Importance of volcanic ash deposits in the soil horizon of the Monteverde cloud forest

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ABSTRACT

Soils derived from volcanic activity are some of the most productive in the world, and the tropical Andisols of Monteverde, Costa Rica are no exception. This study is a general analysis of the importance of one aspect of volcanic activity, historic ash deposition, found in visible, differentiated soil horizons throughout the lower-montane cloud forest ecosystem of Monteverde. This analysis was performed with three separate experiments to explain two hypotheses: (1) The use of volcanic ash in existing root systems, and (2) the importance of historic ash deposit exposure through landslides. Soil was sampled in exposed profiles in six separate sites. Phosphorus and Nitrate nutrient levels were tested at defined points in the soil profile: A-Horizon (organic layer), Upper B Horizon, and the ash layer. Soil samples from site two were sent to the Ministry of Agriculture (MAG) for additional nutrient analysis. Germination rate and success of Phytolacca rivinoides, a gap colonizing species, was tested for soil samples from three differentiated horizons (A, B-Superior and Ash) from each site. Finally, root penetration throughout the soil profile was measured. Results for nutrient tests indicate no difference between soil horizons (Friedman rank-sum, $p = 1$) indicating that the ash layer is not an important reservoir of Phosphorus and Nitrate. Seed germination success was limited (<1%) and no further analysis was possible. Root penetration for the only tested profile shows an increase of dry-weight in the profile surrounding the volcanic ash horizon. Other nutrients or untested properties of this horizon may be a useful source to roots, and possibly important in other biotic ways. Results suggest that ash layers are not a reservoir for limiting nutrients, but may enhance root development through texture or unmeasured nutrients.

RESUMEN

Los suelos producidos por la actividad volcánica son unos de los más productivos en el mundo, y los andisoles tropicales de Monteverde, Costa Rica, no son la excepción. Este estudio es un análisis general de la importancia de un aspecto de la actividad volcánica, la deposición histórica de ceniza; esta se encuentra en horizontes visibles y diferenciados de suelo en el ecosistema del bosque nuboso montano bajo de Monteverde. Este análisis se realizó con tres experimentos separados para explicar dos hipótesis: (1) El uso de ceniza volcánica en sistemas existentes de raíz, y (2) La importancia de la exposición histórica del depósito de ceniza debido a los deslizamientos. Los suelos se muestrearon en perfiles expuestos en seis sitios diferentes. Las concentraciones de fósforo y nitrato se probaron en puntos definidos en el perfil de suelo: El horizonte A (capa orgánica), Horizonte B Superior, y la capa de ceniza. Las muestras de suelo del sitio dos fueron enviados al Ministerio de Agricultura (M.A.G.) para análisis adicionales de nutrientes. El éxito y la tasa de germinación y de Phytolacca rivinoides, una espacie colonizadora de espacios abiertos, se probó en muestra de suelo de tres horizontes diferentes (A, B-SUPERIOR y la Ceniza) de cada sitio. Finalmente, se midió la penetración de las raíces a través del perfil de suelos. Los resultados de las pruebas de nutrientes no mostraron diferencias significativas entre horizontes de suelo (Friedman, $p = 1$), indicando que la capa de ceniza no es un depósito importante de fósforo y nitrato. El éxito de la germinación de la semilla fue limitado (<1 %) y no fue posible ningún análisis adicional. La penetración de raíces para el único perfil estudiado muestra un aumento de peso seco en el perfil que rodea el horizonte volcánico de ceniza. Otros elementos nutritivos o propiedades no investigadas de este horizonte pueden ser una fuente útil de alimento para las raíces, y posiblemente son importantes en otras aspectos bióticos. Los resultados sugieren que estas capas de ceniza no son un depósito para nutrientes limitados, pero pueden aumentar el desarrollo de la raíz por medio de la textura o los nutrientes en el ambiente.
INTRODUCTION

The Andisols of the Monteverde cloud forest are distinct from lowland tropical rainforest ecosystems in higher nutrient quantity, greater richness and depth of organic matter, larger water holding capacity and younger age (Brady and Weil. 1996). These tropical Andisols are formed from volcanic parent material and other ejected materials such as ash. Specifically they are Udands, because they are formed under wet conditions. These soils and others of volcanic origin represent some of the most productive in the world (Ugolini and Dahlgren 2002, Shoji and Takahashi 2002). Their high productivity is mostly derived from the weathering of young volcanic parent rock (Clark et. al 2000). In addition to these weathering processes, infrequent yet substantial quantities of volcanic ash, upwards of three meters at times, interrupt and contribute to the development of some of these soils (Shoji and Takahashi 2000). Evidence of eruption events in the Tilaran formation (Monteverde), exists within many soil profiles throughout the area (Clark et. al 2000). Bands of former ash deposition vary in coloration, texture, depth and thickness.

The Monteverde area has never benefited from a general soil survey, and banded ash layers (henceforth band or Banded-horizon) are not mentioned in the only existing general soil description for the area, (Clark et. al 2000). All of the quantitative information used for this soil description, which is found in Nadkarni et. al (2000), comes from Volcan Barva, which also have tropical lower-montane volcanic soil within Costa Rica and may have in common with Monteverde younger parent materials (even this is only speculation; Clark et. al 2000, Grieve et. al 1990). The limitations of using Volcan Barva to describe Monteverde are apparent, given that volcanic soils are highly variable even on very small-spatial scales (Eggler 1963, Blair and Perfecto 2001). Quantifying the importance of these bands is essential to a better understanding of Monteverde soils and the cloud forest ecosystem.

In what ways are these banded ash layers important to Monteverde today? It is well documented that fresh ash deposits are a source of Phosphorus, a limiting nutrient in many tropical montane ecosystems (Soji and Takahashi 2002, Eggler 1963, Roberts 1939). The impact of new ash deposits on productivity (Vitousek et. al 1995), standing biomass (Vitousek et. al 1995) and landscape regeneration (Vitousek 1997, Griggs (needdate), Tsuyuzak 1989) are also well documented for tropical Andisols. Additionally Walker and Syers (1976) have shown that Nitrate, accumulating from organic sources more rapidly in ash than other tropical soils (Vitousek et. al 1983), and plant available Phosphorus, both commonly limiting nutrients, persist in high quantities within these depositions for upwards of 150,000 years (Roberts 1939).

If inorganic nutrient supply is assumed to persist throughout geologic time in these banded layers, then two direct mechanisms for use of this layer can be hypothesized: Active nutrient uptake through root systems, and exposure through landslides.
**Root Penetration**

Root systems are found to grow prolifically in areas of high nutrient concentration, and little in nutrient poor areas, and can be a good indicator of soil quality (Blair and Perfecto 2001). Evidence from root penetrations in fresh ash deposits indicate higher nutrient uptake than in other non-volcanic soils (Zobel and Antos 1987). Increased nutrient quantity in the ash band could produce an increase in root mass throughout the horizon. Alternatively, some volcanic soils have horizons that inhibit root development and passage (Shoji and Takahashi 2002). The horizons that restrict root growth in the previous study are the sub-surface B-horizon, and are highly weathered leading to low soil fertility. This description is consistent with the B-horizon observed in Monteverde soil above and below the volcanic band. Determining the portion of restriction (complete vs. partial, allowing passage to lower fertile band layers, vs. no restriction) for these soils is crucial to understanding how available the potentially nutrient rich band is to plants in Monteverde.

**Landslides**

Phosphorous levels within disturbed soils have been shown to control the rate of biomass accumulation in tropical montane ecosystems (Frizan, et. al 2002). Once direct exposure occurs through landslides, banded soil could be an important supply of limiting nutrients for re-colonization and growth of gap species. Tropical sub-soils (non-banded layers) exposed in soil turnover have high silicate, clay, and aluminum content, and are often very nutrient poor, limiting re-colonization times (Shoji and Takahashi 2002). Although it is clear a substantial (non-banded) sub-soil exists within most Monteverde soil profiles observed, removal of surface and some sub-surface soil would bring banded soil closer to the surface, promoting increased seed germination, root penetration and plant growth.

Additionally some plants have exhibited a strong preference for the substrate provided by fine-grained ash over coarser soils (Riba and Reyes 1990). In addition to nutrient supply these fine-grain ash substrates provide elevated absorption and water retention, a characteristic shown in other volcanic soils, which can help to retain water in a re-generating landslide (Shoji and Takahashi 2002, Riba and Reyes 1990).

If these banded layers contain high available quantities of Phosphorus and other nutrients, and can be utilized through these direct mechanisms, then they are important for maintaining high productivity within the cloud forest ecosystem. Testing of these hypotheses is done in three separate ways: nutrient testing for Nitrate and Phosphorus, germination experiment using a gap species (*Phytolacca rivinoides*), to test plant fecundity and early growth, and quantitative root penetration analysis within a freshly exposed profile to determine amounts of dry-root weight within these layers.
MATERIALS & METHODS

Site Determination & Soil Preparation

Soil samples were taken at six sites within the Monteverde area. Sites were chosen in three pairs of two (distance between pairs less than 50 m). Because of the extreme local variation found in some tropical Andisols, sites were sampled in pairs to account for potentially extreme intra-pair differences. If one of the site pairs contained very high or very low levels of nutrients, germination experiments results could change correspondingly. The results of these differences, if high, would be used to discuss this local variation in the context of banded soil importance.

Criteria for site determination were based on banded soil depth, thickness, coloration and age of disturbed profile. Sites were selected from human disturbed profiles of varying age, expected to be between 2-15 years. Each of these six were chosen for subtle variation in band characteristics, primarily relating to intensity of coloration and within-site visibility. Sites with especially “weak” banding (very low visibility or very high local variation) were not included in the six sampled. This gradient of characteristics and location is described in Table 1.

Four distinct soil horizons were sampled at each site (see Table 1 and Figure 3 for specifics). The A-Horizon is distinct in organic matter, dark brown coloration and high root density. The Upper B-Horizon has a higher clay content (qualitative texture analysis only used for determining horizons), light brown coloration and low root density. The Band consists of fine to very fine grey to black particulates, with lower root density than A-Horizon. The Lower B-Horizon is typically of similar consistency to the Upper B-Horizon, though often with higher observed clay content.

A clean plastic bag was filled with around 500 grams (g) of soil from each using a clean hand-shovel. The shovel was wiped clean in between separate samplings. Horizon samples were taken 3-4 cm into the profile, to prevent the impact of external weathering on nutrient content. Root and visible organic matter were removed from the samples, and 200 g were placed in aluminum foil containers. Soil samples were then heated to 300° F for one hour and fifteen minutes to sterilize and remove water weight.

Inorganic Nutrient Testing

Sterilized soil samples used for inorganic tests were ground and mixed well in clean, separate containers. Two grams of dry soil were weighed from soil mixtures for each individual nutrient test. Three samples were taken within each Horizon (top three horizons only; A, B-Upper & Band) for all six sites. Quantities of inorganic nutrients, Phosphorus and Nitrate (NO₃), were measured using a LaMotte Soil Kit. A modified Phosphorus test was used, combining two grams of sterilized soil with Universal Extracting Solution to the 14 mL line of the LaMotte soil container.

For quantification of Phosphorus tests, a spectrophotometer was used. After full development of color indicator for the Phosphorus test, the solution was poured into an empty cuvette. De-ionized water was combined with the solution to the lower mark of the blue label. Calibration was performed using a blank cuvette filled with de-ionized water before measurements for each horizon. Transmittance was measured on a scale
from 1-100%, with one corresponding to the highest detectable phosphorus level, and 100 to no phosphorus.

Nitrate tests were only performed for three out of six sites. After color development in the mixture, quantities of Nitrate were analyzed with the LaMotte color indicator chart for Nitrate. Due to restrictions within the procedure (cloudy solutions), I was not able to use the spectrophotometer for additional analysis.

For comparison with on-site nutrient analysis, soil samples from the four horizons (A-B Lower) in site two were sent to the Ministry of Agriculture (MAG), Costa Rica. Sampling procedure was the same as for samples used in on-site analysis, but soils were not sterilized, and no root mass was removed before shipping.

Germination

To test germination rate and success (root to shoot ratio), a gap-colonizing species, *Phytolacca rivinoides* (Phytolaccaceae) with small seeds and a quick germination time were used. Seeds were removed from the ripe black fruits, rinsed, and dried. 30 g of soil was taken from each horizon sample, mixed with 150 mL of de-ionized water and left for five minutes. After five minutes the solution was filtered, using filter paper and a funnel. 10 mL of solution was placed into Petri dishes (3 samples/site), and then covered with clear plastic to prevent evaporative loss of water. Three coffee filters were then cut to six centimeters in diameter and placed into Petri dishes to provide a substrate for *Phytolacca rivinoides*. Ten seeds were placed into each dish at equal distance from the middle. For the first four days of experimentation, seeds received ambient light only (no sunlight entered through windows). For the remaining 14 days of data collection, samples were moved outside where they all received between zero and five hours of sunlight each day (expected average near three hours). In late afternoon glass aquaria were placed over samples to protect them over-night from disturbance.

Root Weight

Root weight was measured in a regenerating pasture for one site, located 15 m from sample site two, at the same elevation (1520 m). I dug a hole, 60 cm (circular width) x 80 cm (depth), to reveal the band in a vertical profile. Roots were then sampled using a known-volume coring technique. A cylindrical volume (452 cm³) of soil was removed from successive depths in the soil profile and deposited in marked bags. 11 total volumes were removed, to a depth of 73 cm. Roots were then sifted out of the soil, cleaned, marked (each bag kept separate) and dried over night. Roots for each individual sample were then weighed in bulk and recorded.

RESULTS

Inorganic Nutrient Tests

A total of 54 Phosphorus measurements were taken within the six sample sites (Figure 1). Results for variation in Phosphorus content in the three soil horizons were not significant (Friedman rank-sum, $p = 1$, Figure 1). Some within-horizon results exhibited a very high
range of values between the three results. The standard deviation for A-horizon results ranged from (+/-) 1.56 to 10.85, Upper B-Horizon (+/-) 2.27 to 11.06, Banded-Horizon (+/-) 3.12 to 12.51.

Measurements for the three nitrate sites, 27 individual samples, indicated no qualitative difference (Table 2). Although difficulties existed in properly determining the range for results (Trace vs. Low values) using the LaMotte color indicator chart, no sample produced results that could be determined as anything other than Trace or Low nitrate quantities.

Results from the Laboratorio de Suelos show no higher nutrient content in the banded soil horizon, with the exception of Iron (Fe) (Table 3). The measurements for Phosphorus agree with on-site measurement, that there were no significant differences between bands.

Germination

Despite ten seeds/Petri dish, three Petri dishes/site, germination success was very low (<1%). This did not provide enough usable data for analysis or statistical tests. The germination that did occur was near the end of the study period, on day 13 and 14. Time was certainly a factor in low germination success.

Root Weight

Results from root penetration in a regenerating pasture near sample site two show an increase near 53 cm depth surrounding the banded soil. This increase in density can be seen in Figure 2. Roots were found in every horizon sampled (A-B-Lower). Root weight peaked in the first two successive soil core volumes. Between 24 cm and 53 cm depth, within the Upper B-Horizon, root weight measurements were highly consistent. After the peak in root weight for the banded soil, 67-73 cm (lower B-Horizon) contained much lower root weight (0.1 g)

DISCUSSION

Results for on-site and Laboratorio de Suelos (MAG) nutrient tests do not support the direct-use hypotheses. Both of these hypotheses, root penetration and landslide use, assume increased levels of nutrients as a basis. High variance is apparent within intra-horizon results (for three measured samples) for on-site Phosphorus tests. Regardless of these variable results, it is clear that no significant trend is present. This variance is likely a result of test resolution. Since quantities of Phosphorus present were low, and exhibited no inter-horizon variation, it is likely that LaMotte test kits were unable to pick up the sensitive differences present.

The results for root penetration analysis seem contradictory when compared to nutrient sample results. Why would root penetration occur if no additional nutrient quantities are present in this layer, and often are lower (Figure 1, Table 3)? Given that only one root penetration analysis was performed, no definitive statement can be made on root penetration to the banded soil layer and the nutrient absorption ability of roots in this layer. Root penetration in fresh ash does show higher nutrient uptake, but it is not
possible to assume that this would be the same for banded soil of unknown age. Results
do suggest that this layer is being used for some nutrient absorption, with many fine roots
observed and measured. Fine roots are more effective at nutrient uptake than larger
woody roots, and their proliferation in the banded layer is perhaps an indication of higher
nutrient absorption capability (Blair and Perfecto 2001). It is also not possible to say if
root penetration is self-restricted (by plants intentionally not producing roots) throughout
the B Upper-Horizon or restricted by soil properties of the B Upper-Horizon itself, as
Shoji and Takahashi (2002) have shown for other volcanic soils.

These results are of particular interest when compared with Walker and Syers
(1976) model for nutrient levels throughout volcanic soils of varying age. In the context
of their model, the lack of significant Phosphorus and Nitrate concentrations in the soil
indicate that these soils are either very young, a few 1000 years at most, or very old, over
150,000 years. It seems unlikely that these soils are very young, due to the well
developed, thick (up to 1 m observed), and nutrient poor B-Horizon found throughout the
Monteverde area. Given that Monteverde is located within the Tilaran region of Costa
Rica, which contains the active Volcano Arenal at a distance of only 15 km, it also seems
unlikely that this area would have not received any sort of deposition since before the
Pleistocene. It is possible that Monteverde’s continually wet climate and tropical
montane temperatures could relate to an increased rate of soil development. Climate,
when combined with time of exposure to weathering, is the primary factor for
determining soil development (Ugolini and Dahlgren 2002). Due to a lack of resources,
the age of these soils and their rate of development remains a mystery.

It seems that without the addition of resources and nutrients associated with
volcanic activity, this ecosystem could reach an irreversible state of nutrient depletion
similar to other highly weathered volcanic sites, relying only on atmospheric additions of
limiting nutrients to sustain productivity (Chadwick et. al 1999). Certainly this is not the
case now, given the young geologic age of the Costa Rican land bridge. It is difficult to
say, without knowing the current age of these soils, how long it would take to reach this
state of nutrient depletion. Long-term tests for additional nutrient release in banded soil
and from volcanic rock formations, and for nutrient cycling efficiency in the forest could
shed light on this question of sustained long-term productivity.

This study was certainly limited by sampling resolution. Given the high degree of
local variation found within ash depositions (Eggler 1963) and soils in general (Blair and
Perfeto 2001), it is difficult to assess how results may have been different if more sites
could have been sampled. Additionally, it would be interesting to conduct germination
experiments with different study species or sampling techniques. Root tests should be
performed at numerous sites throughout the cloud forest, in varying topography and
elevation. This portion of the experiment is certainly worth further exploration, due to
the measured increase (indicative of a positive correlation) in root density surrounding
the volcanic band. Additional soil experiments in Monteverde, including or not including
the importance of banded soil, would also benefit greatly from tests to determine limiting
nutrients. This would additionally help place Monteverde into the Walker and Syers
(1976) model for volcanic soil change-over-time.
ACKNOWLEDGMENTS

To Alan Masters, for his encouragement in my exploration in this seemingly overlooked topic. Also for his help in locating *Phytolacca rivinoides* seeds (maybe we should have gone with radish…), and for helping to bring coherency to a project that seemed in danger of dissolving in its final days. To the Centro de Educacion Creativo, for allowing me to sample soil on their property. Finally to my parents, for financial support and continual encouragement of all my pursuits.

LITERATURE CITED


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Vitousek, P.M. 1997. After the volcano-research into plant colonization of lava ecosystems on Mauna Loa. Natural History.


Figure 1. Phosphorus transmittance readings for three distinct soil horizons in six sample sites, Monteverde, Costa Rica. Numbers in data table are intra-horizon averages between three tests. Light grey bars (left in sites) are A-Horizon. Black bars (middle) are B Upper-Horizon. White bars (right) are Banded-Horizon. A spectrophotometer was used for transmittance readings. Larger readings correspond to lower levels of phosphorus. Error bars are +/- one standard deviation. Results were not significant (Spearman rank correlation, $p = 1$).
Table 1. Soil horizon and sample site characteristics for six individual locations, Monteverde, Costa Rica. All sites were found between 1520 and 1570 m. Sites 1 & 2 were located at the Centro de Escuela Creativo, Sites 3 & 4 on the Estacion Biologica property, and Sites 5 & 6 on the gravel road, 60 m from Estacion Biologica western property line. HR = High Root abundance, MR = medium roots, LR = low root abundance, NR = no root abundance. Band refers to ash deposits found within the Monteverde soil profile.

<table>
<thead>
<tr>
<th>Site</th>
<th>A horizon</th>
<th>B-Up horizon</th>
<th>Band horizon</th>
<th>B-Low horizon</th>
<th>Time of disturbance</th>
<th>Band Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MR</td>
<td>LR</td>
<td>MR</td>
<td>NR</td>
<td>5 years</td>
<td>25-38 cm</td>
</tr>
<tr>
<td>2</td>
<td>MR</td>
<td>LR</td>
<td>HR</td>
<td>NR</td>
<td>1 year</td>
<td>45-52 cm</td>
</tr>
<tr>
<td>3</td>
<td>HR</td>
<td>LR</td>
<td>HR</td>
<td>LR</td>
<td>1 year</td>
<td>53-67 cm</td>
</tr>
<tr>
<td>4</td>
<td>HR</td>
<td>LR</td>
<td>MR</td>
<td>LR</td>
<td>2 years</td>
<td>20-26 cm</td>
</tr>
<tr>
<td>5</td>
<td>HR</td>
<td>LR</td>
<td>MR</td>
<td>NR</td>
<td>15 years</td>
<td>50-55 cm</td>
</tr>
<tr>
<td>6</td>
<td>HR</td>
<td>LR</td>
<td>HR</td>
<td>NR</td>
<td>15 years</td>
<td>45-56 cm</td>
</tr>
</tbody>
</table>

Table 2. Qualitative Nitrate measurements using a LaMotte soil kit for three soil horizons in three different sites, Monteverde Costa Rica. Tr-Low indicates a mid-level between Trace and Low amounts of Nitrate.

<table>
<thead>
<tr>
<th>Nitrate</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Site 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-Horizon</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Banded-Horizon</td>
<td>Trace</td>
<td>Trace</td>
<td>Tr-Low</td>
</tr>
<tr>
<td>B Upper-Horizon</td>
<td>Tr-Low</td>
<td>Tr-Low</td>
<td>Tr-Low</td>
</tr>
<tr>
<td><strong>Site 4</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-Horizon</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Banded-Horizon</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>B Upper-Horizon</td>
<td>Trace</td>
<td>Trace</td>
<td>Trace</td>
</tr>
<tr>
<td><strong>Site 5</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A horizon</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Banded-Horizon</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>B Upper-Horizon</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>
Figure 2. Relationship between dry-root weight and depth in the soil profile, in a regenerating pasture, Monteverde Costa Rica. The y-axis indicates the number of successive soil core volumes (452 cm$^3$), with –1 corresponding to the first volume, -11 corresponding to the last volume (deepest in soil) taken.

Table 3. Soil tests results for four soil horizons (A-B-Lower) in sample Site Two, Monteverde Costa Rica, from the Laboratorio de Suelos, (Ministerio de Agriculturo). Units for Al, Ca, Mg, K are cmol(+)/L. Units for P, Zn, Mn, Cu and Fe are mg/L. The Banded-Horizon (historic ash deposition in the soil profile) exhibited highest nutrient quantities only for Fe.

<table>
<thead>
<tr>
<th>Description</th>
<th>pH</th>
<th>Al</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>P</th>
<th>Zn</th>
<th>Mn</th>
<th>Cu</th>
<th>Fe</th>
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<tbody>
<tr>
<td>A-Horizon</td>
<td>5.9</td>
<td>0.4</td>
<td>5</td>
<td>1</td>
<td>0.2</td>
<td>2</td>
<td>0.5</td>
<td>1</td>
<td>5</td>
<td>32</td>
</tr>
<tr>
<td>Upper B-Horizon</td>
<td>6</td>
<td>0.3</td>
<td>3</td>
<td>0.3</td>
<td>0.04</td>
<td>2</td>
<td>0.2</td>
<td>1</td>
<td>7</td>
<td>37</td>
</tr>
<tr>
<td>Banded-Horizon</td>
<td>6.0</td>
<td>0.3</td>
<td>4.4</td>
<td>0.6</td>
<td>0.08</td>
<td>2</td>
<td>0.3</td>
<td>1</td>
<td>5</td>
<td>49</td>
</tr>
<tr>
<td>Lower B-Horizon</td>
<td>6.4</td>
<td>0.25</td>
<td>3.5</td>
<td>0.3</td>
<td>0.05</td>
<td>2</td>
<td>0.2</td>
<td>1</td>
<td>6</td>
<td>19</td>
</tr>
</tbody>
</table>
Figure 3. A disturbed soil profile in Monteverde, Costa Rica. This profile contains defined horizons, which are distinct in coloration and texture. Ash deposits from volcanic activity can be seen in Monteverde soils. The banded layer (historic ash deposition) in this sample site can be seen from 25-38 cm in depth, and is dark grey in color.