University of South Florida
Digital Commons @ University of South Florida

Tropical Ecology Collection (Monteverde Institute)
Monteverde Institute

November 2009

Understanding the effects of secondary succession on soil nutrient concentration and soil macro-invertebrates

Rebecca Goldstein

Follow this and additional works at: https://digitalcommons.usf.edu/tropical_ecology

Recommended Citation
Goldstein, Rebecca, "Understanding the effects of secondary succession on soil nutrient concentration and soil macro-invertebrates" (2009). *Tropical Ecology Collection (Monteverde Institute)*. 595.
https://digitalcommons.usf.edu/tropical_ecology/595

This Text is brought to you for free and open access by the Monteverde Institute at Digital Commons @ University of South Florida. It has been accepted for inclusion in Tropical Ecology Collection (Monteverde Institute) by an authorized administrator of Digital Commons @ University of South Florida. For more information, please contact scholarcommons@usf.edu.

Understanding the effects of secondary succession on Soil Nutrient Concentration and soil macro-invertebrates

Rebecca Goldstein

School of Public and Environmental Affairs, Indiana University

ABSTRACT

When agricultural land is abandoned, secondary succession is known to occur within the plant community, but little is know about the effects of regeneration on the soil. Since plant richness and productivity is tightly correlated with nutrient availably, I investigated the effect of time after regeneration on nutrient levels and macro-invertebrate richness. I sampled six sites ranging in age of regeneration (0 years, 7 years, 11 years, 19 years, 45 years, and primary) measured at the concentration (lb/acre) of potassium, phosphorous, iron, and nitrate nitrogen and counted the morpho-species richness. Potassium and phosphorous concentrations were significantly correlated with age of regeneration Iron concentration was marginally significant when correlated with age of regeneration but nitrate nitrogen was not significantly correlated with age of regeneration. Morpho-species richness was positively correlated to regeneration time as well. Differences in trends in potassium, phosphorous, and iron may be due to differences in nutrient cycling on a geological scale and movement of water across surface. Lack of significance with nitrate nitrogen may signify a difference in the distribution of nematodes. Morpho-speices may or may not ever return to primary levels, however they do increase compared to pasture levels. In conclusion, secondary succession has an effect on soil in terms of both abiotic and biotic conditions.

RESUMEN

Cuando tierra usada para agricultura queda abandonado la vegetación secundaría empieza a crecer. Pero hay poca información sobros los efectos de la vegetación secundaría en el suelo. Debido que hay una correlación entre la diversidad en la comunidad planta y los nutritentes del suelo, miré los cambios en nutrientes del suelo a traves del tiempo. Tomé una muestra de suelo, en seis lugares, con años diferente de vegetación secundaría (0, 7, 11, 19, 45 y bosque primero). Medí concentración de potasio, hierro fosforo y hielo. También, conté la diversidad de morfo-species. Las concentraciones de fosforo y potasio tuvo una correlación significa con el tiempo. El hierro fue marginalmente significativo con el tiempo. Nitrogeno no tuvo un correlación significativa con el tiempo. Es posible que diferencias entre los nutritivos fue resultado de ciclos de nutrientes y movimiento de agua en el suelo. También el nitrogeno podría ser un resueltado del numero de nematodos. Es posible que la diversidad de morfo-especies nunca vaya a regresar a los numeros que se pueden ver en un bosque primario. En conclusión, vegetación secundaría tiene un efecto a suelo.

INTRODUCTION

The Neotropics have a common theme throughout history; humans have destroyed primary forest for agriculture, abandoned the land when agriculture fails, thus allowing new growth to slowly occur on the farmland (Arnold & Bryan 1997). This makes the Neotropics an excellent place to study Clements's Succession Theory, which states that all destroyed or damaged land will pass through certain stages to return to a climax community, a stable community that is optimal for the region (Merchant 2007). This implies that one should be able to see abandoned farmland slowly change from weedy grasses, to herbaceous plants, to softwood trees and finally return to a climax community of hardwood tree (Merchant 2007). In studies of secondary forest succession in Puerto Rico, Brazil, Venezuela, and Columbia, agricultural land eventually returned to climax community tree species at sapling stage, although the rate of reforestation varied depending on the intensity of the agricultural practice (Aide *et al.* 1995).

Clements predicted the recovery stages that plants pass through, but he did not predict anything about changes in the soil. Nevertheless, succession theory should apply to soil, since plant growth and productivity are strongly correlated with soil nutrient levels (Guariguata & Ostertag 2001). In past studies in the tropics, significant differences were found between soil nutrient levels in primary and pasture, but not between pasture and secondary forest or secondary forests and primary forest (Camargo *et al.* 1999, Fox 2001). Another study found that soil organic matter (SOM) depended on how quickly the secondary stand reproduced biomass, but generally the older the site the more SOM, indicating more fertile soil. (Guggenberger & Zech 1999). These studies imply that nutrients are accumulated during secondary forest succession; therefore there may be succession in soil nutrients. If there is succession in nutrient levels, then overtime the soil should return to concentrations similar to that of primary forest (Guariguata & Ostertag 2001).

Secondary forest succession may also affect the soil macro-invertebrates. In a study in Brazil, it was found that the macro invertebrate community was significantly less species-rich in recently deforested areas than in primary forest. It was also found that in fallow fields, the longer the field was left fallow, the greater the species richness (Mathieu *et al.* 2005). This implies that deforestation and time after deforestation have an effect on macro invertebrate presence and diversity. In a different study, higher macro-invertebrate biomass was found in high quality soils (in this case defined by neutral pH, high organic matter and Ca content) (Decaëns 1998). This study implicated that the highest biomass of soil macro-invertebrates will always be found in the most pristine community, which is the climax community.

The following study investigates the relationship between the years regeneration has occurred and soil nutrient concentration. I predict that as the number of years of regeneration increases, nutrients will move closer to their primary levels because the forest is regenerating. As well, I will investigate the relationship between the number of years of regeneration and the richness of soil macro-invertebrate community I predict that morpho-species richness will increase as the years of regeneration increase because as the forest regenerates there are more niches for macro-invertebrates to fill.

METHODS

Study Sites

This study took place between October 23rd 2009 and November 20th 2009. I chose all my soil sites within 1.5 km of the Hotel Belmar in Cerro Plano, Puntarenas, in Costa Rica. All sites other than primary forest either currently are or once were cattle pastures. I chose one pasture site (age of regeneration 0 years), four secondary forest sites (ages of regeneration: 7, 11, 19, 45 years), and one primary forest (age approximated at >100). The pasture sample was taken at the cattle farm across from el Centro Panamericano de Idiomas (CPI). The 7-year-old sample was taken at the field across from Alan Master's house. The 11-year-old sample was taken in Alan's front yard. The 19 –year-old sample came from the piper patch near the Estacion Biologica.   The 45-year-old sample came from the forest behind the Estacion Biologica on the Sendero Cariblanco. The primary forest sample also came from the forest behind the Estacion Biologica along the Sendero principal.

Ages for the pasture sites and secondary forest ages seven and eleven were determined by talking to Alan Masters. Marvin Hidalgo, the station manager of the Estacion Biologica, helped me determine the 19-year-old forest and the 45-year-old forest. Since no one knew the exact age of the primary forest, I estimated it to be greater than 100 years of regeneration without disturbance. This measure was made to be conservative since using 100 years or 250 years made little difference in the statistics, and I knew there had been at least 100 years without disturbance.

From each site, four soil samples and three macro-invertebrate samples were taken from different parts of the area to obtain a better representation. All samples were taken at least three meters away from any roads or paths. At each site, I dug a hole 15 cm deep with a trowel, and then took a thin, vertical slice of the first 15 cm of soil. Once I returned to the lab, I separated the soil samples from the macro- invertebrate samples and prepared them for various tests.

Soil Chemistry

I mixed the soil samples from the same site together to form a homogenous sample, and then filtered the homogenous sample through a mesh screen to remove rocks, roots, and large annelids. The sample was dried for 24 hours and then tested according to the STH series soil kit by LaMOTTE. I tested potassium, nitrate nitrogen, phosphorous and iron. These tests were chosen because of the nutrients' importance to plant growth and function.

Soil Macro-Invertebrate Sampling

I used the Berlese-Tullgreen funnel method and 50 g of soil from each of the macro-invertebrate bags. I created the funnels by inverting the top of a 1.5 liter bottle and placed a paper towel soaked in ethanol in the bottom half to kill the insects. I used three layers of mesh screen as barriers between the soil and the ethanol. About 10 cm above the top of the funnel, I hung a 25-watt light, which decreased moisture and increased temperature in the soil. This forced the macro-invertebrates to move downward seeking moisture, leading them to the ethanol. The samples remained under the light for three days. The funnels and lights were covered by mosquito netting to keep out nocturnal insects. Any nocturnal insects found in the sample were not counted as morpho-species. The samples were counted under a stereoscope. The macro-invertebrates were identified to class, order, and morpho-species.

Data Analysis

All data was analyzed using regression analysis. Years since regeneration began were recorded on the x-axis and scaled logarithmically (log base 10). This was done to ensure that nutrients and macro-invertebrate reached an asymptote. An asymptote was important because in primary forest nutrients concentrations and species richness remain constant. A logarithmic scale allows this to be factored into the model. The logarithmic scale also gives more weight to changes that occur during the first 10 years, mirroring what is seen in a plant succession cycle (Merchant 2007).

RESULTS

Soil Chemistry

I found a significant correlation between years of regeneration and the potassium concentration within the soil ($F = 10.49$, $df = 5$, $p < 0.05$,Figure 1a). The general trend was negative, implying that over time, potassium levels became less concentrated in the soil. Potassium concentration was the same as primary concentration when the secondary forest had reached 45 years of regeneration (220 lbs/acre). I also found a significant correlation between years of regeneration and phosphorous concentration within the soil, ($F = 24.45$, $df = 5$, $p < 0.05$, Figure 1b). The trend was positive; phosphorous concentration increased with time. However, the concentration at 45 years of regeneration (100 lbs/acre) was not the same as the primary concentration (150 lbs/acre). Iron concentration was marginally significantly correlated with years of regeneration ($F=7.09$, $df=5$, $p = 0.05$, Figure 1c). The overall trend was positive. This implied that iron concentration increases with years of regeneration. Iron concentrations returned to primary levels by 19 years of regeneration. I did not find a significant correlation between years of regeneration and nitrate nitrogen concentration ($F= 0.77$, $df = 0.05$, $p > 0.05$, Figure 1d). There was a general positive trend. However, at 11 years of regeneration the concentration of nitrate nitrogen (150 lb/acre) was higher than at primary levels (100 lb/acre). At 19 years of regeneration, the concentration dropped back down to 20 lb/acre, the same as found in the pasture.

Soil Macro-Invertebrates

63 individual macro-invertebrates were collected representing 49 different morpho-species (Table 1). The maximum number of morpho-species found at one site was ten and the minimum was seven. Morpho-species richness was positively correlated with years of regeneration ($F = 9.40$, $df = 5$, $p < 0.05$, Figure 2). The morpho species richness found in the 45 year old secondary forest (8), was not the same as found in primary forest (10). The number of morpho species consistent from 7 years on to 45 years.

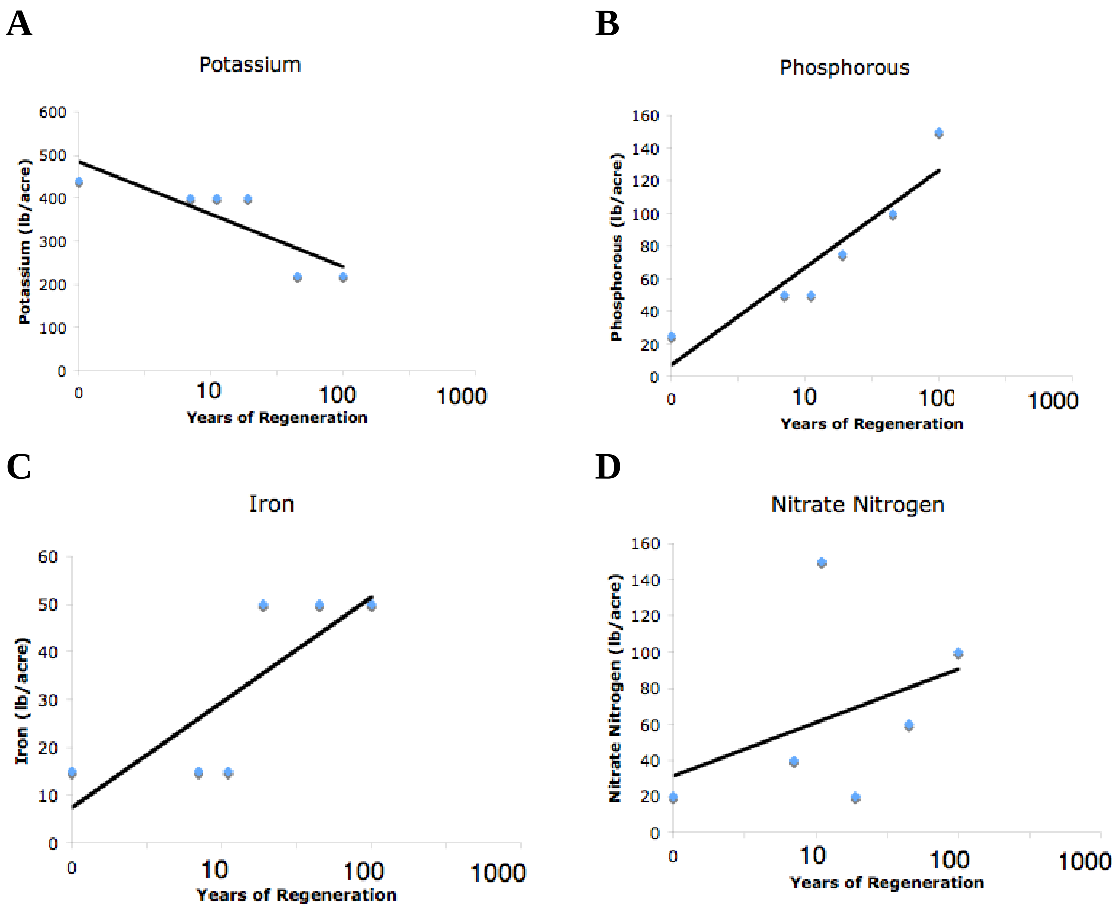

FIGURE 1. Correlations between the number of regeneration and soil nutrient concentration (Nutrient lb/acre). Six sites of different ages from Cerro Plano, Costa Rica were tested (0, 7, 11, 19, 45, and > 100). Figure 1a shows the regression of potassium concentration, modeled by the equation $f(x) = -121.54\log(age) + 484.78$ ($R^2 = 0.72$, $p < 0.05$). Figure 1b shows the regression of phosphorous concentration, modeled by the equation $f(x) = 59.61\log(age) + 7.26$, ($R^2 = 0.86$, $p < 0.05$). Figure 1c shows the regression of the iron concentration, modeled by the equation $f(x)=22.03\log(x)+7.45$ ($R^2 =0.64$, $p = 0.05$) Figure 1d shows the regression of the nitrate nitrogen which was not significant ($R^2 =0.16$, $p > 0.05$)

TABLE 1 Morpho species of macro-invertebrates found in each of the six site. Sites were chosen based on years of regeneration. All site were located in Cerro Plano, Costa Rica.

	Years of Regeneration at the Study Sites					
Morpho-species	**0**	**7**	**11**	**19**	**45**	**100**
Araneae 1		1				
Coleoptera 1		1	2		1	
Coleoptera 2			1			
Coleoptera 3				2	1	1
Coleoptera 4		1				2
coleoptera 5		1			1	
coleoptera 6				1		
coleoptera 7	1					2
coleoptera 8	1					
Dermaptera 1			1			
diplopoda 1		1				
diplopoda 2		1			1	
Diplopoda 3	1				1	
diptera 1		1				
diptera 2						1
diptera 3						1
diptera 4						1
Diptera 5	1					
Hemiptera 1			1	1	2	1
Hemiptera 2	2		4		1	
Hemiptera 3		1	1	1		
Hemiptera 4				1		2
Hemiptera 5		1			1	
Hemiptera 7	1					
Hemiptera 8	1					
Hempitera 6						3
Hymenoptera 1			1			
Hymenoptera 2			1			
Hymenoptera 3				1		
Hymenoptera 4				1		
Isopoda 1				2		
Ixodida 1						1
S	7	8	8	8	8	10
Abundance	8	9	12	10	9	15

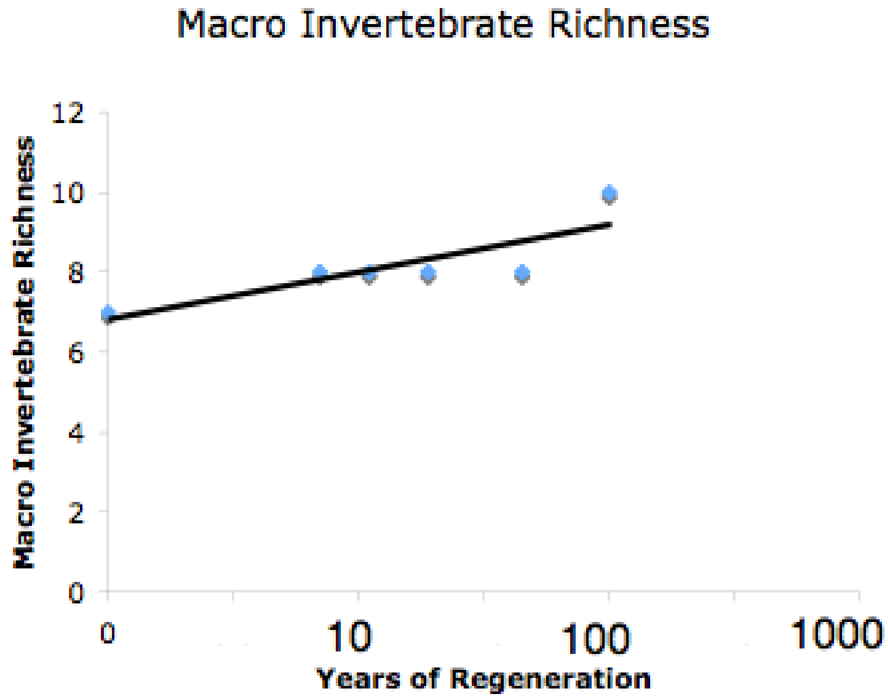

FIGURE 2 Relationship between Macro Invertebrate Species Richness and years of regeneration began. Relationship modeled by 1.18log(age) + 6.82 ($R^2 = 0.73$, $p < 0.05$)

DISCUSSION

My results indicate that the number of years land was allowed to regenerate has a significant effect on potassium, phosphorous, and iron concentrations, but not nitrate nitrogen concentrations. To understand why nitrate nitrogen is not significantly correlated with regeneration time, better understanding is needed of the nutrient. Nematodes, along with bacteria and fungi, are responsible for the fixation of nitrate nitrogen, and there is a significant correlation that higher levels of nematodes indicate higher nitrogen. However, neither nematode richness nor abundance has been found to correlate with regeneration time. Instead, nematode distribution seems to be random (Hanel 1995). Therefore my individual sites may have had different nematode communities, which resulted in the non-logarithmic results of nitrate nitrogen concentrationWithin the two significant trends (potassium and phosphorous), there were differences in the sign of the trend. These differences may be explained by nutrient cycling. Potassium concentration had a negative trend. In the potassium nutrient cycle, only 2% of the total potassium within the soil should be in solution and available to plants. Deforestation may change this balance, because less plants use less potassium, therefore the solution becomes more concentrated (Helmke & Sparks 1996). Concentration may also increase at low levels of vegetation because less vegetative cover increases the temperature of the soil. Higher temperatures drive more potassium into the solution form from the exchangeable and non-exchangeable form (structural form is usually not involved although it is possible). The decrease in soil temperature with more vegetation may drive this equilibrium to deposit more potassium in the exchangeable and non-exchangeable forms and less in solution, based off Le'Chatelier's Principle. (Helmke & Sparks 1996). The concentration of potassium stayed relatively even until 45 years, at which time it dropped. This time coincides with an increase in soft and hard wood trees and the beginning of a significant canopy.(Merchant 2005) The canopy cools the soil. This change in soil temperature combined with more vegetation is probably what causes the decrease in potassium. Phosphorous, however, increased with the regeneration of the forest. Phosphorous is found mostly in the top layer of the soil, under the humus layer. Like the humus layer, it is often affected by erosion and rain, which washing it away. (Jones & Jacobson 2005). In pastures, there is little to no humus present and little vegetative cover, so rain and erosion wash away nutrients in the topsoil more often (Jones & Jacobson 2005). Although tropical rainforest contains less humus than deciduous forest, there is still more humus in a tropical primary forest than in a pasture (Guggenberger & Zech 1999). The more vegetation and humus in the area, the more likely phosphorous is to accumulate. Phosophorous will not accumulate indefinitely. At the equilibrium level in the primary forest, phosphorous is being used and leeched at the same rate it is being renewed (Jones & Jacobson 2005). At 45 years of regeneration, the phosphorous may still be accumulating, even if its at a slower rate than during the first 10 years.

Iron concentration is naturally high in tropical soil because the parent material is volcanic in nature (Loeppert & Inskeep 1996). Looking at Figure 1c, iron content increased overtime, with the major increase occurring at 19 years of reforestation. This increase may be caused by a decrease in water washing away topsoil. Iron occurs throughout the soil, yet iron in the topsoil, created by organic matter decomposition is easily washed away (Loeppert & Inskeep 1996). Changes in pH to a more neutral soil may bring more iron toward the surface. (Loeppert & Inskeep 1996) At 19 years, there are more understory and small woody plants, which would increase the amount of topsoil, decreasing iron leeching. (Merchant 2005). The increase in plants may also help the soil become more neutral helping fulfill the second condition. (Loeppert & Inskeep, 1996)

Like soil nutrients, soil macro-invertebrate richness was significantly correlated with the amount of time regeneration had occurred. All secondary forests had the same richness of macro-invertebrate; the difference occurred between the primary richness and the pasture richness. This same scenario was seen by Matheiu *et al* in 2005. Some morpho-speices were only found in primary forest while others were found only in secondary sites or the pasture. For example, hemiptera 1, 2, and 3 were found in almost all the sites, while diptera 2, 3, and 4 were only found in primary forest. The composition of macro-invertebrates was different in each site, however a larger sample size would be needed to determine similarity. Similarity might give better insight to succession stages within macro-invertebrates.

It is also important to look at which nutrients have reached their primary concentrations by 45 years of regeneration. Both potassium and iron concentrations were at primary levels by in secondary forest age 45. Phosphorous seemed to be along a trend that within 100 years it would reach primary concentrations. However it is unclear from the data if nitrate nitrogen will return to primary concentration. Similarly, richness increases in the macro-invertebrate population between a pasture and any secondary forest. However all secondary forest had the same richness, meaning that local extinctions or long colonization times may affect the biotic portion of the soil more than previously thought. An old secondary forest may be primary in terms of soil nutrients, but not in terms of macro-invertebrates.

Regeneration has a significant effect on both the abiotic factors (soil nutrients) and the biotic factors (macro-invertebrates). The extent of the effect changes depending the specific nutrient or the macro-invertebrates, but the effect is significant. This is important to note for conservation because it implies that soil can mostly regenerate to primary levels. In places such as Santa Rosa National Park in Guanacaste, Costa Rica, the park is currently made up of abandoned pastures. However, given 50-200 years, the soil and the soil community could return to what it was before agriculture. It may be that because of succession, tropical forests are more resilient than previously thought.

Further studies could include looking for a connection between nitrate nitrogen and different types of macro- and micro-invertebrate in the soil. Another study could look at the relationship between soil nutrients and nutrients with in the water nearby to determine the effect of water on nutrient leeching.

ACKNOWLEDGMENTS

I would like to thank my advisor, Pablo Allen for guiding me through this project helping me add new components as problems occurred, and always being enthusiastic about the project. Thank you to Alan Masters and Marvin Hidalgo for helping me find my study sites. A special thank you to Alan for helping me develop my project from an idea to a proposal. Thank you to Yimen Araya for always offering to help me, no matter what I needed. Thank you to my family in the US who supported me and were happy to hear that I was "playing with dirt" for my project. Thank you to my tica family who always were happy when I came home and said that my project was working. . Lastly, thank you to Tyler Reynolds for searching through the computer room closet to find all the STH chemicals.

LITERATURE CITED

ARNOLD M. AND N. BRYAN 1997. What futures for people of the tropical forest. CIFOR.

AIDE M. T., J.K ZIMMERMAN, L. HERRERA, M. ROSARIO, AND M. SERRANO 1995. Forest recovery in abandoned tropical pastures in Puerto Rico. Forest Ecology and Management 77: 7-86

BRADY N. C. AND R.R. WEIL. 1996. The Nature and Properties of Soils. Prentice Hall. New York.

CARMAGO PB, S. E. TRUMBORE, L. M. MARTINELLI, E. A. DAVIDOSON, AND R. VICTORIA. 1999 Soil Carbon Dynamics in regrowing forests in eastern Amazonia. Global Change Biology. 5: 693-702.

DECAENS T., T. DUTOITB, D. ALARDB AND P. LAVELLE. 1998. Factors influencing soil macrofuanal communities in post-pastoral succession of western France. Applied Soil Ecology. 9: 361-367.

FOX, J. 2001. Comparative soil study between primary forests, windbreaks and pasture in Monteverde, Costa Rica. Tropical Ecology and Conservation. (Student Project Unpublished)

GAURIGUATA M. R. AND R. OSTERTAG. 2001. Neotropical Secondary Forest Succession: changes in structural and function characteristics. 148:185-206

GUGGENBERGER G. AND W. ZECH. 1999. Soil organic matter composition under primary forest, pasture, and secondary forest succession, Region Huetar Norte, Costa Rica. Tropical Ecology and Management. 124: 93-104.

HANEL L. 2003. Recovery of soil nematode populations from cropping stress by natural secondary succession to meadow land. Applied soil Ecology. 22:255-270.

HELMKE P. A. AND D. L. SPARKS. 1996. Lithium, Sodium, Potassium, Rubidum and

Cessium. *In* Bigham J. M. (ed) SSSA Book Series: 5 Methods of Soil Analysis part 3 Chemical Analysis. pp 552-4 Soil Science Society of America, Inc. Madison Wisconsin.

JONES C. AND J. JACOBSON 2005. Phosphorous Cycling, Testing, and Fertilizer Recommendations. Nutrient Management Module No. 4 Montana State University Extension Service

LOEPPERT R. H. AND W. P. INSKEEP. Iron. *In* Bigham J. M. (ed) SSSA Book Series: 5 Methods of Soil Analysis part 3 Chemical Analysis. pp 552-4 Soil Science Society of America, Inc. Madison Wisconsin.

MATHIEU J., J.P. ROSSI, P. MORA, P. LAVELLE, P. F. MARTIS, C. ROULAND AND M. GRIMAL.2005. Recovery of Soil Marcofauna Communities after Forest Clearance in Eastern Amazonia, Brazil. Conservation Biology. 19:1598-1605

MERCHANT, C. 2007. American Environmental History: An Introduction. 180-185.Columbia University Press.