SOILS

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Edaphic and climatic characteristics of a site quite well define the quality of that site for plant growth. The importance of soil characteristics to the growth and well-being of aspen in the West is apparent from observations by many authors, from inferences resulting from work with other trees and agricultural crops, and from detailed study of aspen soils and site quality in the Lake States. However, there are not many descriptions of aspen-soil-site relations in the West. Only in recent years has enough soil survey information been collected from the forested areas of the West to define the soil series, and sometimes types and phases, upon which quaking aspen is found. Assessment of site quality is just beginning. For example, recent county soil surveys in Utah include information on forest productivity, including site indexes for aspen (Campbell and Lacey 1982, Carley et al. 1980).

The capacity of soils to hold water and make it available for plant growth is often their most important characteristic. This is discussed in the chapter EFFECTS OF WATER AND TEMPERATURE. Rooting behavior of plants partly depends upon the soils on which they grow; in turn, plant rooting characteristics affect soil properties. Aspen rooting characteristics are examined in the MORPHOLOGY chapter. Other aspects of soils are discussed in the WATER AND WATERSHED chapter.

Parent Rock

Parent rock types are extremely varied in the West; aspen grows on many of them. Berndt and Gibbons (1958) found aspen on soils derived from granite, sandstone, and limestone in Colorado. Severson and Thilenius (1976) found aspen stands on soils from calcareous sedimentaries, slates, quartzitic schists and "Tertiary igneous" parent rocks in the Black Hills and Bearlodge Mountains of South Dakota and Wyoming. Any given community type was likely to be found on soils from two or three different parent rocks. In southern Wyoming, Wirsing and Alexander (1975) reported the climax *Populus tremuloides/Carex geyeri* association on glacial outwash, loess, alluvium, gneiss, subsilicic igneous rock, shale, and limestone.

However, for growing aspen, the quality of soils from these different parent materials varies widely. Retzer[1] concluded that the best aspen in the Rocky Mountains and Great Basin grows on soils from subsilicic igneous rocks such as basalt, and from limestones and neutral or calcareous shales. He also noted that "some of the least vigorous and most diseased aspen" were found on soils derived from granite.

In the area of Crested Butte, Colo., all local parent rocks except igneous appeared to be favorable for aspen (Langenheim 1962). Aspen groves grew more frequently on limestones and shales than on associated conglomerates and sandstones. Limestone beds sometimes were outlined by aspen. Langenheim (1962) credited the correlation of parent rock and aspen distribution to the effects of parent material on succession. Soils that developed from granite, conglomerate, or siliceous sandstone generally had an open herbaceous cover that permitted conifer seedling establishment and, ultimately, replacement of the aspen by conifers.

In Big Cottonwood Canyon, near Salt Lake City, Utah, conspicuous bands of aspen grow along the contour, amidst large areas of mountain brush. Bedrock here is predominantly quartzite, with interbedded layers of more easily weathered limestone. Aspen is found on the soils derived from the limestone (Crowther and Harper 1965). Under the aspen, slopes are less steep, and the soil is deeper and less stony than under the brush.

Jones[2] described soils on many aspen plots—scattered mostly in western Colorado. Soil parent material on those plots included most of the rock types found in the Southern Rocky Mountain Physiographic Province and adjacent plateaus (table 1). No strong differences were observed in soils from these different parent materials. Even the calcium content in soils from calcareous sedimentaries was no higher than in some other soils. Aspen grew poorly or well on soils from almost any type of parent rock. Other environmental factors appeared to dominate aspen site quality in these locales.

The extensive research on aspen soil-site relations in the Lake States has yielded results that appear to be applicable, at least in principle, to the mountain West, particularly in areas that have experienced glaciation. Also, site quality differences between calcareous and non-calcareous parent materials appear to be similar in both areas of the country.

Soil parent materials in much of the Lake States were deposited by continental glaciers; some were later redeposited or modified by streams or lakes. Different glacial fronts deposited parent material of much different character. In northern Minnesota and Wisconsin, for example, parent materials can be classified as (1) Keewatin drift, which is gray, calcareous, and usually fine textured; (2) Cary drift, which is typically, red or brown, coarse-textured, and generally low in bases; and (3) Superior-lobe drift, which is reddish, intermediate in character between the other two, generally fine textured and containing more bases than the Cary drift (Voigt et al. 1957).

[1]*John L. Retzer, unpublished review, 1949. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.*

[2]*John R. Jones, unpublished data and notes, on file at Rocky Mountain Forest and Range Experiment Station's Forestry Sciences Laboratory, at Northern Arizona University, Flagstaff, Ariz.*

In very extensive sampling, Kittredge (1938) found that, on soils of the same textural class, aspen grew consistently and substantially better on the calcareous Keewatin drift. Stoeckeler (1948, 1960) found better height and volume growth and less decay on Keewatin drift. Voigt et al. (1957) found that volume growth per acre of aspen on Keewatin drift averaged about 2.6 times that on the Superior-lobe drift and 4.5 times that on the Cary drift. In a sample by Meyer (1956), 10 of 11 plots with site indexes higher than 70 feet (base age 50) were found on Keewatin drift. The difference in growth on different glacial drifts, and their textural and chemical differences, suggest that moisture and nutrient regimes are very important to aspen growth.

Land Form

In the area of Jackson Hole, Wyo., Reed (1952) found aspen on dry mountainsides as well as on alluvial terraces above the streamside belt of narrowleaf cottonwood and balsam poplar. In the southern Rocky Mountains, Jones[2] examined aspen on almost the full spectrum of land forms. Groves grew on the bottoms of draws and on ridge crests. Extensive stands were found on mountainsides and on the tops of mesas and plateaus. Aspen occurred on a gley soil next to a cattail marsh, and on a 73% slope of an old avalanche track, as well as on old talus with a very thin stony soil. In Wyoming's Wind River Range, Reed (1971) commented that all aspen observed above about 10,200 feet (3,100 m) were on talus slopes with little soil.

Table 1.—Site index (in feet) and oldest stands (in years) on different parent rock types on 53 plots in the southern Rocky Mountains.[1]

Rock types	Number of plots	Average site index at 80 years	Oldest stand
Sedimentaries, noncalcareous	16	58 ± 18	173
Sedimentaries, calcareous	5	53 ± 10	164
Igneous, silicic (acidic)	18	60 ± 15	151
Igneous, mesosilicic	6	54 ± 11	141
Igneous subsilicic (basic)	3	59 ± 5	144
Metamorphic	5	47 ± 10	170

[1]*John R. Jones, unpublished data and notes, on file at Rocky Mountain Forest and Range Experiment Station's Forestry Sciences Laboratory, at Northern Arizona University, Flagstaff, Ariz.*

Figure 1.—Rapidly growing aspen on a deep-soiled flat at the foot of a slope. Dominants averaged 87 feet (27 m) tall at age 79. San Juan National Forest, Colorado.

Aspen commonly grows larger and faster at the foot of slopes (fig. 1) than on their sides, and on benches rather than on the slopes above and below the benches. Topographic concavities, which tend to concentrate moisture, are likely to grow larger aspen than surrounding non-concave situations. According to Baker (1925), aspen grows best on rich, deep-soiled flats with plentiful moisture. It also tends to persist on those sites, especially on fine-textured soils, where thick herbaceous growth inhibits conifer seedlings. Hayward (1945) wrote that the best aspen stands in Utah's Wasatch Range were on benchlands, where the soil was deep and no snowslides occurred. He reported a heavy growth of forbs on those sites. The deep, dark surface mineral horizon (A_1) and the large decaying trunks of old fallen aspen on these benchlands suggested long aspen dominance.

Kittredge (1938) and Fralish and Loucks (1967) sorted growth data in the northern Lake States by parent material types—lake bed clay, outwash sands, and till, among others. They, too, found that growth differed considerably by type, even when soil textures were similar.

Soil Profiles

The soil forming factors of climate, parent material, topography, organisms, and time (Jenny 1941) act in concert to produce soils. Soil texture, structure, color, depth, and other physical and chemical characteristics reflect these factors. With the passage of time, layers or horizons develop in the soil, forming a soil profile. Horizons in some soils are easy to distinguish by visual examination; in others, including many soil profiles under aspen, chemical and physical tests are necessary to clearly delineate the horizons.

The nomenclature used throughout the remainder of this chapter follows the Soil Survey Manual (USDA 1951, with 1962 supplement) and Soil Taxonomy (USDA 1975).

Surface Organic Horizons (O_1 and O_2)

The surface organic horizons consist mostly of plant remains lying on top of the mineral soil. In the absence of a well-developed conifer component, the organic layer under aspen is thin and somewhat ephemeral. These organic layers seldom are thicker than 1 to 1.5 inches (3 cm to 4 cm) (Jones,[2] Reed 1971).

Bartos and DeByle (1981) found that about 1,600 pounds per acre (1,800 kg per ha) of aspen leaves and twigs dropped each year from stands in Utah with basal areas of 75 to 110 square feet per acre (17 m^2 to 25 m^2 per ha). Well stocked, young stands may produce 1 ton of litter per acre (2,250 kg per ha) (Jones and Trujillo 1975a, Zavitkovski 1971). This material, as well as litter from the herbaceous understory, decays rapidly (Hayward 1945, Hoff 1957, Lutz 1956). Van Cleve (1971) found aspen litter weight loss at an Alaskan site had a half time of 651 days. In Alberta, Lousier and Parkinson (1976, 1978) concluded that 99% of the litter crop would decay in 24 years. Bartos and DeByle (1981) reported a 42% weight loss during the first winter on a Utah mountain site. In addition to rapid decay of this litter, animal activity (notably that of pocket gophers) mixes much of the annual litter crop into the surface layers of mineral soil. Thus, by the end of summer, much of the previous year's litter has disappeared from many pure stands of aspen in the West.

Mineral Horizons—A, B, and C

The upper mineral soil horizons (A and B) that are affected by organisms and climate are collectively known as "the solum." Interactions between vegetation and soil are graphically reflected in the characteristics of the solum, particularly if a specific vegetation type occupies a site for a long time.

Under aspen, the thin surface organic horizon is typically underlain by a thick dark A_1 horizon, a mollic epipedon—high in organic matter content and available nutrients and of granular structure (fig. 2). This black or dark brown horizon under the better aspen stands in the Intermountain West is frequently up to 2 feet (61 cm) thick.[3] Morgan (1969) found organically enriched layers 10 to 23 inches (25 cm to 58 cm) thick in Gunnison County, Colorado. Jones[2] found an organically enriched solum 16 ± 8 inches (41 ± 20 cm) thick on 53 plots in the southern Rocky Mountains; the greatest was 35 inches (89 cm). He and Tew (1968) found that humified organic matter usually constituted 10% or more of the upper few inches of mineral soil, decreasing downward. Bliss[4] classified aspen soils in central Utah with mollic epipedons 10-16 inches (25-41 cm) thick in the "Typic" subgroup, and those more than 16 inches (41 cm) thick in the "Pachic" subgroup.

Aspen forest differs from associated vegetation types in character, distribution, and amount of organic matter and nutrients in the solum. As examples, Hoff (1957) found the A_1 horizon under aspen in northern Colorado was darker and contained considerably more organic matter than under adjacent coniferous stands. Tew (1968) discovered that the upper 6 inches (15 cm) of mineral soil under aspen in northern Utah differed from that under adjacent stands of shrubs and herbaceous vegetation by having 4% more organic matter, higher water holding capacity, slightly higher pH, and more available phosphorus.

Aspen are efficient nutrient pumps that enrich the surface soil horizons (Lutz and Chandler 1946, Stoeckeler 1961). Aspen leaves typically have a higher nutrient content than does foliage of associated coniferous trees (Daubenmire 1953, Troth et al. 1976, Young and Carpenter 1967). The rapid decay of aspen leaves provides a relatively quick return of nutrients to the soil (Bartos and DeByle 1981, Daubenmire and Prusso 1963, Hayward 1945).

In addition, herbaceous undergrowth usually is much heavier under aspen than under conifers in the West (Daubenmire 1943, Hayward 1945, Morgan 1969, Potter and Krenetsky 1967, Reed 1971). In extreme cases, herbs may stand 6 feet (2 m) tall (fig. 3). Herbage production approaches that of associated meadows (Ellison and Houston 1958, Houston 1952, Paulsen 1969). Potter and Krenetsky (1967) found that, in northern New Mexico, grasses, with their extensive fibrous root systems and litter of neutral pH, contributed greatly to organic matter in soil beneath aspen. This, in turn, improved soil water-holding capacity, percentage of base saturation, soil structure, and permeability.

The C horizon underlies the solum. It is a layer of unconsolidated material that has not been appreciably modified by soil forming factors, especially by vegetation. C horizons reflect very strongly the characteristics of the material from which they were derived. Usually the C horizon lacks structure, being either single grained or massive. Jones[2] found both types under aspen stands in the southern Rocky Mountains. He described

[3]Aspen Committee, unpublished report, 13 p. 1965. "Guidelines for coordination of uses in aspen areas." USDA Forest Service, Intermountain Region, Ogden, Utah.

[4]Personal communication from Timothy M. Bliss, Soil Scientist, USDA Forest Service, Fishlake National Forest, Richfield, Utah.

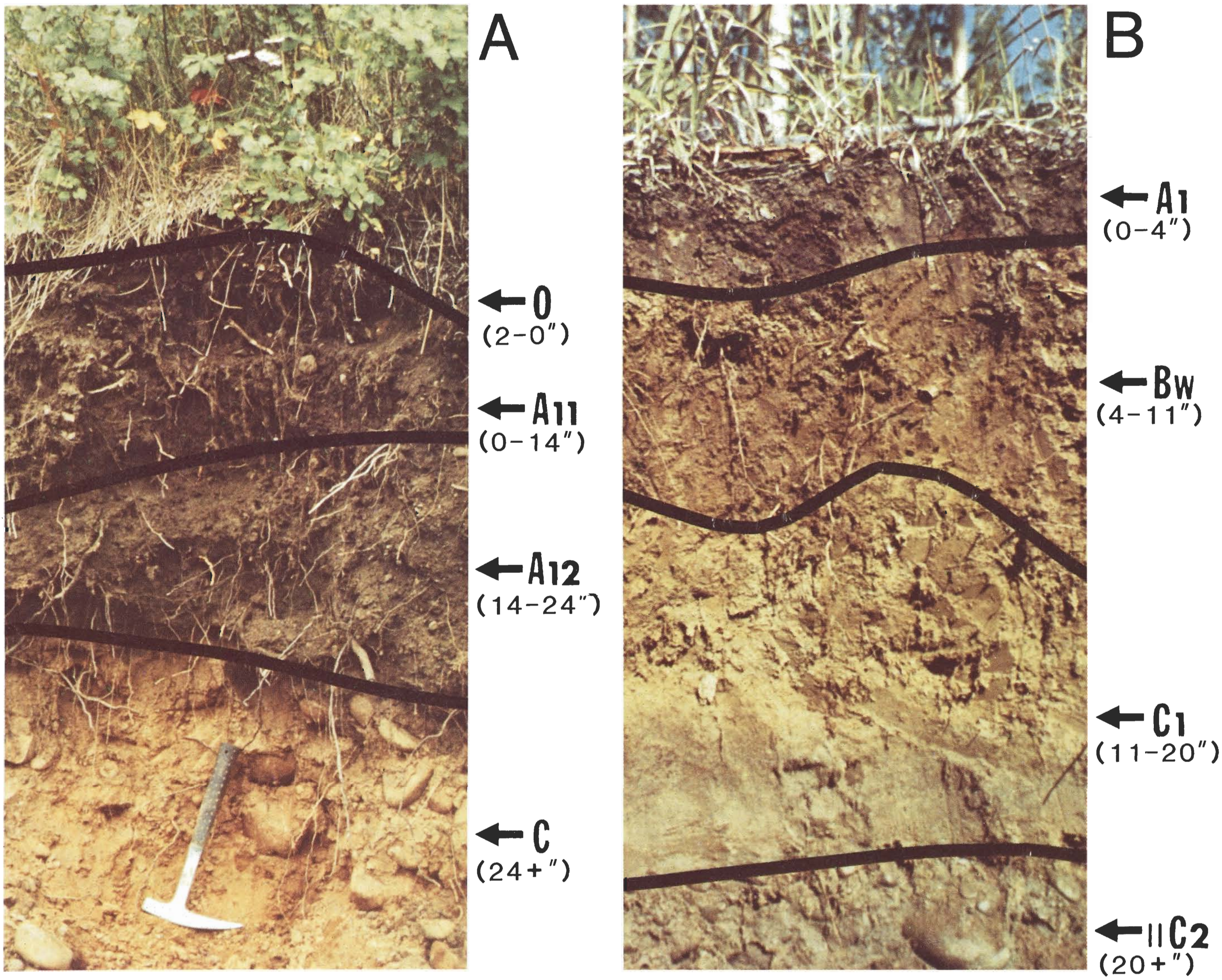

Figure 2.—(A) A mollisol, typical of soil profiles under stable aspen in Utah. A Cumulic Haploboroll with about 2 feet of dark A_1 horizon. (B) A Typic Cryumbrebt profile on a stream terrace in Alaska. Aspen occupies this site, but here is probably seral, and has not been the primary soil-forming factor over a long time span.

massive layers that extended clear to bedrock on a number of plots. The C horizons contained aspen roots, but the massive layers were penetrated only by sinker roots and contained few or no horizontal roots. In contrast, massive layers have not been described in soils mapped beneath aspen by others in the Rocky Mountain Region of the Forest Service.[5]

Jones discovered some sites with no C horizon.[2] Some very shallow aspen soils consisted of the organically enriched A horizon on fractured colluvial rock. In those cases, defining where the soil ended and the underlying rock began was arbitrary, because the organically enriched soil material, with roots, continued downward in the openings between the rocks.

In the Intermountain West, C horizons with strongly calcareous layers have been reported on some aspen sites.[3] A strongly calcareous layer contains considerable free calcium carbonate in unconsolidated material, as distinguished from calcium carbonate in stones; it reflects low precipitation as well as calcareous parent material. Where such a horizon was found within 4 feet (1.2 m) of the surface, aspen growth was very poor. Where it was found within 2 feet (61 cm) of the surface, aspen were not taller than 25 feet (8 m) at age 100.

[5]Personal communication from F. A. Dorrell, USDA Forest Service, Rocky Mountain Region, Denver, Colo.

Soils Under Seral Versus Stable Aspen Stands

If aspen occupies a site for several generations, a typical aspen soil develops. But, if it is seral, particularly to conifers, the solum reflects influences of the vegetation that occupied the site for the longest period of time. Even one generation of conifers can result in a leached, often light colored A_2 horizon underlain by an enriched B horizon. Perhaps the seral nature of aspen on some of the sites reported by Jones[2] accounts for the unusual soil profiles he found in parts of a 120-year-old aspen/forb stand, in which pale A_2 horizons had become thin and discontinuous beneath dark A_1 horizons that were several inches thick. He also found what was probably a gray-wooded soil (no A_1 and a pinkish A_2 that was 15 inches (38 cm) thick) beneath a 170-year-old aspen canopy, with a well-stocked spruce-fir understory, at 10,300 feet (3,150 m) elevation. This indicated long periods of conifer dominance with brief intervening periods of aspen/forb dominance on the site.

On the Fishlake National Forest, in central Utah,[4] the climax or stable aspen stands usually have a black or dark brown A_1 horizon from 16 to 24 inches (41 cm to 61 cm) thick. Common soil subgroups include Lithic, Pachic, and Argic Pachic Cryoborolls. Eroded sites or transition soils between seral and climax aspen stands are Typic or Argic Cryoborolls. In contrast, soils of seral aspen stands on the Fishlake National Forest typically have an A_1-A_2-$B_{21}t$ or A_2-B_{21} horizon sequence, commonly with mixed A and B horizons. The upper boundary of the A_2 horizon seldom is deeper than 12 inches (30 cm) below the surface. Soils with thicker A_1 horizons usually show greater aspen dominance. Common soil subgroups under seral aspen include Typic and Mollic Cryoboralfs, and Boralfic Cryoborolls. Similar soil textures are found under both seral and stable aspen.

Figure 3.—Dense herbaceous undergrowth dominated by larkspur 6 feet (2 m) tall, at the foot of a slope. The mollic epipedon was 35 inches (89 cm) thick. San Juan National Forest, Colorado.

Texture and Stoniness

Soil texture has a major influence on several factors that presumably affect aspen: cation-exchange capacity, water-holding capacity, and permeability to water, roots, and air. For example, in Michigan, Day (1944) found that roots of young aspen penetrated deeply in fine sand, with many sinker roots deeper than 6 feet (2 m); but on a dense lakebed clay, only occasional roots penetrated deeper than 1 foot (30 cm); and, in soil with a dense hardpan, all penetration of the hardpan was through old root channels.

Jones found aspen on essentially the full range of soil textures available in Colorado and northern New Mexico.[2] Sandy loams were most frequent, although loams also were common. Loamy sands, sandy clay loams, and clay loams were occasional. Texture usually did not change much with depth on Jones' plots. Others,[5] however, reported medium-textured surface soils with clay loam or clay subsoils to be common beneath aspen in the central Rocky Mountains.

Stoniness and/or rockiness varies widely, too. Among Hoff's (1957) paired stands, soil beneath aspen was "invariably deeper and less rocky" than beneath conifers. Jones[2], however, found no notable difference in stoniness of soils beneath quaking aspen and Engelmann spruce (*Picea engelmannii*) in the southern Rocky Mountains.

Several studies in the Lake States showed that aspen site index and soil texture were related significantly (Kittredge 1938; Meyer 1956; Stoeckeler 1948, 1960; Voigt et al. 1957). Aspen height growth was strongly correlated to the combined content of silt and clay (Stoeckeler 1960). Stoeckeler (1960) concluded that the optimum texture is about 60-70% silt and clay on sites not having a shallow water table. Meyer (1956) and Voigt et al. (1957) found that aspen grew fastest where silt and clay content was 80% or higher. Strothmann (1960) considered that if 30% or more of the soil volume was occupied by stone or gravel, aspen growth would be reduced. Stoeckeler (1960) also considered a high stone and gravel content deleterious to aspen growth. The extent to which these Lake States findings apply in the mountainous West has not been adequately tested.

Drainage

Probably because of a preponderance of well-drained soils on the western mountainous landscape, the problems of too much water or lack of soil drainage have not been studied for aspen in the West. Nonetheless, aspen occurrence and growth are affected by too much water on some western sites and by too little on most others. The following findings from the Lake States should apply to the West.

Lake-bed clays, despite their high silt and clay content, tend to be very poor aspen sites in both Minnesota and Wisconsin (Fralish and Loucks 1967, Kittredge 1938). They are poorly drained internally as well as externally. Apparently it is drainage in the upper 2 or 3 feet (0.6 m to 1 m) that is critical. Growth is good on many soils with poor drainage at greater depths. The presence of ground water—either as a permanent or an intermittent water table—as near to the surface as 2 feet (61 cm), tends to improve aspen growth in the Lake States. The effect is largest on coarse-textured soils, and trends toward no effect on fine-textured soils (Fralish 1972, Fralish and Loucks 1967, Kittredge 1938, Stoeckeler 1960, Strothmann 1960, Wilde and Pronin 1949). Roe (1935) reported reasonably good aspen growth in swamps on wet mineral soils but poor growth on organic soils (Histosols).

Soil Fauna

Hoff (1957) presented data on invertebrates inhabiting the organic and surface mineral layers under aspen stands and nearby coniferous stands. Invertebrate populations were larger under aspen in 14 of the 15 comparisons, and much larger in 9 of the 15. Though not usually encountered, earthworms were found more frequently under aspen.

Hayward (1945) reported the soil turning activities of pocket gophers and ground squirrels to be much more prevalent in aspen forests than in coniferous forests of the Wasatch and Uinta Mountains of Utah. McDonough (1974) determined that the average pocket gopher mound in a Utah aspen stand was 15 × 18 inches (38 cm × 46 cm) across and 3.5 inches (9 cm) deep. Over a 4-year period, 40% of his 1-meter-square quadrats had one or more new mounds. The mound soil was similar to undisturbed topsoil, but was less compact and more friable. In a subalpine aspen stand in Colorado, Brown and Thompson (1965) found that pocket gopher activity had destroyed the upper part of the B horizon, mixing it with the thick dark A horizon.

Nutrients

As noted earlier, aspen and associated species are excellent nutrient pumps. They effectively withdraw large quantities of available nutrients from the entire rooting depth (more than 6 feet (2 m) on deep, well-drained soils), incorporate those nutrients in biomass, and return a large proportion of that biomass (nearly 2 tons per acre (4,500 kg per ha)) to the soil surface as litter each year. Rapid decay of that litter, combined with animal activity, returns those nutrients to the surface mineral soil. Mollic epipedons often develop. It is not surprising that the A_1 horizon under aspen usually contains greater concentrations of available nutrients than lower horizons. Jones[2] found more of each nutrient, especially potassium, in the A_1 horizon than in the C horizon of his many aspen plots in the southern Rocky Mountains. An average of 30 milliequivalents of extractable calcium per 100 grams of soil was found in the A_1 versus 14 in the C. In contrast, in Engelmann spruce he found an average of only 7 milliequivalents of calcium in each of these horizons.

The higher pH typical of surface mineral soils under aspen implies a greater base saturation of the exchange complex than that found in soils under nearby vegetation types (Jones,[2] Tew 1968).[2] Southard (1958) found a base saturation greater than 80% in the surface horizons under aspen in northern Utah. In central Utah[4], both seral and climax aspen stands growing on soil derived from igneous rock had base saturations of 65-80% in the surface horizon and 80-90% in the subsoil.

In many aspen stands in the West, legumes are prominent or even predominant. Legumes or alder, with their symbiotic nitrogen-fixing root bacteria, significantly improve the nitrogen supply in some forest types (Sprent and Silvester 1973, Tarrant and Miller 1963). Tew (1968) reported slightly greater nitrate production from soils under nearby shrub stands than from aspen in Utah—but it was still good in both cases. Beetle (1974) stated that heavy nitrate fertilization of a Wyoming stand greatly stimulated the grasses; but aspen height growth was not affected, implying that there was sufficient nitrogen for the aspen even before fertilization.

Jones[2] found some mature aspen in the southern Rocky Mountains with good to excellent height growth on soil with medium to low nutrient levels. While adequate nutrient levels are necessary for good growth, apparently the levels below which aspen height growth is retarded are not often encountered in the West. Poor height growth here seems to be caused by other factors. Fertilizing may increase basal area and volume growth, however, even where height growth is not affected (Cochran 1975, Einspahr et al. 1972).

The effect of soil nutrient levels on aspen growth has been much more extensively studied outside the mountain West. In the northern Lake States, the difference in aspen growth on different parent materials, especially its very superior performance on the nutrient-rich Keewatin drift, suggests that soil nutrient content is deficient for good aspen growth on many soils. Stoeckeler (1960) and Voigt et al. (1957) found the site index of aspen there to be significantly correlated with available nitrogen, calcium, magnesium, and potassium in the soil. Einspahr et al. (1972) fertilized a sandy loam soil in Wisconsin with nitrogen, phosphorus, potassium, calcium, and magnesium; this substantially increased volume growth but not height growth. Fertilizing an impoverished soil in Alaska dramatically increased both height and diameter growth (Van Cleve 1973).

In contrast, Fralish (1972) concluded that soil nutrient levels had very little effect on aspen growth in northern Wisconsin. These apparently contradictory results probably came from sampling different extremes or ranges of nutrient levels. However, on very nutrient-poor lake bed sands in the Lake States, the soil nutrient status improved with long periods of humus accumulation; and more nutrients were accompanied by better aspen growth on these moist sites (Wilde and Paul 1950, Wilde and Pronin 1949).