ABSTRACT

Soil studies were conducted at Coweeta Hydrologic Laboratory, N.C., in a deciduous hardwood forest and in a white pine plantation established after clear-cutting and decay of all previous vegetation. These studies demonstrate that the soil under the pine forest, which was planted 14 years after clear-cutting and was 15 years old at the time of the study, differs from the control hardwood forest in the opposite direction to that expected based on relative nutrient demands of young pine forests and mature hardwood forests. The principal difference is a high calcium concentration in the pine soil compared with the control and, related to that, a higher pH than that of the control. Not only is cation exchange capacity significantly higher in the pine-plantation soil but percent base saturation is also higher. The latter characteristics produce a buffering effect, as evidenced by a less variable pH in the pine-plantation soil. These apparent anomalies are attributed to the cations (principally calcium) incorporated into the soil from the entire above- and belowground plant biomass of the former hardwood forest.

It has long been recognized (Lutz and Chandler, 1946; Remezov, 1961) that the development of a soil from parent material and the development of the associated vegetation are mutually dependent processes. In mature ecosystems there is often a concentration of nutrient elements in the upper soil horizons considerably above that found in the parent material, tending toward a composition that reflects the nutrient needs of the associated biota (Remezov and Pogrebynak, 1969). The forest soil and forest floor thereby become major reservoirs for most of the elements required for ecosystem metabolism and structural maintenance (Witkamp, 1971).

At the Coweeta Hydrologic Laboratory, operated by the Forest Service, U.S. Department of Agriculture and located in western North Carolina in the southern Appalachians, the movement of water through the forest floor and soil, along with hydrologic input and output from gaged watersheds, has been studied and monitored since the early 1930s. These studies include watersheds...
CATION COMPOSITION OF A HARDWOOD FOREST SOIL

with native mature hardwood vegetation as well as those in which the vegetation has been modified to estimate water loss through evapotranspiration (Fig. 1). Since 1968 the University of Georgia Institute of Ecology has been carrying out a program of research on the ecological structure, productivity, and biogeo-

Fig. 1 Coweeta Hydrologic laboratory, North Carolina, showing watershed boundaries and numbers.

chemical cycling pathways in several of these watersheds in cooperation with the Coweeta Laboratory staff. Since 1970 this facility has been a research site of the Eastern Deciduous Forest Biome, U.S. Analysis of Ecosystems Program, International Biological Program (IBP).

One of the watershed ecosystems in the IBP study is a mature deciduous hardwood forest comprising 12.46 ha (Coweeta watershed 18). Immediately adjacent is a uniform white pine (Pinus strobus L.) plantation comprising 13.48 ha (Coweeta watershed 17). The hardwood watershed has been undisturbed by man since at least 1924 (Johnson and Swank, 1973). Before that there was a limited, but otherwise undetermined, amount of hardwood cutting and periodic burning of the herb- and shrub-layer vegetation by early settlers and Indians. The major disturbance of this watershed was the complete elimination
of American chestnut (*Castanea dentata*) as a dominant canopy species by the chestnut blight of the early 1930s. Chestnut is now a minor understory species.

The history of the white-pine-plantation watershed was the same as that of the hardwood until January 1942, when, as part of an experiment designed to measure the effect of evapotranspiration on stream flow, all vegetation was cut and left in place to decay. The soil was essentially undisturbed. Annual sprout growth was cut back in most years between 1943 and 1955, during which time a low herbaceous and shrub cover developed. In 1956 researchers planted eastern white pine seedlings to compare water use by pine and by the original hardwood forest.

Therefore two major stresses or manipulations have been applied to this ecosystem, both of which might be expected to influence the soil compartment. Both changes would affect the soil by changing the nature of the forest floor, or litter layer, i.e., the ecosystem compartment from which the upper soil receives its major direct input of materials. The soil as a whole, of course, also receives an input of materials from bedrock and parent material weathering. For the upper soil, however, this is an indirect input through plant uptake and deposition to the forest floor.

The effects on soil structure and physical properties of the nonremoval clear-cutting and annual cutting of sprout growth was investigated by Freeland (1956). In his study watershed 18, the hardwood watershed, also served as the control. After 10 years the only changes he was able to detect were a slight deterioration in the stability of large aggregates in the surface soil layers and a slight trend toward higher soil-moisture content during the growing season. The former change he attributed to the reduced surface litter, which after 10 years was much less than that in the control hardwood watershed. The higher soil-moisture content was attributed to reduced water loss via evapotranspiration during the growing season.

The results of my study show the combined effects on the soil of (1) the input of the entire above- and belowground plant biomass and its accumulated nutrient capital; (2) the passage of 14 years in which the soil had a herbaceous and shrub cover, reduced evapotranspirational loss, and an increased flow of water through the soil mantle; and (3) the abrupt substitution of a completely different tree cover with different nutrient requirements, greater evapotranspiration loss (Swank and Miner, 1968), and a different litter type.

In removal clear-cutting, followed by establishment of a pine plantation, we could hypothesize a gradual decay, or loss, of the basic elements from the soil until a new steady-state condition was established which reflected the lower basic element demand of a pine forest. An opportunity existed here to examine as part of a total watershed study the effects of a transfer of materials from one major ecosystem compartment, the primary producers, to another, the soil (i.e., the decomposition and reservoir compartment). Although its effect is not precisely known, the 14-year gap between clear-cutting and pine planting probably served chiefly to incorporate the large amount of litter into the soil.
METHODS AND MATERIALS

Two sample transects were established in each of the two watersheds. Each transect led from the stream channel to a point 60 m up on both facing slopes. The layout of the transects was affected by the watershed topography. In the hardwood watershed (18), transects were at midwatershed level on each of two stream channels. In the white pine watershed (17), the transects were across the lower and upper thirds of the single channel. These transects were selected in areas with the following vegetation growth forms: (1) broad-leaved deciduous with deciduous understory, (2) broad-leaved deciduous with broad-leaved evergreen understory (*Kalmia* and *Rhododendron*), and (3) needle-leaved evergreen (white pine).

Two plots (2 by 15 m each) were established on each slope of a transect as near as practical to the stream and 60 m upslope. There was a total of 16 plots, 8 per watershed. Every two months, triplicate soil samples from A1 and A2 horizons were taken from the center of each of three randomly selected 0.25-m² quadrats. Litter was also sampled (for the results of this study, see Yount, this volume).

Soil samples were air dried and submitted to the University of Georgia Soil Testing and Plant Analysis Laboratory for chemical analysis. The following is a brief summary of the analytical procedures employed by the laboratory (Jones and Isaac, 1971).

Calcium, magnesium, sodium, and potassium were extracted by means of a mixed-acid extracting solution consisting of 0.05N HCl and 0.025N H₂SO₄, which, because of the conditions of the test, gives results quite similar to ammonium acetate extraction. Sodium was analyzed by atomic absorption spectrophotometry. Calcium, magnesium, and potassium were determined with a Technicon Auto-Analyzer. Soil pH was determined on a 1 : 1 (w/w) mixture of soil and water. Exchangeable acidity was determined by the extent of pH lowering in a mixture of standard buffer solution and soil (Adams and Evans, 1962).

Cation-exchange capacity (CEC) in milliequivalents per 100 grams of soil (meq/100 g) was calculated from the sum of exchangeable acidity and acid-extractable cations. Percent base saturation (PBS) was calculated from the sum of the cations in meq/100 g divided by the CEC.

The high between-plot variability of the soil chemical properties did not permit any analysis of possible trends within a watershed. Since significant differences between plots could not be demonstrated, the data for each parameter were combined by watershed and considered as one sample. When this was done, significant differences between means often resulted, both as a function of watershed and of time.

Freeland (1956) determined the bulk density of the A1 and A2 horizons to be approximately 1.0 g/cm³. This value was used as the best estimate for
calculating area weights of elements. At each sampling point the depth of the A1 horizon was measured. The means of these measurements varied slightly from one sampling time to another, but all were close to 5 cm, which was set as the lower boundary of the A1 horizon. A straightforward conversion then yields a value of 500 tonnes/ha for the weight of the A1 horizon. Similarly the weight of the A2 horizon (from 5- to 30-cm depth) is 2500 tonnes/ha. The area weights of the elements were calculated from these figures and the concentration data. For a more detailed discussion of methods and a detailed data tabulation, see the IBP report by Yount (1972).

RESULTS AND DISCUSSION

As hypothesized previously, removal of native hardwood vegetation and replacement with white pine should eventually result in a soil with a lower steady-state nutrient composition. This was expected for at least two reasons: (1) the higher net productivity of the young pine forest, which results in relatively high nutrient demands on the soil; and (2) the lower nutrient requirements of pines in general, which results in a lower nutrient input to the soil by litterfall recycling.

The most obvious indication that the pine-plantation soil does not conform to this expectation is its comparatively high pH, averaging 5.8 throughout most of the year and varying only ±0.1 pH unit (Fig. 2). This soil is evidently very well buffered. The hardwood-forest soil, by contrast, is considerably more acid, frequently below pH 5.0 and falling as low as 4.7. Two pH peaks occur in the hardwood soil, around September (5.4) and again around March (5.2). The hardwood-forest soil is evidently less well buffered than the pine-forest soil.

This difference in soil buffering capacity can be partially explained by the comparative percent base saturation of the two soils (Fig. 2). The pine-forest soil CEC is 60 to 70% saturated, whereas the hardwood-forest soil varies between 40 and 55% saturated. The higher PBS in the pine soil occurs despite a higher total CEC (around 12 meq/100 g compared with around 7.5 meq/100 g for the native-hardwood-forest soil).

Sodium levels are very similar in the soils of both watersheds in both the A1 and A2 horizons; all levels are quite low, less than 25 kg/ha in the A1 horizon (Fig. 3). Potassium levels are 40 to 100 kg/ha in the A1 horizon and are generally higher in the hardwood-forest soil than in the pine-forest soil.

The divalent cations, calcium and magnesium, do not behave like the monovalent cations. Levels of both elements are higher in the pine-forest soil over most of the year (Fig. 3). The contrast is particularly striking in the case of calcium. Calcium levels in both the A1 and A2 horizons (to a depth of 30 cm) are about twice as high in the pine soil as in the hardwood soil. Calcium alone takes up from one-third to one-half the total cation-exchange capacity of the pine soil.
Since no fertilizer or lime has been applied to the soil in the pine watershed, the only conceivable source of the additional calcium and magnesium is the accumulated nutrient capital of the entire above- and belowground plant biomass incorporated into the soil after the original hardwood vegetation was cut and left in place to decay.

By comparison and contrast, in the Virelles mixed-oak forest in Belgium (Duvigneaud and Danaeyer-De Smet, 1970), calcium and magnesium in the total vegetation (aerial and underground) were 1248 and 102 kg/ha, respectively, compared with 13,600 and 151 kg/ha in the soil. The soil in the Belgian forest is calcareous, however; whereas that at Coweeta is derived from acidic metamorphic bedrock.

At Coweeta in the native-hardwood-forest soil, total calcium to a depth of 30 cm varies between 170 and 500 kg/ha and total magnesium between 130 and 270 kg/ha considering seasonal variation. In the pine soil total exchangeable calcium varies between approximately 600 and 1200 kg/ha and total exchangeable magnesium between 160 and 500 kg/ha (Table 1). Thus there is between
Fig. 3  Soil cations, A1 horizon to 5-cm depth. —○—, pine. —◇—, hardwood. Vertical lines denote ±1 SE (N = 24).
### TABLE 1

**TOTAL CALCIUM AND MAGNESIUM IN HARDWOOD-FOREST AND WHITE-PINE-PLANTATION SOILS TO 30-cm DEPTH (kg/ha)**

<table>
<thead>
<tr>
<th>Watershed</th>
<th>5/70</th>
<th>7/70</th>
<th>9/70</th>
<th>11/70</th>
<th>1/71</th>
<th>3/71</th>
<th>5/71</th>
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<tbody>
<tr>
<td>Calcium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White pine</td>
<td>1176</td>
<td>1231</td>
<td>874</td>
<td>982</td>
<td>901</td>
<td>771</td>
<td>627</td>
</tr>
<tr>
<td>Hardwood</td>
<td>457</td>
<td>499</td>
<td>170</td>
<td>418</td>
<td>367</td>
<td>353</td>
<td>188</td>
</tr>
<tr>
<td>Excess in</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pine soil</td>
<td>719</td>
<td>732</td>
<td>704</td>
<td>564</td>
<td>534</td>
<td>418</td>
<td>439</td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White pine</td>
<td>224</td>
<td>244</td>
<td>505</td>
<td>405</td>
<td>160</td>
<td>214</td>
<td>161</td>
</tr>
<tr>
<td>Hardwood</td>
<td>198</td>
<td>145</td>
<td>239</td>
<td>273</td>
<td>160</td>
<td>224</td>
<td>130</td>
</tr>
<tr>
<td>Excess in</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pine soil</td>
<td>26</td>
<td>99</td>
<td>266</td>
<td>132</td>
<td>0</td>
<td>-10</td>
<td>31</td>
</tr>
</tbody>
</table>

418 and 732 kg/ha excess calcium and between 0 and 266 kg/ha excess magnesium in the pine-plantation soil.

Day (1974) determined the total aboveground nutrient standing crops in the native hardwood watershed. Total aboveground calcium is 551 kg/ha, and total aboveground magnesium is 48 kg/ha. Data for root nutrient standing crops are not yet available, but an estimate can be made using the Virelles mixed-oak-forest data (Duvigneaud and Danaeyer-De Smet, 1970). Multiplying the Coweeta aboveground data by the ratio of total to aboveground calcium (1.44) and magnesium (1.26) in the Virelles forest, we obtain an estimate of 793 kg/ha for the input of calcium into the white-pine-forest soil from the total above- and belowground vegetation. For magnesium the corresponding estimate is 61 kg/ha. By this estimate there appears to be sufficient calcium in the hardwood watershed vegetation to account for the excess calcium in the pine-forest soil. Magnesium, however, does not exhibit such a clear and consistent excess nor such good agreement with estimated plant-biomass pools. Perhaps further research will show that excess magnesium, if any, is in some other ecosystem compartment for part of the year.

The other principal soil cations, potassium and sodium, do not exhibit any consistent differences in amount between these two watersheds (Table 2). For these two elements, Day (1974) found aboveground plant pools of 233 kg/ha for potassium and 48 kg/ha for sodium. Converting the potassium figures to total above- and belowground plant-biomass pools, as we did for calcium and magnesium, we obtain an estimate of 326 kg/ha. Data for sodium in the Virelles forest were not given.
TABLE 2
TOTAL POTASSIUM AND SODIUM IN HARDWOOD-FOREST AND WHITE-PINE-PLANTATION SOILS TO 30-cm DEPTH (kg/ha)

<table>
<thead>
<tr>
<th>Watershed</th>
<th>5/70</th>
<th>7/70</th>
<th>9/70</th>
<th>11/70</th>
<th>1/71</th>
<th>3/71</th>
<th>5/71</th>
</tr>
</thead>
<tbody>
<tr>
<td>White pine</td>
<td>225</td>
<td>260</td>
<td>176</td>
<td>225</td>
<td>210</td>
<td>173</td>
<td>153</td>
</tr>
<tr>
<td>Hardwood</td>
<td>241</td>
<td>200</td>
<td>163</td>
<td>219</td>
<td>206</td>
<td>193</td>
<td>135</td>
</tr>
<tr>
<td>Excess in pine soil</td>
<td>-16</td>
<td>60</td>
<td>13</td>
<td>6</td>
<td>4</td>
<td>-20</td>
<td>18</td>
</tr>
<tr>
<td>White pine</td>
<td>143</td>
<td>20</td>
<td>27</td>
<td>22</td>
<td>26</td>
<td>21</td>
<td>61</td>
</tr>
<tr>
<td>Hardwood</td>
<td>125</td>
<td>24</td>
<td>29</td>
<td>28</td>
<td>24</td>
<td>21</td>
<td>71</td>
</tr>
<tr>
<td>Excess in pine soil</td>
<td>18</td>
<td>-4</td>
<td>-2</td>
<td>-6</td>
<td>2</td>
<td>0</td>
<td>-10</td>
</tr>
</tbody>
</table>

It seems reasonable to attribute the difference in calcium, pH, and base saturation between the soils of these two ecosystems primarily to an input of calcium from the clear-cutting and decay of the plant biomass in what is now a white-pine-plantation forest ecosystem.

Thus we can expect the calcium level in the soil of the white-pine-plantation watershed to decrease over a number of years (with a corresponding decrease in soil pH and base saturation) to a lower steady-state level. In fact, the approach to a new steady-state may have been accelerated by the unusually wet spring in 1971 (see Yount, this volume). The level of calcium, as well as that of all other soil cations measured, was considerably lower in May 1971 than in May 1970.

ACKNOWLEDGMENT

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