4

SOIL, WATER, AND TOPOGRAPHY

Soil, water, and topographic features combine to form a physical substrate that poses several kinds of forces in the ecosystem. Soil is a mechanical barrier to many organisms—ground squirrels, woodchucks, and other burrowing animals; and the distribution of these animals is partly a function of the distribution of different soil types. This is particularly true on a local scale; soil depths and densities determine the location of burrows. Water provides mechanical support for animals: firm support when frozen, and a moving mechanical force for swimming animals when it is flowing. The flow characteristics of water are a function of topography. The mechanical force with which water scours the substrate is dependent on the amount of sediment or abrasive material being carried by the water.

Soil, water, and topography are all a part of the thermal regime of an organism. Soil has particular thermal characteristics such as conductivity and temperature profiles. Water has a high heat of vaporization, and a considerable amount of heat energy can be dissipated by the evaporation of water. This is particularly important for plants and animals in hot environments. Topography affects the thermal regime of the soil, as a slope facing the direction of the sun's location absorbs more radiant energy than one facing away from the sun. There are often marked differences in vegetation on such slopes, not only on the long slopes of mountains but on the small slopes of local topographic features.

Different types of soil absorb energy at different rates, and the transfer of heat energy within the soil is a function of the conductivity of the soil. This is a function of the soil density, compaction, wetness, and other physical characteristics. Animals may select different soil types for bedding on in response to other thermal conditions. Deep litter, for example, is a warmer substrate than wet, bare soil and is utilized by animals for bedding under conditions that cause a high heat loss. Plants respond to the thermal conditions in the soil, too; cold, wet soil supports less vegetative growth. Bogs are good examples of areas with retarded growth, and areas of permafrost are the most extreme examples.

Soil, water, and topography all play a part in the nutritive relations of both plants and animals. Fertile soil supports the most abundant vegetation if water is adequate, although specific nutrient requirements of different plant species may vary. Too little or too much water affects the health of plants. Topography is related to both water and soil fertility because soil formation is partly a function of the topographic characteristics. Water erosion does not occur on level land, and the development of the soil profile there is different from that on hills because there is more stability in the top layer of decaying humus. Decomposition of the humus results in the release of elements that percolate into the lower layers of the profile.

None of these physical features—soil, water, and topography—can be analyzed in isolation. All are interrelated, and it is necessary to consider their relationships in order to maintain an ecological perspective. The entrance of a single organism into this complex system of interactions complicates things very quickly. Thus we begin by looking at physical characteristics of the ecosystem, assembling a series of simple models that illustrate how these physical characteristics can be considered as factors and forces in an ecological analysis that eventually includes both plants and animals.

4-1 SOIL

Soil formation is a function of the interrelationships between parent material, climatic features, thermal characteristics, biotic influences, and the topographic features of the area. The student of analytical ecology must approach the soil system with insight into the functional relationships between these factors and forces. The soil scientist, specializing in the analysis of at least some of these relationships, has a greater understanding of them than can be presented here, of course. Students with a special interest in soil characteristics in relation to an organism will find several references at the end of this chapter that cover the subject in greater detail. Let us consider here some of the basic physical and chemical characteristics of soil before relating soil characteristics to other functions in the ecosystem.

PHYSICAL CHARACTERISTICS. Mineral soil is a composite of mineral particles and decaying organic matter. Large mineral particles predominate in gravelly or sandy soils. In soils with a finer texture, the few large mineral particles that may be

TABLE 4-1 THE CLASSIFICATION OF SOIL PARTICLES ACCORDING TO U.S. AND INTERNATIONAL SYSTEMS AND THE MECHANICAL ANALYSES OF TWO SOILS USING THE U.S. SYSTEM

	U.S. Department of Agriculture System			*International System*
Soil Separate	*Diameter Limits (mm)*	*Analyses of Two Typical Soils* Sandy Loam (%)	*Clay Loam (%)*	*Diameter Limits (mm)*
Very coarse sand	2.00–1.00	3.1	2.2	
Coarse sand	1.00–0.50	10.5	4.0	2.00–0.20
Medium sand	0.50–0.25	8.2	6.3	
Fine sand	0.25–0.10	25.3	8.4	0.20–0.02
Very fine sand	0.10–0.05	22.0	9.6	
Silt	0.05–0.002	21.1	37.2	0.02–0.002
Clay	below 0.002	9.8	32.3	below 0.002

SOURCE: *Soil Survey Manual* (U.S. Dept. of Agriculture Handbook No. 18, 1951), p. 207.

present are embedded in other more finely divided materials. Fine-textured soil that has been deposited by wind contains no large particles. Such a wind-deposited soil is called *loess*.

Soil particles are classified according to size based on diameter (Table 4-1). The particles are not necessarily spherical, of course; the angular characteristics of a particle are a function of the amount of abrasive action it has received. Pebbles in streams are often very round. Soils developing from glacial till may contain rounded particles if the source of the till had been subject to the action of moving water.

Soils containing large percentages of sand are said to be *light* soils. They have a low water-holding capacity and drain rapidly. If there is little organic matter in the sandy soil, it is very loose with no stickiness. Soils with high percentages of silt and clay are *heavy* soils. These soils have a fine texture, with slow drainage and high water-holding capacity. They are also sticky when wet, with poor aeration. Clay expands on wetting, with the release of heat energy. Drying results in the absorption of energy and the contraction that follows results in the formation of hard clods.

The distribution of soil particles of different sizes results in different physical characteristics of a volume of soil, including the particle density, air space, and specific gravity. These characteristics can be measured for particular soils. They can be calculated for a given volume of soil if some assumptions are made about the shapes and distribution patterns of the soil particles. The measurements are of value in describing the soil in geographical areas, and the calculations are of value in assembling a functional model that describes the interaction between factors and forces present.

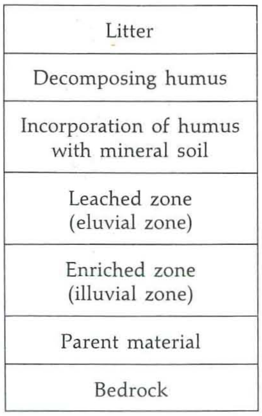


FIGURE 4-1. Schematic display of zones or horizons in a soil profile. Local characteristics are dependent on the nature of the parent material, climate, topography, vegetation, and time.

SOIL PROFILE. Soil particles—sand, silt, and clay—are not scattered throughout a developed soil in a random fashion but are organized in a soil profile. This profile consists of the surface soil, subsoil, and parent material. Soil scientists divide the soil profile into layers or horizons that develop as a result of the processes of soil formation (Figure 4-1). The top layer or horizon includes litter and raw humus. Decomposition occurs in the moist litter, resulting in humus that can be incorporated into mineral soil. Incorporation of humus with mineral soil results in a dark-colored mineral horizon. In areas with significant rain fall this dark horizon grades to a lighter-colored leached horizon as water percolates through the soil. This is called an *eluvial zone.* Materials carried by the percolating water are deposited in an *illuvial zone.* The local characteristics of the entire soil profile are dependent on climate, vegetation, parent material, topography (especially drainage patterns), and time. Additional material on the soil system may be found in Buckman and Brady (1969) and Black (1968).

SOIL WATER. The amount of water in the soil has a definite effect on plant growth. It is also quite a variable physical factor, particularly in soils that permit water absorption at a fairly rapid rate and in areas of intermittent rainfall.

What happens to water at the surface of the soil? Four distributions are possible: (1) evaporation, (2) run-off, (3) absorption by the soil, and (4) surface collection. Evaporation results in the removal of water with little or no effect on soil structure. Run-off water has the potential for changing surface characteristics through erosion, as well as flowing in streams and rivers. Water absorbed by the soil is of particular interest to the analytical ecologist since it has such an important role in the productivity of plants. Surface water, including oceans, lakes, ponds, and intermittent pools, has the potential for changing a terrestrial system to an aquatic one, depending on the time factor.

Soil water has been classified into general categories, including water vapor, hygroscopic water, capillary water, and gravitational water. Water vapor is found in the air spaces between soil particles. Hygroscopic water is found on the surface of soil particles. Capillary water is found in the spaces between soil particles in which the distance is sufficiently small to permit surface tension to hold the liquid water. Gravitational water is found in the larger spaces between soil particles and is drawn away by the force of gravity. Air and water vapor then replace the gravitational water.

Soil water moves in three ways, including capillary adjustment, percolation, and vapor equalization. *Capillary adjustment* results from the adhesion of water to soil particles and the cohesion of water molecules. These forces result in the movement of water upward from the water table. *Percolation* results from the force of gravity; free water moves downward between soil particles because the force of gravity is greater than the surface tension and capillary forces. If there is insufficient water to saturate the profile down to an impervious layer, gravitational forces will be overcome by capillary forces and the downward movement of water will continue owing to capillary action. *Vapor equalization* within the soil results from variation in the vapor pressure within the macropores. The vapor pressure in the macropores is a function of temperature (that is, more water vapor can be present when temperatures are higher), resulting in fluctuation in vapor pressure that reflects changes in the temperature profile in the soil.

The water left after drainage by gravity is the maximum capillary water, and soil under those conditions is at field capacity. As capillary water is removed by evaporation and plant absorption, the point is reached at which plants cannot absorb water fast enough to offset water loss from transpiration. When that inbalance exists, the *wilting point* has been reached. If plants dehydrate beyond the point of recovery, the amount of soil moisture present is called the *permanent wilting percentage*.

These considerations of soil water are general descriptions of soil-water relationships. Consideration of the actual forces that determine these relationships is beyond the scope of the present discussion, although soil characteristics and water absorption are taken up later in the chapter. The student of analytical ecology must comprehend the kinds and the extent of factors and forces present and then proceed with analyses that are no more detailed than his comprehension permits.

CHEMICAL CHARACTERISTICS. Soil fertility varies greatly from one area to another and is a function of the nature of the parent material, the climatic factors in the area, the erosion history, and the plant growth. Plant growth is, of course, determined by the other three factors as well, illustrating once again the interrelationship between physical and biotic factors.

The primary nutrients and organic matter in surface soil are found within certain percentages of abundance in different soil types (Table 4-2). Primary nutrients may be detected chemically in a soil, but the important factor to consider in terms of plant growth is the chemical form of the nutrient in the soil. Nitrogen, for example, may be found in proteins in the soil and in that form is largely unavailable to growing plants. Subsequent decomposition of organic matter with the breakdown of proteins to amino acids and then to the formation of nitrites and nitrates makes the element nitrogen available to plants. Further examples

TABLE 4-2 PRIMARY NUTRIENTS AND ORGANIC MATTER IN SURFACE SOIL WITH PERCENTAGES FOR TWO REPRESENTATIVE ANALYSES

		Representative Analyses	
Constituents	**Expected Ranges (%)**	**Humid-Region Soil (%)**	**Arid-Region Soil (%)**
Organic Matter	0.40-10.00	4.00	3.25
Nitrogen (N)	0.02-0.50	0.15	0.12
Phosphorus (P)	0.01-0.20	0.04	0.07
Potassium (K)	0.17-3.30	1.70	2.00
Calcium (Ca)	0.07-3.60	0.40	1.00
Magnesium (Mg)	0.12-1.50	0.30	0.60
Sulfur (S)	0.01-0.20	0.04	0.08

Adapted from "The Nature and Properties of Soils" by H. O. Buckman and N. C. Brady.

of different forms in which primary nutrients may be found are shown in Buckman and Brady (1969, p. 27).

Organic matter is of significant importance in determining the quality of the soil. It plays a role in the physical structure of the soil by keeping it loose and friable, with enough binding effect on the soil particles to keep the nominal particle size from being too large or too small. The decomposition of organic matter is also an important source of nutrients. Thus organic matter plays both a physical and a chemical role in the dynamic soil system.

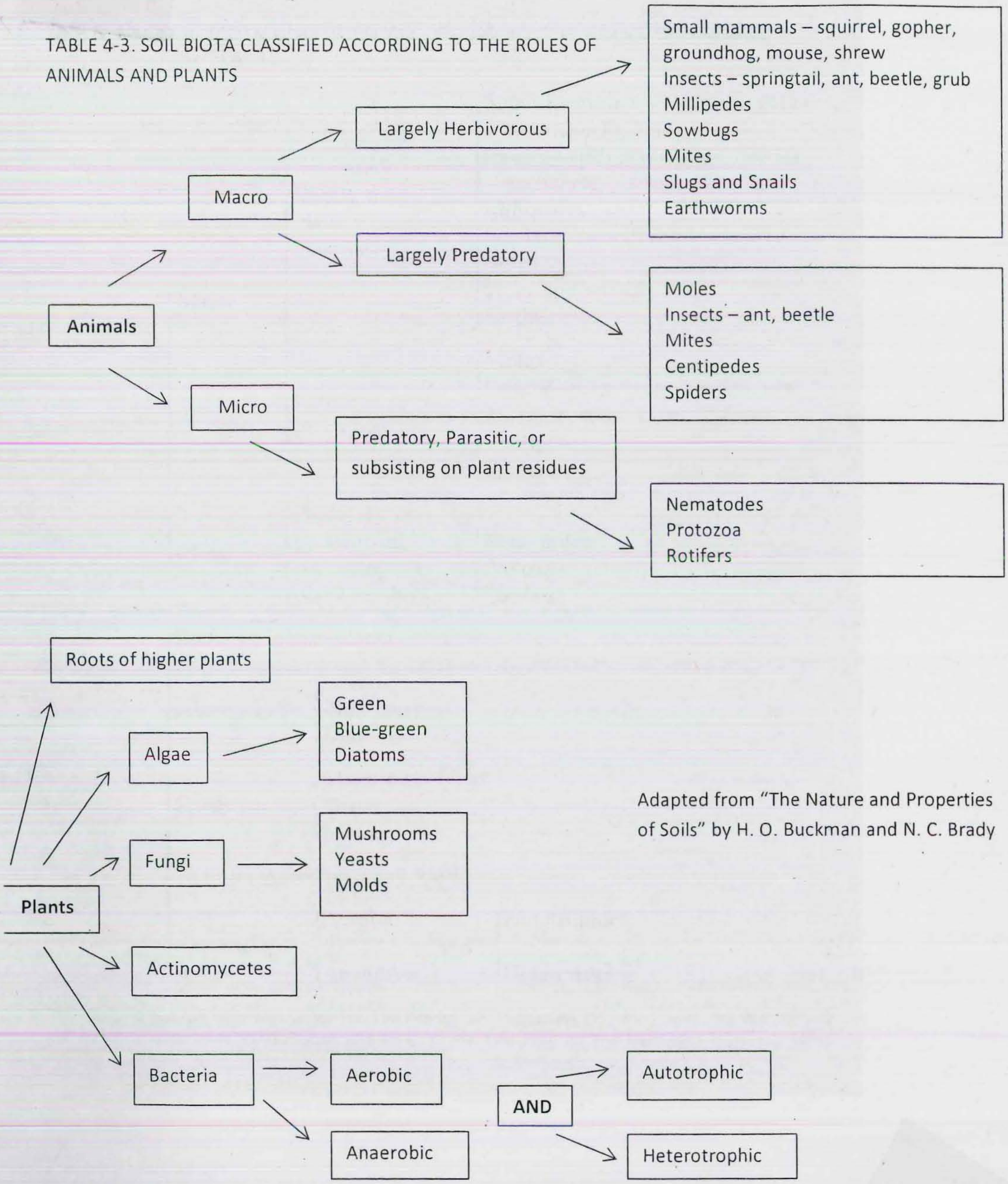
The biochemical processes that result in the release of nutrients are very complex and are a part of the life processes of soil bacteria. Soil conditions, including water, thermal, and chemical factors, have a significant effect on the rate of decomposition. Wet soils, for example, have very slow rates of decomposition. Wet soils are always colder, too, because of the high thermal capacity of water and the high heat of vaporization. Soils with a low *p*H are also characterized by low rates of organic decomposition. The combined action of all of these factors is most pronounced in bog soils, with their characteristic low *p*H, high organic content, wetness, and subsequent slow plant growth. Black spruce (*Picea marianna*) are found on these soils, and trees just a few feet tall may be 50 or more years old.

BIOLOGICAL CHARACTERISTICS. Soil is a dynamic entity because of the action of biological organisms in synthesizing and decomposing organic materials in the soil along with the mechanical action of larger organisms as they live in the soil. Buckman and Brady (1969) have two excellent chapters on "The Organisms of the Soil" (ch. 5) and "The Organic Matter of Mineral Soils" (ch. 6). The following summary is taken largely from their text.

A classification of the soil biota, according to the roles of organisms as primary consumers, secondary consumers, predators, parasites, decomposers, and so forth, is given in Table 4-3. The metabolic activity of these organisms results in an intake and release of matter and energy within the soil. Gases, liquids, and solid wastes are released, and their body tissue is constantly being replaced in an endless cycle.

The roots of higher plants living above ground make a significant contribution to the organic material in the soil. The roots grow as a result of the translocation of matter from the part of the plant above the ground. The energy of the sun is captured in the process of photosynthesis, stored as chemical energy, translocated in soluble form to the subterranean plant parts, and either metabolized

TABLE 4-3. SOIL BIOTA CLASSIFIED ACCORDING TO THE ROLES OF ANIMALS AND PLANTS



Adapted from "The Nature and Properties of Soils" by H. O. Buckman and N. C. Brady there or stored in an insoluble form where these products become available for decomposition by other subterranean plants, for consumption by animals feeding below ground, or for mobilization and metabolism during the growth of a new plant. This intense biological activity results in a greater abundance of organisms in the root zone or *rhizosphere* than any other part of the profile.

The roots have several functions that result in different soil characteristics. They function as binding agents, holding the mineral soil together. Nutrient uptake occurs in the roots, beginning a nutrient cycle that is completed upon decomposition. Organic acids formed at root surfaces act as solvents. Dead cells slough off the roots and serve as a substrate for microflora.

Is that all?

Almost 700 species of soil fungi have been identified. The most important of these fall into two groups: molds and mushroom fungi. The molds may be either microscopic or macroscopic. They are found in greatest numbers in the surface layers where there is an abundance of organic matter. Some prefer a low *p*H; they are important in the soil development processes in forests where higher acidity is a characteristic of the soil. Mushroom fungi are very important decomposers, attacking such complex compounds as cellulose, lignin, gums, and starch, as well as proteins and sugars. They compliment the action of molds, bacteria, and other decomposers in the soil formation process.

Microorganisms are abundant in the soil. The number of bacteria alone in 1 gram of soil may range from 100,000 to several billion! (Buckman and Brady 1969, p. 15). Other microorganisms include algae and actinomycetes.

Soil bacteria are classified as autotrophic or heterotrophic. Autotrophic bacteria derive energy from the oxidation of mineral constituents of the soil—such as ammonium, sulfur, and iron—and carbon from carbon dioxide. These are the bacteria involved in nitrification, sulfur oxidation, and nitrogen fixation. Their importance is great because of the significance of these processes in the life cycles involving the soil and atmosphere. The heterotrophic bacteria obtain energy and carbon directly from organic matter. Autotrophic and heterotrophic bacteria function together in a dynamic redistribution of matter with the expenditure of energy within the soil.

Actinomycetes are unicellular plants that have about the same diameter as bacteria. They are filamentous, often profusely branched, and produce fruiting bodies similar to those of molds. They are second to bacteria in number in the soil. They function as decomposers, releasing nutrients for absorption by other plants.

Is that all?

Over 60 species of algae have been isolated from soils. Three general groups—blue-green, green, and diatoms—are found, with the most prominent species present in the soil being the same the world over. Soil algae are most abundant in the surface layers (upper one inch) since most of them contain chlorophyll and function much like the higher plants in photosynthesis. Algae are present in subsoils in the form of spores or cysts (resting stages) or in vegetative forms that do not depend on chlorophyll. They do not perform particularly important functions, although their biomass does contribute to the total organic material in the soil. The abundance of different species is apparently related to water and crop characteristics.

Animals, both macroscopic and microscopic, are found in the soil. Rodents (ground squirrels, for example) and insectivorous animals (moles and shrews) live in the ground, along with insects, millepedes, sowbugs, mites, snails, slugs, centipedes, spiders, and earthworms. The action of some of these animals—rodents, moles, and ants, for example—is often confined to particular areas. Some animals tend to be territorial, resulting in a distribution that is dependent on soil conditions and animal behavior.

Many of the animals in the soil begin the process of decomposition by feeding on organic matter, breaking it up mechanically, utilizing parts of it, and excreting parts of it, thus beginning a cycle of breakdown that continues in various forms until the bacteria and fungi have completed the process. Of all soil animals, earthworms have been given the most attention. They ingest soil, grind it, digest the organic matter, and excrete the unused portions (earthworm casts). This process increases the available plant nutrients, as well as aerating the soil and transporting the soil material vertically within the soil profile.

Microscopic animals in the soil include nematodes, protozoa, and rotifers. Nematodes are divided into three feeding types: (1) those that live on decaying organic matter; (2) those that prey on other nematodes and earthworms; and (3) those that are parasites for a part of their life cycle of the roots of higher plants. The first two types fit into the natural biota associated with soil formation. The third type can cause serious crop damage. Protozoa and rotifers are thought to be a part of the organic decomposition process, although their importance is unknown and undoubtedly varies from one soil to another.

4-2 SOIL CLASSIFICATION IN TRANSITION

Soil classification has been undergoing major changes in the last few years. Prior to 1960, soil classification was based largely on how the soils were thought to have formed, that is, the soil genesis. This results in the need for considerable subjective judgement. The soil classification that came into use in the sixties is based on the properties of the soil as identified in the field. This results in the classification of the soils themselves rather than the soil-forming processes. Thus soils of an unknown genesis can be classified—geological and climatological factors are not considered directly—and a greater uniformity is expected since the soil itself is being judged.

This system is based on the use of surface and subsurface diagnostic horizons for soil identification. Soils are identified by general terms followed by more specific terms in the same way that plants and animals are classified. Plants and animals are grouped into phylum, class, order, family, genus, and species. Soils are classified into order, suborder, great group, subgroup, family, series, and type. Many of the root words from which the names of these categories were derived have meanings (for example, the Order, Aridisol comes from the Latin word *Aridus*, which means dry) just as many plant and animal names have meaningful derivations. Some names, however, are nonsense words and others are associated with people or places. This is most true for the soil series.

Students of ecology need to be aware of the changes in soil classification when referring to the literature. The old system was used prior to the sixties, and currently there is a transition to the new system with continued testing of procedures and terms. The new classification system is discussed in detail in the USDA publications (Soil Survey Staff 1960; 1967) and Smith (1963).

4-3 EUTROPHICATION

Surface water constitutes over two-thirds of the total area of the earth's surface. Oceans, lakes, rivers, streams, ponds, and intermittent pools are all a part of this vast surface area, and each has its own particular system characteristics. It is interesting that the huge volumes of water in the oceans should support some of the largest organisms (whales) and some of the tiniest (plankton), as well as the fragile algae on the tide flats. The massive force of water in the oceans is too great for rigidly structured organisms, hence their anatomies are such that they conform to these mechanical forces.

Variations in the physical and chemical characteristics of bodies of water in time is an important ecological consideration. Generally, the smaller bodies of water are subject to the greatest variations, simply because of their smaller mass. It is important for students of ecology to analyze the significance of such variations. Organisms must cope with each variation rather than the average effect of several. No organism lives or dies by the average effect of many factors and forces; rather it is faced with a host of forces that act independently in some cases and interact in others.

The movement of water from the soil to lakes and ponds results in an accumulation of minerals and a subsequent increase in the fertility of the water. This is a natural phenomenon due to geological and biological aging and is called eutrophication. This results in changes in the vegetation patterns. Shore-line vegetation becomes more abundant and plankton density increases. In time, a floating mat of plants may develop along the shore, especially in small ponds where wave action is slight. Organic sediments also accumulate at the bottom of lakes or ponds. Anaerobic conditions frequently develop there in the advanced stages of succession, resulting in a more rapid accumulation of organic material as decomposition subsides. In the most advanced successional stages, the bogs that are formed are transformed into a terrestrial system as open water disappears and vegetation covers the basin completely.

The process of eutrophication just described is very slow geologically. The activities of man increase the rate. Agricultural practices such as plowing expose topsoil that is more subject to erosion than is undisturbed soil held in place by natural vegetation. Recent developments in tillage practices result in less disturbance of the topsoil by utilizing the concept of minimum tillage. Corn, for example, can be planted in sod with resulting high yields. Such a practice requires the use of selective herbicides since corn is not able to compete with forbs and grasses without some help.

Agricultural practices are often considered the cause of problems relating to environmental quality and pollution. The use of fertilizers, herbicides, pesticides, and other synthetic compounds was challenged by environmentalists in the sixties and seventies. It is true that agricultural practices result in a faster rate of redistribution of matter and energy than would occur in undisturbed ecosystems. Arguments related to ecologically isolated observations have often resulted in insufficient analyses of the total ecology, however. The use of fertilizers has been condemned without regard for the fact that their use on land with a high production potential results in increased yields from fewer acres, permitting a reversion of marginal land to nonagricultural uses. Thus lands with steeper slopes that should not be tilled can be left to natural succession, and this may result in a net reduction in erosion and mineral relocation. Herbicides and pesticides also contribute to increased yields, and this can result in wiser use of the total land and water resource. This is discussed further in Aldrich (1972).

If used correctly, but that does not, in fact, happen

Even when used correctly, necessary?

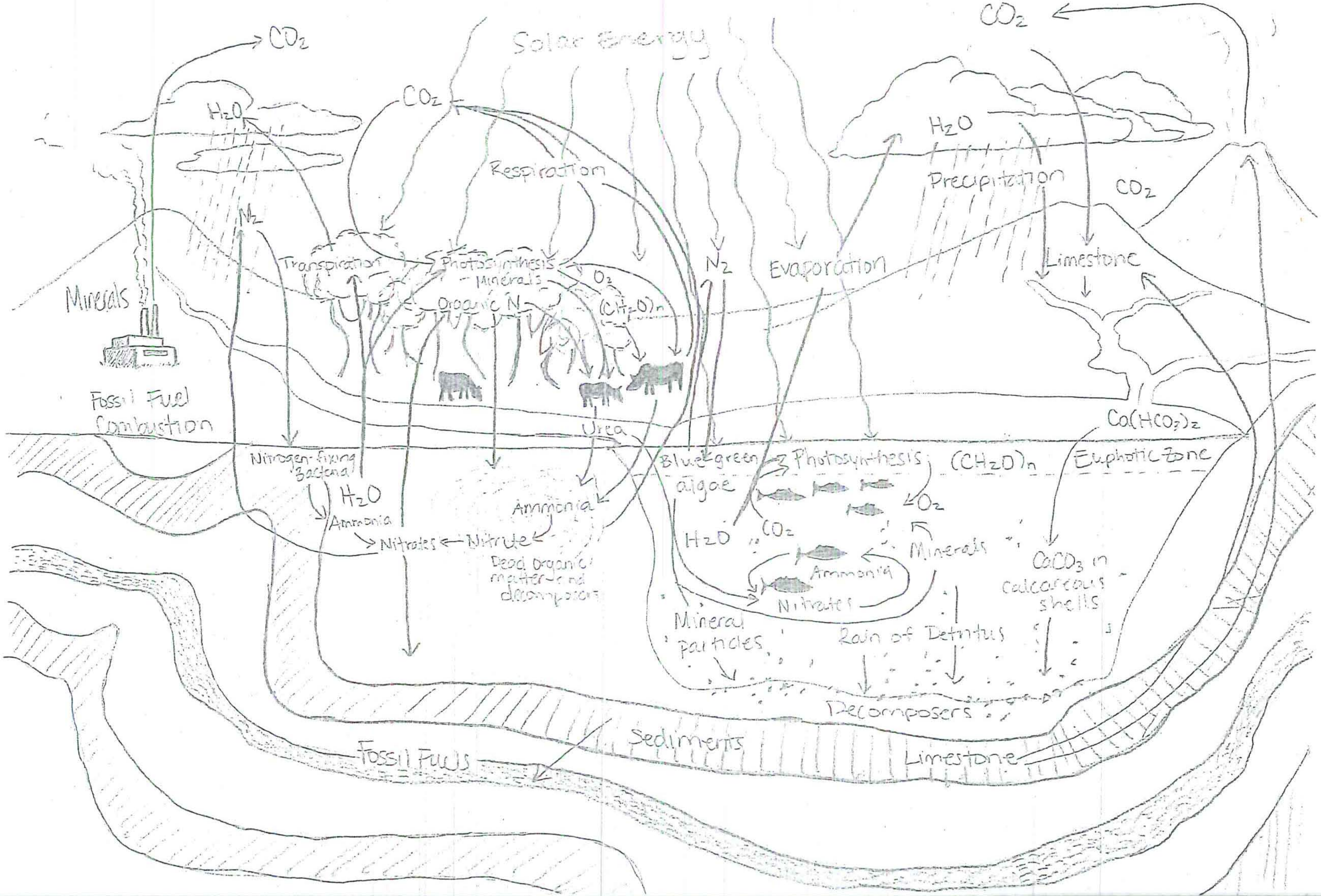
It is not the author's intent to elaborate on the benefits and detriments of agricultural practices, ecological theories, environmental philosophies, and so forth, here. It is my firm conviction that meaningful insights into the effects, both short- and long-term, of all of man's activities can only be gained after careful attention has been given to the functional relationships between organism and environment. This is possible only through analytical procedures that evaluate the relationships between energy and matter through time in both the physical and biological components of the ecosystem. There is a grave danger in looking at isolated effects without a consideration of the causes as well as other related effects in the total ecological complex. Thus I suggest that students in analytical ecology turn their attention to understanding life processes of plants and animals in relation to the physical processes of energy and matter redistribution in the earth-atmosphere interface.

4-4 BIOGEOCHEMICAL CYCLES

Life is supported on the planet Earth by the continual cycling of matter through the release of energy. The sole source (almost) of this energy is the sun. The other component necessary for these cycles to continue (the component apparently lacking on other planets in our solar system) is liquid water.

Cycles of interest to the ecologist include energy, water, oxygen, carbon, nitrogen, and mineral cycles. These are depicted in Figure 4-2 and discussed further in a series of articles in the September 1970 issue of *Scientific American*. These articles describe the general pathways of energy and matter as transformation involving the sun, atmosphere, earth, and organisms takes place. They are guides to specific analyses that can be completed by students in analytical ecology of limited systems, such as aquaria, terraria, chambers, and so forth. The concept of life as a continual redistribution of matter with the expenditure of energy falls within these cycles. The remaining chapters in this book deal with more specific interactions between energy and matter. Those discussed are of interest to many ecologists, and those not included in this text (of which there are myriads) can be analyzed with the same type of modeling approach. The

FIGURE 4-2. Major cycles of the biosphere. (Adapted from "The Biosphere" by G. Evelyn Hutchinson.)



student will note that there is a greater emphasis on single organism—environment relationships within a simple format than on large scale, but very general, analyses that include populations, trophic levels, biomasses, or gross ecological units. There are many exciting relationships between an individual organism and its environment, and comparisons between different kinds of individuals, such as male and female, pregnant and nonpregnant, large and small, young and old, and so forth, are of great interest because of the different roles that individuals play. At some time in the ecological future, the sythesis of these types of analyses of individual relationships (autecology) will result in a better understanding of community ecology (synecology).

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IDEAS FOR CONSIDERATION

Use a Soil Conservation Service soils map to identify the different soil types in a local area. Characterize each of these soil types according to the physical and chemical characteristics that affect the interactions of topography, water, and the soil, and consider the possible relationships between these soil types and the plant communities found on them. Can you develop a model that is useful for predicting the type (not necessarily species) of plants you would expect under these conditions?

Determine the air space (by the water-displacement method) in containers filled with spheres of different sizes. Measure the air space for containers filled with uniformly sized spheres and spheres of various diameters. Do measured values agree with those predicted using geometric formulas? Can you relate this technique to soil with different ratios of sand, silt, and clay?

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