EFFECTS OF DEFORESTATION AND SUCCESSION ON SOIL AT CERRO CUERICÍ, COSTA RICA

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Abstract: The consequences of changes in land use are often apparent in the plant community, but effects on soil characteristics are frequently overlooked. We attempted to quantify differences in pH, conductivity, and the depths of the O and A horizons brought about by changes in land use by analyzing soils of the Cerro Cuericí region of Costa Rica. Three common community types of this region are pasture, secondary-growth alder forest, and primary-growth oak forest. We predicted that pH would be lowest in the pasture and highest in the alder forest. We expected to find the thinnest O and A horizons in the pasture, and deepest horizons in the oak forest. By sampling soil pits in the three sites, we found that oak forest and alder forest pH were similarly low, while pasture pH was significantly higher. The O horizons of the oak forest and alder forest were significantly deeper than those of the pasture, and the A horizons of the alder forest and pasture were significantly deeper than those of the oak forest. Our results suggest that the creation of pasture through deforestation and burning can significantly alter the chemical and physical properties of soil.

Key Words: Quercus copeyensis, Q. costaricensis, Alnus alcucuminata, *oak, alder, pasture, land use, pH, soil horizon depth, organic matter*

INTRODUCTION

The characteristics of a given soil are determined by parent material, climate, biota, topography, and time (USDA 2000). When forested land is cleared, the subsequent alteration of organic inputs and sunlight and the loss of chemical and physical processing of rainfall by the vegetation can have a significant impact on the chemical and physical properties of the soil (Schulz 1960, Parker 1985, CONF 2003). That impact is further magnified when cleared land is burned for agriculture. Burning volatilizes much of the nutrient content of the organic material in the soil, and subsequent agriculture or grazing removes some of what remains (NRCS 1996).

Until the mid-20th century, the slopes of Cerro Cuericí, in the San José province of Costa Rica, supported primary-growth oak forest dominated by *Quercus copeyensis* and *Q. costaricensis* (Fagaceae). Beginning in the 1940's, settlers cut sections of the forest and burned them to create pasture and farmland. Since that time, parts of the deforested areas have regenerated, producing secondary stands dominated by nitrogen-fixing alders, *Alnus alcucuminata*

(Betulaceae). Other areas remain as grazed land (*Carlos Solano, personal communication*).

To investigate how the historical patterns of deforestation, burning, grazing, and secondary growth in this system may have altered the chemical and physical properties of the soil, we made three assumptions. First, each of the study areas originally consisted of old-growth oak forest with similar soil characteristics, including low pH. Second, the land which is currently pasture or secondary alder forest was burned after the original oak forest was cleared. Third, the parent material and rainfall regime were constant across all sites.

We hypothesized that the transition from oak forest to pasture, and succession to alder forest, would cause significant changes in pH, depth of O horizon (the organic layer), and depth of A horizon (the topsoil). To more fully document differences among sites, we also measured soil conductivity; however, we had no basis for predicting a particular trend in conductivity.

Compared to oak and alder soils, we expected pasture soils to have a lower pH due to anticipated higher leaching rates in the pasture, which would cause mineral cations to be replaced with hydrogen ions (Kricher 1997). Because oak frequently tends to dominate in highly acidic soils (Finzi 1998), we predicted that oak soils would have a lower pH than alder soils.

Nutrient turnover rates should be highest in the pasture due to the rapid consumption of biomass by cattle, accessibility of nutrients in manure, and high decomposition rates under intense sunlight. Low input and rapid uptake result in a low net deposition of organic matter and nutrients, leading us to expect the O and A horizons to be thinnest in the pasture. We predicted the O horizon to be thickest in the oak forest because of lower litter temperatures under the dense canopy and high tannin concentrations, resulting in slow decomposition rates (Coley 1983). Additionally, we predicted that leaching rates would be low in the oak forest due to rapid uptake of precipitation by the standing biomass, thereby allowing dissolved organic material to accumulate in the A horizon. Finally, we predicted that the O and A horizons would be of intermediate thickness in the alder forest. Decomposition rates should be faster than in the oak forest because of high concentrations of nitrogen and lower concentrations of tannins in the leaf litter, encouraging microbial activity (Coley 1983).

METHODS

Study system: Our study sites were located on the property of the Estación Biológica Cuericí (elevation

2600 m), in San José province, Costa Rica. We selected three sites for our study, one for each of three successional stages: grass pasture, alder forest, and oak forest. The pasture site was immediately to the east of the biological station, the alder site was 60 m to the southwest, and the oak site was 200 m to the northeast. To ensure that the soil column was not artificially homogenized, we chose a pasture site that had never been tilled. To minimize the effects of erosion we selected sites with similarly shallow slopes.

Field methods: We sampled on 28-29 January, 2007. At each site, we established a haphazardly-oriented 35 m transect. We randomly selected five distances along this transect, and for each distance we randomly selected points between zero and three meters from to the left or right of the transect. At the first, third, and fifth points, we dug a soil pit deep enough to determine depth of the O and A horizons. We qualitatively observed the density of the roots in both the O and A horizons within each soil pit. For each of the five points on each transect, we collected 20 mL of A horizon soil from each of three holes within a 1.5 m radius and combined them into a homogenized three-part composite sample for each point. Using this composite soil sample, we measured pH and conductivity using 50 : 50 soil : water slurries.

Statistical analysis: A MANOVA was used to determine the differences in pH, conductivity, O horizon depth, and A horizon depth among the three sites. We then performed four one-way ANOVAs comparing each of the four variables among the three sites. Finally, we conducted Tukey-Kramer Highly Significant Differences tests (α = 0.05) for pH, O horizon depth, and A horizon depth, and we conducted a power analysis for conductivity.

RESULTS

We found significant differences in the depth of the O horizon, the depth of the A horizon, pH, and conductivity among the three sites (MANOVA: $F_{8,6}$ = 53.11, P < 0.0001). There were significant differences among sites for pH (ANOVA: F_{14} = 74.97, P < 0.0001), O horizon depth (ANOVA: F_{8} = 27.62, P = 0.0009), and A horizon depth (ANOVA: F_{8} = 40.53, P = 0.0003), but not for conductivity (ANOVA: F_{14} = 3.50, P = 0.063). Conductivity was marginally significantly higher in the pasture than in either the alder or the oak. A power analysis of conductivity showed that only 3 more samples were needed to demonstrate significant differences. pH was significantly higher in the pasture than in either forest type (Fig. 1). There was no significant difference in pH between alder and oak forests (Fig. 1). There was no measurable O horizon in the pasture. Although the mean depth of the O

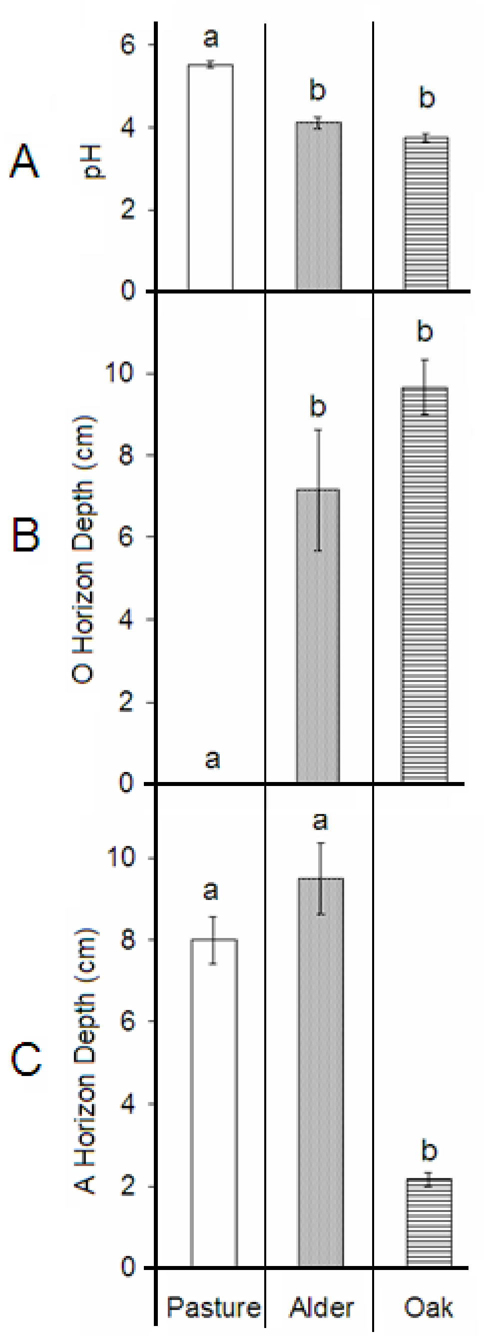

Figure 1. Each panel shows comparisons of soil characteristics: (A) pH, (B) O horizon depth, and (C) A horizon depth across sites. Different letters (a,b) indicate significantly different values among sites.

horizon was 35% greater in the oak forest than in the alder forest, this difference was not statistically significant (Fig. 1). The A horizons in the pasture and the alder forest were 73% and 77% deeper, respectively, than that of the oak forest (Fig. 1). The A horizon was 19% deeper in the pasture than in the alder forest; this difference was not statistically significant (Fig. 1). In the alder and pasture sites, we noted that the majority of roots were located in the A horizon. However, in the oak forest, fine roots dominated the organic layer.

DISCUSSION

Human alteration of forest and subsequent succession can have substantial impacts on the physical and chemical properties of soils. We found significant differences in pH and soil horizon depth between primary oak forest, open pasture, and secondary alder forest.

The trend observed in conductivity, with higher conductivity in the pasture compared to the oak and alder forests, may be biologically significant. Although direct correlations between conductivity, pH, and nutrient availability have not been established, it was shown in Heinger et al. 2003 that conductivity is one of several variables that influence changes in nutrient concentrations. This trend in conductivity is consistent with differences found in the other soil characters measured here, and the potential for direct relationships between conductivity and factors such as soil nutrients may be further investigated in future studies.

Contrary to our predictions, pH was highest in the pasture and not significantly different between the two forested sites. A potential explanation for the high pH of the pasture lies in the fact that ash is alkaline. Therefore, the slash-and-burn agriculture practiced here could have increased soil pH (Kricher 1997). It is possible that the alder soils had lower pH than expected because the relatively rapid decomposition of alder leaf litter may produce humic acids (Anon. 1975).

As predicted, the pasture site had the thinnest O horizon. However, the alder and oak O horizon depths were not significantly different from one another. The slow decomposition rate of oak leaves may be offset by relatively low input rates of oak litter, while the rapid decomposition of alder leaves may be offset by relatively high input rates of alder litter. Oak litter input rates may be lower than alder input rates because later successional trees, such as oaks, tend to have leaves with longer lifespans than those of secondary growth trees, such as alders. The net result is an O horizon of comparable depth in both forest types.

The unexpectedly thin A horizon in the oak forest could be related to our observation that fine roots and mycorrhizal hyphae were abundant throughout the O horizon. This finding indicates that a large portion of nutrients mineralized from organic matter is taken up directly by vegetation via mycorrhizae and is rapidly incorporated into standing biomass. Therefore, it is likely that organic material has no opportunity to accumulate in the A horizon of the oak forest. In contrast, the alder forest lacked the dense mat of fine roots and mycorrhizal hyphae present in the oak forest. We assumed that the young volcanic soils of the region are relatively phosphorous-rich; thus, local plant communities are nitrogen-limited. Since the alders fix nitrogen, they are less constrained by nutrient availability in the litter layer. Therefore, alder leaf litter is free to move as fine organic material into the A horizon.

Despite our expectation that the alder forest A horizon would be thicker than that of the pasture, the two were not significantly different from each other and both were deeper than that of the oak forest. Since the alder forest was originally pasture, we suggest that its deep A horizon formed at that time, probably because decomposition rates in pasture are high and nutrient uptake rates are low, contrary to our original hypothesis. Transition to forest may have simultaneously increased both litter input and nutrient uptake, while maintaining the alder A horizon depth at levels characteristic of pasture.

Our results show that changes in land use around the Cuericí Biological Station have significantly altered the chemical and physical properties of the soil. Specifically, the creation of pasture through deforestation and burning increased soil pH, and subsequent biological activity deepened topsoil at the expense of the organic layer. By determining the input rates of litter in alder and oak forests and the nutrient limitations in these communities, further studies could substantiate the mechanisms we propose to explain the observed differences between successional stages. Although the patterns we observed may be specific to this oak-pasture-alder system, they demonstrate that the impacts of succession extend beyond the above-ground biotic community to the soil beneath.

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