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Gully Erosion Stabilization in a Highly Erodible Kandiustalf Soil at Pindorama, São Paulo State, Brazil

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Erosion and loss of topsoil are the greatest challenges for agricultural sustainability. The increase of degraded soil threatens the productivity of agriculture and agroindustry, therefore undermining socio-economic development. Soil erosion is primarily caused by unrestrained water flow. The loss of nutrients from topsoil decreases plant growth and soil productivity because sub-soils are generally less fertile. Agriculturally valuable soil stock is finite because top soils are not renewed as fast as they are degraded and eroded. Degradation of agricultural land threatens the sustainability of growth and welfare of many people around the world that depend on agriculture for their livelihoods (Pagiola 1999). In these areas, agriculture is unsustainable unless the soil is rehabilitated to reverse the degradation process. In the 1980s a new economic development concept arose, incorporating social and environmental preservation, and a new ideal emerged: sustainability, defined as a set of practices that involves resource management appropriate to satisfy human needs while maintaining or enhancing environmental quality and conserving natural resources. This new ideal involved no-tillage soil conservation practices, graded level terraces, and improving road levels to better conduct excess runoff (Vieira 1997).

Accelerated erosion is a result of human misuse of soil where the losses are no longer compensated by the geologic substrate or by alluvial contributions. Since 1945, an estimated two billion hectares of agricultural land, almost 18% of Earth's vegetated land, have been degraded as a result of a human activity and almost 11% of Earth's vegetated land has been degraded, significantly reducing productivity (Pagiola 1999). Gully erosion is responsible for many degraded areas and is very difficult to control.

Gullies can be branched, deep, present irregular walls, and present "U" transverse profiles. This form of erosion is the most complex and destructive, as it is the product of the combined action of superficial and underground runoff leading to a morpho-hydro-pedologic imbalance due to inappropriate use and occupation of the soil.

In Brazil, although there are no exact data, deforestation followed by inadequate agricultural activities are major degradation factors. In the São Domingos river watershed, in Pindorama, São Paulo state, Brazil, erosion susceptibility is mostly in the Classes I (very high) and II (high). This is a severely gully-eroded landscape in a Kandiustalf soil area, well drained, with average slopes from 2 to 10%. There are 50 years of accumulated data on erosion experiments at the Polo Regional Centro Norte, and some soil conservation practices have been specially developed to reduce erosion problems in the countryside and agricultural areas (Vieira et al. 1997). In this paper we report on the success of a gully erosion stabilization project started in 1997 to restore original water flow and stop erosion, resulting in the local sustainability of the soil, plant communities, and the reestablishment of native animal communities (Vieira et al. 1997, Abdo 1999).

This restoration took place at the Polo Regional Centro Norte-APTA research center, located in the municipality of Pindorama, São Paulo state, Brazil (21° 13' S; 48° 55' W). The entire reserve encompasses 532.8 ha, including native forest fragments that are considered a Biological Reserve under São Paulo state law 4960/86. The climate of this region, according to Köppen classification (Lepsch and Valadares 1976), is tropical and humid, with a dry season during winter and a rainy season during summer. The average annual rainfall is 1258 mm. The average temperature during the summer months is 23.8°C (January, February and March) and the average temperature during the winter months (June, July and August) is 19.3°C.

The native forest area (144 ha) is considered a conservation unit because it supports a diversity of regional endemic species and requires special management and protection. These forest fragments are classified as seasonal semi-deciduous tropical forest of the Atlantic Forest biome (Abdo 2009) and are very important for local floral and faunal diversity. In a tree survey of two toposequences, in two different fragments, 572 individual trees were assessed, encompassing 108 species from 33 families (Abdo 2009). The families that represented the largest number of individuals were the Meliaceae with nine identified species and the Myrtaceae with six species. The dominant species in the forests are *astronium graveolens (guaritá)* followed by *acacia polyphylla (monjoleiro)* and *ceiba speciosa (paineira)* in area 1 and *guarea kunthiana (canjambo)* and *guarea macrophylla (peloteiro)* in area 2 (Abdo 2009). There is a list of 235 recommended species for restoration projects in São Paulo state (Resolução SMA 21 2001) and of the species inventoried in the remainder of the Biological Reserve, 45 species are required species by the recommendation legislation. The Shannon Diversity Index (H') was 3.38 for both fragments, and is in accordance with other survey results from the state of São Paulo in past years in semi-deciduous tropical forest of the Atlantic Forest biome (Abdo 2009). The reserve also supports a diversity of bird species. An avifauna survey conducted by Otaviano and Barros (2012) found 129 species. Four bird species that visit the reserve are under extinction risk: *Momotus momota, Herpsilochmus longirostris, schistochlamys melanopis* and *sporophila collaris.* (Otaviano and Barros 2012).

The soils of Polo Centro Norte, Pindorama, SP, Brazil are classified as Kandiustalf. These soils have a sandy texture in the surface layer (A horizon) and clay loam in the subsurface layer (B horizon). This difference in the texture of soil horizons makes them highly susceptible to erosion processes due to differentiation of water infiltration velocity in the different horizons (Lepsch and Valadares 1976, Embrapa Solos 1999). This susceptibility to erosion was aggravated by inadequate management of the area, which for decades had been used as pasture with no soil conservation practices. For example, a coffee crop planted downhill, without enough conservation measures such as contours and vegetation between rows, had very low production and was soon transformed into pasture after degradation. Excess runoff has also increased the depth of cattle tracks towards the water in the lower part of the area. As a result of these degradation processes, a gully formed approximately 700 meters long and in some places up to 15 meters deep (Figure 1). Before 1997, large amounts of soil and sediment flowed down the eroded gully and into lower drainage channels.

The main objective of this restoration was to restore the gullies caused by rapid soil erosion. To stop the erosion, controlling the velocity of surface runoff and water flow was the first priority. Four dams and four sunken ponds were built perpendicular to the erosion direction. The construction of the dams started in 1997 and was finalized in 1998. Each pond was connected to the next one by concrete overflow channels to prevent channel erosion to stabilize the erosive process. The distance between dam walls was calculated to allow water flow starting a level slightly lower than the previous level of the previous dam so that water would flow from pond to pond, reducing the velocity of surface runoff and decreasing soil erosion. The positions of the ponds were marked out and existing vegetation was removed so that the soil in the central part of the ponds could be strongly compacted, generating a strong internal dam wall so the water could not pass through. After the areas of the dams were determined, each four to six meters wide, a technique called "cut off" was used. This technique consists of removing upper soil material until a very firm soil is reached, typically a more clay soil. Once the central part of each dam was completed, soil to fill the "cut off" was brought from different areas.

Figure 1. Gully erosion before restoration in 1997, Polo Regional Centro Norte, APTA, Pindorama, SP, Brazil.

Figure 2. Dam construction, 1998, Polo Regional Centro Norte, APTA, Pindorama, SP, Brazil.

Figure 3. Concrete spillway channels to allow excess water flow between ponds.

This material was originated from a B horizon layer, clay soil, and it was placed in 20–30cm layers. Each layer was compacted manually or with pressure equipment pulled by a tractor. When a layer was fully compressed, a new layer was poured, and so on until the desired height of the dam was reached (Figure 2). To enable the free running of excess water flow, concrete spillways channels were constructed to minimize dam wall erosion under storm conditions and uncontrolled runoff (Figure 3).

After the construction, the sides of the dams were covered with grass, *Paspalum notatum*. The surrounding area was also covered with grass to avoid erosion, which could compromise the investments done as well all the stabilization work (Figure 4). Additionally, the agricultural experimentation area located above the gully was maintained with continuous vegetation cover to avoid soil erosion and cattle and horses were removed from the neighboring area to avoid grazing by the water and to preserve native vegetation.

Thirteen years after the beginning of the project, the stabilization/rehabilitation process can be considered successful, offering farmers a solution to gully erosion problems, minimizing their loss of soil, and returning the land to a productive state (Figure 4). Currently, further restoration is being done with reforestation of native tree species and an agroforestry system in the edges of the ponds (Figure 5). The planting started in April 2011 and is under preliminary evaluation.

Although the reforestation is in a preliminary stage, native flora species have been observed sprouting in the area as well as the fauna. Many birds and some capybaras (*Hydrochoerus hydrochaeris*) have been observed in the area (Figure 6). Ninety species of birds have been observed in the pond area during the months May, June, and July 2012. The capybara in fact was a problem for young trees once they ate the buds and new tender leaves, preventing evaluation of plant growth and production in the first year (August 2011–August 2012).

In the example presented, the gully formed by previous unsustainable agriculture practices was stabilized, avoiding pollution and forest destruction just above the eroded area and ensuring the area's stability. The area that was previously used for agriculture was unviable to any activity due the progressing erosion and is now without erosion risk and suitable for native habitat restoration. Although no longer used for agriculture, the area could be used for fishery, ecotourism, and other economic uses.

Actions taken to reverse erosion processes should be based on a multidisciplinary approach involving researchers, social scientists, and community members. In this example, stopping the erosion processes and recuperating the soil were the first steps. The engineering work for dam construction was carefully planned to allow water flow through the slope without transporting sediment. Excluding cattle from the restoration site allowed natural revegetation to establish. Finally, reforestation of the area has attracted new flora and fauna. In this study that aimed to restore a gully erosion area, the actions based on drainage divide concept were able to minimize the local soil losses.

Figure 4. View of the dams in 2011, Polo Regional Centro Norte, Pindorama, SP, Brazil.

Figure 5. Reforestation and agroforestry system in the edges of the ponds for vegetation cover restoration.

Figure 6. Examples of fauna visitation in the area after gully restoration, Polo Regional Centro Norte, Pindorama, SP, Brazil. A: Asa-branca or black-bellied whistling-duck (*Dendrocygna autumnalis*), B: Capybara (*Hydrochoerus hydrochaeris*). C: Garibaldi or chestnut-capped blackbird (*Chrysomus ruficapillus*), D. Frango-d'água-azul or American purple gallinule (*Porphyrio martinica*), E: Jaçanã or wattled jacana (*Jacana jacana*). Photo credit: Otaviano and Barros (2012).

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Vertebrate Fauna Evaluation After Habitat Restoration in a Reserve within Mexico City

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Little is known about how animals respond to restoration activities (Majer 2009). The presence of vertebrates has beneficial effects on restoration because they participate in processes that accelerate or influence the success of the restoration (Majer 1989, Tucker 2000). It is important to implement animal monitoring programs in order to effectively assess restoration outcomes.

The Pedregal de San Ángel ecological reserve (PSA), Mexico City, protects the xeric scrub community dominated by *Pittocaulon praecox* growing on a lava field. The PSA supports 32 protected species and 54 species endemic to Mexico (Lot and Cano-Santana 2009). However, the reserve is embedded within the city and suffers disturbances such as: fire, garbage, and introduced exotic species, both plants and animals (MacGregor-Fors et al. 2010). Since 2005, two sites located within buffer zones of the PSA have been subject to ecological restoration (A8 and A11). A8 (0.51 ha), is surrounded by buildings and soccer fields,