

Formation of Soils in North Carolina

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Soils in North Carolina can trace their ancestry to the formation of planet earth. As the molten magma cooled that portion of the earth's surface that was destined to be politically designated as North Carolina acquired a chemical composition that determined the proportion of chemical elements available within the material that we now call soil. The basic ingredients that formed most of the soils in North Carolina were acid igneous rocks. By earth-wide standards these rocks are rich in silicon and aluminum but poor in the life essential elements of phosphorus, calcium and magnesium. Geologic ages before the land surface acquired any similarity to that of the present, the cooling crusts were twisted and turned to reshape portions of the original granitic rock structure into metamorphosed masses of gneiss. Melting and solidifying processes concentrated certain elements into potassium-rich mica schists, silica-rich quartz dikes, and iron- and magnesium-rich mafic dikes within the crustal lithosphere.

Additions were made via volcanic activity that spread ash and molten flows over some of the gneiss and granites. These materials were eroded, redeposited and compressed into shales, slates and limestones. The surface plates of the earth continued to shift and what is now the western part of the state was thrust upward to form the Appalachian mountains. Wide basins were formed to the east of the mountains and sediment from eroding surfaces settled into them forming the Triassic Basins. Tectonic upheaval subsided, and erosion became the major influence shaping the land surface of what was to become North Carolina. Over the millennia, soil materials eroded off the piedmont and mountains. The Blue Ridge formed the highest point in the eastern part of the United States. Erosion to the west of the Blue Ridge was carried toward the Mississippi basin. To the east of the Blue Ridge eroded sediments were deposited to form the continental shelf of the North American continent. As the relative elevation of land continued to rise, the position of the Atlantic Ocean receded to the east, and broad nearly level areas of sediment became exposed as land surface, now known as the coastal plain. Sea level fluctuated over 400 feet in the last 5 million years creating seven levels of sediment surfaces, separated by scarps (escarpments) that are markers of the former coast line within the coastal plain.

The most significant aspect of geologic history on soil formation within North Carolina is a legacy of material that is chemically poor with respect to chemicals such as phosphorous, calcium and magnesium needed to support life. Most of the limestones which contained the calcium- and phosphorus-rich materials of dead organisms were thrust westward into what is now Tennessee or eroded and deposited deep within the sediments

under the coastal plain. The slates, granites, and gneiss exposed on the eroding slopes of the piedmont and mountains are acidic and contain only small amounts of phosphorus, calcium and magnesium, with potassium being in relatively good supply.

North Carolina was untouched by the massive continental glaciers that pulverized the limestones and granites of what is now Canada. With the aid of flowing waters and dusty winds, that fertile silty material was deposited over vast areas in the Midwest of the United States. The materials on the coastal plain, most of which were chemically poor at their origin, were exposed to further chemical depletion as they were eroded and transported to their present location. Only the relatively basic sediments in the Triassic Basins and basic gabbro and diorite rock exposures can be considered chemically fertile soil forming material.

Graced with appropriate temperature and moisture North Carolina has climatic conditions that are amenable to many plant species and ample water is available during the long frost-free season. Paleoclimatic evidence does not indicate extreme differences within the recent past. Although cooler climatic conditions have been present no glacial activity has been detected in North Carolina.

Most of the state averages about 45 inches of precipitation each year. Average precipitation is slightly higher near the coast, decreases to about 35 inches in the Asheville basin and reaches about 80 inches in some of the mountains in the southwest part of the state. Temperatures over most of the piedmont and coastal plain dictate evapotranspiration requirements of about 30 inches of water each year. Cooler temperatures in the mountains dictate somewhat less evapotranspiration. Although yearly weather conditions fluctuate around these averages there is an average annual surplus of about 15 inches of water if all the precipitation infiltrates into the soil. Most of this surplus water comes during the winter months, percolates through the soil and recharges the ground water.

Change with time is intrinsic to the concept of soil formation. If soil composition could not be changed in response to ambient conditions all soils would have only properties of the geologic material from which they form. Several soil properties are dictated by the composition of the parent material and several soil characteristics common in other areas of the world can not develop in North Carolina simply because the ingredients necessary for their development are not present. For example, the redistribution of carbonate to form calcic horizons is a significant feature of soils formed in material that contains abundant amounts of carbonate. Calcic horizons are not found in North Carolina.

Base Saturation Patterns

The interaction of water and plants redistributes chemical elements within the soil profile in addition to both adding and removing some elements. Plants obtain hydrogen and oxygen from water. Almost all other chemicals in plant tissue, except carbon, are taken up through their roots.

Carbon enters the plant as CO₂ through the stomata of the leaves and combines with nitrogen, phosphorus, calcium, magnesium, iron, copper, zinc, sulfur, boron, etc. extracted from the soil to form organic compounds of these elements in the plant tissues. Potassium, extracted from the soil, does not form organic compounds but is retained in the cytoplasm and vacuoles of the plant cells. Plants combine these inorganic elements from the soil with the CO₂ from the air to form organic compounds in their roots and above ground parts.

Most of these organic compounds are deposited as organic litter on the soil surface not to the total soil volume from which the plant roots extracted the essential elements. Potassium quickly leaches from the dead plant cells as an inorganic ion. As microbes consume the plant tissues and respire the carbon as CO₂ the other essential elements are released from their organic compounds as inorganic ions. The result of this “biocycling” is a concentration of life essential elements in topsoil despite the leaching effect of the percolating water.

When biocycling and leaching processes are imposed on infertile parent materials soil profiles are formed within which exchangeable base cation contents decrease with depth, i.e. Ultisols. When these processes are applied with equal vigor to fertile parent material a vertical pattern of decreasing, then increasing, base saturation with depth develops, i.e. Alfisols. In North Carolina, major examples of these processes in identical climatic, topographic, vegetative and age settings are the formation of Ultisols such as Cecil soils formed in acid parent materials and Alfisols, such as White Store soils formed in basic Triassic Basin parent material.

Clay Movement

Vertical water movement patterns within soil offer an explanation for the formation of subsoil clay accumulation, i.e. Bt, argillic and kandic horizons. Most rainfall events are of a limited duration during which water passes rapidly through the larger pores in the uppermost layers of the soil. After rainfall ceases the velocity of the percolating water slows and eventually ceases as it is drawn by capillary action into the smaller (less than 0.01 mm diameter) voids. It is from voids with diameters between 0.01 and 0.0002 mm that plant roots extract water between rainfall events. Water held in pores less than 0.0002 mm in diameter retain water at such great tensions that it can not be extracted by plants. The energy of the rapidly moving water as it percolates through the surface horizons has the ability to suspend clay-sized particles and carry them downward. As plants extract water the suspended clay does not pass into the root and is concentrated into the smallest pores where subsequent water flow rates of high velocity can not again suspend it.

In most soils the amount of clay suspended in each rain event is extremely small, but over several years, perhaps centuries, enough clay is translocated from the upper part of the soil to form argillic or kandic (Bt) horizons. If the clay translocation process (lessivage) is rapid, visible coatings of oriented clay (clay skins) are formed on root channels and ped faces in subsoil horizons. If lessivage is slow, as when little clay is

present in the surface horizons, mixing (pedoturbation) processes destroy the fragile clay skin structures, and the clay is mixed into the matrix, but the greater clay content of the subsoil remains.

Clay depletion in the surface horizons and accumulation in the subsoil is a feature common to almost all soils formed on stable landscape positions in North Carolina. It has been hypothesized that this should not occur in poorly drained soils, but it does. The reason appears to be that even if the water table is within the Bt horizon for much of the year there are periods of time during most years, usually during the summer, when subsoils are not saturated and conditions are present for the lessivage process to take place.

Soils with thick sandy surfaces, primarily the Typic and Arenic Kandiodults of the coastal plain, have almost no clay skins within the upper Bt horizons. It is probable that the lessivage process is slow because surface horizons lack both clay and weatherable minerals from which clay can form. In sandy, quartz-rich materials like those in the Sandhills region little clay is accumulated in the subsoil. The lessivage process is slow and soils on rapidly eroding surfaces, like the slopes in the mountains, do not accumulate enough clay to form argillic horizons although clay skins are often present in Bw or cambic horizons.

Soil Organic Matter Distribution

The content and distribution of organic matter in soils results from the interaction of plants, water and temperature. Since there is no organic carbon in geologic rock, except that derived from plants and buried by sedimentation, the organic carbon we find in soil owes its existence to carbon dioxide extraction from the air via plants. Organic carbon is usually the only element determined to estimate organic matter content of soil. Soil organic matter is also the major source of nitrogen in the soil.

Nitrogen, like carbon also comes from the air. Although 78 percent of the air is nitrogen it is present as N_2 and not directly available to plants. Plants secure almost all the nitrogen they need as nitrate (NO_3^-) or ammonium (NH_4^+) from the soil. Small amounts of nitrogen are converted from N_2 by electrical discharges, lightning, and added to the soil in rainwater. Nonsymbiotic microorganisms living in the soil are capable of converting N_2 and incorporating it into their cells. As these microbes die and their bodies decompose the nitrogen they contain is released into the soil solution mainly as nitrate. Precipitation and nonsymbiotic microbial fixation together contribute approximately 20 pounds of nitrogen per acre to the soil each year. Leguminous plants have a symbiotic relationship with nitrogen fixing microbes (Rhizobium) that “fix” N_2 and pass it along to the legume plant. Plants readily consume nitrogen, and it becomes a component of their tissue subsequently to be released as that dead tissue is decomposed. Nitrogen, released as organic tissue decomposes, moves as nitrate (NO_3^-) in oxidized water but is reduced in anaerobic soil water and returns to air as N_2 and other nitrogen gases.

Organic matter in soils is transient. Microbes in the soil consume the organic carbon of the dead plant and animal tissue. Of the carbon consumed, about 25 percent is incorporated into microbial cells, and about 75 percent is released as CO₂, which escapes the soil and returns to the air. Individual microbes have a short life expectancy and with each generation the 75 percent conversion of organic carbon to CO₂ takes place as a new generation of microbes decomposes the cells of the dead microbes. The only new supply of organic carbon is the cells of plants that extract carbon from the air, or of animals which have eaten plants to obtain carbon and other nutrients for their cells. Organic carbon decomposition releases the mineral nutrients that the plants have taken from their total rooting volume and concentrates them in the surface layers of the soil. This results in the spatial association of fertility (N, P, K, etc.) and organic matter in the topsoil horizons.

Temperature and moisture conditions are satisfactory to produce abundant plant growth in all parts of North Carolina. Therefore the availability of organic carbon via plant litter appears not to be limited. To explain the different soil organic carbon contents we find among soils we need to examine those factors that control the rate at which organic carbon is destroyed and returned to the air as CO₂. Soil microbes use O₂ to decompose soil organic carbon. In soils that are saturated with water for much of the year O₂ within the soil is often in short supply. In poorly drained soils, much higher contents of organic carbon are maintained than in well-drained, better-aerated soils.

There are over a million acres of organic soils (Histosols) in the state. They are formed where during recent geologic time organic production has exceeded organic matter decomposition and a thick layer of almost pure organic matter overlies the mineral substrate. We have to say "almost pure" because trees, partially rooted in mineral substrata have been uprooted by wind and mixed mineral material upward into the organic layer and some deposition of mineral dust has occurred. Histosols form when saturated and anaerobic conditions are present throughout most of the year and organic carbon oxidation is slow and nitrate reduction is rapid. As a result much of the organic material in the uncultivated Histosols in North Carolina has carbon:nitrogen ratios well above the 32:1 ratio considered necessary to allow plant available nitrogen to be released during slow decomposition.

Soil microbes respire more slowly when cool, and therefore, it takes longer for each generation of microbes to decompose the plant tissue and organic remains of the past microbial generation. The residence time of each organic carbon atom in the soil is thus longer, and organic carbon contents in cool soils are greater than in warm soils. In the cooler soils of the high mountains, organic carbon contents are greater than in the warmer areas of the state. Soils on the south-facing slopes in the mountains contain less organic carbon than soils on the north-facing slopes because they receive direct sunlight and surface horizons become warmer for longer periods of time each cloudless day.

The temperature to which a given amount of radiation will heat soil depends upon the heat capacity of the soil. Heat capacity is the number of calories needed to raise the temperature of a substance 1° C. Water has a much higher heat capacity than air, thus water content in the soil is the major determinant of a soils heat capacity. Dry soil has a

lower heat capacity than moist soil, therefore maximum daytime temperatures near the soil surface are higher than those in moist soil. Sandy soils retain less water than finer textured soils when dried to the point that plants begin to wilt. Therefore, they warm to higher surface temperatures and organic carbon contents are lower than in finer textured soils. Lower maximum temperatures are also present in the surface horizons of more poorly drained soils where higher water contents keep their maximum temperatures below those of surface horizons in adjacent well-drained soils.

Farming operations cause daily maximum surface soil temperatures to increase. Simply removing the shade and surface litter present under native tree vegetation reduces soil organic carbon contents about 30 percent after only a few years. Where drainage has been installed to lower the seasonal high stand of the water table even greater organic carbon content reductions are experienced. Extreme reduction in soil organic carbon content has resulted in parts of the eastern North Carolina “Blacklands.” Since European settlement, drainage and fires have combined to oxidize some of the organic soils (Histosols) and expose the mineral substrate where farming is now conducted.

Erosion and Sedimentation

Natural geologic erosion and deposition processes have shaped the characteristics of most soils in the state. Over geologic time the surface of the land (soil) is not stable. The surface of the land at any given site is either rising in response to deposition or lowering in response to erosion and dissolution of the mineral materials. From measurements of the constituents dissolved and suspended in the major rivers of the Atlantic coast it is estimated the land surface is lowering at a rate of 1.6 inches per 1000 years. Approximately 55 percent of the materials are lost by dissolution of minerals and 45 percent as suspended load in the rivers.

Average rates are extremely misleading because the erosion and deposition processes are localized both in space and time. The spatial arrangement of these processes has created extreme contrasts in soil properties within North Carolina. Erosion is most intense on steep slopes and along major rivers where the kinetic energy of flowing water suspends and moves soil material. Dissolution losses have the most impact on soil properties where soil surfaces are stable and mineral alteration and lessivage have produced the thick, quartz-rich sandy surfaces and kaolinite-rich kandic horizons of the upper coastal plain. On the steep slopes of the mountains, physical removal by surface erosion and physical displacement via landslides change the absolute position of the soil surface so rapidly that the impact of lessivage is minimal with only Bw or cambic horizons being formed in the soils. Argillic and kandic horizons are present only in areas of stable landscape. In the piedmont, with lesser slope gradients, the rate of erosion is less than in the mountains. The soil surfaces are being lowered at a slower rate, and argillic (Bt) horizons are present in all soils except those on the most erosive sites. The level upland surfaces in the coastal plain experience little erosion and are sites for the thickest soils with the most contrasting “textural” profiles, i.e. Kandiudults and Paleudults.

Alternating erosion and sedimentation has created extreme spatial contrast of soil properties in the flood plains and low terraces of the major river systems within the coastal plain. These alluvial areas are subjected to extreme contrasts of erosive energy as floodwater reshapes the channels by cutting new channels while filling old channels with sediment. Floodwater velocities differ greatly both in time and space. Therefore the texture of the deposited sediment contrasts greatly within small distances. Long-term deepening of the major river channels has left former floodplains as stable terraces upon which soils with argillic (Bt) horizons have formed. However, spatial variations in texture, a result of the past sedimentation and stream bank erosion processes experienced during the time the terrace was in a flood plain landscape position, remain. As the river channels deepened, the water tables under the adjacent terraces deepened. Differential settling of the contrasting textures has resulted in the formation of small depressions, often called “potholes,” of more poorly drained soils interspersed within the well-drained soils of the terraces. The intimate spatial mixture of textures and depths to water tables force even detailed soil surveys to represent these areas with map units that have high percentages of included contrasting soils.

Erosion processes remove more than surface soil material. In the mountains, landslides scour linear slopes and pile colluvium at the base of slopes. Landslides and the slow creep of soil material down the slopes result in the formation of shallow soils, and often rock outcrops, near the crest of the ridges and deep soils on the lower part of the slope. Except along major rivers, little deposition remains in the flood plains irregularly eroded in flash floods. On the coastal plain, where river gradients decrease, broad flood plains are present. The piedmont has intermediate flood plain width.

Mineralogy and Particle Size

Most soils in North Carolina contain less silt than soils in the glaciated areas of the Midwest of the United States. Low silt content has profound influence on the available water holding capacity of soils. When silt-sized particles are packed together in soil, pores ranging from 0.0002 to 0.01 mm in diameter are formed. Pores of this size are responsible for retaining water for plant use between rain events during the growing season. Low silt content soils in North Carolina retain approximately 0.1 inch of available water per inch of soil depth. Silty soil in the Midwest retain double that amount.

The granitic nature of most rock, and sediment derived from that rock, precludes high silt content in the soils of North Carolina. The major component of the granitic rock is quartz that weathers by dissolution. Dissolution rate per unit weight of quartz is dependent upon the surface area of the individual particles. Sand-size particles dissolve very slowly while silt- and clay-size particles of quartz dissolve at a relatively rapid rate. Almost no quartz of clay size is present in soil.

Silt contents are greatest in the slate belt and the northeastern part of the coastal plain but seldom exceed 50 percent. Soils formed in the Midwest commonly exceed 60 percent

silt, the abundance of silt-size particles resulting from physical crushing by glacial ice and concentration by wind, i.e. loess.

Most soils in the coastal plain are Siliceous. The sand and silt in Siliceous soils is 90 percent or more quartz (SiO_2) and less than 10 percent weatherable minerals. A distinct boundary between Mixed and Siliceous mineralogy exists at the Suffolk scarp at an elevation of 20 feet. To the east and below the Suffolk scarp the soils contain more than 10 percent weatherable minerals and are recognized as having Mixed mineralogy. The weatherable minerals are thought to be derived from sediment originating from material dislodged from areas to the north by glaciation during the last ice age and deposited when the ocean edge was at the Suffolk scarp.

The mineralogical composition of soils within the flood plains in the coastal plain depends upon the area being eroded by the watershed of individual rivers. The flood plains of rivers with headwaters in the piedmont usually have Mixed mineralogy resulting from saprolite material eroded from some areas within the piedmont. The flood plains along rivers in the coastal plain that have headwaters only within the coastal plain usually have Siliceous mineralogy.

Granitic and gneissic rocks form a large portion of the piedmont and mountain areas of the state. Quartz is the most abundant mineral. The second most common minerals are feldspars and micas. Feldspars weather by rearrangement of the silica and aluminum into clay minerals such as gibbsite and kaolinite. On the more stable slopes in the piedmont this alteration takes place at the contact of the saprolite and bedrock, usually well below the soil profile. The upward sequence of alteration within the saprolite is from feldspar to gibbsite, gibbsite to halloysite, then halloysite to kaolinite very near the bottom of the argillic horizons. Gibbsite and halloysite are usually found only within a few inches of the hard rock. The gibbsite appears to rapidly acquire silica, from percolating water to form the halloysite. The halloysite appears unstable when subjected to drying and alters to plate-like-shaped kaolinite in the upper part of the saprolite.

In the mountains where there is a rapid exposure of feldspar minerals by the erosive action of creep and landslides considerable feldspar of sand size is often incorporated into the soil. Gibbsite, apparently forming directly from feldspar weathering, is a significant component of both the silt and clay fractions in cambic horizons. Kaolinite is the dominant clay in most soils in the mountains. Kaolinite forms from both feldspar and biotite. Alteration of sand-size biotite to sand-size kaolinite, with both minerals being present in the same particle, has been observed. Sand-size kaolinite is rigid and easily fractures to smaller silt- and clay-size particles.

In the acid soil environment of almost all soils in North Carolina aluminum ions are abundant. This leads to the formation of a secondary mineral known by several names: soil chlorite; hydroxy interlayered vermiculite (HIV); pedogenic chlorite; with hydroxy interlayered mineral (HIM) being the preferred designation. In its formation Al^{3+} and OH^- ions precipitate as $\text{Al}(\text{OH})_3$ and AlOOH in the interlayers of 2:1 minerals like

montmorillonite and vermiculite forming a very stable 1.4 nm (14 Å) mineral. HIM is a minor, but consistent, clay-sized component of nearly all soils in North Carolina.

The basic materials of the Triassic Basins and smaller bodies of gabbro, metagabbro and diorite alter to montmorillonite when exposed to weathering in and below the soil. In the Triassic Basins the montmorillonite may have been formed prior to deposition. The presence of appreciable quantities of montmorillonite in clay textured subsoils renders these horizons quite impermeable when wet. The shrink-and-swell characteristics of montmorillonite produces physical movement as the soil wets and dries creating angular blocky structure with slickenside features on the ped faces. Base saturation percentage in and below these horizons is usually much higher than horizons formed from acid igneous rock and many of these soils are Alfisols.

Soil Color

Most soil colors are related to the distribution and composition of iron and organic carbon compounds in the soil. Iron is a constituent of most initial materials in North Carolina, and its movement in response to site specific conditions often differentiates soils within the state. Most often iron is present in silicate minerals but can occur as iron oxides. Iron oxides are particularly visible in soil because of their red and yellow color. Organic carbon is visible as black color in soil material. Most silicate minerals, quartz and kaolinite being the most common in North Carolina, are gray or nearly white in color. Most micas and feldspars are also gray except iron-bearing biotite mica that can be brown to black in color and some pink feldspars.

As previously discussed, organic carbon is derived from the air, and after a brief sojourn darkening the surface A horizons of the soil, most—but not all—returns to the air as carbon dioxide. Organic carbon can also translocate within soil and leach to surface waters especially in sandy materials. Iron, however, is translocated both vertically within the soil profile and laterally among soils on the landscape. To be translocated iron must first be free of its silicate parent mineral. This requires dissolution of silica. Iron silicates are most abundant in basic rocks such as gabbro and diorite. Biotite is a common iron-bearing mineral in gneiss. Under warm conditions, percolating water dissolves silicates more rapidly than under cold conditions. During the eons of time that iron-bearing minerals in North Carolina have been exposed to percolating water considerable iron has been released from the iron bearing silicates of the geologic material. If the environment into which the iron is released contains O_2 , the iron forms a ferric (Fe^{3+}) oxide of red or yellow color. Particles of oxide precipitate on the gray-colored quartz and kaolinite minerals. Small amounts of iron oxide, acting as paint, impart a red or yellow color to the soil.

In an absence of O_2 , iron is reduced to a ferrous (Fe^{2+}) form which is soluble in water and thus able to move with the water. Water exposed to air contains dissolved O_2 . For water to lose its dissolved O_2 , microbes need to be actively respiring. Under the

deciduous vegetation that once covered North Carolina, the leaves deposited each autumn blanketed the soil surface. Coarse texture surface horizons overlying more clayey and less permeable subsoils of well-drained soils may become saturated for short periods of time mainly in the winter when plants are not transpiring. During warm winter days, the sun warms the surface, and the sugars, carbohydrates and starches of the decomposing organic litter provide an ample source of available carbon to microbes. Respiration is rapid; oxygen is consumed; and nitrate, manganese and iron are reduced as long as the soil is saturated. The nitrate is liberated as N_2 and other gasses. The manganese and iron are reduced to soluble ferrous and manganous forms and free to move as water percolates deeper into the soil with each subsequent rainfall. After each rainfall event some water drains from the soil, the larger pores empty of water and fill with air. Oxygen from the air filled pores diffuses into the reduced water, and the ferrous iron oxidizes to a ferric iron. Red ferric iron is mainly hematite, and yellow ferric iron is goethite. Most soils have a mixture of the two. Manganese, being less readily oxidized than iron, is often observed as black ped face coatings somewhat below the main horizon of iron accumulation.

This process is sporadic and suitable conditions for iron reduction in the surface horizons may occur only a few days each year, or be lacking in many years. The result is low iron content and gray-colored E horizons near the surface of most of the well-drained soils and yellow- to red-colored B horizons. The gray color of the iron poor surface horizons seldom extends to the surface because organic carbon of decomposing plant material added to the surface forms dark colored A horizons.

Plinthite

Of particular interest is the behavior of iron within landscapes on the coastal plain. Sediments on the coastal plain contain relatively few iron bearing silicates because of silicate weathering prior to erosion and movement from the piedmont. Depositional environments are anaerobic so most iron oxides were reduced and removed at the time the sediments were deposited. Most soils in the coastal plain have relatively low iron oxide contents. However, continued desilication of the few remaining iron silicates in the sediments releases some iron, and perhaps some iron is imported as aerosol dust.

Centers of the broad, nearly level interstream divides are saturated for long periods of time each year, some for the entire year. Abundant plant litter supplies fresh carbon each year. There is an inadequate O_2 supply for microbes to quickly decompose the annual additions of plant litter so organic carbon contents are high, and oxygenated rain water is quickly reduced after it enters these poorly drained soils. As the reduced water near the top of the water table moves toward the river valleys between rainfall events, plant roots extract some water from the top of the water table. As air replaces that water in the soil pores ferrous iron oxidizes and precipitates as red or yellow ferric oxide. The result is a "rim" of moderately drained to well-drained soils with yellow- to red-colored, iron-enriched subsoil horizons at the edges of the interstream divides and gray-colored, iron-depleted poorly drained soils in the interstream centers.

Often the subsoils near the edge of the interstream divides that have been stable for long periods of time acquire rather high amounts of iron oxides that partially cement the other soil particles forming a feature called plinthite. Once substantial masses of iron cemented material have formed they restrict water movement and are not easily dissolved by future reduction. To a lesser extent these same features are observable in the piedmont, but the more rapidly changing landform associated with ongoing geologic erosion of the steeper slopes probably precludes complete plinthite formation. Only “red and gray reticulate mottling” is observed in the lower B and upper Cr horizons of soils formed on the lower side slopes.

Spodic Horizons

Some of the organic compounds added as plant litter or formed as the litter is decomposed are soluble or suspendable and move with water in the soil. Such organic compounds are not easily decomposed by microbes, and most seem to be organo-mineral complexes containing short-range-order (amorphous) aluminum oxides. It is probable that such complexes move out of the surface horizons in all soils, but they appear to be retained and decomposed by microbial activity in the Bt horizons of soils that have appreciable amounts of clay.

In sandy soils, especially those with water tables near the surface, a high concentration of these organo-mineral complexes move to surrounding streams and rivers imparting a black or “coffee” color and acidity to the water. Some of the mineral-organic complexes are retained in a subsoil horizon at the upper surface of the seasonally fluctuating water table to form Bh or spodic horizons. A layer or horizon that is repeatedly saturated and aerated for extended periods of time during the year seems to be necessary for these features to form. Spodic horizons seldom occur in well-drained or excessively drained sands but may be extremely thick in some locations with large water table depth fluctuations. Iron oxides are associated with spodic horizons in some soils that have an abundant supply of weatherable iron silicates, but the Spodosols in North Carolina are in iron-poor sandy sediments of the coastal plain and most contain little iron oxide.

Dispersive Soil Material

Sodium-rich soil material is uncommon in humid areas. Sodium is a hydrated ion and when present in sufficient quantity causes soil material to disperse. Sodium is quite mobile in soil, and with appreciable amounts of leaching water, the sodium released upon feldspar weathering is usually removed, ending up in the oceans. Sodium-rich feldspars (plagioclase) are a component of several geologic materials, but little exchangeable Na^+ is present in most soils in North Carolina. Some mafic materials present in the Triassic Basins, diabase and other mafic rocks release Na^+ and Mg^{2+} upon weathering in the saprolite. When sodium-rich saprolite material is weathering below slowly permeable Bt horizons and on convex portions of the landscape, it is protected from leaching, and

exchangeable Na percentages approach the 15 percent usually considered necessary for dispersion. In the very low salinity soil water in North Carolina it has been found that exchangeable Na⁺ saturation as low as 5 percent, if accompanied by about 15 percent exchangeable Mg²⁺, is sufficient to induce dispersion if this material is used in earthen dams. Only rare occurrences of this material have been found where all of the above conditions are present.

Sulfur Rich Soil Material

Prolonged contact of sulfur and iron in a reduced environment can produce insoluble iron sulfides. Such conditions occur in clay textured materials saturated with brackish water which are also receiving ferrous iron from fresh water sources. When these materials are drained and become oxidized sulfuric acid is produced. The resulting material is extremely acid, often too acid for the growth of plants. Commonly known as “Cat Clays” or “Acid Sulfate Soils,” they are identified as Sulfaquents in soil taxonomy. Only very limited areas of such soils are known to exist in North Carolina. Most are on islands and clayey beaches near the mouth of the Cape Fear River where fresh waters of the river enter the Atlantic Ocean. Apparently because the other major rivers from the state enter sounds within which the salt concentration is much lower than in the ocean, occurrence of sulfuric horizons in North Carolina is rare compared to occurrences in South Carolina and Maryland.

Human Influence

Intensity of human habitation has increased greatly since European settlement started about 300 years ago. Human evaluation of the soils in North Carolina was well expressed by Professor Mitchell in 1822 when he said:

“The soil of this State is pronounced, by those who have traveled extensively on both Continents, to be of a middling quality. It is of that kind which seems most to demand the employment of science and skill in its cultivation, and to promise that they shall not be employed in vain. Our grounds are neither so fertile that they will produce spontaneously what is necessary to the sustenance and comfort of our citizens, not so sterile that we have reason to abandon them in despair.”¹

With few exceptions all the soils in North Carolina are composed of mineral material derived from acid igneous rock containing scant quantities of the life essential elements calcium and phosphorus. Blessed with near ideal temperature and moisture for abundant plant growth, the limited supply of these and other life essential elements that plants must obtain from minerals were concentrated in the surface horizons of the soils, but even the

¹ Quote from a speech by Professor Mitchell to the North Carolina Agricultural Society in 1822 and printed in the North Carolina Department of Agriculture Monthly Bulletin No. 15, 1882.

richest of surface horizons contain very limited amounts. These amounts were quickly removed and transported from the fields in food and fiber crops grown and sold to urban areas.

The first European settlers practiced what is now known as “slash-and-burn” agriculture. After the trees were cut and burned, the land was cultivated for a few years harvesting the stores of essential nutrients contained in the ashes. The organic carbon in the soil rapidly oxidized in response to the removal of the cooling shade further releasing essential elements. As these stores of organically bound elements became exhausted, land was abandoned, and the farmers moved to clear yet uncultivated lands. In the words of Professor Mitchell (*ibid*),

“But, in the process of time, as this system goes on, the planter will look down from the barren ridges he is tilling, upon the grounds from which his fathers reaped their rich harvest, but which are now desolate and abandoned and enquire whether he can restore them to their ancient fertility at a less expense than he can cultivate those lands of an inferior quality with which he is now engaged.”

Fortunately natural concentrations of phosphorus and calcium were available and could be mined from some near surface sediments in the coastal plain. As farming intensified and spread across the state, resupplies of essential nutrients via fertilizer and lime became available. Over the history of farming in North Carolina, considerable amounts of lime and phosphate have been added to the soils that were cultivated, and today the cultivated soils are more fertile for the production of food and fiber crops than they were in their natural condition.

Calcium and magnesium from the liming materials have moved downward in the soil and replaced some of the natural acidity in the subsoil. This enables the roots of crop plants to extend to greater depths in subsoils, naturally too acid and calcium poor to permit their elongation, and extract more available water during rainless periods in the growing season. Phosphorus contents of the plowed surface horizons have been increased, but being insolubilized by iron and aluminum, phosphorus has not migrated downward in most agricultural soils and subsoil contents are very low. Potassium supplies have been maintained by fertilization.

Annual supplements of nitrogen are placed on cropland and pasture to bolster the amounts naturally extracted from the air by rain and N-fixing bacteria. Liming and fertilization have taken place for approximately 200 years in many parts of the state. This is but a short time in the formation of the soils in North Carolina. However, these practices have significantly improved the soil’s ability to produce crop yields per acre that are now approximately three to four times greater than obtained by the first cultivators.

As farming became more mechanized, many areas—primarily those of steeper slopes—were no longer cultivated and have been occupied by forest. Even land abandoned by early

slash-and-burn farmers as infertile still has enough fertility to support the growth of pine and hardwood trees, which have a much slower rate of nutrient uptake from the soil than food crops. Forest regrowth occurs naturally on abandoned cropland in the state, but landowners wanting high rates of tree growth often find it profitable to add lime and fertilizer.

Summary

Soil is what soil does. At the interface between the lithosphere and atmosphere on the land mass of planet earth, soil directs the exchange of water and heat, supplies most of the essential elements of life, and holds plants upright so they can utilize the energy of the sun to produce organic compounds necessary to all life on the planet. Soil becomes a mixture of organic and mineral materials within which the organic and inorganic chemistries interact with a multitude of life forms. Each soil is located at a site where a unique array of environmental and human activities combine to create features and functions that identify that soil as different from all other soils. No two soils are exactly alike. People have attempted to group soils of similar function and form thereby facilitating human understanding. Within North Carolina, over 300 kinds of soil have been identified by these human efforts, but in reality each identified kind of soil encompasses many soils, each somewhat unique and different.

Many known species of soil are not represented in North Carolina. Limited by the composition of the geologic materials from which they form and moderate climatic differences, soils in North Carolina may be considered monotonously similar. Most have features and functions that only slightly differ. Although soil differences in North Carolina may be small when compared to the total spectra of soils on earth, many of these differences are critical to human uses. Science is required to understand these soil differences. Skill is required in the application of science to assure continued formation and function of soils in North Carolina.

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