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ABSTRACT

Animal agriculture is one of the largest causes of deforestation, converting primary and secondary forest into pasture for cattle. By severely altering the landscape, major ecosystem changes occur, including changes in soil properties. I compared the soil of four types of land plots in Las Llanos, Monteverde: primary forest, pasture, reforested pasture, and fallow pasture. I tested the compaction, decomposition rate, presence of water stable aggregates, and arthropod diversity within each plot. Primary forest had significantly lower compaction, and seemed to have higher decomposition rates and higher proportions of large aggregate sizes. The reforestation site resembled both pasture and fallow pasture, especially in the case of compaction and decomposition. The four sites had individuals from many of the same arthropod orders, but primary forest had the highest number of individuals. Of the four sites, the primary forest seemed to have better soil quality than the others. The lack of regeneration in the reforested soil may suggest that forest does not return quickly to its natural state. Thus, when considering ecosystem protection, conservational efforts should be prioritized.

Estudio de diferentes propiedades del suelo en bosque primario, pasto, y bosque en regeneración en Los Llanos, Monteverde

RESUMEN

La agricultura animal es una de las mayores causas de deforestación, ya que convierte el bosque primario y secundario en pastos para el ganado. Al alterar el paisaje, ocurren cambios importantes en el ecosistema, incluyendo cambios en las propiedades del suelo. Comparé el suelo de cuatro tipos de uso de tierra en Las Llanos, Monteverde: bosque primario, pastos, pastizales reforestados y pastos en barbecho. Estudié la compactación, la tasa de descomposición, la presencia de agregados estables en agua y la diversidad de artrópodos en cada sitio. El bosque primario presentó una compactación significativamente menor, y pareciera tener mayores índices de descomposición y mayor proporción de agregados grandes. El sitio de reforestación presentó resultados similares al de pastizales y pastos en barbecho, especialmente en el caso de compactación y descomposición. Los cuatro sitios presentaron atrópodos de muchas de las mismas órdenes de artrópodos, sin embargo el bosque primario obtuvo el mayor número de individuos. De los cuatro sitios, el suelo del bosque primario parece tener mejor calidad que los otros. La falta de regeneración en el suelo reforestado sugiere que el bosque no regresa rápidamente a su estado natural. Por lo tanto, al considerar la protección de los ecosistemas, los esfuerzos de conservación deben ser priorizados.

Cattle ranching, which often entails deforestation, introduction of novel organisms, and in many cases the introduction of agro-chemicals, has intense effects on cultivated land and surrounding ecosystems. It is a widespread practice in Costa Rica, and has the potential to severely reduce soil quality. Soil quality assesses the success and presence of biological and biochemical processes fundamental to ecosystem function (Dick 1994). Soils vary, especially in response to use and management, and these changes can be measured and tested (Larson and Pierce 1994).

In response to the deforestation of primary forest for cattle pasture, reforestation projects attempt to regenerate natural habitats. At La Calandria Biological Station in Los Llanos, Monteverde, reforestation projects—started in 2001—have aimed to reforest some land that was once pasture. In order to understand if reforested areas are truly regenerating the natural habitat, it is crucial to understand the soil conditions. The quality of soil properties can provide information on overall ecosystem health.

To determine the soil quality of various types of managed land, I assessed four different properties: (1) soil compaction (2) presence of water-stable aggregates (3) decomposition rate (4) arthropod diversity. Soil compaction is essentially a measure of soil density; soil that is more compact will have higher density and less porosity. Soil compaction can influence root growth, inhibiting smaller roots from growing in more compacted soil (Materechera *et al* 1992). Aggregates are particles of soil that bind together. Testing their water stability measures how well they stay together under forces of water. Larger aggregates are generally considered favorable, as they increase soil oxygenation, decrease erosion, and enhance plant growth (Kemper and Rosenau 1986). Decomposition rate measures how quickly organic matter decays. It is an essential process for nutrient regeneration within the soil. In this study, arthropod diversity measures the number of orders found at each site. A study by W. A. Reiners and collaborators (1994) noted that conversion of forest to pasture showed obvious and significant effects on species composition and richness. Arthropods are essential in trophic interactions. Changing vegetation can decrease their diversity, thus altering the trophic structure, impacting ecosystem function (Haddad *et al*, 2009).

Since cattle farming is such a large industry in Costa Rica (and the world), it is crucial to understand how this industry affects long-term soil health. Additionally, it is valuable to understand how well reforestation programs can recover the natural habitat, years after regenerative projects have been established. In order to assess this, I ask:

How does soil compaction, water stable aggregates, decomposition rate, and arthropod diversity differ among pasture, reforested pasture, fallow pasture, and primary forest?

METHODS

I conducted my study in May 2017, at La Calandria Biological Station and an adjacent farm, Finca las Americas. La Calandria has various reforestation plots from multiple types of cultivated land. I studied two sections of La Calandria and two sections of Finca Las Americas, each with a different land history. Site 1 was current pasture used for cattle grazing (Finca). Site 2 was pasture that was left fallow since 2001 (La Calandria). Site 3 was reforested pasture (La Calandria); the site was reforested beginning in 2001. Site 4 was primary forest that is virtually untouched (Finca). The study sites were adjacent, so in theory, the soil quality had the same starting health before human activity. Additionally, each soil site was at the same elevation, so there is no differentiation due to altitude. On each site, I tested soil compaction, aggregate stability, decomposition, and arthropod diversity.

Soil Compaction

I used a soil core to find soil density, and collected ten samples from each site (n=40). Compacted soil is associated with higher bulk density (Brady 1984). For each trial, I collected a core of soil and measured its length. The length was then multiplied by the core's circular area (the entrance point of the core) to obtain the volume of the extracted soil. I then dried each soil sample overnight to evaporate excess water within the soil, and eliminate mass discrepancies due to additional water weight. After weighing each sample separately, I calculated the density using the formula density = mass/volume. I used ANOVA to determine differences.

Water Stable Aggregates

I used a wet-sieving methodology developed by Cambardella and Elliott (1993). This method divides aggregates by size, and stacked in sieves of increasing hole size—the four sieve hole sizes were 125µm, 250µm, 500µm, and 2000µm. I first collected and dried soil from each of the four sites. For each trial, I measured 300 grams of dried soil, and poured this into the stacked sieve apparatus. The sieves were submerged in a bucket of water for 2-3 minutes. The apparatus was then removed and re-immersed for three minutes. I drained excess water, and the sorted aggregates were dried overnight separately. After the drying period, I weighed the aggregates to determine their proportions in each soil sample. I conducted three trials for each plot—a total of twelve trials. I used ANOVA to determine differences.

Decomposition Rate

I used an adapted methodology from Cornelissen (1996). I collected leaves from the same tree, to keep the species uniform. I dried the leaves overnight to remove excess water. I then measured three grams of dried leaves, and put the weighed amount into a mesh bag with small holes. At each of the four sites, I buried two bags 10 cm underground. After 12 days, I collected the bags, removed excess dirt, and dried the leaves over night. I weighed the leaves and assessed the decomposition rate by calculating the difference in leaf weight.

Arthropod Diversity

I built pitfall traps. I set up three pitfall traps at each site (12 traps in total). I followed a modified version of Greenslade's methodology (1964). I dug a five cm wide hole, the size of a plastic container, and placed the container in the hole, making sure the entrance of the cup was level with the ground. Each container was the same size. I mixed a solution of alcohol and water in each pitfall trap, so that the caught arthropods could not climb out. I placed elevated petri dishes over the traps to protect them from rainfall. I left them for 24 hours before collection. I identified collected arthropods to order level. I checked the traps on two different occasions.

RESULTS

<u>Soil Compaction</u>

The primary forest plot was significantly less compact than the reforested, pasture, and fallow plots. (Figure 1, $F_{(3,36)}=31.01$, $p<0.0001$). Compared to the primary forest plot, the reforested, pasture, and fallow plots showed higher average density (Figure 1). Since soil compaction is related with mass bulk density (Brady 1984), these three plots are more compact than the primary forest. Among the pasture, fallow, and reforested plots, the soil density did not differ significantly. The reforested plot had approximately the same average density as the fallow and pasture plots, and thus resembled pasture more than primary forest.

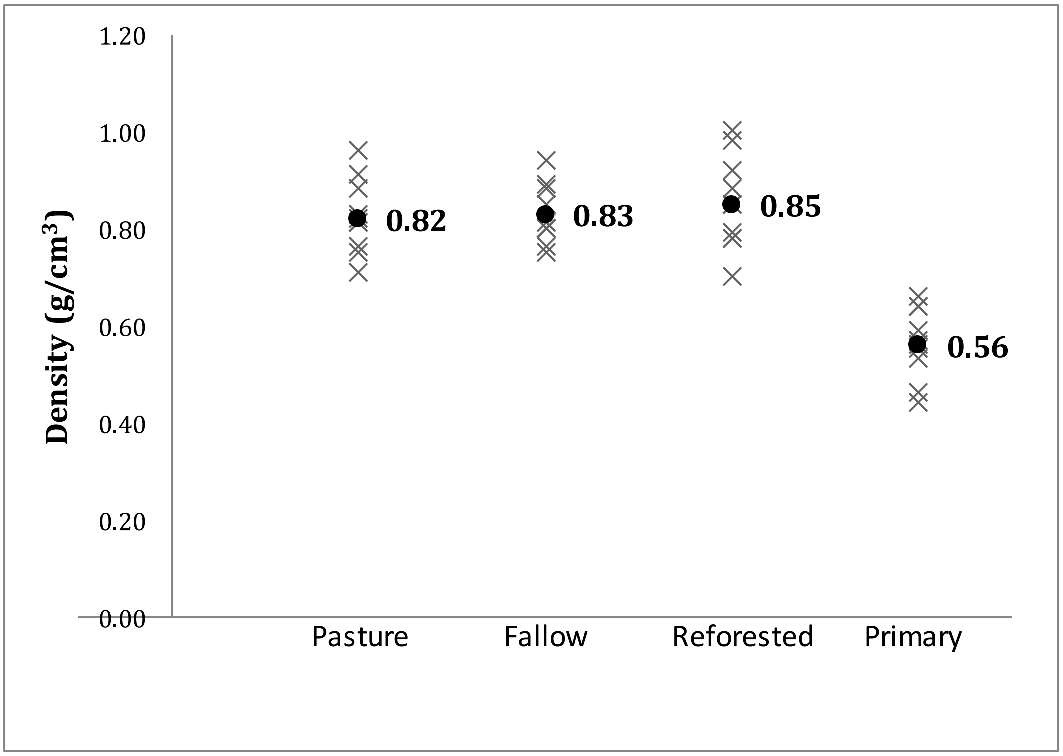

Figure 1. Density of soil cores. Each individual trial is denoted as an X. There were ten trials per plot, and the average of each set of trials is denoted with a circle.

<u>Water Stable Aggregates</u>

There was no statistically significant difference between all four plots. Note that the sums of the average percentages are not exactly 100%, but range between 99.96-100.04%. This slight discrepancy occurs because these percentages are averages taken from the individual trials.

Primary and reforested plots show a general trend of having more 2000 μm aggregates—27.8% and 37.6% respectively (Figure 2). Additionally, fallow and pasture plots had higher proportions of 500 μm, 250 μm, and 125 μm aggregate class sizes. In all four plots, the 125 μm aggregates had significantly smaller proportions than the other aggregates sizes.

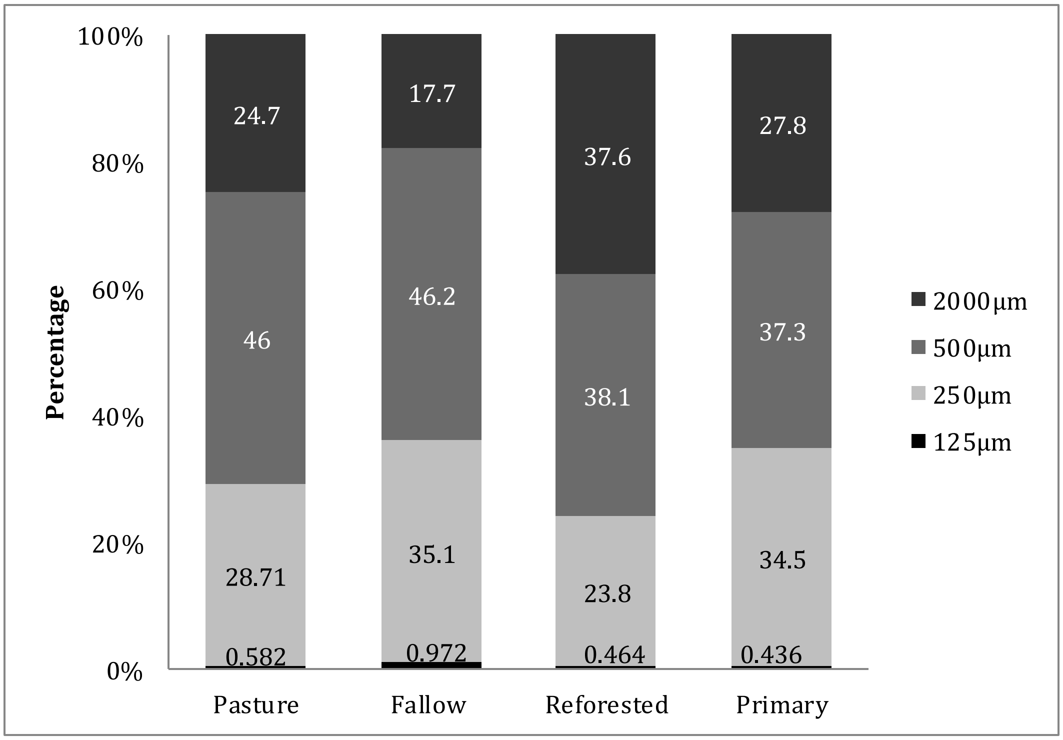

Figure 2. Soil aggregate percentages by sieve size. Each bar sums to 100%, and the proportions of each aggregate class are distributed within the bar.

<u>Decomposition Rate</u>

The decomposition rate of primary forest is higher than the rates of the reforested, pasture, and fallow plots; the decomposition rates among the reforested, pasture, and fallow plots showed no empirical difference. Pasture had a change of 0.1 and 0.2 grams over the twelve days. Fallow pasture also had a change of 0.1 and 0.2 grams. Reforested Pasture had a change of 0.3 and 0.1 grams (Figure 3). The data, therefore, suggests no major difference between the decomposition rates of these three sites. The primary forest, however, showed higher decomposition rates than the three other sites, with a change in mass of 0.8 and 0.9 grams. I did not conduct a statistical analysis, as there were only two trials per plot.

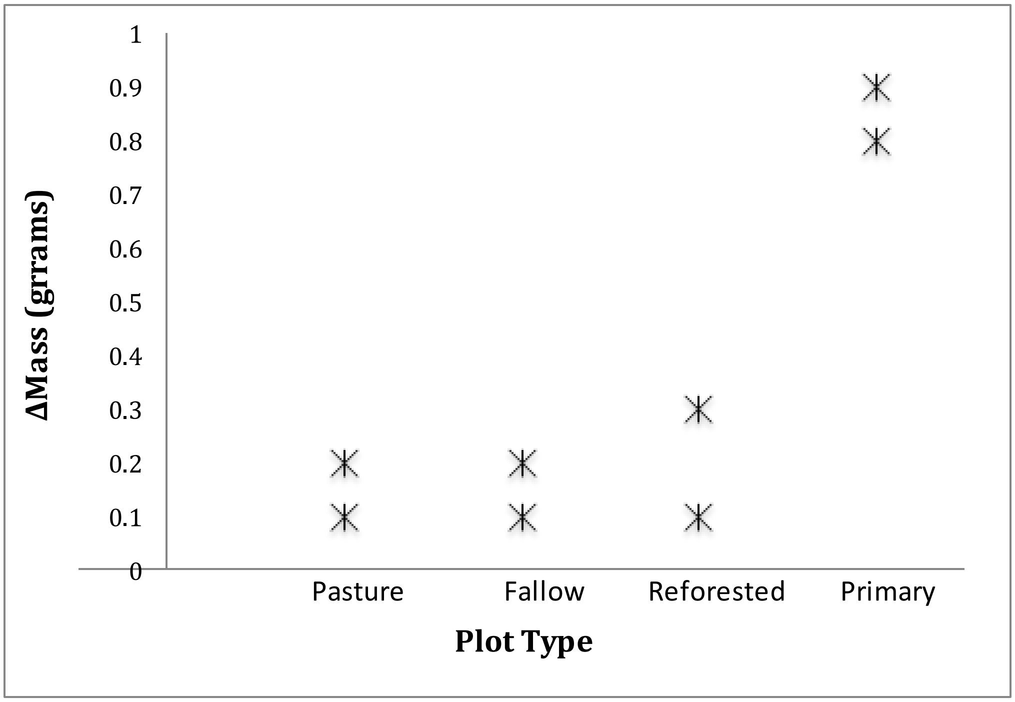

Figure 3. Change in mass over a twelve day period.
Each data point represents the change in mass in one decomposition bag. There were two decomposition bags per site.

Arthropod Diversity

I found a total of seven orders and one taxa of arthropods among the four sites. I collected the most individuals at the primary forest plot (432), the second most at the reforested plot (239), the third most at the pasture plot (229), and the least at the fallow plot (126) (Table 1). I found high numbers of purple springtails (ranging between 110 to 400 individuals) in each pitfall trap, which accounts for the large number of Collembola at each site. With the exception of the Coleoptera, Acari, and Diptera, primary forest had the largest number of individuals within each order. I found similar orders of insects at each of the four sites with the exception of Diptera, which was only present at the primary forest site. While I found a greater number of individuals at the reforested plot compared to pasture, the difference is only 10 individuals.

Table 1. Number of Arthropod Individuals Classified by Order and taxa (Acari) at Each Site. The collected arthropod individuals are organized by the site they were found at and the order they belong to.

Plot Type	Coleoptera	Hymenoptera	Acari	Orthoptera	Araneae	Dermaptera	Diptera	Collembola	Total
Pasture	7	7	2	4	3	0	1	205	229
Fallow	2	5	2	5	1	0	1	110	126
Reforested	2	4	12	4	1	0	1	215	239
Primary	4	9	10	6	3	1	0	400	433

DISCUSSION

The decomposition and compaction tests showcased a trend of superior soil quality within the primary forest plot. While I predicted that primary soil would show the best results of the four plots, I did not expect the reforested plot to closely resemble the pasture and fallow plots. Cattle farming has been shown to increase soil compaction, potentially resulting in severe structural damage (Mulholland and Fullen 1991). My results coincide with this study, as the pasture had relatively high compaction. However, the fallow and reforested plots also had high relative soil compaction. Reforestation efforts at La Calandria commenced in 2001, giving the reforested soil approximately 15 years to regenerate. Despite the site's abundance of trees and roots, compaction was statistically the same as pasture. This may be due to a long temporal requirement for detectable changes in soil (Dick 1994).

Additionally compaction may be related to the pasture, fallow, and reforested decomposition rates. Among these three plots, higher compaction was associated with slower decomposition, and vice versa for primary forest. Compaction of soil may be associated with a decrease in porosity and oxygen pockets within the soil, causing a decrease in the microbial decomposition process (Dittmer and Schrader 2000). Physical and biochemical changes in soil can deter rapidly from human land use (Islam and Weil 2000), but based on my results, regeneration of natural function is a much longer process.

The water stable aggregates showed no significant difference among the four plots. Soil with more organic matter generally has higher stability (Haynes and Swift 1990), so I originally predicted that primary forest would have the largest proportion of the 2000 μm aggregate class. However, Nyamangara *et al* (2001) found that cow manure treatments increased aggregate stability. The influx of cow manure may increase the amount of organic matter within the soil, increasing its stability. Another study conducted by Islam and Weil (2000) found that grassland and naturally forested soils had similar aggregate stability. Based on my data, the reforested and primary forest sites may have higher 2000 μm aggregate proportions, but further testing with a larger sample size is necessary.

The arthropod diversity analysis shows slightly contradictory results. Primary forest had the highest number of arthropod individuals in both total number and in five out of eight orders. However, I also found most of the same orders at the pasture plot. I was initially surprised by these results, as I expected the simplified vegetation in pasture to minimize the amount of habitable arthropods. Many arthropods, however, are predators. If prey items can survive in pasture grass, than these predators will be attracted to the area. Additionally, I was only able to check the pitfall traps twice. Conducting more checks and laying out more traps may have provided for a better survey. During the two weeks I conducted my study, the rainfall was unusually heavy, which also may have accounted for the small number of individuals found.

Considering my results, where primary forest soil seem to have better quality in at least two of the four categories, conservational efforts are of high importance. My study alludes to the notion that soil does not regenerate quickly. The reforestation plot of 15 years tested more similarly to pasture than primary forest. While there may have been trees, vegetation, and forest inhabitants, life underground may not be functioning as well as it once did. Soil is the basis of healthy ecosystems and functioning biochemical processes. Understanding the slow change and regeneration of soil—and the rapid changes caused by humans—may indicate the need for serious consideration when changing ecosystem landscapes for human-related purposes.

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