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Examining the Impact of Pau Jacaré (Piptadenia gonoacantha) Growth on Soil Fertility in the Brazilian Atlantic Rainforest

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1 Introduction

Over the course of this project I examine the effects of the Pau Jacaré, *Piptadenia gonoacantha*, tree on soil health in the Atlantic Rainforest of Brazil. The soil in this area is degraded as a result of unsustainable farming practices, and by conducting soil tests I aim to determine if planting the Pau Jacaré in and around degraded areas, through projects like forest corridors or agroforesty, may help restore soil fertility.

1.1 Introduction to Tropical Forests

Tropical forests are one of the most important ecosystems in the world in terms of area and diversity, if not the most important. They represent 56% of world's global forest area and contain 15 of the 25 world biodiversity hotspots (Turner 2004). A more detailed breakdown reveals that tropical forest ecosystems hold 44% of the world's plants, 35% of the terrestrial vertebrates and 1.4% of the land area. Along with diversity these areas contribute enormously to the stability of Earth's natural cycles; they are invaluable in watershed protection, carbon fixing and nutrient cycling. They also provide very tangible benefits to humans including fuel for heating and cooking, construction material, food for human and animal consumption, medicines and various ways to supplement income. However, while humans can benefit greatly from tropical forests, overexploitation of the resources has led to huge losses and will likely continue to cause problems. Since 1961, global consumption of forest products has risen by 50%, consequently causing countries to remove over 500 million acres of forest cover. This transformation has produced a mosaic of degraded land (Perrakis 2003). The destruction of forest obviously takes a toll on the diversity and ecological health of the area: decreasing forest patch sizes render the areas less ecologically valuable and make them more vulnerable to further disturbance.

The current rate of deforestation of tropical closed forests is 10.7 million hectares per year, an area 3 times the size of the Netherlands (Bennett 2003)! This means that no larger tracts of forest exist and areas are all separated by intensified human land use. It becomes very difficult to conserve flora and fauna especially because fragmentation inhibits gene flow and the maintenance of diversity. Much of the deforestation is caused by the conversion of forest

into agriculture: approximately 15 million hectares of forest are given over to agriculture each decade or “15 acres per minute” (Turner 2004, Forsyth 1995).

1.2 Tropical Soils

An important aspect to consider when examining agriculture in the tropics is the quality and fertility of the soil. One may think that because of the incredible abundance of plants and wildlife, that the soils are ideal for growth and would produce a great yield. In reality, the great diversity of the rainforest is maintained through an intricate network of nutrient cycling in which it is impossible to find a large reservoir of nutrients located in one spot, ready to be used up. The success of the rainforest is essentially dependent on the survival of white threads just under the surface; these are the symbiotically intertwined rootlets of forest trees and strands of fungal mycelia (Forsyth 1995). This relationship is known as a mycorrhizal association in which both members are responsible for the production and uptake of different nutrients. Trees typically provide the energy sources while the fungi provide nutrients through processes like phosphorus and potassium cycling. The fungi thrive just below the forest floor because of a constant temperature and high humidity. Their “relentless jaws” and quick digestive process are responsible for the quick disappearance of forest debris and the rapid turnover of nutrients. Untouched tropical lowland rain forests are mature ecosystems meaning they have reached a steady state in which dead matter is quickly transmuted and converted back into living matter. This means no surplus of nutrients, no bank of minerals and little accumulation of humus: everything is in balance. It is this lack of excess and the efficiency of mycorrhizae that are responsible for the apparent poverty in the soil; nutrients are either actively being used by trees or are leached away. As a result, when trees are cut down and the soil becomes exposed, nutrients can easily be washed out. The temperature of soil increases and eventually it dries out. This in turn speeds up the loss of organic matter and kills the intricate mycorrhizal mat. The tree ashes lost due to erosion are not easily replenished and it is difficult to input new nutrients through rainfall, especially when soil becomes hard and nonreactive. Tropical soils are often lateritic, meaning they are quite poor and stained with iron compounds. They quickly lose fertility and upon interaction with sun and rain they become as hard as pavement. Essentially, once exposed, these soils are totally unproductive and “dead”.

When attempting to continually use tropical soils it is necessary to take into account their acid nature. They are low in cation exchange capacity because they are deficient in base cations. They become dependent on the application of ash. Organic matter is also added to provide cation exchange sites to the soil and to help protect plant roots from the effects of low pH and consequent aluminum toxicity (Bryan 2000).

The Atlantic Rainforest is a tropical ecosystem that has been affected a great deal by agriculture, and continues to experience population growth and deforestation. Soils here are quite degraded and the area suffers from forest fragmentation and a loss in biodiversity. A region within the Atlantic Rainforest will be the focus of this study, so it is necessary to further explore the virtues of this area as well as the difficulties that it faces.

1.3 The Atlantic Rainforest

The Atlantic Rainforest of Brazil is an area of astounding diversity in both flora and fauna, taking its place among the top five "biodiversity hotspots" in the world. It takes up approximately 13% of Brazil's land area and can be classified as a neotropic moist broadleaf forest ecoregion (Olson 2001). It stretches from 8-28˚S in latitude and has an average rainfall of 2000 millimeters. This ecosystem has a higher biodiversity than the Amazon; 50% of the tree species are endemic, meaning they exist only in this region (Perrakis 2003). Many trees are tall which allows for the existence of three canopy stories. Vegetation types include tropical evergreen mesophytic forest, tropical semi-deciduous mesophytic broadleaf forest and mixed forest at higher altitudes (Turner 2004).

Originally, before a great deal of development, the Atlantic Rainforest covered close to 1.3 million km^2 of land. Today only 100,000 km^2 of fragmented forest remain, close to 7% of the original area (Evans 2004). The area is experiencing such a large amount of deforestation because of huge demographic growth in the last 50 years or so. It is estimated the 1.2 million species will disappear by 2020, this is 25% of all those existing in the 1980's (Turner 2004). The Atlantic Rainforest region is currently home to approximately 108 million people, two thirds of the Brazilian population, and continues to grow at a rate of 3.2% per year (Turner 2004). Anthropogenic pressures in the area first arose in the 16^{th} century with Portugal's colonization efforts, characterized by agricultural and timber expansion. More specifically, exploitation

began with dyewood and logging for timber and fuelwood. Since then, cattle, sugar and coffee have become the main money-making ventures; however, they all require a great deal of land, meaning more forest must be cut down. This is exacerbated by the low market prices for these products: more land must be cleared every year in order to make a great enough profit. Continual population growth combined with a greater demand for goods creates the great challenge of integrating socio-economic development with conservation of the region's incredible biodiversity.

1.4 Minas Gerais

Minas Gerais is one of the 27 Brazilian states and as is suggested by the name, "General Mines", it supports a relatively large mining industry. Minas is located within the Atlantic rainforest and is home to a population of 18 million with 32% residing in rural areas (Turner 2004). Farmers live in scattered homesteads and land is relatively well distributed; however, this also means that most of the forest is owned by farmers leaving it susceptible to their private uses. As a result of an intense land occupation movement half of the forest in the area was lost between 1920 and 1940 (Turner 2004). While at first, farmers' actions on their own land went unchecked, the government soon began to realize that intense clearing led to ruined soil and large stretches of unproductive land. To deal with this an Atlantic Forest code was created and one of the main conditions was that 20% of each property must be occupied by Legal Reserves of forest (Evans 2004).

Minas is an area of gold and iron ore workings which run on charcoal from the Atlantic rainforest. The main products in the region are coffee, milk, beef, feijao (beans), eucalyptus, wood, charcoal, sugarcane and maze. These all require land to be cleared, meaning very few pristine forest patches remain in the area. Shifts in forest cover and land use area are directly linked to agricultural expansion, with burning having a huge effect of forest distribution. In addition, the steep terrain of the area and unsustainable cultivation lead to soil erosion and degradation. The exhausted soil has very low productivity which ties right back into the vicious cycle of continual forest clearance: land is used, soil is depleted, so land is needed. Because of low market prices for the products being exported out of the area, the region is very poor. The difficulty of transportation across difficult terrain on bad roads only adds to the isolation of the

area, both from the market and credit. Perhaps the best way to deal with the negative pressures of development is to demonstrate that there is value in keeping forest untouched, like water conservation, for example. The most important next step in Minas Gerais and other areas within the Atlantic Rainforest is to find strike a balance between development and conservation. The Iracambi Research and Conservation Center in the state of Minas Gerais is attempting to do just this.

1.5 Iracambi

Nestled in the Graminha Valley near the town of Rosário da Limeira, Iracambi Research and Conservation Center is within the buffer zone of Serra do Brigadeiro State Park (LeBreton 2012). With broader goals of pursuing sustainable development and counteracting deforestation the center has focused on projects in developing sustainable communities, managing natural resources and researching ecosystems. My research will be based at the Iracambi Research Center because it is an ideal location to do work on soil restoration and reforestation. The area is dominated by coffee and eucalyptus plantations and cattle pasture all of which take a toll on the soil. The center has been exploring ways to reduce the negative effects of farming and finding less harmful practices. Alternative income-generating products from forest land are being explored in order to find more incentive for forest conservation. Many of the solutions that Iracambi is trying out are being experimented with all around the region and should be given a better look.

2 Proposed Solutions

Development in the Atlantic Rainforest has reduced biodiversity and produced fragmentation in the region. A number of solutions have been proposed to fix what has already been done and to continue with development in a more sustainable way that is better suited for preservation of natural ecosystems. Forrest corridors and agroforestry are both relatively new ways of dealing with the consequences of deforestation and both show a fair amount of potential.

2.1 Forest Corridors

2.1.1 Fragmentation

Forest corridors are largely a response to extensive deforestation, more specifically to forest fragmentation. Destruction of forest brings about problems like species loss, endangerment and extinction as well as decreased quality of land, water and soil (Bennett 2003). Forest fragmentation refers to the changes that take place when the clearing of forest segments leaves patches of vegetation isolated from each other (Perrakis 2003). The landscape becomes a sort of mosaic with sections at different stages of regeneration and different severities of fragmentation (Turner 2004). Such patches create more edge space, which means more areas that are susceptible to abrupt habitat transitions. Particularly forests that are surrounded by cleared agricultural areas become subject to new microclimates with higher temperatures, more wind and erosion, and different nutrient cycling patterns. Other key elements that are affected include seed dispersal, pollination and predator-prey relationships. All of these elements naturally tie into the theory of island biogeography which states that as available habitat area decreases the number of species also decreases. A smaller forest area will almost necessarily produce fewer representative habitats, making it difficult or impossible for certain species to survive. From here it may proceed that "fragments linked by a corridor of similar suitable habitat are likely to have greater conservation value than isolated fragments of similar size" (Bennett 2003).

2.1.2 What are forest corridors?

Forest corridors relate very much to the idea of connectivity, or how elements within a landscape are arranged to facilitate or impede the movement of various organisms (Bennett 2003). A corridor can be described as a "linear habitat embedded in a dissimilar matrix, which connects two or more blocks of large habitat" (Perrakis 2003). The goal here is to promote conservation by improving living conditions for certain wildlife populations. More specifically, corridors are implemented in an attempt to maintain genetic variation, facilitate migration, and increase viable habitat in case of a disturbance. In effect, corridors can function as habitats, conduits, filters, sources and sinks. When put in place, they should reflect the ecology of the area and should contain a mix of pioneer species and fast growing succession species. They will

ideally also include nitrogen fixing species, frugivorous attracting species, mutualistic species, and rare or threatened species. It is difficult to generalize the size requirements for corridors from area to area; however, to qualify for protection a corridor's width should be at least 10% of its length with a minimum width of 100 meters (Evans 2004). They should also be incorporated into a system of multiple corridors, in order to have visible effects.

2.1.3 Implementation and Challenges

Theoretically, forest corridors make sense and sound like an excellent idea. In reality, there have actually been quite few successfully implemented corridors and many are critical of their effectiveness and feasibility. Firstly, corridors can bring about adverse effects like the spread of diseases and new disturbances, invasion of exotic species, and exposure of biodiversity to new predators (Perrakis 2003).

Secondly, the implementation of such a corridor comes with high costs, both real and opportunity. Labor is required to initially plant a corridor and then continue observation and maintenance. Alternative land use presents an opportunity cost: it becomes difficult to reconcile the economic potential of the land with the implementation of a corridor. Much of this comes down to the will of the local people; it becomes critical to work together with the stakeholders, those whose livelihoods are dependent on the area being considered for restoration. If positive relationships with the local populations are not shaped from the start, much opposition can result. Small-scale famers in particular are concerned with making enough profit to support their families, and not about giving up parts of their land for conservation efforts. It is also difficult to enforce the maintenance of such corridors; past environmental legislation has left many skeptical of the rules surrounding corridors.

Finally, because of the difficulty of implementation it has also been difficult to assess the ecological effects of such corridors. There is a lack of real evidence of success and there no set of "rules" established to properly set up a corridor; much of this process is dependent on the specific landscape. Many of the positive effects that have been seen are species-specific, with few improvements in the status of the entire ecosystem. There is also a lack of monitoring before and after the establishment of a corridor, so it is hard to deduce how it truly affects the surrounding landscape (Perrakis 2003). For this reason, corridors are often proposed as purely

precautionary measures for biodiversity conservation, and are favorable as part of a more holistic conservation approach.

The concerns with the practicality of forest corridors and the willingness of local farmers to follow legislation on the matter leads us to consider a conservation method that may have more tangible benefits – agroforestry.

2.2 Agroforestry

Offering a more effective way of bridging the gap between conservation and sufficient need provision for society, agroforestry refers to strategically growing native plants and trees, usually woody perennials, next to agricultural crops (Perrakis 2003). Similar to forest corridors, agroforestry plots provide benefits like an improved microclimate, nutrient cycling, soil fertility, organic matter, disease barriers, topsoil loss mitigation, less erosion and increased crop yields (Turner 2004).

2.2.1 Adding Agroforestry to Forest Corridors

Much of the work that has been done with agroforestry has been in relation to forest corridors and afforestation. Agroforestry may be a way to eliminate some of the costs created by forest corridors and make it more feasible for farmers to engage in conservation without incurring financial losses. Farmers can make money from the agricultural crops while protecting corridors and creating more suitable natural habitats. Implementing agroforestry adjacent to forest corridor areas has been one of the most common propositions. The agro-plots could act as semi-natural habitats by promoting "faunal mobility, gene flow, shelter habitats, watershed protection" and decreasing edge effects (Turner 2004). Additionally they can act as buffer zones and protect the core of native vegetation. In terms of specific plant types, fruit trees are especially effective because they provide a perennial cover which protects the soil and recycles plant nutrients and organic matter (Perrakis 2003). For this purpose farmers have used papaya, avocando, mango, banana, carambola, biriba, orange, tangerine and acerola. Native plants like Embaúba have been planted in the midst of these to create better habitat for wildlife and to maintain soil health.

2.2.2 Nitrogen Fixation

In addition to justifying forest corridors, agroforestry is being used as a faster means of restoring soil. Traditional farming methods, relying on cover crops and hedgerows, are no longer cost-effective and require a great deal of land. One of the main soil components easily lost when land is overused is nitrogen, which is essential in the growth of any crop. Thus, origins of agroforestry include a focus in restoring nitrogen by planting leguminous plants next to annual crops (Bryan 2000). Nitrogen is easily leached from soil after extensive agriculture so there must be a way of replenishing the supply. The goal of agro-ecosystems is to increase nitrogen fixation by increasing the capacity of rhizobial bacteria, which will be discussed in more detail later on. Different crops have different nitrogen requirements and much of this depends on rainfall, temperature and soil texture, depth and structure.

Leguminous plants that are planted among agricultural crops provide necessary nitrogen and decrease and even eliminate the need for fertilizer. This in itself decreases the costs for farmers. The stable, organic form of nitrogen, exuded by these nitrogen-fixing trees, remains in the soil much longer than its synthetic counterpart (Bryan 2000). Not only do these trees improve soil quality and promote better crop growth, but they also have their own uses like fuelwood, building materials, food, vitamins and medicine. While several international nitrogen-fixers have been identified for this purpose, few native Atlantic Rainforest species have explored.

Agroforestry systems also come with risks, of courses. Many nitrogen-fixing trees used in the plots are powerful pioneer species that are very competitive for water and sunlight. This will likely lead to a loss in production, and may even shut down the system before allowing the long-term benefits of improved soil to come through. Trying to balance these risks and benefits will likely be a huge factor in trying to promote agroforestry as a good way of growing food to local farmers.

2.3 Using the Jacaré

After examining forest corridors and agroforestry as solutions to some of the problems created by deforestation it is clear they both rely on some use of local ecology. In fact it is impractical, it not impossible, to devise a solution in an area without utilizing elements that the

area so readily provides. Both agroforestry and forest corridors require the use of local, fast-growing trees which are well-adapted for the environment of the Atlantic Rainforest. This is where the Pau Jacaré, or *Piptadenia gonoacantha* comes into play. It is known to for its fast growth and prevalence in the area, making it an ideal subject to consider for restoration efforts.

3 Pau Jacaré (*Piptadenia gonoacantha),* the Alligator Tree

As mentioned previously, there are a number of native trees that have been considered for use in forest corridors or as the leguminous, nitrogen-fixing component in an agroforestry plot. The Pau Jacaré, or *Piptadenia gonoacantha* is one of these; however, there have been few well-recorded trials in such conservation and restoration efforts. This tree is a member of the Leguminosae-Mimosoideae family, and has a multitude of names including pau-jacare, jacare, angico-branco, monjoleiro, monjolo, icarape and casco-de-jacare by which it is known in different regions (Lorenzi 2002). It is important to consider the attributes of this tree in order to more accurately assess its viability as a restorative species.

3.1 Distribution

The presence of the Pau Jacaré has been noted largely in tropical, subtropical and humid areas (Ramalho Carvalho). More specifically it ranges from 2˚S in Pará to 28˚50'S in Santa Catarina. It is common in the South and Southeast regions of Brazil, being especially prevalent in Rio de Janeiro, Minas Gerais and Mata Grosso do Sul (see Figure 2). The species experiences rare and infrequent dispersal in the Atlantic forest and in the semideciduous forests of the Parana River basin. It is particularly common in the state of Sao Paulo at altitudes between 500-700m. It grows best in shady, semi-deciduous regions but can survive in areas of dense forest, lowlands, sub-mountain expanses and intermediate forests. The *Piptadenia gonoacantha* is a heliophyte and hygrophyte selective plant. The Jacaré is also characterized by its ability to grow in poor conditions and act as a pioneer species or secondary starter. Because it is a colonizer, it invades abandoned land and has at times been used to restore degraded areas. Pioneer species are highly competitive and require a great deal of light for optimum growth; as a result the Jacaré occurs almost exclusively in secondary growth areas known as capoeiras and capoeiroes, which contain mainly low-growing shrubs and often represent a transitional stage for a

regenerating forest. Depending on the area the density of the tree ranges from 3-18 trees per hectare.

1. 

2. 

Figure 1. Brazilian States ("States of Brazil")
Figure 2. Distribution of Jacaré trees within the Brazilian States. (Ramalho Carvalho)

3.2 Morphological Information

In height, the Jacaré typically ranges from 10 to 20 meters and has a trunk diameter between 30 and 40 centimeters. From a distance it appears to have narrow, thin branches and an irregular, relatively flat treetop. It is a slightly spiny plant with well-marked, incision-like rectangular plaques on its bark. The bark is around 5mm thick and when young, the branches and trunk have woody longitudinal crests. When trees grow older the crests are less defined, so it is often necessary to look up to younger branches to verify the tree's identity. The tree has compound, bipinnate leaves that are 10-15 centimeters long with 4-8 pairs of pinnae. The pinna themselves are 5-7 centimeters long and hold 30-40 pairs of leaflets. The Jacaré produces a leguminous fruit made up of a flat, dehiscent, grayish pod, with 4-7 seeds (Lorenzi 2002). Upon flowering there are many white, yellow, and cream-colored flowers usually gathered in small bunches and surrounded by 5-9 long spikes.

3.  

Figure 3. Photographs of *Piptadenia gonoacantha* trunks taken by author.

4.  5. 

Figure 4. Picture of Jacaré flowering. book

Figure 5. Picture of Jacaré seed pods ("Pau Jacare - Piptadenia Gonoacantha - Muda De 40 a 60cm.")

3.3 Reproduction and Phenology

Reproduction for the *Piptadenia gonoacantha* occurs sexually, by means of hermaphroditic plants, and through pollination usually done by bees. This process typically begins when the tree is 3 years of age and the soils surrounding it exhibit elevated fertility. The Jacaré flowers from November to April, and fruits from April to August. The dispersal of fruits and seeds occurs by means of gravity, wind and animal pollinators. Cattle have been suggested as an additional vector of seed dispersal; however, most local famers say that this is not a

dependable method and that trees are too tall for cattle to reach the seeds (Ott 2002). When attempting to grow Jacaré from seed, the fruits must be harvested directly from the tree when they begin to open spontaneously (Lorenzi 2002). Next, they should be left in the sun to allow for the opening and release of the seed. One kilogram of fruit will yield approximately 18,000 seeds with short storage viability. As soon as seeds are harvested they should be set to germinate, with no treatment, in seed beds or directly into individual containers with a clay-sandy substrate. If kept in semi-shade, sprouting will occur within 5-10 days and germination is plentiful. The seedlings develop quickly and are ready for planting out in the field within 3-4 months. Plants in the field grow rapidly, easily reaching a height of 5 meters within two years. It is important to note though that different numbers of seeds are produced each year so it is difficult to gauge how many seeds can be collected (personal communication with Toni, the Iracambi nursery supervisor). Additionally, the planting method described in the book is applicable to a large number of native plants and does not account for various natural changes, like precipitation or heat, which are bound to affect the growth of a tree.

3.4 Uses

There are a number of uses that have been considered for various parts of the Pau Jacaré. The wood is moderately heavy with a density of .75g/cm^3, making it hard to cut, but soft to work with (Lorenzi 2002). It has a thick texture, an irregular grain and a medium resistance to attacks from xylophagous organisms. This wood has been used for indoor finishing, furniture frames, door panels, manufacturing of toys and packing cases. It is also considered to be one of the best for firewood and charcoal. In addition to the wood, the flowers have a high melliferous value meaning its resources can be harvested by bees and turned into honey. Apart from these easily tangible uses the Jacaré has been deemed by some as indispensable in successful heterogeneous reforestation when replanting areas for permanent preservation.

3.5 Soil and Symbiosis

The soil quality necessary for Pau Jacaré varies considerably based on the region. It can grow in both rich and poor soils but is absent from cerrados, which are vast savannah regions in Brazil located mainly in the states of Goiás and Minas Gerais (Ramalho Carvalho). Some growth

is sustained in low fertility, rocky areas as well as in areas of average fertility deemed unsuitable for agriculture. The Jacaré has also been found to have a symbiotic relationship with *Rhizobium* bacteria, responsible for creating nodules that facilitate nitrogen activity (Lorenzi 2002). Inoculation is recommended in some areas because of decreased survival, but generally there is evidence that this relationship is strong enough to create a large root system, allowing for successful growth in less fertile areas.

4 Considering Soil

Perhaps the best way to assess the impact of the *Piptadenia gonoacantha* on its surroundings is to look at its effect on the soil. In order to do so it is first important to recognize which properties in the soil are most critical. The importance of nitrogen-fixation has been mentioned earlier in discussing agro-forestry, but there are a plethora of other soil characteristics that affect the fertility and health of an area. They can play a huge role in determining whether the Jacaré can be effectively planted as a means to restore soil health.

4.1 The Basics

It is often difficult to define soil because of its wide range of functions; we consider its origins, its physical characteristics for engineering purposes as well as its ability to sustain life. For the purpose of this study the ability of the soil to grow plants is the most important function, as this is a good way to assess the health and fertility of the soil. Once these qualities are known we can study the way various plants affect the soil and help determine which plants are best for restoration purposes. Thus, based on an agronomic definition, soil is “the unconsolidated cover of the earth, made up of mineral and organic components, water and air and capable of supporting plant growth” (Kohnke 1995). Furthermore, various systems have been developed to quantify the value of soil, all of which are based on its crop-producing capacity. The most basic interaction between soil and plant is photosynthesis; plants are capable of converting carbon dioxide and water from the ground into sugar, carbohydrates and fat. Light energy from the sun provides the fuel necessary for the reaction. Further synthesis of proteins requires nitrogen, sulfur, phosphorus, carbon, oxygen and hydrogen. Plants contain 20% dry matter which is largely made up of hydrogen, oxygen, carbon and nitrogen provided by

air and water; however, smaller parts of the dry matter are no less important. They originate from the soil and are critical for plant growth. Overall, soil serves four essential functions for plant growth: it anchors plant roots, supplies water, provides air and furnishes roots with minerals for nutrition.

4.2 Components: an Overview

As a whole, soil is made up of air, water, solid particles and houses large populations of microorganisms. The solid particles can be either mineral or organic (Kohnke 1995). Minerals are divided into 4 soil fractions by size: gravel, sand, silt and clay. Organic matter is readily decomposable material consisting of either fresh plant or animal residue. As far as solid elements go, clay and organic matter are the most important in plant nutrition because they are chemically active, meaning they allow for easy passage of nutrients. Space between the solid particles is occupied by water and air. The water flowing through these pores is very much a solution as it is enhanced by various minerals which then serve as nutrients for plants. Plant roots require oxygen for everyday functioning so the parts of pores not occupied by water are occupied by air. Large pores allow for a sufficient amount of oxygen to continually be funneled to the roots. Even so, because of respiration by the plant roots soil air typically contains more carbon dioxide than oxygen; this makes large pores all the more important. Microbes are another important source of nutrients: they present them in a usable form and add stability to soil crumbs thus giving them resistance to erosion.

4.3 Physical Properties

As mentioned above, gravel, sand, silt and clay are the major solid components of soil. In this set, sand and silt are inert, meaning they provide little in terms of nutrients and transport; instead, they create a solid skeleton for the soil (Kohnke 1995). Clay, on the other hand, is chemically active and is adsorptive of water, gas and various dissolved substances. Two of the most important types of clay are kaolinite and smectite. Of the two, smectite is smaller and more reactive. The reason for clay’s high reactivity is its negative charge; charged cations surround each particle and these cations can be exchanged for one another. In terms of mineral exchange, positive ions are absorbed after which minerals are given off. The clay structure

depends largely on the interaction with the cation. For example, small cations like calcium and magnesium can get close to the particle, thus neutralizing the clay's negative charge. This allows for the particle to cling together closely, they are flocculated. Other ions, like sodium, are larger and are surrounded by water, meaning they cannot effectively neutralize the negative charge. This causes repulsion, they are dispersed.

When judging the texture of a soil we must look at the relative proportion of various grain sizes. It is generally said that the best soils, with the most fertility, are those that are composed of 10-20% clay (Kohnke 1995). Surface area of particles is also important in chemical reactions: the greater the surface area is that a substance exposes the greater its ability to enter into chemical and physical reaction. Understandably, clay has a huge surface area. The structure of soil is also important when judging for its fertility and its ability to support growth. Structure describes how individual particles are arranged in relation to each other. Particles are arranged into small groups called aggregates, which can then arrange to form larger groups, called peds. Soil with granular structure is most desirable for plant growth; this means particles are arranged with rounded edges so both large and small pores are formed. Soils in good tilth are soils in optimum condition and are defined by water-stable aggregates. This type of aggregation requires both organic matter and clay. Pore space is another important element of soil structure. Pores are responsible for providing aeration within the soil system. In fact, the number of large pores defines the system's aeration capacity. Small pores are equally as important because they allow for capillary action which brings up water to a level where plant roots can use it. Finally, the color of soil is another good physical marker of soil health. Darker soil typically means more organic matter. As previously discussed, organic matter is associated with improved aggregation and a good water-holding capacity. Dark soils can also retain heat better, and then radiate it at night.

4.3.1 Moisture

Water is essential in plant growth, which is why determining soil moisture can give us a good idea of whether or not it is capable of supporting life. Soil should act as a storehouse of water; precipitation enters during the infiltration process and the soil must be structured in

such a way that an appropriate amount of water is retained, but excess water is drained to prevent water logging. Soil in good tilth prevents massive water runoff.

4.4 Chemical Composition and Growth

In order to be a hospitable environment for plant growth and organisms, soil must contain appropriate chemicals. Knowing the relative amounts of chemicals present in soil is an excellent way to predict whether the soil will successfully house certain plants. Five elements are responsible for 95% of a soil's weight. Potassium has been called the most important nutrient for plant growth and it is present in large amount in soil; however, because it is present largely in rock formations its availability to plants is actually quite limited. This is the case for many nutrients, so it is important to determine which fractions of elements are readily available for plant use (see Table 1 below).

Table 1: Element availability[1]

		Amount available		
Element	Symbol	Percent of Soil	Pounds per acre of plow layer	Ratio of total to available for of element
Nitrogen	N	0.006	120	17
Potassium	K	0.0083	166	2000
Calcium	Ca	0.10	2000	7
Phosphorus	P	0.0017	35	25
Magnesium	Mg	0.018	360	27
Sulfur	S	0.0012	24	17
Iron	Fe	0.0001	2	20,000
Manganese	Mn	0.002	40	60

[1]Table adapted by author from Kohnke's Soil Science Simplified, p29 Table 4-2

Soil reaction is usually defined by its alkalinity or acidity which means it is essential to determine this value before deciding to grow plant in a certain area. Most crops grow best in a slightly acidic soil (pH 6.5-6.8), though there are those that prefer high acidity (pH 4.0-5.5) or neutrality (closer to pH 7). A low pH occurs when excess hydrogen ions bind to clay particles. In cases where soil is too acid, calcium carbonate can be added in order to neutralize the clay.

As noted previously, the chemical activity of clay and organic matter means that there are exchangeable cations present in the soil. When there is a prevalence of cations like calcium soil is more likely to be fertile and well-structure. Too many hydrogen cations cause excess

acidity and the release of aluminum compounds, which can be toxic to the soil. Anions are also present in soil, the most important of which are phosphate, sulfate, nitrate, chloride and bicarbonate. Calculating the amount of soluble salts in the soil (by determining electrical conductivity) can help determine if there is an excess or deficiency. Generally it is said that soils with over 0.2% soluble salts are too saline for optimum plant growth.

The key elements of plant life and survival in soil are the absorption of water and nutrients, transpiration of water from plant to the atmosphere, photosynthesis, synthesis of complex organic compounds and respiration. Apart from carbon dioxide and oxygen which can be collected from the atmosphere, other plant nutrients originate from the soil. Table 2 provides a good representation of what elements are needed for plant growth.

Table 2: Elements Used in Plant Growth[1]

Used in Large Amounts		Used in Small amounts from Soil Solids
Mostly from air and water	From soil solids	
Oxygen (O)	Nitrogen (N)	Chlorine (Cl)
Carbon (C)	Phosphorus (P)	Iron (Fe)
Hydrogen (H)	Potassium (K)	Manganese (Mn)
	Calcium (Ca)	Boron (B)
	Magnesium (Mg)	Copper (Cu)
	Sulfur (S)	Zinc (Zn)
		Molybdenum (Mo)
		Cobalt (Co)

[1]Table adapted by author from Kohnke's Soil Science Simplified, p36 Table 5-2

Out of the following, the most limiting elements for crop production are nitrogen, potassium and phosphorus followed by calcium, magnesium and sulfur as secondary elements. Nitrogen is responsible for rich green color that we see in healthy plants. It also promotes above-ground growth and affects the protein content and quality of the plant's fruit (Foth 1970). Phosphorus is essential in energy transfer within the plant; it is prevalent in the roots which are responsible for water and nutrient uptake. Potassium greatly affects the health of the root system and tends to offset negative effects of extraneous nitrogen. Additionally, it takes part in the synthesis of starch and distribution of carbohydrates in the plant. In large-scale farming nitrogen, potassium and phosphorus must often be added in order to replenish the supply of nutrients that has been used up (Kohnke 1995). Optimum amounts of each essential nutrient will produce a "maximum yield" of a crop. Determining the amounts of each element in the soil

is important in determining how much and what kind of fertilization is needed. There are also physical markers that can alert a farmer to a deficiency or excess of a certain element. For example, a deficiency in nitrogen is marked by yellowing leaves, phosphorus deficiencies stunt growth and produce a purplish color, and potassium deficiency causes marginal firing on the leaf.

4.5 Nitrogen Fixation

As we have established, nitrogen is incredibly important in plant growth so the way it is made available to plants requires special attention. Nitrogen has often been called the primary limiting nutrient for plant growth, thus a lack of nitrogen has led to reduced agricultural yields around the world (Moore 2002).

In order to begin exploring the role of nitrogen in the soil we must first look at its presence in the atmosphere. Our air is composed of 80% nitrogen gas (N_2), with approximately 6400 kg of nitrogen above every hectare of land. It comes in a stable diatomic form so it is inaccessible for plants, meaning they must convert, or “fix” it in order to use it. This is where we get a process called nitrogen fixation during which atmospheric nitrogen is converted to ammonia (NH_3) by means of an enzyme called nitrogenase. Nitrogenase is a biological catalyst found naturally in certain microorganisms like *Rhizobium* or *Frankia*, for example. Nitrogen fixation can occur when these microorganisms are bound closely to higher plants. Leguminous plants can fix atmospheric nitrogen because of the symbiosis they have established with rhizobia that live their root nodules. Rhizobia typically infect root hair of large leguminous plant and produce nodules which then serve as homes and energy reserves for the bacteria. The bacteria, in return, take free nitrogen from the soil and air and convert it into a form that the plant can use.

$$N_2 + 8H+ + 8e^- + 16\ ATP = 2NH_3 + H_2 + 16ADP + 16\ Pi$$

(Deacon, “Nitrogen Fixation”)

To allow for cleavage and then the reduction of N_2 into ammonia, ATP is used for energy; the sugars that provide the energy are manufactured by the plant during photosynthesis and are then transferred to the nodules. It is estimated that for every gram of

N_2 fixed, 1-20 grams of C must be fixed during photosynthesis. The source of electrons for fixation is sunlight, which ultimately breaks the triple bonds of atmospheric nitrogen (Bryan 2000). Nitrogenase, the enzyme responsible for the conversion, is oxygen-sensitive so low oxygen is achieved within the system through compartmentation, active respiration and synthesis of leghemoglobin. To conduct the conversion, the nitrogenase enzyme uses ATP energy from the sugars transferred to the nodules. It is also important to note that a nitrogen-fixing system requires more phosphorus because of extra energy uses in plant growth, nodule formation and ATP synthesis (Moore 2002).

There are, naturally, a wide range of factors that limit the nitrogen-fixing abilities of a give system. These include excessive soil moisture, which stunts the development of root hairs, drought, which reduces the number of rhizobia in the soil and causes nodule decay, soil acidity, P deficiency and excess mineral N, which inhibits the rhizobium infection process. Climatic factors like temperature and light are also very important: extreme temperatures make this process much more vulnerable, and light regulates photosynthesis, which is a key step in fixation.

Nitrogen-fixing trees can be used very effectively in restoring areas with poor soil and in reforestation. Many nitrogen-fixers are also pioneer species; they can successfully mine and accumulate nutrients from deep below the surface (Moore 2002). This gives other plants better access to nutrients, which in turn encourages further growth. Additionally, constant leaf drop provides organic matter which enriches the soil, and the root system stabilizes the soil and provides aeration channels. Nitrogen fixation is so valuable to soil health and plant growth that various methods to amplify this process have been used. Inoculation is the introduction of extra Rhizobia into soil to ensure proper nodulation and nitrogen fixation. These inoculants tend to persist in the soil for a long time, which means further inoculation is not needed for many years. Drawbacks include weak responses to inoculation by native leguminous species, and a wide variability in yield responses in time and spaces.

4.6 Soil Specifics in Area of Study

The area of study is within the Graminha Valley where soils are categorized as red-yellow latosols (latossolos vermelhos-amarelos). These are a type of Ferralsol, which are

extremely weathered soils often found in humid tropical climates with tropical rain forest or semi-deciduous forests (Faccio Carvalho). These soils are quite poor chemically, exhibiting a low ion exchange capacity, unstable nutrient reserves that are easily leachable and difficulties with phosphorus fixation. As mentioned previously, the low soil pH may lead available aluminum to reach toxic levels. On the other hand, these soils are quite permeable and have a relatively stable structure, but become susceptible to erosion after forces like forest clearance or overgrazing.

4.7 Focus on the Jacaré

After examining the problems the Atlantic Rainforest faces, particularly with regards to soil, and considering some of the more broad solutions, I would like to focus on the interaction between the soil and a native tree, the Pau Jacaré. The effects on soil structure and chemical activity (ion exchange capacity) will be examined, as the importance of these qualities has already been discussed. Special attention will be given to nitrogen, not only because it is critical in the tree's development but also to assess the potential of the Jacaré in agroforestry or forest corridor projects. Examining a common, native tree is important as it may prove to be a practical and feasible solution for this area.

5 Materials and Methods

5.1 Sampling

Soil samples were taken from 4 different land use areas within the Graminha Valley between June 20th and July 4th. Areas were selected in an attempt to mirror the natural succession and development process and with the goal of isolating the effect of the Pau Jacaré. One of the areas was open pasture, another was individual Jacaré trees within a pasture and two of the sites were relatively dense stands of Jacaré within regenerated forests of different ages. A more detailed description of each study site follows. Trees were selected randomly for the most part, but samples were collected from trees that were similar in size. Samples were taken at 3 varying distances from each tree, or from a selected point within a pasture (1m, 3m, 5m). This was done in order to assess how widespread the effects of Pau Jacaré growth are on surrounding soil or to get a good assessment of soil quality in the area in the case of open

pasture; such a system was used for individual trees, Jacaré stands and open pasture in order to maintain a systematic approach. Three samples were collected at each distance along the dripline of the selected tree, at even distances along the appropriate radius value from the tree (see Figure 6).

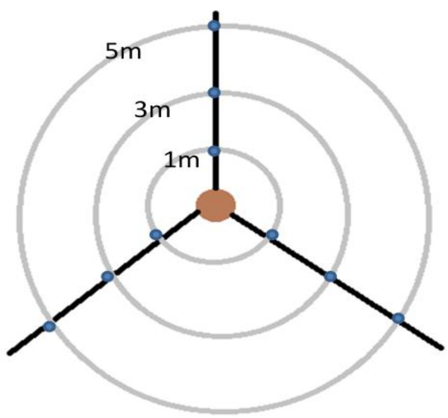


Figure 6: Sampling scheme for each testing location (tree or individual point). The brown center represents the chosen tree or point within pasture; each blue dot represents the sampling locations at radii of 1, 3 and 5 meters. The 3 samples on each radius circle were mixed together to create an average of the stratified layer.

This was done in order to obtain an average of soil quality for that distance; mixing samples in this way tends to “reduce distribution and segregation error” (Kohnke 1995). Based on the idea of stratified sampling, all samples were taken from the A horizon of the soil, “a zone of organic matter accumulation and maximum biological activity”, and usually came from a depth of 5-8cm (Foth 1970).

5.2 Study Sites

“Mata Sozinha”(MS) – This area, translated as “lone forest”, is characterized by secondary growth forest which has been regenerating and developing since 1989. Prior to this it was used chiefly as cattle pasture (see Figure 7). The area sits at elevations ranging from 700 to 800 meters and is bordered below by cattle pasture and wetland vegetation, with older forest growth near the stream. This forest was chosen principally because of the prevalence of Jacaré (*Piptadenia gonoacantha)* trees. Based on previous vegetation assessments done by Jeffrey Ott in 2002, the Jacaré makes up 24% of all living trees and 41% of living trees with a diameter

greater than 10 cm (Ott 2002). This relatively dense stand of the Jacaré allows for a good assessment of the effect of the tree on soil health in a 20-year old regenerated forest.

Figure 7. The picture shows the "Mata Sozinha" in 1989, when the entire area was clear and being used for cattle pasture. The darker green area to the right has been regenerating since that time and is home to the Jacaré stands used in this study. The greener pasture below was used for pasture sites and individual Jacaré trees sites.

Forest Behind Centro (CF) – This area is also a secondary growth forest located behind the living area of Iracambi volunteers. Previously this land was used as pasture and housed a donkey breeding business but has been untouched and regenerating since 1980 (LeBreton 2012). A small number of trees were planted to initiate regeneration but no large-scale scheme was implemented. This forest also has several Jacaré stands (though less dense than in the "Mata Sozinha") and allows for a good assessment of Jacaré effects on soil on a slightly larger time scale, 30 years.

Open Pasture areas (P) – Several open pasture areas were selected to represent a completely deforested area in which Jacaré trees do not grow and thus cannot have any effect on the soil.

- *Pasture Below "Mata Sozinha"* – area below the regenerated "Sozinha" forest that is still used as cattle pasture. (Note: not used by cattle as frequently as other pastures, because a river must be crossed to reach the area)
- *Pasture above Centro* – area above Iracambi residence currently used as cattle pasture (frequented by cows daily).
- *Pasture adjacent and to the left of Mata Sozinha* – this area is currently used for cattle grazing, never allowed to regenerate.

Individual Tree Locations (PWT) – Individual trees were selected to better isolate the soil effects of Jacaré trees.

- *Pasture Below Mata Sozinha*: A solitary Jacaré tree in pasture approximately 25 cm in circumference (Note: This tree is located within 2 meters of another unidentified tree – this proximity may have an effect on soil tests and prevent the derivation of the unique effect of Jacaré on soil.)
- *Hill to the right above road to Robin and Binka's* – This is a relatively open area with solitary trees each separated by at least 3 meters. The area was previously pastured and in the early 1990's Robin LeBreton planted the area with macadamia trees, but due to high maintenance needs the project was abandoned and currently the area is untouched (Personal communication with Robin). Two individual Jacaré trees were selected for soil measurement purposes; both circumferences were between 35 and 45 centimeters.

See Appendix 2 for a map of the area with sampling sites included.

5.3 Analysis

Once collected, the samples were weighed, dried and weighed again to calculate moisture. While still moist a Munsell Soil Color Chart was used to determine a color – only one of the distances was used for each tree because no significant color difference was noted when moving away from each tree. Using the dry soil, soil tilth, pH and conductivity were assessed. Soils were then taken in for further analysis to the soils lab at the University of Vicosa, part of the Departamento de Solos. They were tested for basic macronutrients and nitrogen.

6 Results

6.1 Soil Tests from Lab

36 soil samples were analyzed at the Departamento de Solos at the University of Vicosa; they were tested for pH, potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), aluminum (Al), H+Al, sum of bases (SB), organic material (MO), phosphorus remnant (P-rem), CTC effective (SB+Al), CTC ph 7 (SB+H+Al) , aluminum saturation (m), saturation by bases (V), and nitrogen (N). See Appendix 1 for the complete layout of these results.

Various statistical tests were conducted to compare land use areas, and to determine how strong the effects of the Jacaré may be moving away from the tree.

6.1.1 Nutrient Variables

In order to compare land use areas, averages for each nutrient were calculated.

Table 3: Averages for Nutrients in the Four Land Use Areas

Sites	pH	P	K	Ca	Mg	Al	H+Al	SB	CTC1	CTC2	V	m	MO	P-rem	N
CF	4.73	2.34	59.7	1.95	0.62	1.12	10.3	2.72	3.84	12.9	18.1	50.9	8.46	19.7	.31
MS	4.29	1.84	29.3	0.35	0.21	1.4	11.5	0.64	2.04	12.1	5.24	68.6	5.88	18.0	.25
PWT	5.61	1.89	25.8	2.20	1.02	0.25	7.88	3.28	3.54	11.2	30.3	9.59	6.90	19.4	.26
P	5.51	2.71	77.7	2.11	1.40	0.30	6.82	3.74	4.04	10.6	34.6	26.5	9.30	25.5	.35

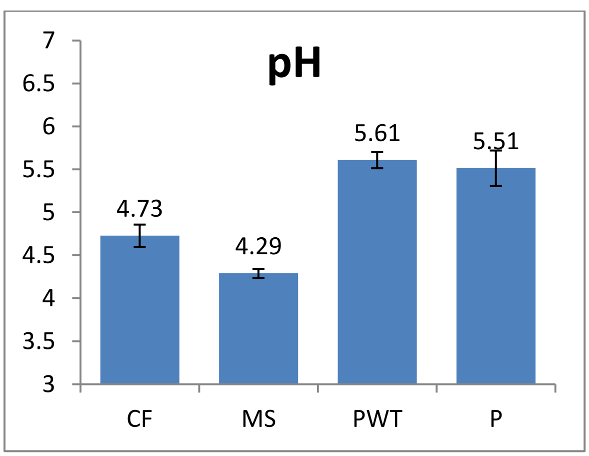
Single factor ANOVA tests comparing the four land use areas were done for each variable. P-values for each variable are shown below.

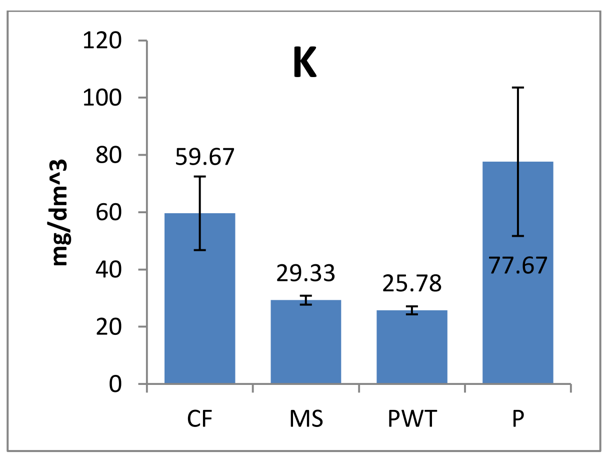
Table 4 : P-values Comparing Land Use Areas[1]

	pH	P	K	Ca	Mg	Al	H+Al	SB	CTC1	CTC2	V	m	MO	P-rem	N
p-value	**5.14E-08**	.070	**.048**	.071	**.004**	**8.15E-07**	**1.95E-05**	**.033**	.119	**.006**	**.005**	**.0003**	.151	.1167	**.019**

[1]All p-values in bold indicate significance. This means that the corresponding factor varies significantly between at least two of the land use areas.

Graphs for variables that are most relevant for further Jacaré discussion are included below.





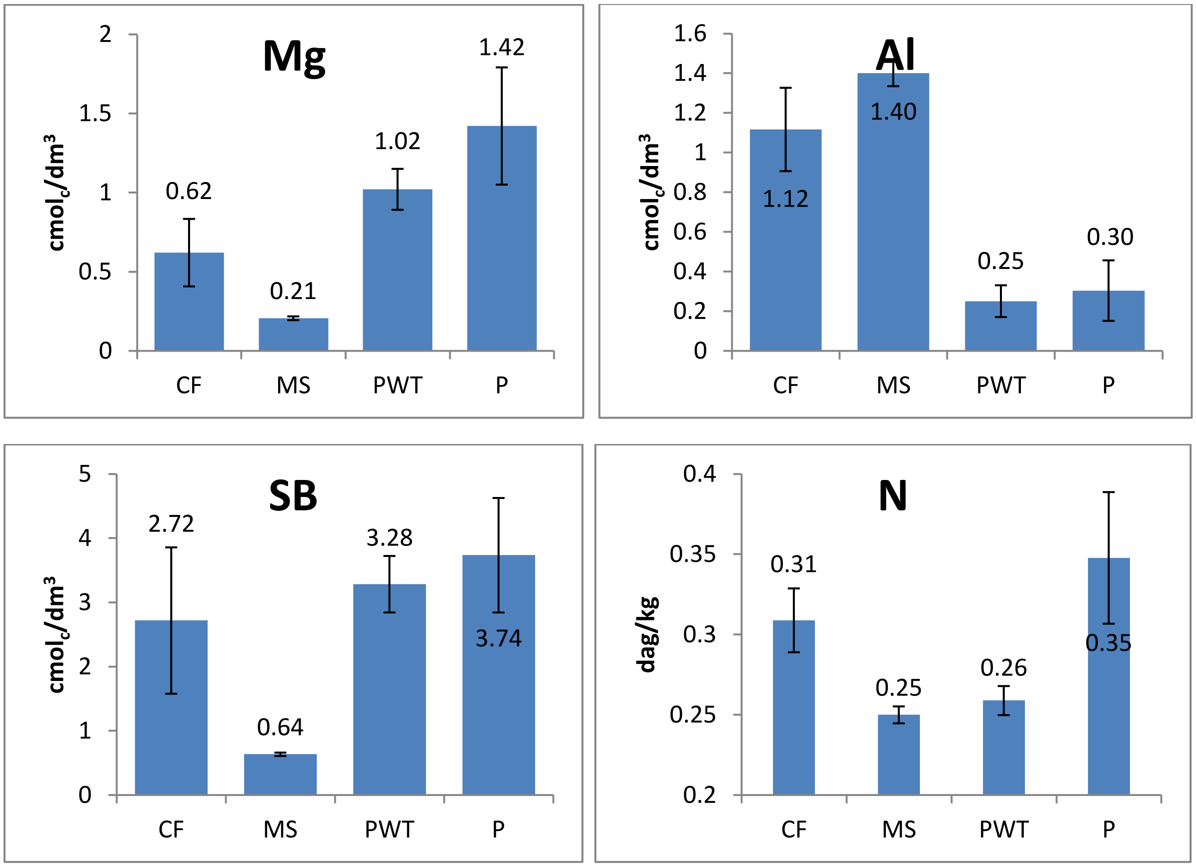


Figure 8. All of the following graphs show the averages of given nutrients based on land use area. These nutrients will be discussed further when considering the effects of the Pau Jacaré. Error bars were created by calculating the standard error of means for each average.

Additionally, in order to better see the effects of solely the Jacaré tree, T-tests were done between pasture and trees within pasture for all nutrients. The results of this are included below.

Table 5: Pasture vs. Individual Tree P-values

	pH	P	K	Ca	Mg	Al	H+Al	SB	CTC 1	CTC 2	V	m	MO	P-rem	N
p-value	0.684	**0.028**[1]	0.063	0.895	0.323	0.761	0.326	0.656	0.552	0.188	0.655	0.235	**0.033**	0.114	**0.050**

[1]Bolded numbers represent the statistically significant values. This means that for the given nutrients there is a significant difference between pasture and individual Jacaré trees within pasture.

6.1.2 Distance Variable

In order to better assess the effect a single tree has on the soil directing surrounding it, and whether the effects change significantly with increased distance from the tree, individual Jacaré trees within a pasture were sampled. To evaluate this, T-tests were done between each pair of distances: 1m-3m, 1m-5m and 3m-5m.

Table 6: P-values Comparing Distances for Trees within Pasture															
	pH	**P**	**K**	**Ca**	**Mg**	**Al**	**H+Al**	**SB**	**CTC1**	**CTC2**	**V**	**m**	**MO**	**P-rem**	**N**
1m-5m	0.55	0.56	0.49	0.71	0.86	0.77	0.86	0.81	0.72	0.59	0.91	0.9	0.73	0.77	0.68
1m-3m	0.41	0.28	0.44	0.71	0.22	0.8	0.72	0.53	0.48	0.96	0.64	0.68	0.47	0.58	0.83
3m-5m	0.82	0.49	1	0.44	0.23	1	0.83	0.37	0.28	0.52	0.52	0.8	0.92	0.75	**0.03**[1]

[1]The bolded value represents the only significant results in distance comparison. There was a significant difference in nitrogen between 3 and 5 meters.

6.2 Physical qualities

Physical tests were done directly after soil collection and included tilth, color and moisture.

Tables for each of these are presented below.

Table 7: Soil Tilth[1]		
Land Use	**Soil Classification**	**Percentages**
Centro Forest	Sandy Loam	80% sand, 10% silt, 10% clay
Mata Sozinha	Sandy Loam	83% sand, 15% silt, 2% clay
Pasture Trees	Sandy Loam	80% sand, 17% silt, 3% clay
Pasture	Sandy Loam	86.67% sand, 11.67% silt, 1.67% clay

[1]Tilth was determined by using a Lamotte Soil Texture kit. Soil was air-dried before conducting the texture tests. The soil was divided into 3 main components: sand, silt and clay, as shown in the 'Percentages' section.

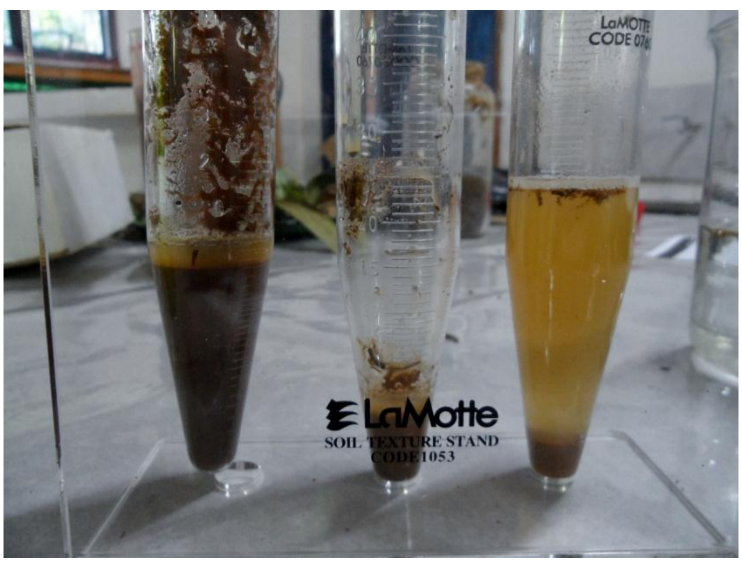


Figure 9. This image shows the texture test process. The containers hold silt, sand and clay, respectively.

Table 8: Color by Land Use Area[1]				
Sample Number (from 1m distance)	**Centro Forest**	**Mata Sozinha**	**Pasture with Trees**	**Pasture**
1	10YR 3/6	5YR 3/4	5YR 3/4	10YR 3/6
2	7.5YR 3/4	5YR 4/6	7.5YR 4/6	10YR 3/3
3	7.5YR 3/3	5YR 4/6	7.5YR 4/6	5YR 3/4

[1]Color was determined using the Munsell Soil Color Chart. Samples from each of the 3 locations in each land use area were assessed. Only soil from a distance of 1m was assessed because there was no significance between 1m, 3m, and 5m.

Table 9: Moisture (%)[1]				
Sample Number (averaged for distances)	**Centro Forest**	**Mata Sozinha**	**Pasture with Trees**	**Pasture**
1	7.0095	7.4141	11.6016	16.0705
2	6.6846	5.251	4.1124	15.681
3	6.8597	9.2316	2.5225	10.0756
Average	**6.8513**	**7.2989**	**6.0788**	**13.9424**

[1] In order to calculate moisture, soils were weighed directly after collection, then air-dried, then weighed again. The following formula was used in calculations: %water=[wt.(moist)-wt.(dry)]/(wt.(dry)*100**.** Soil moisture values given for each sample number are already averaged between 1m, 3m and 5m.

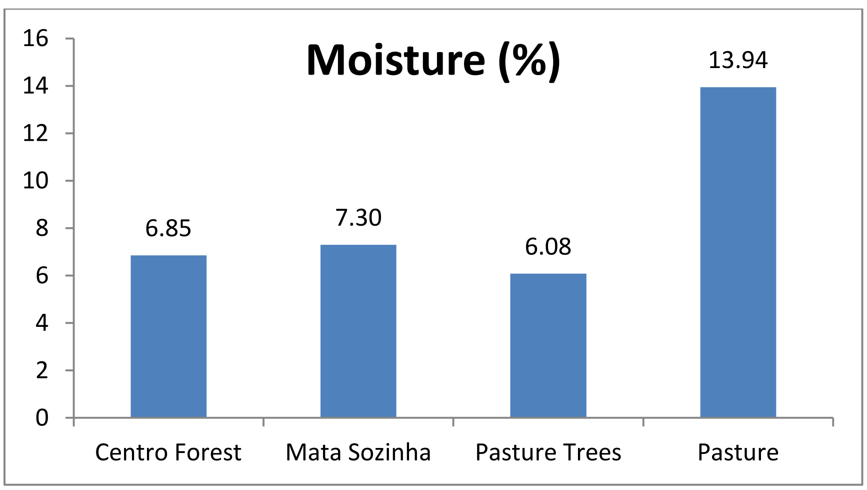


Figure 10: This figure demonstrates the moisture averages for each land use area.

6.3 Qualitative Observations during sampling

During sampling it was noted that retrieving soil from forest areas like the "Centro Forest" and "Mata Sozinha" was much easier than from pasture, or individual Jacaré trees within pasture. Soil appeared to be more porous and crumbly, making it easier to dig to the appropriate depth. Additionally, the forests contained no grass meaning that the soil was more accessible than pasture soil. Soil in forested areas also tended to be of a brown coloration, rather than the red tints found in pasture.

It is also important to note that the slopes from which samples were taken varied in steepness; this may have had an effect on the distribution of organic matter and water flow.

7 Discussion

When interpreting the results for the Pau Jacaré it is important to refer back to the soil qualities necessary for successful growth. In this study the Jacaré is being considered as a subject for reforestation efforts, like forest corridors, and alternative farming methods, like agroforestry. In both cases it is important that the tree grows quickly, and that it creates a suitable environment for other plants to grow. Out of the variables I tested for, I will focus on the pH, potassium, nitrogen, magnesium, aluminum, the sum of bases and all of the physical qualities. The importance of all of these variables has been discussed earlier, and by assessing them I will come closer to judging the viability of the *Piptadenia gonoacantha* in restoration efforts. These will also be given a closer look because they showed significant (p-value) differences between land use areas (See Table 4).

For the variables that were sent in to be tested in a lab, the actual numbers mean little without a way to compare them to other soil types. In this case it is helpful to look at rating table established for farmers that judges the quality based on a range of numbers.

Table 10: Chemical Classification[1]						
Very high acidity	High Acidity	Medium Acidity	Low Acidity	Neutral	Low Alkalinity	High Alkalinity
<4.5	4.5-5.0	5.1-6.0	6.1-6.9	7.0	7.1-7.8	>7.8

Agronomic Classification[2]				
Very Low	Low	Fair	High	Very High
<4.5	4.5-5.4	5.5-6.0	6.1-7.0	>7.0

[1]The following table was adapted from ALVAREZ V. et al. (1999); ("Fertilidade de Solos")
[2]The agronomic classification refers to the fertility and ability of the soil to grow crops well at the given acidity.

Chemical Variable	Unit	**Table 11: Nutrient Level Classification[1]**				
		Very low	Low	Fair	High	Very High
Organic Material	dag/kg	0.70	0.71-2.00	2.01-4.00	4.01-7.00	>7.00
Calcium (Ca)	$cmol_c/dm^3$	0.40	0.41-1.20	1.21-2.40	2.41-4.00	>4.00
Magnesium (Mg)	$cmol_c/dm^3$	0.15	0.16-0.45	0.49-0.90	0.91-1.50	>1.50
Aluminum (Al)	$cmol_c/dm^3$	0.20	0.21-0.50	0.51-1.00	1.01-2.00	>2.00

Sum of Bases (SB)	$cmol_c/dm^3$	0.60	0.61-1.80	1.81-3.60	3.61-6.00	>6.00

[1]This table was adapted from ALVAREZ V. et al. (1999). ("Fertilidade de Solos"). As in the previous table, the classification refers to the ability of the soil to successfully grow crops.

For acidity, pasture and individual trees come out with a 'fair' classification, 30-year forest (CF) has low, and 20-year forest (MS) has very low. This seems to suggest that in terms of acidity, which directly relates to the availability of ions, pasture has better suited soil for agriculture. The same type of results came back for potassium, magnesium, nitrogen and the sum of bases. On average, pasture land had the highest values (indicating fair or high agronomic value), while Mata Sozinha, the 20-year forest, had the lowest. For aluminum this was reversed; high aluminum count can produce toxicity so again, this supports the idea that pasture soil may be more fertile. This is the opposite of what one may predict; a forest able to harness so much growth may be expected to have better conditions for additional growth than an area where nothing has grown for years. This goes back to the enigma of tropical soils: they support so much growth but are poorly adaptable to agriculture. All of the nutrients are constantly being cycled and are never logged in one place for a long time. It is likely that this continuous movement is what prevents the soil from holding all of these nutrients, and what produces lower numbers in soil tests. Pasture soils may appear to have higher numbers of the nutrients, but they are also much more susceptible to removal. Even a small disturbance is capable of washing away these exposed nutrients, leaving the soil worse off than before and incapable of repossessing the nutrients.

The land use area comparison gives a good idea about the impact of the Pau Jacaré as part of a larger regenerating forest; however, it is difficult to derive any sort of 'specialties' from such comparisons. Individual trees in pasture were compared with empty pasture; this was done to better isolate the effects of the tree. The only significant values were for phosphorus, organic material and nitrogen and for all of them empty pasture had a higher value (See Table 5). Again, this seems counterintuitive, but the previous discussion of tropical soils can shed light here. Especially when a tree is isolated it requires a great deal of nutrients to begin growing and to survive. This probably leads it to use up more nutrients, and extract them from the soil as it sets up a more stable cycle. It is possible that once a stand of Jacaré trees is established and a stable cycle is developed, that more nutrients become available for other

plants to grow. This relates to the process of succession, and some evidence for this exists in the comparison between the 20-year forest (MS) and the 30-year forest (CF). Though many of the values are not statistically significant, some variables show that nutrient levels are significantly higher for the 30-year forest. Perhaps, once the Pau Jacaré has firmly established its ground, it begins to release some of its nutrients and give way to other species.

For physical tests it is important to compare the results to the information existing about physical characteristics that make soil more or less suitable for growth. Beginning with tilth, I observed all of the study sites to have "sandy loam"; however, they still varied slightly in their clay content. The forest behind Centro (CF) had the highest clay content, at 10%, and pasture had the lowest, at 1.67%. Generally, it is said that soils are most fertile with clay content from 10-20%, suggesting that forest soil may be more fertile. In addition, individual trees within pasture seemed to be surrounded by higher clay content, 3%, perhaps indicating some sort of clay-holding capacity by the Jacaré. Next, color should be considered. It is difficult to make any conclusions about the numbers gathered from the Munsell Color Chart (Table 7) because many of the values are similar across all four land use areas. However, during sampling it was noticed that soils within the forests (CF and MS) appeared darker, suggesting that more organic matter is being processed in these ecosystems. Organic matter is crucial to plant growth, so it makes sense that these areas are forested and actively support a great deal of life. Moisture is another important physical quality that was calculated to compare the land use areas. As can been seen in Figure 10, pasture has the highest moisture, while pasture trees have the lowest. This may be counterintuitive, because soils with trees are expected to be more hospitable, thus providing moisture for further growth. However, it is likely that moisture around trees is smaller because the trees are using up the moisture. Just as with nutrients, the trees in forests are in a stable cycle in which no excess moisture is offered. As for individual trees, they may have the lowest moisture because they are solitary and are struggling to survive, thus requiring more water.

Another aspect of the study was to consider how widespread the effects of the Pau Jacaré may be, if any obvious ones exist. I wanted to determine if Jacaré effects decreased the farther you got from the tree. To do so, individual trees in pasture were compared with pasture. Individual trees were used rather than the Jacaré stands in regenerating forests, to

limit the effects from surrounding trees and to better isolate the Jacaré. The results of this t-test are shown in Table 6; the only significance was found for nitrogen between 3 and 5 meters. A lack of significance in the majority of the variables may mean several things: the Jacaré may have no detectable effects, or they may not vary with distance. It is also possible that the distances used were too great to detect a significant difference.

With all of the results I have gathered it is important to allow for errors in measurement. Though I tried to control for variables like tree size, soil depth and slope, these were difficult to keep constant throughout the entire sampling process. It is also possible that some of the results that turned out to be "statistically significant", with a p-value of less than 0.05, are actually accidental or due to a factor completely unrelated to the Pau Jacaré, like rainfall, or animals, or pollutants.

8 Conclusions

On a large scale, it is difficult to make any sweeping conclusions about the effects of the *Piptadenia gonoacantha* on the fertility and health of soil in the Atlantic Rainforest. With the amount of data I have gathered it is not possible to say that the effects I have seen are caused purely by the Pau Jacaré. However, some significant results have been found, giving us an idea about what kind of effect this tree has on the surrounding soil. Younger areas that have dense Jacaré stands have fewer nutrients readily available in the soil, especially when compared to pasture. This is a characteristic of a healthy balanced system within a tropical forest, and perhaps when such Jacaré stands get older they can provide more nutrients. It is also clear from the prevalence of this species in the area, that it grows well here, due to a combination of factors including climate, precipitation, elevation.

The Pau Jacaré does not appear to provide an abundance of any specific nutrient; however its role as a pioneer species could be extremely beneficial for setting up forest corridors. Its capacity to fix nitrogen is still not clear but the way in which it creates a balance within the soil may be used in agroforestry. Though problems may arise with its competitive nature as it takes a lot of nutrients at the beginning of its growth stages, it can be used later on once stands have aged and growth has slowed. A stable nutrient cycle will likely promote growth and provide a good foundation for a healthy agroforestry plot.

I believe that the *Piptadenia gonoacantha* is a good subject for reforestation projects. Using older Jacaré stands for agroforestry projects may prove to be quite fruitful. Perhaps, this species can be used to create a forest corridor and once an appropriate amount of time has gone by, agroforestry can be added on. Carrying this out may be difficult because of extremely delayed benefits: farmers may not be willing to plant a forest corridor knowing that only in 30 years they can use parts of it for agriculture. Some sort of economic incentive to initially plant these forests may be needed in order to fuel the process. If such a plan is enacted it is also important to show the benefits that the Jacaré offers: not only does it help create and maintain healthy soil that may sustain other growth, but it can also be used by farmers for additional profits, or projects, like fence posts.

9 Future Research Suggestions

Although the soil analyses I conducted were not conclusive, they show potential for using the Pau Jacaré in restoration efforts. It is clear that this species grows well in poor soils, because all of the sampled locations are in some stage of regeneration after severe soil depletion. In future projects, more soil tests should be done, especially with nitrogen. If the Jacaré is proven to be a steady nitrogen-fixer this would be critical in agroforestry projects. Though costly, it would be extremely valuable to create an experimental agroforestry plot with the Jacaré and see how it interacts with crops. This would enable us to make a fair assessment of whether or not this species is fit for such projects.

If the Jacaré is to be grown for the purpose of sustaining agriculture or reforesting, more studies should be done on its seed-producing capacity. It is difficult to predict when the tree will produce seeds, so it may be valuable to either develop some method of storing the seeds, or to plant as many Jacaré as possible when the seeds are available. Finally, the Pau Jacaré is obviously not the only native tree available in the Atlantic Rainforest. Further studies should be done exploring other trees for restoration projects, because each tree has something different to offer.

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Appendix 1: Original Soil Data

REF_CLIENT	pH	P (phosphorus) mg/dm^3, ppm	K (potassium)mg/dm^3, ppm	CA (calcium)cmolc/dm^3	MG (magnesium)cmolc/dm^3
CF01, 1m	4.62	3	49	0.19	0.22
CF01, 3m	4.51	1.7	36	0.27	0.22
CF01, 5m	4.37	4.9	43	0.27	0.3
CF02, 1m	4.36	1.4	28	0.23	0.15
CF02, 3m	4.51	1.6	26	0.28	0.17
CF02, 5m	4.5	1.5	28	0.2	0.16
CF03, 1m	5.13	2.2	91	4.11	1.27
CF03, 3m	5.19	2.4	121	4.7	1.37
CF03, 5m	5.37	2.4	115	7.26	1.73
MS01, 1m	4.26	2	36	0.41	0.17
MS01, 3m	4.24	1.6	34	0.44	0.21
MS01, 5m	4.28	1.7	26	0.38	0.21
MS02, 1m	4.07	1.7	26	0.22	0.18
MS02, 3m	4.15	1.5	34	0.31	0.26
MS02, 5m	4.62	1.9	32	0.36	0.27
MS03, 1m	4.26	1.9	24	0.38	0.18
MS03, 3m	4.31	2.6	28	0.32	0.18
MS03, 5m	4.43	1.7	24	0.36	0.2
PWT01, 1m	5.77	1.6	24	3.45	1.11
PWT01, 3m	6.02	1.9	32	3.77	1.71
PWT01, 5m	5.97	1.5	30	2.45	0.96
PWT02, 1m	5.29	1.8	22	1.17	0.46
PWT02, 3m	5.36	2.8	26	1.52	0.83
PWT02, 5m	5.32	1.8	20	0.86	0.59
PWT03, 1m	5.39	1.7	26	1.93	0.97
PWT03, 3m	5.73	1.7	22	2.37	1.43
PWT03, 5m	5.62	2.2	30	2.24	1.13
P01, 1m	6.02	3.6	265	2.2	2.09
P01, 3m	5.93	4.3	105	3.37	3.03
P01, 5m	6.05	3.3	101	2.63	2.4
P02, 1m	5.91	3.4	40	3.9	1.71
P02, 3m	5.65	2.2	69	3.13	1.58
P02, 5m	5.96	1.9	61	3.4	1.82
P03, 1m	4.68	1.7	22	0.18	0.07
P03, 3m	4.61	2	18	0.11	0.04
P03, 5m	4.81	2	18	0.1	0.05

AL(aluminum)cmolc/dm^3	H+AL cmolc/dm^3 (method Ca(Oac))	SB (base saturation, sum)cmolc/dm^3	CTC_T_1 (effective, SB+AL3) cmolc/dm^3	CTC_T_2 (ph7, SB+ (H+AL)cmolc/dm^3	V(%)saturation by bases
1.66	10	0.54	2.2	10.54	5.1
1.37	9.8	0.58	1.95	10.38	5.6
1.46	9.7	0.68	2.14	10.38	6.6
1.56	12.2	0.45	2.01	12.65	3.6
1.56	12.6	0.52	2.08	13.12	4
1.56	12.6	0.43	1.99	13.03	3.3
0.49	8.9	5.61	6.1	14.51	38.7
0.29	8.4	6.38	6.67	14.78	43.2
0.1	8.2	9.28	9.38	17.48	53.1
1.66	12.7	0.67	2.33	13.37	5
1.37	12.6	0.74	2.11	13.34	5.5
1.37	11.6	0.66	2.03	12.26	5.4
1.37	10.6	0.47	1.84	11.07	4.2
1.07	9.8	0.66	1.73	10.46	6.3
1.27	11.1	0.71	1.98	11.81	6
1.66	11.9	0.62	2.28	12.52	5
1.56	11.8	0.57	2.13	12.37	4.6
1.27	11.3	0.62	1.89	11.92	5.2
0	5.3	4.62	4.62	9.92	46.6
0	4.8	5.56	5.56	10.36	53.7
0	5.6	3.49	3.49	9.09	38.4
0.49	10.6	1.69	2.18	12.29	13.8
0.59	9.7	2.42	3.01	12.12	20
0.49	9.7	1.5	1.99	11.2	13.4
0.39	8.9	2.97	3.36	11.87	25
0.1	7.9	3.86	3.96	11.76	32.8
0.2	8.4	3.45	3.65	11.85	29.1
0	5.6	4.97	4.97	10.57	47
0	5.5	6.67	6.67	12.17	54.8
0	5.6	5.29	5.29	10.89	48.6
0	5.2	5.71	5.71	10.91	52.3
0	5.2	4.89	4.89	10.09	48.5
0	4.8	5.38	5.38	10.18	52.8
0.88	9.7	0.31	1.19	10.01	3.1
0.98	9.8	0.2	1.18	10	2
0.88	10	0.2	1.08	10.2	2

M (%)saturation by Al3+	MO (organic material) dag/kg	P_REM mg/L (phosphorus remnant)
75.5	4.03	16.3
70.3	5.91	18.6
68.2	4.97	18
77.6	5.24	13
75	7.66	11.7
78.4	8.19	11.9
8	19.14	25
4.3	3.22	32.4
1.1	17.8	30.2
71.2	4.57	15.4
64.9	7.39	15.1
67.5	5.64	17.1
74.5	5.64	17.3
61.8	5.64	20.4
64.1	5.78	18.6
72.8	5.91	18.3
73.2	6.18	22.5
67.2	6.18	17.6
0	5.71	21.3
0	6.72	32.3
0	5.71	24.6
22.5	6.85	13.8
19.6	7.39	14.9
24.6	6.85	12.7
11.6	7.39	18.2
2.5	7.12	16.8
5.5	8.4	19.9
0	11.75	31.5
0	14.44	32.1
0	12.43	34.5
0	8.4	29.2
0	9.4	34.3
0	8.19	25.8
73.9	6.31	14.4
83.1	6.45	16.3
81.5	6.31	11.4

Appendix 2.

See attached PDF file for map of sites and area.

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