1986). They occupy 3.2% of the Brazilian territory and are distributed in patches within the Cerrado, Caatinga, Atlantic forest, and Amazon biomes (Sevillha et al., 2004; Scariot and Sevilha, 2005). Deciduous seasonal forests occupy highly fertile areas that are frequently associated with limestone rocks, which makes them appealing for both agriculture (Scariot and Sevilha, 2005) and limestone mining (Haidar, 2008). Over the last 40 years, the land occupied by limestone quarries in Brazil increased 10-fold (MD, 2015). When the area occupied by a limestone quarry expands, the forest is cleared and the topsoil is removed along with vegetative material and seeds. This material, usually discarded into mine dumps (Haidar, 2008), may be repurposed for the restoration of degraded areas.

This study aimed to evaluate the potential of using topsoil to restore a seasonal forest. Many root and stem fragments are transported in the topsoil, which may result in the propagation of trees and lianas through resprouting. In addition, the topsoil holds a dense seed bank of ruderal herbaceous and shrubby species, which may increase seedling recruitment in deposition areas. Following plant propagation in the new site, improved growth and establishment conditions might be provided by a thicker layer of deposited topsoil and a longer period of water availability before the onset of the dry season. The first goal of this study was to evaluate the effect of the method of topsoil deposition, which also affects the thickness of the topsoil layer, on the restoration of forest diversity and structure. We hypothesized that depositing soil without leveling (by forming mounds with a maximum height of 1.25 m) would be the most effective approach, because leveling the soil is likely to damage propagative material; leveling the soil into a 40-cm layer and a 20-cm layer should result in decreasing levels of success. The second goal was to evaluate the contribution of vegetative propagules and seeds in the topsoil for forest restoration. The third goal was to estimate the sizes and relative densities of different types of vegetative propagules with resprouting ability in the deposited topsoil. Concomitantly, we evaluated the maximum depth that allowed resprouters to emerge from the deposited soil. This is an important question, because there should be a depth past which the emergence of seedlings and resprouters is no longer possible, and depositing a thicker layer of topsoil becomes irrelevant. Lastly, we tested the effects of irrigation during the first dry season after topsoil deposition on the survival of woody species. We hypothesized that water stress caused by drought would increase the mortality of the regenerating plants (Tanner and Barberis, 2007; Paine et al., 2009; Ferreira et al., 2015), and that irrigation during this period would help the regenerating community overcome this constraint (Hoffmann, 1996; McLaren and McDonald, 2003; Tanner and Barberis, 2007). This assistance may be particularly relevant for resprouters, since it takes months for root and stem fragments to grow new above- and belowground structures.

## 2. Methods

### 2.1. Study sites

The study was conducted at a site in the north-central region of the Federal District of Brazil (15°34′S, 47°53′W), between November 2013 and March 2016. Mean annual precipitation is 1495 mm (min–max range 1157 mm–1948 mm, series from 1990 to 2015), and 93% of the rainfall is concentrated between October and April. The mean temperature of the hottest month is 22.7 °C, and of the coldest month, 19.2 °C (calculated from INMET, 2015). The cleared vegetation consisted of a deciduous seasonal forest, which was markedly deciduous in the dry season and had a canopy height around 20 m, basal area of 22 $m^2$/ha, and high abundance of lianas (Haidar, 2008). The translocated soil is a highly fertile Cambisol originated from predominantly calcareous rocks of the Paranoá group (ZEE-DF, 2009). The studied forest is in the Cerrado biome (Ribeiro and Walter, 2008) and borders semi-deciduous forests on slopes, cerrado *stricto sensu* on less fertile Cambisols, cerradão in interfluvial areas and gallery forests along watercourses.

The topsoil included vegetative materials and soil that were removed to allow for the expansion of the limestone quarry of Fábrica Tocantins Cimentos, owned by the Votorantim group. A 2.1-ha area was cleared of all vegetation and the topsoil was removed and deposited on a 1.9-ha area at a site 1.4 km away from the removal site. The deposition site had been used as pasture for a long time and was dominated by the African grasses *Andropogon gayanus* and *Urochloa decumbens*, resulting in a high level of soil compaction and low regeneration of the native vegetation (Fig. 1g). The original vegetation at this site was also a seasonal forest, as was evident by the present of remnant trees typical of this vegetation, such as *Aspidosperma subincanum* Mart. ex A.DC., *Anadenanthera colubrina* (Vell.) Brenan, *Myracrodruon urundeuva* Allemão, and *Terminalia phaeocarpa* Eicheler. The soil is of calcareous origin, deeper and flatter than the soil at the removal site.

### 2.2. Vegetation clearing and topsoil translocation

In May 2013, 2.1 ha of forest near a mining quarry were cleared. First, most of the woody vegetation < 10 cm DBH was cut with a brush hook in preparation for chainsaw cutting. All woody vegetation ≥10 cm DBH was cut with a chainsaw and the tree trunks were dragged by a crawler tractor to the log deck. Four months later, in November 2013, the remaining vegetation and the topsoil were removed and promptly deposited on the restoration site. A hydraulic excavator with a 1.5 m bucket was used to remove the vegetation and the topmost 30 cm of soil. Initially, the soil was scraped to a depth of 30 cm and mounds of soil containing leaf litter, whole plants, root and stem fragments and seeds were formed. Then, the mounds were transferred with the excavator into dump trucks with a load capacity of 12 $m^3$ (Fig. 1c–f) to transport the material to the deposition site. The deposition site had already been scarified to a depth of 30 cm with a crawler tractor to loosen the soil and temporarily remove all grasses (Fig. 1g–i). To spread the topsoil, the truck bed was raised and the truck moved slowly along the field, forming 1.25-m tall mounds. In both leveling treatments, the soil was leveled with the excavator, targeting a thickness of