mation of island moors as in Germany: a bog on a hill. Nothing can be done to remedy this unless money is available to dig up the whole thing.

Sphagnum moss is powerful and wide spread. High temperature favors fungi and plant diseases of all kinds. In some cases species have been restricted by these agencies; mountain larch fails in valleys because it is attacked by fungous diseases there which it cannot combat.

8) Temperature affects animals in the forest.

Warm countries have more insects than cold countries, and also more insect-enemies. There is here a more vigorous motion of equilibrium in Nature. The greatest devastation of forests by insects has been in the north, as by the gypsy moth, tamarack saw-fly, etc. It has been claimed that this is due to the presence of a pure forest as against a mixed forest, rather than to climate. But in the south we have also a big pure forest, so this does not hold. The mosquito and black fly, etc., are far worse in the north, especially in the far north than in the south. There are not enough insect enemies in the north; this condition is better in the south.

9) Temperature affects soil and soil life.

In cold soils there are less bacteria, less insects, less mechanical and biological destruction, and less transformation and mixing of materials than in warm soils. In cold soils organic materials change to peat or duff. In hot soils all mulch is decomposed, eaten, transformed and mixed with inorganic materials; therefore there is no mulch in the tropics, and no humus. The forests have a clean floor all the time; even large limbs disappear in a short time; the soil is seldom black there. Constant activity is going on; insects dig them up, and fungi are hard at work. Railroad ties last much better in the north; the Canadian Pacific Railroad buys almost any kind of timber for ties, because the various species are so much more durable in the north that there is a greater choice and use than in the south.

Temperature favors disintegration of rock material in the soil. Frost is an important agent in breaking rocks; the water gets in and rusts it by oxidation. Also ~~formations~~ formation of acids and other substances, as secretions of bacteria, and roots. Carbonic acid is included. These are very potent agencies, and are better in high temperatures, except frost, which is ineffectual in the south and influential in the north. Rock therefore disintegrates more rapidly in the south except in certain cases, as rock in air. It is slow in dry countries, as in Egypt.

10) The temperature of the tree's branches, leaves, etc., are determined by the temperature of the air, (of the soil with roots).

The wood is warmed by warm air. Frost cracks are common in the north and spoil much timber. These were formerly thought to be seasoning checks; this idea was incorrect (hot air). Beech in the winter is full of frozen water; in very low temperatures that ice bursts and cracks the wood. Frost cracks sometimes heal over.

Occasionally trees are injured by heat, especially in the case of direct sunlight on a thin-barked tree; this ~~produces~~ produce sun-scalds, as on beech and basswood. A dense stand opened up frequently gets scalded.

High temperature requires increased moisture, because of the stimulation of transpiration. This affects Forest Distribution. With low temperature and more relative humidity good forests result.

3. Climatic Factor of Moisture.
We will consider here precipitation and relative humidity but not soil moisture.

a. Moisture conditions in the United States and North America.
1) The average precipitation in the United States is 30 inches. From Ann Arbor east to the mouth of the St. Laurence and ~~and~~ south to the Sabin river runs the line of 40". To the north and northwest the precipitation is less then 30". The 20" line runs from the Rio Grande river north to Hudson's Bay. See maps giving the various lines. Also on pages 50-51 of this report. The Pacific coast has good precipitation.

2) Distribution of rainfall thru the year. See Henry's Climatology of the United States.
a) East of the Mississippi River precipitation occurs all year. Four weeks of drouth is a long period. Relative humidity increases both east and west from the Mississippi valley to the coasts.

b) On the great plains, Kansas northward: there is a small total precipitation, 20"-30". A large proportion of this comes during the 6 months of spring and summer, from May to September. The relative humidity is low; there is much dry wind and therefore few trees.

c) The Great Southwest. This is a region of summer rains, regular monsoon rains, and rainy seasons. The precipitation is low, 15"-20", of great irregularity; wet seasons alternate with dry. There are great flood rains, accompanied by great erosion. Low relative humidity is the rule. The prairie is desert; forest (live oaks) occurs only on high plateaus and mountains.

d) The California coast region west of the Sierras. The precipitation is low. Winter rains are common after the land is cooled. There is great relative humidity, and the winter rains are fairly regular.

e) Northern California to Alaska. Precipitation occurs during all seasons, becoming heavy north of Portland, Oregon. The relative humidity is great. This is the area most favorable to tree growth.

f) The Sierras of California to Oregon. In the southern portions, in outlying mountains (St. Gabriels?), the temperature is high; the region is too dry for good tree growth. In the main Sierras the mountains rise high enough so there is more and regular precipitation with high relative humidity on the west side; there is less precipitation and low relative humidity on the east side. The result is a heavy and mixed forest on the west slopes, and a pinery on the dry east side.

g) The Cascades from Southern Oregon to British Columbia. The west side is the wet side. It is heavily forested, with no lower timber line (California has both lower and upper timber lines). The east side is dry; the relative humidity is great on the west side, amd low on the east side. This produces dense mixed forests on the west side and a pinery on the east side. Heavy rains and excessive snows are common, often 20 feet of snow being common. When this snow melts a tremendous flood rushes down the west slope, especially in Washington.

h) The Middle Rockies, Pueblo to Southern Montana. Precipita-

tion occurs in all seasons at a high altitude, and is comparatively light; the relative humidity is fair or low. Pine grows at lower levels and spruce at higher altitudes.

i) The Northern Rockies, Southern Montana to British Columbia. The western chains and western exposures are more humid, have a greater precipitation, a fair relative humidity and a more complex forest than the east side. The east side and slopes, especially the outlying mountains to the Black Hills, are dry, of low relative humidity, and are covered with a pure pinery. The western complex forest includes Douglas fir, cedar, and hemlock.

j) Canada. East of Winnipeg there is a precipitation of over 30" all year. West of Winnipeg the precipitation is low all year, with long dry spells; the low temperature produces a high relative humidity, so that even spruce forests can thrive.

3) Precipitation varies locally.

This is true especially of mountain countries. As a general thing, in areas of low precipitation, especially in regions of seasonal rains (southwest), the precipitation varies greatly from year to year, and is less dependable than in regions of considerable rainfall.

4) Precipitation from Michigan to the south is practically all rain; to the west and east there is almost as much snow as rain. In the western mountains there is much snow. Snow covers seeds and seedlings, but breaks much timber; it often facilitates logging on the level. It is a good protection against fire.

b. Effects of Moisture on the Forest.

Moisture is an important factor with the forester. All operations are easier, safer, cheaper in wet countries.

1) About 4 inches of rain is necessary during the summer months, for good forest growth.

2) Moisture, like temperature, affects composition. In dry districts there are normally few species. It is drought and low (relatively) relative humidity which makes the fringe forest, mesquite and scrub oak. High relative humidity adds species in California in spite of little rainfall. A great abundance of rainfall with low temperature (in Washington) gives a monotonous forest. This is due to the temperature rather than the moisture. In a dry climate we have few and intolerant species, as pines and oak. Since they lack water they must have light, so are intolerant.

3) Moisture affects reproduction: easier in wet regions, difficult and precarious in dry regions. Arizona has a rather uncertain thing with her natural reproduction. Both natural and artificial reproduction are costly and uncertain. Artificial reproduction is difficult in dry situations. The trouble lies in the germination and seedling stage. Remember this in your operations: it means that you must watch for the right moments.

Insects like gadflies and vermin like rodents are worse in dry country. Seed production is usually good in dry regions, because the soil commonly is good, the stands are open, and have plenty of light. Sprouting also is good here. The capacity to sprout is maintained for tion occurs in all seasons as a [illegible], the fog [illegible] [illegible]; the relative humidity is fair or low. Pine grows at lower leve[illegible] and spruce at higher altitudes.

4) The Northern Rockies, Montana [illegible] to [illegible] [illegible] bia. The western slopes and western exposures are more humid, have a greater precipitation, a [illegible] relative humidity and a [illegible] [illegible] rest than the east side. The east side and slopes, especially the eas[illegible] lying mountains to the [illegible], are dry, of low relative humidity and are covered with a [illegible]. The western [illegible] [illegible] includ[illegible] Douglas fir, cedar, and hemlock.

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[illegible] [illegible] [illegible] rains [illegible] [illegible] in dry country. [illegible] is [illegible] good in dry [illegible] [illegible] the [illegible] [illegible], [illegible], [illegible] [illegible], [illegible] [illegible] [illegible] [illegible]. The capacity to sprout in [illegible] for a long time in dry regions, as witness oak and chestnut. Oak also sprouts in spite of constant browsing. The only danger limit is to have too many leaves, which would take too much water. Otherwise good conditions for food manufacture are obtainable.

4) Moisture hastens growth. It stimulates height growth and also diameter and volume growth. Height growth suffers most in a dry region. Volume in Puget Sound region is 3 times the volume in Michigan. A dry climate leads to a slow rate of growth. Good soil with great relative humidity increases the species.

5) Moisture affects the form of the tree. In dry situation we have intolerant timber, large crowns, short and big bodied timber, big limbs, and gnarly and crooked growth. Scrub oak and mesquite are examples.

The finest forms of timber are found only in humid districts.

6) Moisture increases tolerance and favors tolerant species. This is important. We have no tolerant species in dry regions. Moisture favors density and growth in volume per acre.

7) Moist localities give the largest trees but not necessarily the oldest. One of the oldest junipers in existence was in a Nevada desert.

8) Moist forests produce good quality of timber. In regard to size and cleanness it may be said that only a moist country will give first-class material. In regard to fine-grained, hard and handsome timber dry localities often produce a fine quality of material. All the different qualities of woods are obtainable in all climates and even in the same locality. In dry localities there is less softwoods than in wet places, but the latter has the hardest as well as the softest woods. A very cold climate does not give species of really hard wood, tho good larch is obtained in the high Alps.

9) Moisture reduces frost danger. Moist regions have less frost than dry regions. Ice normally hurts trees. Snow generally protects them. Hail always injures forest trees, and causes expensive losses.

10) Moisture affects leaves, brush, etc. about the same as with the trees themselves. It often favors weeds, as chapparal of southern California, which are helped by relative humidity more than are trees and can defy forest growth. Usually dry forests are clean forests, with no brush. Moisture helps fungi, decay and disease. Yet the sum total is that we have more good timber per acre in moist land than in dry country. There are more defects in wet land forest, but more timber.

11) Moisture and animal troubles. Generally insects and other enemies are less serious in wet than in dry forests. Dry situations give more insects, as there are fewer enemies of insects. In this respect, however, moisture is not as strong a factor as temperature and composition.

12) Moisture affects soil. Precipitation favors decomposition, fungi, bacteria, worms and soil activity. It helps mechanically in mixing particles of organic and inorganic materials. This beneficial

action, however, reaches a limit beyond which excessive precipitation leaches the soil, carries the salts to greater depths, washes soils on slopes and carries the best away. In cold districts heavy precipitation favors moss growth, duff and peat, and thus hinders or stops soil life. It tends to a bog or moor condition, or at least to low soggy soils.

c. Moisture conditions as affected by the forest.

1) An increase in precipitation due to the presence of forest is doubtful, except in very large areas, or in mountainous countries.

2) An increase of evaporation due to transpiration is greater in the forest than without, and is greater the better the forest cover is. A young forest transpires more than an old one and a dense forest more than an open one. Therefore the amount of evaporation and transpiration is in proportion to the amount or volume of wood formed each year. Then a stand of spruce at 40 years will transpire more than a stand at 100 years.

3) Evaporation from the soil itself is materially lessened by forest cover. This is important, but is not often considered. It results in a conservation of moisture.

4) The forest reduces air circulation. There is less carrying away of forest moisture and therefore the relative humidity is greater. This is also important.

5) Better percolation is obtained where the soil is mulched and soft. The soil is normally less frozen in the forest than outside, in the winter. This often hinders logging.

6) Melting of snow is less rapid in the forest and therefore the run-off is lessened. This effect is due to shade, lack of wind, mechanical obstacles like brush, etc.

7) Trees prevent part of the precipitation from ever reaching the ground. This is due to the leaves, branches and twigs, which take much of the rainfall for themselves. It is important with light rains, where there is not much water supplied the forest, and also with young growing stuff under trees. Seedlings may be hindered in getting moisture. Sometimes some of the tall stuff must be cut off. Dense conifers keep more water from the ground by holding it than do the hardwoods, and especially spruce is notable in this respect. Investigators should include snow as well as rain in their investigations, experiments and measuring.

4. Climatic Factor of Wind.

Generally the forester is interested in the prevailing winds as well as storms, preferably the former. Bulletin 86, United States Forest Service, is a good reference.

1) All the United States and Canada are in the region of westerly and northerly prevailing winds, many of them variable.

a. Along the ocean, winds are normally from and to the ocean. Northeast winds are strong, cold but moist, and prevail in our north-east country and Canada. East winds are quite strong but are rarely tornadoes, are generally moist, and are common along the North

Atlantic coast. Heavy south and southwest winds are frequently stormy, often with tornadoes, in the South from Maryland to Texas. This is the Great Region of storms in the United States. These are normally wet winds.

b. Southeast winds (summer monsoons) are common in Texas and from the Gulf of Mexico to Arizona and southern Colorado. These winds come in June with clouds and heavy precipitation. Southwest, west and northwest winds are usually dry, hot in summer, cold in winter, stormy, often with tornadoes, and occur in the Great Plains and the Great Lakes region. These winds vary in different years. In this same area are the "northers" ~~which~~ & which are heavy and cold winds preceded by sultry spells. They are common in Canada. They can be foretold, as the cattle make for shelter in sultry spells.

c. East and west winds, much modified by topography, occur in the Rocky Mountains. This modification takes place as the winds pass from the mountains to the plains, and vice versa. From the plains they are dry and hot in the summer; from the mountains they are cold (but not always). "Chinook" winds are great bodies of air moving down, causing pressure and ther fore a rise in temperature. They occur also in the Alps. They are not warmed by the Japan current, as some claim; that is fiction. Chinooks often last several days. "January thaws" may be similar in nature to these chinooks.

d. In the Rockies and on the Pacific coast we get east winds from the dry desert and west winds from the moist mountains. These winds are famous in southern California. The west winds are steady, strong, rarely stormy, cool, moist, producing high relative humidity, and induce precipitation when the land surface is not too hot.

2) Regions of severe storms.

These are found in the Gulf states, especially in summer. A cyclone is a large movement of air on a large scale and is dependent on barometric conditions. A hurricane is a straight-away blow. A velocity of over 50 miles an hour becomes dangerous.

The Great Plains is a remarkable area of winds and storms, extending from Colorado up into Canada. The winds are mostly strong straight-away blows.

The Northwest and Pacific coast are remarkable for their calms, which last for weeks at a time. This calms often hinder the traffic at Puget Sound.

3) In all mountains all winds are more or less local in direction, either up or down the mountain, or up or down the valleys. All mountains have storm points, which act as wind centers. This is noticeable in the Grand Canyon. Hurricanes can occur anywhere, especially near oceans or plains. Tornadoes are most common in the most stormy parts of the country, or the storm centers. Stormy winds are worse in higher altitudes; storminess increase to the south and decreases to the north.

4) Effects of wind on forest are:

The wind dries soil, plants and air.

a. This drying effect is most serious in dry regions, as in the Rocky Mountains and the Sierras, and even in the Great Lakes. On the Pacific coast the winds bring moisture and increases the relative

Atlantic coast. Heavy north the southeast winds are frequently storm, often with tornadoes, in the south from Maryland to Texas. This is th Great Region of storms in the United States. These are normally wet winds.

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4) Effects of wind on forest crop:

The wind dries soil, plants and air.

a. This drying effect is most marked in dry regions, in the Rocky Mountains and the Sierras, and even in the Great Lakes. the Pacific and Gulf winds bring moisture and increase the relativ humidity, making it possible to grow timber and fruit trees there without irrigation, which was otherwise impossible.

Bulletin 86 tells of the amount of drying which a wind can do. A high 20-foot white pine hedge in Nebraska reduced the evaporation to 40% of that in the open air, by actual measruement; this was true when the wind only blew 10 miles per hour, just ordinary winds. A forest could easily have reduced it to 1/3, or 33%. This helps more in hard winds than in light winds, and more in hot than in cold winds.

b. The drying effects of the winds (especially on transpiration) have driven the forest from the plains. Thus were red fir and spruce driven out from the lower Rockies; thus were hemlock, ash, beech and chestnut driven from the fringe forest.

5) Wind affects forest composition, chiefly by drying. ~~Srub~~ Scrub oak woods in Texas and Kansas are caused by this effect, with a low relative humidity. The drying winds reduce the composition of the fringe forest to the more thick-skinned species of marked intolerance.

6) Wind affects growth, reducing the rate of growth and the size of timber, producing scrubby timber.

7) Windy sites produce: crooked, gnarly, knotty, short and big-bodied stuff. Exceptionally strong winds produce more spiral growth than is found on quiet areas.

8) Wind reduces forest density with dry sites. This tends to intolerant trees.

9) Wind blows down, mutilates and destroys timber and hinders almost all of our important operations in the forest, especially thinning and natural reproduction.

10) Wind dries out wood and prevents germination of seedlings, and their development.

11) Wind affects weeds, grass, and brush less than it does tree growth, and often helps these enemies of the forest.

12) Wind drifts the snow. In bad cases it piles it up in gullies and leaves the ground bare to the detriment of tree growth. Then on thawing the snow melts from its piles and runs away without doing any good.

13) Wind mutilates tree crowns in the stand and opens the way to fungus diseases, and decay, especially on good sites. This statement applies more to forests in humid regions, as fungi in dry places are often affected themselves.

14) Wind is the chief difficulty in fire protection. Prairie fires have especially strong drafts. In the hills the wind goes up, until it reaches the ridge top.

5. Climatic Factor of Light. Read Bulletin 92.

1) Light is necessary for food. Light regulates fruiting, cleaning, density; behaviour of the stand, weeds and brush growth, etc. Different species have different food supplies, and this affect the composition. Tolerant trees replace the intolerant trees.

2) Diffused and direct light.

Plants will grow in diffused light on the north side of houses, etc.

Sensitive paper is often used to measure light. June has better light than January; a bright day has better light than a cloudy one. The intensity of light has been measured at different latitudes, at the equinoxes (with equal day and night), and at sea level for reference.

We are interested in latitudes 30° to 60°:
Note: Total light equals direct light plus diffused light.

Total light at lat. 30° : 500 units.
" " " " 60° : 250 ". Grows less to N, ½ as intense.

(Diffused light at lat. 30° : 200 units.
(" " " " 60° : 160 "

(Direct light " " 30° : ? units.
(" " " 60° : 330 " .

At lat. 49° diffused light equals direct sunlight.

North of lat. 49° the diffused light becomes more important than direct light. South of lat. 49° direct light is more important. As you go up a mountain direct light becomes more important. Trees of high altitudes are characterized by spindly dense crowns, thick clustered leaves, and thin and light colored bark.

3) In the forest light comes from the top and side. In dense spruce stands the light comes from the top. In general the reduction of direct light under the tree is considerable but not absolute. The leaves stay green as long as there is enough light for photosynthesis. Much light is diffused; much goes thru leaves and around them.

4) The minimum amount of light which enables green leaves to work varies with different plants. Most of our bushes quit when the light becomes less than 2% of full sunlight. The leaf must ~~marry~~ carry on, not merely <u>some</u>, but <u>enough</u> photosynthesis to <u>feed</u> itself. Trees differ probably because of differences in chloroplasts, tolerance, etc.

5) The ability to stand tolerance or shade is affected by temperature, moisture, soil, and the age of the tree. A young tree may be more tolerant than an old one.

6) Plenty of light and foliage means much fruiting and early, much food and growth, but tends to large crowns and heavy and short-bodies timber.

7) Attempts have been made for 50 years to measure light in the forest, and determine the amount of light necessary. Theodore Hartig was the first to attempt this, and he was followed by Wiesner, who more than anyone else has continued this method of investigation. Science is still behind practice in this respect.

The minimum amount of light plus 50% of this minimum constitutes the working light, at which the tree does normal work.

a. Tolerant trees require 1½% - 5% of full light: Taxus, Abies, Tsuga, ~~Hy~~Picea, Fagus, Aesculus, Carpinus, Tsudotsuga (3-5%). The trees from Taxus to Carpinus in this list require 1½-3%.

If the spruce minimum is 2% of the total light, then the working light is 2 plus $\frac{2}{2}$ = 3% of total light.

b. Intermediate species require 5-10% of the total light: white pine, redwood, white cedars, incense cedar, elm, basswood, magnolia, red oak.

c. Intolerant species require 10-15% of total light: oaks (live oaks?), chestnut, hickories, walnut, sycamore, birch, hard pines, junipers, white-barked pine, tulip poplar.

d. Very intolerant species require more than 15% of total light: (some to 30%, tamarack 1/3 of all light): larch, cypress, poplars, willows, ash (?), whitewood. It makes a difference whether the light is measured in the south or north, high or low, etc.

8) Members of the same genus generally differ but little in tolerance. This is true of the yew, balsam, spruce, hemlock, red fir, beech, blue beech, horse chestnut, tamaracks, poplars, willows, and ash. Some of these are disputed.

In some genera the species are known to differ considerably: the genus of pines (see above) has such variety; oaks have much difference, as do maples: the silver maple is intolerant, the sugar maple is tolerant.

9) Tolerance varies with latitude. Red oak seems less tolerant at lat. 50° N with 350 units of light than at lat. 30° with 500 units. It really has the same tolerance, but the one at lat. 30° can stand more light, more cover. The actual cover is inversely proportional to the amount of light. This may be demonstrated by using a slat frame admitting light. With tolerance statistics always mention latitude, altitude, humidity, exposure, age, site, etc. Remember this when reading such statistics.

10) Tolerance is increased by exposure. Tolerance is not the amount of shade that can be put over a tree. Chlorophyll changes with age, not range. Don't mix it with shade.

In regard to Bulletin 92 it may be remarked that red fir is not intolerant; this is a debatable subject, as are also white pine, hickory and oak; opinions differ.

6. Climatic Factor of Soil.

A) General and Historical Facts.

a. The soil is the greatest subfactor in the progress of Forestry. All others are insignificant compared with it. Most site classifications are based on soil, on the quality of the land.

b. References: Hilgard, King, and Lyon & Fippin are the best books on soils.

The minimum amount of light [illegible] of the minimum constitu[illegible] the working light, at which the tree does normal work.

a. Tolerant trees require 1% - 3% of full light: [illegible] pine, [illegible] hemlock, beech, Abies, Carpinus, Juniperus (3-5%). The trees from Taxus to Carpinus in this list require 1%-3%.
If the spruce minimum is 2% of the total light, then the working light is 2 plus 4 = 6% of total light.

b. Intermediate species require 5-10% of the total li[illegible] [illegible] pine, redwood, white cedar, incense-cedar, pine, basswood, ma[illegible] [illegible], red oak.

c. Intolerant species require 10-15% of total light: [illegible] oaks (live oaks), chestnut, hickory, walnut, sycamore, birch, [illegible] pines, junipers, white-bark pine, cottonwood.

d. Very intolerant species require more than 15% of t[illegible] light (some to 30%, however 1/3 of all light [illegible]), cypress, poplars, willows, ash (?), cottonwood. It makes a difference whether the light measured in the south or north, high or low, etc.

b) Members of the same genus generally differ but little in tolerance. This is true of the firs, spruces, hemlocks, and [illegible] beech, blue beech, hornbeam, tamaracks, poplars, willows, and some of these are dominant.
In some genera the species are known to differ considerably: genus of [illegible] (see above) has good variety, oaks have much difference as do maples: the silver maple is intolerant, the sugar maple is tol[illegible] ant.

c) Tolerance varies with latitude. Red oak [illegible] long tole[illegible] at lat. 50 with 300 units of light than at lat. 40 with 500 units. It really has the same tolerance, but the one at lat. 50 can stand more light, more water. The actual cover is inversely proportional to the amount of light. This may be demonstrated by using similar trees admitting light. With tolerance statistics always mention latitude, altitude, humidity, exposure, age, site, etc. Remember whenever reading such statistics.

d) Tolerance is increased by exposure. Tolerance is not the amount of shade that can be [illegible] over a tree. Chlorophyll [illegible] with age, not larger. Light [illegible] in [illegible].
In regard to tolerance [illegible] may be [illegible] remember that red fir is not intolerant; this is a debatable subject. [illegible] pine, hickory and oaks [illegible].

6. Climatic Factor of Soil.

A) General and Technical Facts.
a. The soil is the greatest net factor in the progress of [illegible] [illegible] all others are incidental. [illegible] it, most site classifications are based on soil, on the quality of the land.

b. [illegible], [illegible] and both [illegible] heat [illegible] on soils.

c. In most countries soils vary in wide limits even on as small areas as 40 acre lots. Several kinds of soil may be on adjacent lands. Soil quality and kind is reflected by the growth thereon, especially in forests and particularly in mountain country.

d. In large portions of the land surface of the northern hemisphere soils have been moved by glaciers, ice, wind and water, and therefore large portions of land are deficient in soils, bare rock being left by the glaciers, or at least shallow soil depths. This condition may be seen near Quebec. Other places, on the contrary, may have heavy deposits of glacier material over the regular soils.

Wind and water transport vast quantities of soil, particularly water which covers valley lands. Winds especially are important in arid and semi-arid lands and in coast regions. Wind can often cover the land with sand very rapidly, especially on railroad lines in fills and cuts in the southwest and elsewhere.

Much of what follows is a part of a Review of Soil from the Forester's standpoint.

In most of our land the soils are still in place and are called sedentary soils, being in place on the underlying rock. The quality of the soils depends on the kind of rock which produces them. (Rock, gneiss, schist).

Learn how to make soil maps and soil reports from the Bureau of Soils, Department of Agriculture. They have made soil maps for about 20 years.

B) Distribution of the Great Soil Areas in the United States and Canada.

a. Labrador, Quebec and the Maritime Provinces, part of New England and Ontario: this is a glaciated ~~land~~ area from which the soils have largely been removed, leaving bare rock, or thin soils on level and elevated ground, filling depressions with soils of various and variable characters from coarse sand to clay.

b. South along the sea coast from New Jersey to Texas: this is a vast area of sandy lands crossed by river bottoms and interrupted by swamps. The river bottoms have rich alluvial soil. The sands are mostly poor sands. This area includes the Southern pinery.

c. North of the Southern pine sands: a large area of soils in place, mostly loam, clay and limestone areas. This includes the Appalachians and the Central Hardwoods. Nearly all the river valleys are in bottom lands with deep alluvial soils.

d. North of the Central Hardwoods region of c.: a large area covered with glacial drift where ice and water have arranged the materials usually in deep layers. It is a large area, in which sandy and gravelly lands usually predominate; often the heaviest lands occupy, not the bottoms, but the ridges. It is quite a contrast to the Southern lands. All Jack pine lands are glaciated lands. Sands are usually poor in humid regions, as they leach readily. They may reach depths of 200 feet or more.

e. The Great Plains country: here are for the most part fine loam lands, accumulated by wind and water. Probably much of the effect due to winds was thru shifting, but water influenced the arrangement of soils. The grain is frequently flocculated, like grains of bread. The chief formation is loams and clays, with here and there sands. Here come the sand hills of Nebraska. Alkali lands occur in restricted portions of this area; carbonates are conspicuous, and the land is poor for agriculture.

f. Arid lands of the great west: these are very variable in character, from the coarsest sands of the northwest to the finest and heaviest clays (adobe clays) of the southwest. Uniformly, the soils are fertile; on restricted areas occur alkali soils, as in the Bad Lands.

g. Soils of the Mountains of the west: In the Sierras, Cascades, and Rockies the soils are extremely variable, ranging from newly disintegrated granite and rock material in sand, to the very best of clay and loam land.

h. Over the humid and arid far Northwest:(N. Cal. to British Columbia): there is here a large sheet of erupted rock. It is a basalt country, and a territory of deep soils and fertile lands, a good country. Disintegration of soils is the main feature.

On the east arid side the soils are relatively little disturbed. In the mountains and on the coast plains the soils have been greatly disturbed by water and ice. The soil has been much washed by rainfall.

C). Soil affects the Character of Forests.

a. The Southern pinery is entirely a soil forest both in regard to the pinery proper, and the bottom and swamp lands.

b. The mixture of scrub pine, shortleaf pine and hardwoods is caused, not by climate, but by soil. This occurs just north of the southern pinery, in the hardwoods region.

c. Limestone soils have given us juniper stands in Tennessee. They have also affected the forest growth of a large part of Kentucky.

d. Sand soils produce the pinery of the Great Lakes country; a mixture of clay and sand gives belts and islands of hardwoods forest. It is soil which determines by its character and moisture the tamarack and cedar swamps and even separates these two.

Soil modifies the pinery, changing it from a mixed forest of white to Norway pines to Jack pine; soil and soil moisture are the potent influences in the composition of hardwood forests.

e. Sands produce the cross-timbers of Texas in the midst of prairie (also in Oklahoma), and repeats the same thing in Wisconsin, Minnesota, and the North.

f. Soils have but little affected the forests of the Great West. In the Far West the climate is the chief factor, producing and differentiating forests. Soil may influence quality somewhat.

g. Viewing soil moisture independently of climate, we may say that lack of forest is due to soil moisture, but it is better to say

that this is due to climate rather than soil. Irrigation comes in here. Also, climate affects soil moisture and vice versa. That soil does have some effect is shown by the fact that cottonwood in Nevada has the same climate as on the pairie.

D) Relation of Various Soils to Tree Growth and Agriculture.

a. Good moist loam lands are good for raising all the species that will grow in a given climate. Timber has good growth and reproduction. With a good climate and favorable topography such lands are normally agricultural lands, and in nature they are stocked with hardwoods until an average yearly temperature below 50° F. is reached, when they change to conifers, in the north.

b. Heavy clays,are hard for the farmer to handle; they are strong and endure. Much organic fertilizer is required to keep them mellow. They are fair for forest. Hardwoods grow readily even on the hardest of clays, especially in Michigan and Ohio. But these lands usually become agricultural lands.

c. Lean clays, which are derivative of shales, occur in Maryland, Virginia and Carolina, and have a fair growth of hardwoods, but often tend to a scrub growth (scrub oak) and usually to a mixture of hardwoods and conifers. Many are nor really clay lands, but are soils in which the finer silts predominate and are really dificient in true clay.

d. Sands tend to pine. The coarser and leaner of these sands are usually stocked with scrub pines and other forms of hard pines. Only oak in the United States competes as a scrub on these sandy lands. They are poor agricultural lands unless the climate and markets make certain conditions possible, as intensive work for certain industries. They are largely forest lands. In arid districts the sands are not poor, but are often rich chemically, because of the lack of moisture to leach the salts out of the soil; irrigation transforms these sands to fertile soils.

e. Very dry soils may be either poor sands, as in humid country, or arid lands in dry country of deficient rainfall.

f. Swamps,or wet soils furnish a variety of conditions:
1) Good clay or silt soils, the best of agricultural lands, often stocked with normally big timber, largely hardwoods. Only in excessive cases do they tend to conifers, which then are cypress, cedar,etc

2) Muck soils, containing a moderate amount of inorganic constituents, and stocked with hardwoods. If organic material predominates to excess these soils tend to peat; the hardwoods recede and cedar, tamarack and spruce come in, in the United States. In the Old World scrub pine replaces tamarack, with birch.

E) History and Literature of Soils and Soil Study.

Soil Study is based on the following topics:
a. What soils are made of.
b. How they are made.
c. Soil characters and qualities: chemistry, physics, biology, fertility, arrangement and topography.
d. Soil cover. Forest cover.

c. Sands. There is great variation in sandy lands; narmally they are free from larger stones. Before giving analyses of some sandy soils it may be well to say a word as to the size of the particles (texture) of these various materials. Coarse grit is 1-3 mm. in diameter; ordinary sand is 0.1-1 mm or 100-1000 microns; silt is 0.01-0.1 mm or 10-100 microns; sand is 100-1000 microns. The best known classification is that of the United States Bureau of Soils, as follows:

Fine gravel	2.000-1.000 millimeters (mm.)
Coarse sand (a)	1.000-0.500 mm.
Medium sand (b)	0.500-0.250 mm.
Fine sand (c)	0.250-0.100 mm.
Very fine sand (d)	0.100-0.050 mm.
Silt	0.050-0.005 mm.
Clay	0.005-0.000 mm.

A classification given by Professor Roth is as follows:

Grit	1.0-3.00 mm.
Sand (a)	0.5-1.00 mm.
Sand (b)	0.3 mm.
Sand (c)	0.12-0.16 mm.
Silt (a)	0.07 mm.
Silt (b) (quartz)	0.01 mm.
Clay	----

This latter classification is the one referred to in the following samples of soils from the Southern pinery region:

Sample 1: grit 7%; sands: a) 17%, b)19%, c)10%; silt 35%; clay 8%. Finest sand 4%.

In making these sample analyses they used sieves for the fine particles, and water for clay. The particles are classified by the time they take to fall thru a certain distance in the water. Summing up this sample, we notice that the sands form 57%, silt 35%, and clay 8%.

Sample 2: grit 3%; sands: 7%, 3%, 4%, 5%; silt 69%; clay 8%.

Sample 3: grit 4%; sands: 0.8%, 6%, 8%, 4%; silt 69%; clay 4%.

Here we have had much sand and little clay. Finer sands vary much in wide limits even in the same neighborhood, silt or quartz varying from 30% to 70%.

In making the analyses the grit is sifted thru different sized meshes to separate it. Clay settles in water about 8 inches per day.

d. Loam soils. Loam is a combination of sand and clay.

Samples:	#1	#2	#3
Sand	15%	1%	6%
Silt (fine)	62%	62%	54%
Silt (coarser)	8%	16%	17%
Clay	10%	17%	19%

The clay here forms about 10-20% of the loam. Silt predominates.

e. Clay soils. The following is an average of several clays:

Clay proper forms	25-47%
Silt "	24-35%
Sand "	1- 5%
Oxides (humus)"	Scattering. FeO, etc.

So even in clay soil, the clay does not form the bulk of the soil.

f. Per cent of clay in various soils.

Generally we can say that clay forms, in:

Very sandy soil, about	1-3%
Ordinary sand	3-10%
Sandy loam	10-15%
Clay loam	15-25%
Clay soils	25-35%
Heavy clays	35-45%

There are very few soils in which clay goes over 50%. The ~~heavy~~ heavy clays of Michigan have less than 30% of clay. Heavy adobe clays of the southwest have 45% clay. The black waxy lands of Wyoming, Kansas and Texas are very heavy clays; they look loke organic matter and humus, but are really clay.

g. Humus content of various soils.

Humus is all the organic matter in the soil. Most soils contain some organic materials. In clay lands a larger amount of humus is required to produce any effect than in sand land. In clay land there may be 3-5% of its weight in humus; sands are good with half that amount or 1-3%. A clay soil can, however, take care of as much as 10-15% of
h. humus without being muck; 8% of humus makes sand a muck soil. Trees
ck suffer on over 15% of muck, therefore peat soils do not raise good trees
il. Peat fuel may contain 85% or less of organic material.

i. Dust soils.

Dust soils are very interesting to the forester. Such are the grayfish lands and putty soils of the South, and some of the glacial wash in the West. They are regular milky rivers, formed from the finest of silt. These soils are large amount of very uniform fine silt forming a sort of an impervious soil, due to the property it possesses of packing together into a very coherent mass on account of the fineness and uniformness of the particles. Cypress ponds of the south with cypress and black gum are due to the packing of the fine uniform silt preventing the running of water.

Silviculture 2 + began here.

The following of a putty soil is given from Hilgard (Roth):

Soil separates	Diam.	%
Sand	0.1-0.5	44 → characteristic
silt (a)	0.070	7
" (b)	0.050	8
" (c)	0.036	8.5
" (d)	0.025	6
" (e)	0.016	18 → odd thing in this soil
Clay	-----	7.5

These dust or putty soils behave very much like heavy clay, tho they contain much sand and little clay. They are very difficult to plow. They become impervious in spite of tillage, and act like putty. If tilled they become like extremely hard clods. They occur often in pine lands and are very rich in the finer silts.

Hardpan in California and other places underlies sandy loams. This hardpan gets impervious to water, and when dry is as hard as a rock. It is rich in the finest silts, and lacks clay. An analysis of a hardpan is given at the top of the next page.

Analysis of a hardpan: Cal.:

Sand	37%
Silt (a)	30
Silt (e)	14
Clay	8

Dust soils are much ground up and worked over by shifting winds and is worn very fine. It causes much trouble to irrigators in Washington thru its tendency to suddenly become impervious. Dust soils are peculiar and interesting soils. They contain a relatively large amount ~~which~~ of very fine silt which is all of a size, and layers very closely. Hilgard suggests that the small amount of clay which is present acts somewhat like the linseed oil in putty.

j. Iron rust sands and other Hardpans.

The true iron rust and other hardpans are of a different origin from the above hardpans. They occur on the northern German plains and in the Baltic region. There is usually a bed of coarse sand; underneath this at a depth of 2 to 3 feet is a layer of hard rusty material. Humic acid gets down and form hard layers by acting as a glueing cement which cements together the particles, making a hard compound. It occurs in cold countries and is best in damp climates; the upper soil bleaches to a lead sand, and all of it is thoroly worthless and useless. It is hard to reforest on, and is a great obstacle to the forester. To get rid of this hardpan tremendous steam plows are used in Europe, with a double engine on each side of the plow. It breaks up the hardpan, but if the action is not repeated the hardpan glues together again in a few years.

G) Composition of Soils

What is the soil made of? What are its consituents?

a. Composition of the earth's crust in general

The earth is estimated to be composed of : 7% air and water
93% solid.

The crust at a point six miles down is supposed to be about as follows:

50%	O.
27	Si
8	Al
5.5	Fe
4	Ca

It has also been estimated that the crust in this six miles is composed as follows:

60%	SiO_2
15	Al_2O_3
6	Fe oxides
4	MgO
5	CaO

b. Principal minerals in the soil:

1) Quartz: forms practically all of our sands, the larger part of our silts, and in the form of a fine flour (very fine silt) makes materials closely resembling clay. Quartz is very constant in soil, and is not affected by weathering: it is persistent and uniform. In the form of sand and silt it forms the principal body of soils and of sands, loams and clays.

2) Feldspar: there are two varieties of feldspar:

Orthoclase: potash, good for soil; monoclinic.

Plagioclase: soda (lime); triclinic.

Potash feldspars are the most common, but are none too resistant

to weathering. They decompose gradually. a pure potash (K) feldspar will weather in place and change to kaolin, which is more like chalk than clay.

Clay is a remarkable substance; there is nothing just like it. Kaolin when pulverized will, with the addition of water, form clay. Clay in fresh water does not settle easily. Clay in a fresh water river may strike the salt water of the ocean, and then it precipitates like the curdling of milk (flocculation). It joins together in flakes or crumbs. Two phases of flocculation may be expressed thus:

1) Clay seizes silt particles and incrusts them;
2) It joins two particles of clay together.

The above action of clay frequantly takes place in the Mississippi River in the south.

Here also are mud banks penetrated by steamer channels. They really are clay banks with variable amounts of silt from the river. If pressure be added they form shale; add water and heat and this produces a metamorphosis to hard bare rock back to feldspar (?). (Quartz,mica, silicates of (Al),feldspar,and back again,etc.)

3) Hornblende and pyroxenes: hornblende represents the amphiboles, augite represents the pyroxenes. They are silicates of Mg with also CaO, Fe, and Al.present.

There are two types of these minerals one being rich in Al, the other being poor in Al. The black color is due to Fe and therefore they weather readily with water and air, as the iron oxidizes. Thus the soil recruits itself with minerals from the decomposition of rocks.

These minerals give color to soils. They are generally associated with quartz and feldspars.

4) Micas: micas occur in granites, especially gneisses and schists, in which latter they are the most abundant. Mica and quartz form most of the schists. Micas do very little for our soils; they occur in connection with quartz, and therefore a poor soil may be due to a ~~poor~~ coarse quartzite.

5) Zeolites: are silicates containing water (hydrous silicates), and are secondary forms. They may be spoken of as the original rocks in process of decompositions. They occur everywhere with decomposing feldspars. Zeolites are very important because they prevent leaching of salts in the soil; they readily remove bases with the substitution of other bases, and since they are rather easily soluble in strong mineral acids, the bases so combined are more readily available to plants than in most combinations found in the soil, and yet are not readily leached out of it.

6) Calcite ($CaCO_3$): often limestones come from the shells of animals, as snails and mussels. Diatoms build walls of silica which are ordinality indissoluble. Nature works under tremendously long periods of time.

Water containing carbon dioxide (CO_2) will dissolve shells and thus limestones often do not show shells. Shells in river and ocean mud are not pure but are mixed with silt, sand and clay; they are good for soils.

7) Dolomite ($Mg(Ca)CO_3$): may contain as high as 45% of Mg.

Dolomite soils are in bad repute, in both the United States and Europe. They are barren soils. MgO becomes poisonous to plants unless CaO is present.

8) Gypsum:($CaSO_4$): does not occur extensively. In gypsum lands it takes the form of a sand. Gypsum is a good fertilizer for bad alkali lands; it acts as a corrector of the alkalies.

9) Iron oxides and hydrates: these substances are freed from rocks by decomposition. They give color to soils, and form an important part of the soil by becoming colloid materials with large water capacities. But too much of these substances is not good; some salts of Fe are injurious.

c. Various rocks contributing to soil and the Value of their product.

Rocks: are of three classes: eruptive, sedimentary, and metamorphic. Van Hise considers that sedimentary and metamorphic rocks are not different from each other except in degree.

a) Sedimentary rocks:

(1) Limestones are frequent and of many varities. They may contain as much as 50% of foreign materials. They occur everywhere, all over the earth. Marble is considered as metamorphic rock. Limestones are found in all stages of development, and in general it may be said that they make good soils. There are some exceptions; limestone bluffs are not good soils: the drainage is poor, the soils are washed. Water runs off easily, and carves out underground runways and caves, with very rapid circulation. Limestone regions are apt to be poor in well and cistern supply.

In decomposition soil loses a large part of its lime and becomes silt and clay. In non-glaciated country we may have:

	Indissoluble material	Lime
Soil	78%	1.4%
Sub-soil	71%	1.4%
Limestone	11%	80.0%

Limestone soils are apt to sometimes be too good for forest purposes. In order to make 100# of limestone soil it was necessary to dissolve upwards of 700# of original rock. Leaching must occur simultaneously with soil formation. Lime leaches out of limestone when it disintegrates; this is an important process.

(2) Sandstones:, conglomerates, etc., to quartzite: these are composed of sands and gravels which originated from the eruptive rocks, were decomposed from these rocks, washed over and cemented into new rocks. The cements varied vrom iron or pure silica to clay, and often varied with the coarseness of the sand. Soluble materials leach out into the soils, which is a good process for the soils. Sandstones vary in hardness to false quartzite. Calc limestone makes a good soil.

(3) Shales, clays, slates: are hard, with a metamorphic tendency. They are of the same composition as granites, with 50-75% SiO_2. Their decomposition leads to a variety of soils. They vary in resistance to decomposition, as some are very soft; they usually make stony lands, and are very variable in quality from good fertile soils to poor and extremely lean soils. Ordinary slate lands are good enough for hard-

woods, and affect drainage and water circulation. The Appalachian slates when slanting let lands slip, and thus give rise to slips.

b) Metamorphic rocks.

Metamorphic rocks undergo changes from their original structure of igneous or sedimentary rocks thru the agencies of heat, pressure, and water. Practically all of the material in metamorphosis becomes crystalline. Here we find quartzite; granites weather slowly and deeply, producing a deep and good soil. Orthoclase yields potash, as also does syenite. They may tend to heavy clay lands.

Diorites and diabases give more potash than the last named rocks, the diabase being the better of the two, tho not very extensive; they are good for soils. Mica schists and gneisses are modifications of granite with much mica layered. They consist of mica and quartz, with little feldspar; they produce lean and coarse soils.

c) Eruptive rocks.

Eruptive rocks may be either acid or basic. Silica is found here. They usually produce good soils, tho sometimes stony in character. They may be considered as occurring in three forms:

1) Massive forms: basalt is common here, particularly in columnar form.

2) Broken lava, sometimes in cracked layers, in Northern California.

3) Spongy form or pumice stone. Large areas in the northwest, as in the Cascades, are covered with pumice sands.

H) Methods of Soil Formation, or, How Soils are Made.

There are three general phases in the formation of soils:

Physical changes: weathering, disintegration.

Chemical changes: decomposition, recomposition.

Transportation.

Physically

a. Rock breaks up due either to change of temperature or to freezing of water in crevices. Chemical action by water dissolves it and transfers it. (With plenty of time and plenty of water almost anything will dissolve, even the most indissoluble of substances, to some extent). Leaching of materials is important.

Rock weathers faster in a hot and desert country,; also by freezing; by being broken mechanically; and by being ground by glaciers, water and winds. Much rock is worn and dissolved by water, especially such as contains acids (CO_2). Part of the rock is carried in solution; this is very important in connection with the formation of fresh soil.

Plants assist the physical work; they protect and hold the rock surface, and their roots hold the soil.

b. Chemical action is one of decomposition and recomposition. This process is aided by temperature in some parts of the country, and by humidity. Egyptian monuments which lasted for thousands of years in the dry climate of Egypt were brought to America, and they undoubtedly will not last in our humid climate; they have already shown signs of giving way. Water and carbon dioxide are again the main agents in chemical decomposition of rocks, together with other acids, soluble salts and alkalies. Plants aid physically, but also add chemical substances

or secretions which are able to dissolve other substances. Fungi dissolve rock and wood alike. There is a continual process of chemical disorganization and of recomposition to other forms, and to new forms.

These processes are now going on as in the past and they will go on indefinitely. Leaching is a good example.

c. Soil transportation. Many soils are not in place, especially in glaciated regions; a great part of the surface of the earth is overlaid with alluvial or water soils; wind-carried soils and loess cover over 1/6 of the land area, which really is an immense area.

All rivers and other run-offs carry away materials and soils bodily, and deposit them as sorted materials, classified to coarse, fine and heavy soils, and characterized by deposition of like soils. Ground water constantly carry away a part of the soil; the amounts are usually small individually, but the aggregate is large. Leaching plays an important part here. This action is faster in a wet country than in a dry one. Both surface and underground run-offs or transportations are influenced by the character of the soils thru which they pass, and by absorption and solution.

d. Humus formation. The formation of humus is due to the actions of living organisms, especially bacteria which decompose organic material. The chief product of this action is CO_2. H_2CO_3 or carbonic acid is used as the measure of decomposition. This process is influenced by the influences of bacteria life. Any injury to bacteria injures humus formation, which depends on:

temperature
moisture
freedom from poisonous materials (iron salts)
mineral matter.

Humus formation takes place ten times as fast at 80° summer than at 50°. Dry soil stops the formation of humus. 45% of water content gave an action which 17 times as fast as was obtained from 7% with humus (compos). Oxidation is an important factor in forming humus. If humus be left in a pile for a sufficient length of time it will change to peat, then to lignite, and to anthracite.

Nutritive salts necessary: bacteria need K, NaO, etc., for growth Plenty of lime allows an easier formation of humus. Oxygen gives aeration, which is very favorable to the process.

A distinction should be made between decomposition and fermentation: the former often includes the latter: fermentation produces a change to:

1) marsh gas
2) to ?
3) to hydrogen.

The change of leaves to humus is interesting. The steps of this process are substantially as follows:

1) Leaching out of salts.
2) Leaves are more or less broken, by animals, etc.
3) Decomposition by filamentous fungi.
4) Further decomposition to humus by bacteria.

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In 1000# of white oak leaves there are: 90# mineral salts
including 23# NaO
5# K

During the first about 3.5 to 4 pounds are dissolved.

The following table shows the contents in C,H,O,and N of cellulose, oaks, peat, brown coal and anthracite:

100#: TABLE

Name	Cellulose	oaks fresh	oaks rotten	peat ground	peat 6' below surface	brown coal	anthracite
C	44#	50#	56#	58#	64#	69#	95#
H	6	6	5	5	5	6	2.5
O	49	43	39	36	27	24	2.5)
C	--	--	--	0.8	4.1	0.6	)

Oak gains C and loses O.
Peat gains C, loses O, gains N; valuable for humus.

Humic acids.

A peat bog is sour below the surface, because of humic acids, of which there are several: ulmic, humic,crenic and apocrenic acids. Ulmin compounds are injurious to the soil; humin compounds are beneficial. With much water the bacteria produce ulmin substances which soon attain a concentration that kills the bacteria and then is purely chemical in nature. It is brownish (seen in swamps, etc.). The solution gives a litmus reaction indicating acidity, therefore the soils are called sour soils. The acidity is due to: ulmic acid, and to apocrenic acid, reacting easily with alkalies to form alkalic compounds. Ulmin is itself indissoluble, but is soluble with an acid. These soils produce sour soil vegetation. In reclamation lime is used. All soils tend to sourness under cultivation, especially when very wet. Calcareous soils resist this action longer and are longer lived and more fertile than non-calcareous soils. Humic acids are poisonous to plants; strong, & attack minerals.

Properties and nature of Humus: humus is distinctly a colloid; it swells and <u>shrinks</u> with water. Peat shrinks very much; if it is thoroly dried you cannot swell it again. Humus increases with the number of roots growing in it. It is porous, plastic, adhesive, colloidal; its volume increases several times upon absorption of water; it is very absorptive of gases and moisture; its dark color absorbs heat and it warms readily. Its density is 1.4. It is composed of C,N,and O, and has a complex formula. It may be produced:

1) Artificially by caustic alkali on sugar or cellulose;
2) Change in fibre by bacteria and fungi producing ulmin and humin;
3) Oxidation of ulmin and humin acids to crenic and apocrenic acids;
4) Ulmin and humic acids form indissoluble salts with Ca
Crenic and apocrenic" " soluble " "

Therefore the absence of Ca and Mg from clays by leaching, gives fire-clays.

Humus is important in regard to nitrogen. The amount of N varies according to the locality. Stable manure humus gives 4-8% N, wood gives

2%, straw gives 2-4%. ~~Mass~~ Much loss of humus takes place under tilling. The continual raising of one cereal depletes the soil of N. When, in one case, wheat was raised continually for 8 years, there was a total loss of 1700# of N per acre for soluble nitrates (Schneider). Only 350# of it was utilized for the product. The humus loss was 1 ton per acre per year. With rotation an equlibrium obtains with N.

Humus decreases downwards. Drier soils are apt to contain more N.

All humus with moisture and oxygen is unstable and is worked over by bacteria. Some Polypera work the material over to humus and then quit, leaving it to other fungi to finish. First come filamentous fungi; then bacteria; then humus destroyers bacteria which completely destroy the humus as such and transform it back to its chemical constituents, and finally there is no humus left. Or if the humus is not destroyed it becomes sour; this sour humus and peat are injurious to plants:

1) They prevent plants from getting water. They produce a physically dry and arid soil.

2) They are deficient in nutritive salts.

3) They hold nutritive salts with a tremendous tenacity, so that plants are unable to get them.

Effects of Humus on Soil:

1) Beneficial:

a) Moisture. As a colloid it takes and holds moisture readily

b) Furnishes material for soil activity, for bacteria.

c) Colloid helps to loosedn soil, and thus increases aeration

d) Colloid helps to hold plant foods.

2), Injurious:

a) Muck heats up, dries to a powder; sour acids injure plants Humic acid develops to a cement and forms a hardpan.

I) Physics of the Soil.

a. Composition and structure. Discussion was ~~omitted~~.omitted.

b. Nature of sand and silt. Sand and silt are made up of small individual particles, which do not form a lump structure, and therefore will "pack" readily. There are two characteristics of packing:

1) Individual grain gives a small surface and therefore less water holding power.and surface tension; sand has less surface than clay and so clay holds water better than sand.

2) Bad aeration.

With sand and silts there are certain characteristics:

1) More leaching
2) Less plant food
3) Less humus
4) Less water
5) Less organic life.

c. Clay and its part in physical composition; colloidal character of clay.

Clays act as a cement and past, enwrapping particles of sand and holding them together. These particles cling and form lumps, giving good tilth and a mellow soil.

Clay is characterized by small particles, good capacity for holding water, good mineral salts; it contains more plant foods, more humus, more organic substances and plant and animal life; it has better

aeration, which helps smaller forms of life.

A large amount of extremely fine silts in the clay soil gives the putty soil, which differs from the pure clay both in composition and in action with respect to site and plants growing on it. The particles are about 25 microns in diameter.

Clay is very plastic, this being a characteristic property, since clay is a hydrous aluminum silcate. This plasticity is restricted to particles of very small size; a plastic clay will not hold 8 inches of water in 24 hours. The addition of salt ($NaCl$) will flocculate clay. Sodium carbonate (Na_2CO_3) will prevent flocculation of clay.

Further information in regard to clay and its properties may be found in references on Soils as mentioned above, and also in Bulletin 388, U.S.Geological Survey, entitled: The Colloid Matter of Clay and its Measurement.

d. Weight of Soils.

The average specific gravity of rocks is about 2.5. Heavy rocks contain iron. Soils have half the volume weight of the soil rocks. In other words, they are half rock and half atmosphere.

The weight of soil is the result of two factors: the absolute specific gravity, and the volume of pore space in the mass. An average specific gravity of soil material is often accepted as 2.65. The weight of a given volume of soil may be determined from the pore space and specific gravity of the materials, by use of the following formulae:

.1) $Ws = Ww \times (2.65 \times (100 - P)$.

Where Ws = Weight of given volume of soil
Ww = Weight of volume of water equal to volume of soil
P = Per cent of pore space
(100 - P) = Per cent of volume occupied by soil

2) Or the following formula may be used, and is often more convenient:

$Ws = Ap.Sp. \times Ww$.

Where Ws = Weight of soil
Ap.Sp. = Apparent specific gravity
Ww = Weight of volume of water equal to that occupied by the soil.

Following is a table of weights of a few soils:

Soil	Vol.Wt. or apparent Sp. Gr.	Wt.per cu.ft.	Wt.per acre-ft.
1. Clean sand	1.76	110.0#	4,800,000 #
2. Coarse sand	1.60	100.0	4,356,000
3. Medium sand	1.54	96.0	4,200,000
4. Fine sand	1.48	93.0	4,080,000
5. Sandy loam	1.30	81.0	3,550,000
6. Fine sandy loam	1.32	82.5	3,590,000
7. Silt loam	1.24	77.5	3,400,000
8. Clay loam	1.22	76.0	3,330,000
9. Clay	1.17	72.6	3,180,000
10. "Gumbo" clay	1.10	68.5	3,000,000

--Lyon and Fippin.

This table shows that the finer the soil the lighter its absolute weight. Clay soils may range from 60 to 90 pounds in weight, according to their fineness and state of granulation. Sand soils weigh from 90 to 110 pounds. In practice, soils are spoken of as "light" and "heavy", but this use of these terms does not apply to the weight of the soil. The term light is applied to sandy soil because the particles move freely; on the other hand, a clay is termed heavy because of its cohesiveness, and difficulty in working by the farmer.

A dry sand may weigh 89#; a dry clay may weigh 75#.

e. Pore space and arrangement of particles in various soils.

Pore space is space not occupied by soil particles. In a mass of particles there is some unoccupied or pore space. It the particles are fine, then the intervening spaces are correspondingly small; if large, the spaces are large. Theoretically, pore space is independent of the size of the particles, with any given arrangement. There would be as much pore space in a cubic foot of buckshot as in one of marbles. But in the soil this is not true. For, the finer the particles, the larger the proportion of pore space is found to be.

A clay has much more total pore space than a sand, altho the individual spaces or openings between the particles are much smaller in the clay. The approximate % of pore space in a soil may be calculated by use of the following formula:

$$P = \frac{Vs - \frac{Vw}{2.65}}{Vs} \times 100 = \frac{Vp}{Vs} \times 100$$

Where P = Per cent of pore space
Vs = Volume in c.c. occupied by the soil
Vw = Weight of water equal to weight of soil in grams
Vp = Volume in c.c. of pore space in soil
2.65 = Specific gravity of soil particles.

Another and more simple formula which may be used in the calculation of the pore space is as follows:

$$P = 100 - \frac{\text{Ap. sp. gr.}}{\text{Ab. sp. gr.}} \times 100$$

Where P = Per cent of pore space
Ap. sp. = Apparent specific gravity or volume weight
Ab. sp. = Absolute specific gravity of soil material
100% = Total space occupied by soil mass.

The different amounts of pore space in soils change ~~s~~ the character of the soil materially. Hilgard gives the following figures which may be used as convenient standard figures, for % of pore space in various soils:

Packed sand soil has less than	50%	pore space.
Ordinary " " " "	60%	" "
Clay soil " " "	47- 50%	" "
Forest soil has	50- 65%	" "
Farm soil has	35- 50%	" "

Lyon and Fippin give the following relations between texture and pore space for soils in field condition:

	% by volume
1. Clean sand	33.50%
2. Coarse sand	40.00
3. Medium sand	41.80
4. Fine sand	44.10
5. Sandy loam	51.00
6. Fine sandy loam	50.00
7. Silt loam	53.00
8. Clay loam	54.00
9. Clay	56.00
10. "Gumbo" clay	58.46
11. Heavy clay	47.19
12. Very heavy clay	65.12

The reason for the greater porosity of the finer soils appears to be, that the smallest particles are so light that they do not settle so closely together in proportion to their ~~sis~~ size as do the sand particles, because of the greater friction between their surfaces. When this is overcome by mixing in water, such material becomes dense. Treatment greatly affects the structure and therefore the porosity of the soil.

The diameter of the individual pore spaces is of importance, as well as the total volume of pore space, since these determine the capacity of the soil to retain and move water and to permit the circulation of gases in the soil mass, as well as to facilitate the extension of the plant roots.

The best arrangement of the soil is that of "crumbs". There are several possible arrangements of the soil particles, belonging to the following general forms.:

1) In columnar order, with each particle touching its neighbors at only four points. The unoccupied or pore space is 47.64% of the total volume occupied by the spheres.

2) In oblique order, with each particle touching its neighbors at six points. The pore space is 25.95% of the total volume.

3) These spheres may be gathered into larger spheres which rest together in the second order. The pore space is greatly increased, being 74.05%.

4) On the other hand, if there are spheres of several sizes so that the small ones may rest in the spaces between the large ones, the total pore space will be reduced below 25.95%, and the spaces may continue to be filled in by smaller spheres until the mass is practically solid, without pores.

It is of course recognized that under field conditions these ideal arrangements do not pertain, but these figures illustrate the

underlying factors which determine differences in pore space, and, also differences in other physical properties. Soil particles are irregular in shape and uneven in size. When brought very close together, as occurs in mixing in a wet consition, their molecular attraction is brought into operation and, especially when dry, they are held together very securely. In this way the normal molecular attraction of the soil particles is increased by the deposition around them of the material in solution.

Applying these principles to the soil, it is observed that there may be two general arrangements of the particles.

1) Each particle may be free and separate from its neighbors. This is a separate-grain structure. That is, each particle of soil functions separately. When by proper manipulation the particles are so packed together that the small particles quite completely fill in the spaces between the large ones, so that a very dense mass is formed, the structure is termed "puddled". The term puddled, in this connection, is related to the fact that such an arrangement san be obtained only in fine-textured soils when they are mixed (puddled) in a very wet condition, so that the fine particles will move into the large spaces.

2) On the other hand, the small particles may adhere to the large ones, or a number of small particles may adhere together as a group or granule. When a number of united particles function together as a single larger particle or granule, the structure is termed "granular". This arrangement is also termed the crumb structure. According as these groups are prominent or inconspicuous, the soil is said to be well or poorly granulated.

But when the granules reach large size, so that they interfere with the best functioning of the soil, they are termed clods. That is, a clod is an unsizable granule.

It is well known that a box of baseballs, or a pile of boulders, or even a box of sand, does not adhere together to any appreciable extent. That is, in all the coarse-textured classes, dertainly down to the size of very fine sand, there is very little tendency to granulate. But in the silt, to a small extent, and in the clay, to a very great extent, granulation is strong.

This crumb arrangement, then, is the most desirable; the particles are glued together by clay and other agents into lumps or crumbs. This lumps may take very irregular shapes. This structure is desirable for <u>all</u> soils. All of our arid soils are rich in lime, much of this being glueing by lime carbonate. The crumb structure may be changed by interference with the character of the clay. It is advisable <u>not</u> to plow wet soil: the clay puddles and forms baked lumps. Inundation also produces baked clay.

In Nature the roots give the soil good tillage; the roots continue this tillage, and protection of the soil by mulch is maintained. The most important function of mulch in the forest is to protect the soil. I It prevents packing by water, etc.

A certain amount of moisture and cold is often desirable, for tillage. Freezing helps the crumb condition and destroys the puddled condition of clay. The soil expands in frost, and cracks in dry weather. Clay will not crack when there is less than a minimum of 15% clay in the soil; in good land; the minimum is less on poor land.

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f. Color of soil. Cause, effect.

Pure quartz, limestones, and similar soils are almost colorless; white sands are good examples. A great variety of colors are, however, exhibited by most soils. These colors are not usually the result of the color of the individual particles which make up the bulk of the material, but is rather the result of material which <u>adheres</u> to the particles.

Color in soil is due to two main causes: iron compounds, and organic matter. Iron compounds produce red, yellow, blue and gray colors; organic matter, as humus, produces a dark color, often some shade of black or brown. When these are combined, various intermediate tints are obtained. For example, when a red soil is rich in decayed organic matter--humus--it becomes of a rich brown color.

About 5% of organic matter will change a gray clay to a black "waxy" land; a small amount will give a strong color. Brown soils are common over the humid portion of the United States. Red soils are found in the South from New England to Texas, and also in arid countries and in the tropics. Gray soils are found in sandy lands, especially in the far Northwest, in regions of great rain.

The color of soils, especially as regards iron compounds, is not fully understood, but it is safe to say that much color is the result of different forms of iron in the soil. In the boulder clay of the glaciated sections a bluish color is common, which seems to be due to the presence of protoxid of iron (FeO), resulting from the great deficiency of oxygen. Where this comes in contact with carbonated water, it may be changed to the carbonate of iron, which is gray, and consequently along the ~~roots~~ line of roots and in the bottom of ponds this gray color may be found.

Where there is an abundant supply of oxygen, the iron takes on the sesquioxid (Fe_2O_3) form, which has a deep red color, typified by iron rust. Where the red soil stands much in contact with water, it may become yellow by the hydration of the iron (Fe_2O_3 plus H_2O). In many regions a dark-colored soil is looked upon as a fertile soil. This relation has developed because of the association of a dark color with the presence of organic matter, with ~~its~~ all its beneficial effects, while the light color indicates its absence. This relation does not hold universally, but it is quite a reliable guide.

The only instances where the color of the particles themselves give color to the soil is in some of the clean quartz sands mentioned above, where the white color of the dominant mineral gives color to the mass. In some dark shaley sands this same principle obtains.

Soils may be classified by their color; color of soils is connected with their temperature and physical condition; these two points are useful in the field. To the experienced person, the color of the soil is a valuable guide to its condition and productiveness. Mottled and uneven color, for instance, indicates poor aeration, frequently the result of deficient drainage.

g. Area of surface of soil particles.

The surface area of soil particles bears an important relation to the capillary action of that soil; the greater the area of the surface of the particles, the more moisture is held on their surfaces. A large surface also increases the rate of chemical solution, by which the food constitutes contained in the mineral particles become available for the plant's use. Another important property of an immense surface area of soils is to retain food materials in a semi-available form,. In capillary water the water is practically held between two plates, and the larger these plates the more water will be held. Consequently the more surface per pound of dirt holds more water; dry soils absorb water.

There are here two classes of soils:
1) Crystalloids: sand.
2) Colloids: clay, iron hydrates, zeolites, humus.

The crystalloid has only the outside surface; the colloid has particles composed of smaller particles (like wood) and a lot of inside surfaces all accessible to water. Those inside surfaces of immeasurable surfaces (particles?) are greater than the outside surfaces of measurable particles.

Surface may be measured by its hydroscopicity.
Given 1 gm. soil: area of particles in metres is:

moderate fine sand	1.3	square metres
loamy sand	56.	" "
sandy loam	85.	" "
mild clay	120.	" "
heavy clay	265.	" "
extreme: heavy potter's clay, Fe hydrate	900	" "

A few standard figures (or stock figures) may be given:

soil	surface	
1# sand	400 square yards	
1# loam	20,000 " "	, more than 4 acres.
1# heavy clay		" " 20 acres.
1# wood		

The surface area of a fine-textured soil is greater than the firt thought might indicate. This immense area exposed by soils is shown by the following table, which gives: (1) The area in square feet of one gram of the soil; (2) The surface area per pound of the same soils; (3) The approximate weight per cubic foot of the material in the field; (4) The approximate area of surface in one cubic foot of these soils as they occur in the field.

	I Area per gm. Sq. ft.	II Area per lb. Sq.ft.	III Approx.wt per cu.ft	IV Surf.area per cu.ft. Sq.ft.
1. Coarse sand	0.8900	405.0	100	40,500
2. Medium sand	1.0440	473.0	96	44,500
3. Sandy loam	1.8000	816.0	83	66,600
4. Fine s'dy loam	1.6600	756.0	82	62,000
5. Silt loam	2.9600	1,340.0	77	104,000
6. Clay loam	4.0250	1,825.0	75	136,500
7. Clay	4.4130	2,000.0	71	142,000
8. Sand hill	0.0708	32.2	110	3,540
9. Hobart clay	7.2820	3,316.0	60	200,000

From this table it appears that one pound of the average agricultural soil may have from about 400 ~~hun~~ square feet, in the case of coarse sand, to 2000 square feet internal surface area, in the case of the average clay. A more reasonable basis of comparison, because of differences in volume weight, is that of one cubic foot of the material, as shown by the fourth column, from which it appears that these soils have from one to three acres of surface area. These are strikin differences, particularly those between soils 8 and 9, which represent extremes in light and heavy soils, respectively. Number 8 is the sand-hill soil of the Carolinas, and is of exceedingly low agricultural value. Number 9, Hobart clay, occurs in eastern North Dakota, and is derived from shale rock. The range in surface area per cubic foot of these soils is from 1/12 acre, for the sand, to almost 5 acres for the clay. The latter contains 76% of clay in the subsoil, the former 2%.

The surface area of the particles in a given weight of soil may be calculated from the formula:

$$S = \pi D^2 N.$$

where S = Surface are in square centimeters
D = Mean diameter in centimeters
N = Number of particles in the class or separate.
pi = 3.1416 (Particles supposed spherical).

h. Relation of water to soil.

Water as a substance is very remarkable. It is used as a unit of weight, of heat, and being a poor conductor of heat is much used chemically. Other chharacteristics will readily occur to the reader, as resistance to compression, thirst quenching, fire-extinguishing, etc.

There are three forms in which water may exist in soils:

1) Gravitational or free water, which free to move thru the soil under the influence of gravity.

2) Capillary or film water, which is held against gravity by the surface tension of the films of water surrounding the soil particles

3) Hygroscopic moisture, taken from the air; it condenses from the tamosphere on the surface of the soil particles, when the soil is allowed to become air-dry.

The hygroscopic power of taking water from the air is proportional to the surface.

Sandy loam	takes	2½%	of its weight	from	the	air
Clay	"	8 %	"	"	"	"
Fe hydrate soil	"	18 %	"	"	"	"

From Hilgard we learn that hygroscopic water is of great importance in regard to plants and trees. Sach, in an experiment, showed that he could raise plants in dry soil, by the aid of water from humid air. In California people do the same thing with oranges, spruce, etc., on land that was formerly desert land, with no irrigation. They did this by utilizing hygroscopic water, which is not only important, but is often fully sufficient for the purpose.

Hygroscopic water may be said to be related to temperature of the soil, as it prevents over-heating of the soil. The amount of moisture in the soil may be misleading, for a sand with only 8% water may produce better crops than a heavy clay with 15% water. This is because the sand

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The hygroscopic capacity of a soil depends on the texture of the particles and the content of organic matter. Since hygroscopic moisture is a function of the surface exposed, it results that the larger the surface area exposed by the soil particles, the greater the hygroscopic capacity of the soil. Reference to the table on page 110 shows fine-textured soils or clay soils to have the greatest surface area, and these hold the most hygroscopic moisture. Sand soils, with a relatively small surface area, hold a small amount of this form of water. This fact is illustrated by the following table:

	% hygrosc. water at 21° C.
Very fine sand	1.8%
Silt	7.3
Clay	16.5
Muck	48.0

The above soils were pure separates derived by mechanical analysis. These figures serve to show the direct relation between:

1) The surface area exhibited by the soil particles and the hygroscopic moisture retained.
2) Hygroscopic moisture and temperature
3) Hygroscopic moisture and humidity of the atmosphere.

The hygroscopic moisture decreases with increase in temperature. It varies directly as the relative humidity of the atmosphere with which the soil is in contact. Consequently, in the air-dried condition, while a soil always retains some moisture, it seldom exhibits its maximum hygroscopic capacity. Under average conditions of humidity, a light sand may retain from 0.5 to 1%, a silt loam 2-4% and a clay 8-12%. This is of course unavailable for plants.

Capillary water is used for plant food. It is the film or capillary moisture which supports plants. The roots of ordinary crops are adapted to take the moisture needed by threading their way between the soil particles, where they may come in intimate contact with these moisture films and absorb the needed supply of water, with being excluded from the air supply which promotes their growth. For, in the capillarily moist soil, the water is retained chiefly in the very small spaces, and the large spaces occupied by air.

A maximum amount of capillary completely fills the pore spaces. The pore space may range from 35% in a clean sand to 60-70% in a well granulated clay, and 80-90% in a muck soil. The following table gives sample figures:

	I Wt. per cu. ft. #	II % pore space	III # water per cu. ft.	% water in soil IV. at saturation
Dune sand	80#	52%	32.5#	40.5%
Coarse sand	81	51	32.0	39.5
Fine sandy loam	83	50	31.5	38.0
Light silt loam	83	50	31.5	38.0
Clay	68	59	37.0	54.5
Humus	15	80	50.0	333.0

50% of pore space per cubic foot gives 30# of water. The optimum content lies between 40% and 60% of filling up, equivalent to about 25% of the volume or 15# water. Ordinary soil has 10-15# water per cubic foot.

1 cu.ft solid dirt	150# water
1 " " water	60# (or 62.5#, more precisely)
1 cu.ft.dirt (porous)	75# water.

In stating the moisture content of soils five different methods have been used. These are:

1) in terms of % based on the dry weight of the soil.
2) In terms of % based on the wet weight of the soil.
3) In terms of the % of volume based on the total volume occupied by the soil.
4) In cubic inches per cubic foot, or cubic centimeters per liter or per cubic meter.
5) In inches in depth of water over the surface of soil.

For a discussion of these methods see Lyon & Fippin, pages 138-140.

Plants are readily killed by inundation, or too much water, especially most farm plants. It is a matter of general experience that for for most farm crops the saturated condition of the soil is unfavorable to the best development. There are, of course, many plants which are adapted to such conditions, as for example the swamp type of vegetation. About the only cultivated crops of this sort are rice and cranberries; grass, ash, water oak, gums, cypress and the sycamore can also stand water. Other plants and trees will be killed in one season if flooded, as by the building of a dam, as happened at Ann Arbor a couple of decades ago, on the Huron River.

Practically all of the common cultivated crops, from vegetables to fruit trees, are adapted to growing in soil from which the gravitational moisture has been removed. The gravitational water is directly injurious to the growth of these plants, and its practical removal from the soil constitutes the practice of agricultural drainage, which may be considered as a phase of soil management. It may therefore be stated that gravitational water in the root zone is injurious to most farm crops, and consequently it is in a sense unavailable. It is the film or capillary water which supports plants.

Gravitational water may be defined as that portion in excess of the hygroscopic and capillary capacity of a soil. It is not retained by the same forces, and is, therefore, free to move under the influence of gravity, in so far as the condition and the character of the soil will permit. The amount of gravitional water depends on the total pore space of the soil on one hand, and on the total hygroscopic and capillary capacities on the other hand. It is the difference between the total capacity of the soil for water, and that held in the other two forms. It is measured by that amount which will flow from a soil having all its pores filled with water. Under such conditions the soil is said to be saturated. That plane in the soil to which level all of the pores are filled with water--saturated--is known as the water-table. This region of saturation is sometimes known as the "ground-water".

Gravitational water is directly injurious to upland crops, but when it exists ad a depth of 4-6 feet below the surface, it may serve

as a reservoir from which moisture is withdrawn by capillarity, to offset losses by evaporation. Water may be removed by capillarity from the saturated zone to the point where the loss is taking place, and under these conditions the ground water--when then becomes capillary water--is directly beneficial, and the process constitutes a form of natural sub-irrigation.

Rise of capillary water.

In this connections look up the diagrams in Hilgard: Soils, on page 204.

Water rises fastest in sand, from 0.45 mm. to 15"-18". In salty soils the rise is rapid and to a great height, especially in the southwestern soils of lime and potash. In clay the rise of water is slow but it continues to a good height.

Soil	Rise		Time	
~~fine silt (0.016 mm)~~	~~60"~~	~~in~~	~~250 days~~	~~(friction)~~
~~silt (0.025 mm)~~	~~120"~~	~~in~~	~~475 days~~	
Clay	60"	in	250 days	(friction)
fine silt (0.016 mm)	120"	in	475 days	
silt (0.025 mm)	105"	in	300 days	
fine sand (0.075 mm)	36"	in	144 days	
coarse sand (0.3 mm)	15"	in	180 days	

Water-holding capacity of Soil.

The water-holding capacity of soils should vary with the size of the grains. Finer particles give a greater capacity.

Diam. mm.	% in vol. cu.in.
1 - 2 mm.	3.5%
250 - 500 microns	4.8
100 - 170 "	6.0
10 - 70 "	35.0
clay packed	43.0
clay tilled	32.0

Entrance and movement of water in soil:

Water in the soil is derived mainly from precipitation. The entrance of this water may be hindered by ground cover; it may be facilitated by coarse grass and a mellow stage (mulch helps in this), and also prevents runoff.

Movement is soil is fastest in coarse sand, and slowest in clay. It is faster in the beginning and then gets slower; it is faster in warm than in cold weather.

Liquid water is not quite separate from capillary water.
Water levels are variable.

Evaporation from the soil may take place:
1) From dirt
2) From plants (transpiration)

Evaporation from dirt depends on:
1) Temperature. Twice as much water will evaporate at 65° F. as at 50° F.
2) Relative humidity of air.

Table

Given 100 sq. cm. of moist earth 12" deep.
Evaporation per hour in grams:

Wind blows at	Sandy	Clay
0	0.25	0.5
6	3.0	3.0
12	4.5	4.5
18	5.5	6.0
24	6.5	8.0

Evaporation also depends on the lay of the land and varies with the cover. For instance, 1" mulch may be reduced 1/3 or ¼. It depends on how dry the soil is, and on the tillage. It varies also with the character and also with depth--shallow limestone soils "burn out".

A living cover invariably reduces evaopration from the soil itself altho the transpiration plus evaporation from the soil is greater. The general average precipitation is about 30"; of this 50% evaporates, 33% runs off, and 17% is unaccounted for.

Another source of loss of soil water is percolation, which is the downward movement of water by gravity. The amount of loss in this way is very great; water percolates most rapidly in large spaces, and whether these large spaces are the result of coarse texture or of a loose, cloddy structure, the final result is the loss of water. The rapidity of such loss is directly dependent on the size and volume of the pore spaces in the soil.

i. Temperature of soil.

Soil temperature depends on water, sun and wind; on the color of the soil, and other characteristics. The factors affecting soil temperature may be mentioned as follows:

1) Heat supply
2) Specific gravity of the soil
3) Specific heat of the soil
4) Color of the soil
5) Attitude of the surface
6) Conductivity of the soil
7) Circulation of air above the soil
8) Water-content of the soil

For further discussion of these factors read Lyon & Fippin, pages 453-463.

Water is the great regulator of soil temperature. In June, 1889, the following figures were obtained (Germany):

	Max.	Time	Min.	Time
Air	22.5°C	2 pm.	12.5°C	4 am.
6"	22.9	4 pm.	17.3	6 am.
12"	18.0	10 pm.	16.5	10 am.
24"	16.0	6 am.	15.7	6 pm.

Diurnal changes practically disappear about 3 feet down in the soil. Yearly changes may be noticed as far down as 75 feet. At 30 feet down the temperature the temperature is about 2° F.

j. Aeration of soil.

There are two process by which aeration of the soil may be improved:

1) Bring oxygen into the soil
2) Take CO_2 out of the soil

From 8% to 10% of the soil volume must be air, to benefit grasses; below this point good grasses wither, and sedges and ~~lowml&~~ hollow stemmed plants of interior aeration come in.

Air movement may be produced by any one or more of the following phenomena:

1) Gaseous duffision
2) Movement of water
3) Change of atmospheric pressure
4) Change of temperature in soil or atmosphere
5) Suction produced by wind.

Air motion in the soil depends on the soil; it is better in coarse sand than in fine clay. An experiment showed that:

Well packed clay allowed 1.6 litre air to pass thru;
Well tilled clay allowed 100-400 litres air to pass thru.

Air may occur in solution in soil; air in globules is very resistant. The amount of ~~of~~ air in soil depends directly on pore space and water. In a soil containing 50-60% of pore space, the air space should occupy 15-30%, and the remainder of the pore space should be water. The composition of that air in the pore spaces varies; it contains more CO_2 than the outside air; it has a <u>high</u> relative humidity (often saturated in the forest); there is generally less oxygen and more nitrogen than in the outside air.

The outside air is by weight: 75% N., 25% O.

Soil absorbs gases. Easily compressed gases are easily absorbed; ammonia is more easily absorbed than O and N. A soil can absorb enormous amounts of CO_2, so much, even, that it can be leached out. Absorption is helped by the presence of mineral compounds in the soil. The three colloids most important in aiding absorption in the soil are clay, humus, and iron oxides.

Oxygen is necessary for bacteria action. Deficient air gives reductive fermentation, and wastes nitrogen salts.

At this point we will digress from Mr. Roth and insert some discussions of this matter of soil, from Mr. Leigh J. Young.

Soil does seven things for the forest cover:

1) Gives mechanical support
2) Furnishes water
3) Furnishes mineral plant food
4) Furnishes organic plant food
5) Furnishes free oxygen
6) Temperature
7) Must be absence of poisons (alkali).

Soil is apt to be deficient in potash (K) and phosphorus (P).

There are 3 classifications of soil:
1) Physical.
   Texture, size of particles: gravel, sand, silt, clay.
2) Chemical
   Sand, loam, clay, etc.
3) Origin
   Soils in place; transported by wind, water, ice, or gravity.

The three main constituents of soil are: sand, clay and humus. Loam is a soil itself and may contain all three constituents. Agricultural soil: 1 gram contains 2-25 million grains.

Origin soils are sometimes classified according to their transporting agents:
1) Alluvial: by water: fine, stratified.
2) Colluvial: by gravity: coarse.
3) Aeolian: by wind: very fine.
4) Glacial: by ice: irregular.

Soil physics:
1) Available soil water)
2) Aeration) Important factors.
3) Temperature)

Uses of water to plants.
1) Chemically: furnishes O and N.
2) Transpiration current.

An acre of good forest uses 5000# water per year chemically and 250-750 tons per year for transpiration currents. A beech in Europe lost 2½-10 tons of water per day during the growing season. A layer of 1" of water over an acre weighs 113 tons.

Water is lost to plants in three ways:
1) Run-off
2) Evaporation from soil
3) Water that sinks into the ground to the water-table (Percolation).

Hardwoods transpire much more water than conifers, as a class, and so the latter have shallow root systems and are able to live on less water.

Amount of Water used on Forest and Farm

Location	Tons dry matter produced per A per year	Inches water needed per year
Forest	1-2	2-7
Farm	4-9	16-40

Factors affecting available soil moisture:
1) Precipitation
2) Catchment %
3) Water holding capacity of soil
4) Evaporation from soil
5) Water withdrawn by plant roots
6) Ability of soil to raise water by capillarity and other movements. Height of water-table.
7) Underground seepage

1) Precipitation is affected by geographical location and topography.

2) Cathhment % is the % of all precipitation actually entering the soil. It depends on:
a) Soil cover.
b) Degree of slope. A greater slope has more runoff and therefore a smaller catchment %.
c) Texture of soil.
d) Character of precipitation. &
Amount
Nature (sudden, fast, or slow)
e) Character of ground surface
Frozen, plowed, baked, dusty, etc.

3) Water holding capacity of soils.
This depends on texture, depth, and amount of organic matter in the soil.
Soil texture may be considered in two parts:
a) Physical composition: size of particles.
b) Consistency of soil:
i density of particle arrangement
ii structure of soil
flocculent, simple, compound, etc.

Flocculency decreases the water holding capacity of soil 25%, and it increases the air spaces; the resulting ventilation is the desirable feature of flocculent soil, especially in clay. Clay is the cementing agent of the particles and crumbs in clay and loam; calcareous material in sand produces the same effect.

Capillary water occurs in smaller pore spaces or often as forming a film about hygroscopic water, the films clinging to particles. Capillary water is available to plant roots; hygroscopic water usually is not.

Free or hydrostatic water occurs in the larger pores in the upper soil. It sooner or later gravitates toward the water-table. In an impervious layer is present above the water table the water gathers just above this layer.

Hygroscopic water: film cligging to particles.
Hydrostatic water: free or gravitional water moving down to the water-table.

Water holding capacity of soil is affected by pore space and the size of soil particles. The arrangement of particles affects the pore space (see page 107). The size of the particles theoretically has no effect on pore space. ~~Saml~~ Small particles really tend somewhat to more

pore surface, because they are light and not packed down by gravity.

An average dry soil requires 4"-6" of rain to saturate the first foot of surface soil or from 20-32# per cubic foot. One cubic foot of ordinary garden soil loam has about 1 acre or surface exposed by the particles.

Amount of surface is important because:
1) More surface = more capillary water.
2) Chemical effect on surface is greater with greater surface of particles.

Water-holding capacity is of two kinds:
1) Maximum: when saturated.
2) Minimum: contains only capillary water; this is the usual capacity meant unless otherwise specified.

Density of arrangement of soil particles:
Increases minimum water holding capacity, therefore cultivation decreases waterholding capacity.

Effects of forest cover: Flocculation in soil increased by:
1) Mixture of organic life.
2) Action of roots
   Physical) Opens up ground.
   Chemical)
3) Cover favors organic life, as bacteria.
4) Cover favors underground animals.

Evaporation is affected by 4 factors:
1) Climate: temperature, humidity, wind.
2) Soil: nature: texture, depth, color, salts with affinity for water.
3) Cover: vegetation, humus, etc.
4) Topography: slope, exposure.

Relation of Evaporation to Relative Humidity and Temperature.

Relative humidity	Ave. Temp.	Am't Evap. per day
constant 84%	10.7°C	increase 0.24 mm.
84	12.0	0.40
84	17.0	0.50
74%	17.6°C	decrease 0.93 mm.
79	constant 17.7	0.62
89	17.0	0.38
91	17.2	0.25

Effect of Texture on Evaporation

Soil	Time	% of Vol. Bottles of successively smaller volumes.					
		100%	95%	90%	85%	80%	70%
Lime sand	18 days	1336	1603	1751	1763	1860	1935
Coarse sifted humus	10 days	1978	2219	2242	2461	2625	2800

8 days difference.

The figures in the table are the evaporation per 1000 sq.cm. of surface exposed, in grams.

Effect of Tilling of Soil on Evaporation

Soil	Loss per acre Tilled	Loss per acre Untilled	Time
Clay	129 bbls.	167 bbls.	7 days
Sandy loam	77 "	172 "	7 days
heavy loam (clay)	158 "	189 "	7 days
Average	121 1/3"	179½ "	

Transpire from 250 to 750 tons of water per acre per year.

King's results with evaporation experiments:

Thru rise of 1 ft. 2.37# per day per sq.ft.
2 ft. 2.10
3 ft. 1.23
4 ft. 0.91

This indicates a distinct decrease of evaporation from increasing depths.

In general the mass of tree roots do not go down more than 3 ft. (Young). On the average the water table is about 20 ft. below the surface in most soils. This leaves a gap between the roots and the water table.

Summary of:
Factors affecting Available Soil Water:

1) Precipitation
2) Catchment %

Soil receives
- a) slope
- b) character of precipitation
- c) soil cover
- d) character of soil (chiefly physical)
- e) character of surface (frozen, dusty, etc.)

Soil holds

3) Water holding capacity
- a) texture (pore space and surface of particles, etc.)
- b) depth
- c) amount of organic matter

Soil loses

4) Evaporation
- a) soil cover
- b) climate
  - i. wind
  - ii. temperature
  - iii. relative humidity
- c) topography
  - i. slope and aspect
- d) soil factors
  - i texture
  - ii color
  - iii depth
  - iv character of surface (rough or smooth)
  - (v amount of water already in soil
  - (vi chemical composition
  - (vii certain soluble salts

5) Amount withdrawn by plant roots
6) Replacement of ~~matter~~ water by capillarity.
- a) Rise from water table
  - i depth of water table

6) a) ~~ii~~ texture
iii arrangement of soil layers
b) Equalization
i texture

7) Underground seepage that comes near surface at foot of slopes, etc.

We will now return to Mr. Roth:

J) Chemistry of Soil.

a. Importance of ~~unit~~ amount of plant food in soil.

Of chief interest to us is the amount of plant food in the soil, how long it will last, and how best to replace it. Do not favor the extreme notion that the physical condition of the soil is more important than the chemical condition.

Forest trees need less of plant foods, less of chemical materials, and they return much to the soil. But they are grateful for supplies, and respond readily to good soils. For nurseries we always want good soil.

b. Forest vs. other crops with respect to chemical needs.

Fertile lands have the best growth of timber and vegetables. Fertile land is necessary for profit. The soil replenishes chemical materials rather slowly. Hopkins in Illinois studied the problem as to how long potassium and other chemicals would last in the soil; he claims that the supply is limited. But it is probable that if agriculture is carried on the soils will remake them up, but only if the farmers do the right thing by the soil. China has good soil, and it has been kept good by 4000 years of tilling (King of Wis.).

On lean of pineries even the forester must handle the soil carefully to keep it in good contition. But generally he need not bother about the chemical condition of soils.

c. Amount of compounds present in good and poor soils.

Table

Materials	Rich dark land: Cal.	Fla. pine land	Rich red land: Hawaii	
Insoluble material	53%	95.6 %	15.8%	
Soluble materials				
silica	1~~0~~.00%(19)	0.8 %	14.00%	
potash	0.67	0.12	0.45	
lime	2.11	0.06	0.26	
Mg	2.26	0.04	0.67	
Fe peroxide	5.23	0.22	39.05	
Al_2O_3 ?	7.40	0.45	14.6	Figures
Phosphoric acid	0.071	0.09	0.19	should be
Humus	3.06	mere trace	3.35	checked up.
Nitrogen	0.67	" "	0.11	
Hydroscopic H_2O	10.70	less--1%	18.5	

Compare the above soils with each other. Lime takes the controlling position chemically; clay, humus, and iron salts are important physically. With these four present the soil can do with a comparatively small amount of K and N.

A soil that is poor in its physics is apt to get poor in its chemistry, and one that is poor on its chemistry is poor in its physics and is hard to make good.

d. Ability of forester to remedy soil thatis chemically poor.
The forester does not fertilize or do anything with the chemical condition of the soil as a general thing. He affects the physical condition: he keeps a good stand of timber and humus, and this results also in aiding the chemical condition, besides providing protection to the soil.and soil cover.
Theory: natural betterment of sand soil by protection, increasing quality of timber, species, and undergrowth, resulting in the so-called "Climax Forest".

e. Amounts of salts needed by soils. and plants.
The following figures are given for northern countries (Not the tropics):

0.25% K is a minimum for useful agriculture.
0.5 % K " " maximum " " "

The tropics, which are wet, can do with less K; such are Hawaii, the Philippine Islands, and the southern part of China.
Up to 1% is alkali lands.

0.05% phosphoric acid: minimum for good results.
0.25% " " : maximum " " "

0.1 % nitrogen: minimum for good farming.
0.2 % " : maximum " " " , rich.

0.1 % lime: minimum for sandy land.
0.6% " : " " clay " .

f. Effects of Salts on Soil. What do the salts do for the soil itself.

Lime carbonate is readily dissolved by water containing CO_2, and therefore is readily distributed thru the soil. Lime produces flocculation of clay and both produces and assists in the condition of tilth., and its maintenance. In dry lands it also acts as a cement to hold the particles together. It helps to form crumbs of soil, making larger openings and helping the movements of water and air. It makes the soil mellow helps aeration and water movement. About 2% of lime is sufficient for the average soil.

Chemical lime helps to maintain the neutrality of soil by binding the acids which form in the soil; it helps bacterial life and the development of humus. It is a necessary ingredient of soil with direct nitrogen gathering by bacteria; this is also true of tubercle bacteria. Otherwise there would be no work. It helps to make plant food available, especially in regard to potash and phosphoric acid. It offsets the injurious effects of magnesia and the alkalies; gypsum is much used in this respect The maximum amount of lime for good effect is 8%; above this point lime itself becomes injurious to the soil.

Magnesia is one of our important ingredients in the soil; it is more important in the eastern United States than in the west. It acts in the soil as lime does, in loosening it for air and water. It enters as

a reagent in freeing phosphoric acid and making it available, but it readily becomes a nuisance. Much magnesia is injurious to the soil. It is mischievous to plant growth, especially if the soil be deficient in lime. It may interfere with imbibition (?).

Insoluble residues (silicates) vary in large limits; they are greater in humid than in arid countries.

The humid east has 85% of indissoluble materials.
The arid west has 70% of indissoluble materials.

Soluble silicates are interesting and important in every soil. Much of them come from clays and zeolites.

Potash and Soda go readily into solution, act as reagents in the soil, and therefore are helpful in all kinds of decomposition and recompositions. In arid lands they tend to accumulate as sulphates and soda phosphate, forming alkali soil, destroying the flocculence of the soil, and puddling it. In this respect they are mischiev~~i~~ous both physically and chemically.

Tropical soils vary from those of the temperate zone, especially in a chemical way. Tea soils in India are good; they may have a low % of Mg and Na, and lime, lower than might be expected. Shading opposes alkali formation and helps the soil: because:

1) It decreases evaporation and prevents the alkali from gathering at the top of the soil in excessive amounts.

2) The effect of transpiration of trees is increased and brings water up from lower levels and thus prevents the deposition of alkali at the surface.

g. Grass Land Humus. Humus in the soil on grazing areas.

The term humus refers to the entire mass of decayed vegetation on the top soil. Since plant materials in the humus are complex products of decay they vary as the kind, proportion and nature of the lower organisms causing this decay and the conditions under which they work. The quality of humus is determined by the nature of the original plant materials and the condition of decay. The identity of plant life is lost in humus; this is significant of the importance of humus.

Humus may be considered as a "stream of material" compared with the mineral consituents of the soil.

The nitrogen of the soil is held almost entirely in the humus. The average quantity of humus in a grass lands soil is 3.5%.

50-58% of this humus is organic C.
(0.146?) ~~2.46%~~" " " " N. Very low; dry soil surface.
(0.066?) 0.166% " " " " N. Subsoil.

In an old meadow you may often find 0.25% N. low

In only moderate growth texture influences decay. The presence of lime is unfavorable to the rapid decay of humus. The low nitrogen supply is due to the small proportion of clover cover.

Condition of humus: the elements in humus may be divided in two groups: soluble and insoluble in alkali ~~&&&&&~~ solutions. The soluble group is usually richer in N and is often more influential on the soil fertility than the insoluble group. Some modern writers confine the use of the term "humus" to this more soluble division of humus matter. Less than half of the total humus is soluble, alkalies forming 44.29% in the

humus of grass lands.

Cultivated land: soluble materials (alk.) form 75% in the humus.

Part of the humus may exist in the soil in combination with lime and other bases, becoming soluble only after weak acid action occurs. In grass land only 33.5% of lime may be extracted with acids.

Grass land varies in different areas:
Total organic matter varies 2-9%.
Free humic acid varies 0.8-1.6%.
The soil needs lime in proportion ~~in~~ to the amount of free humic acid present.

K) Biology of the Soil.

Biology of the soil is important in regard to the decay and production of humus, weathering, and the action of bacteria. Study why certain soils do certain things; we don't know yet surely; analyses do not always explain everything.

Climate (especially moisture and temperature) and Food Materials in the soil are the most important factors in determining the life in the soil, and form the foundation of Soil Biology.

There are four agents to be considered in Soil Biology:
a. Bacteria
b. Filamentous fungi
c. Higher plants and their effect on soil
d. Animals.

a. Bacteria.

Bacteria predominate mostly in rich tilled soils, which contain more organic life. They are less in forest soils, but ~~they~~ this varies. Nearly all bacteria are sensitive to light; they vary in oxygen requirements, but need it in general; they are sensitive to changes in moisture conditions, and die in very dry conditions. All bacteria have their optimums. They are sensitive to the action of acids; sour humus and swamps are comparatively free from bacteria.

Bacteria excell in adaptation and utilization of all forms of energy. They vary among themselves as to their working temperature, from freezing to very high temperatures; some are capable of much higher temperature than others.

Bacteria life is generally well distributed thru soils except under peculiar conditions, where they secrete something which is detrimental to themselves beyond a certain point; ordinarily they are associated with other organisms which may work over these secretions and thu prevent harm. Thus bacteria may be cooperative in a sense. These secretions are known as toxins and anti-toxins.

Some bacteria needing oxygen may be associated with others which do not need oxygen and which may perhaps even produce it as a by-product

Bacteria often change, due to temperature and moisture changes:
1) Kinds in soil
2) Proportion of kinds
3) Total number
4) Activity.

The bulk of bacterial action takes place in the upper 12" of grass or agricultural lands; in forests it goes a little deeper. Bacteria always abound in large numbers, when present; the greatest number per centimeter in rich clay was 600 million bacteria; the upper inch usually contains most. The abundance of bacteria varies widely, even in adjacent localities, and yields from soils vary in about the same proportion.

Reproduction of bacteria is very rapid: cell division may be completed in 30 minutes, which rate would produce 50 generations in 24 hours if carried on continually. One of the chief values of stable manure is the fact that it supports and retains bacteria life in the soil (Hilgard).

Bacteria produce two principal effects:
1) Change of organic material in soil, both animal and plant.
2) Secretions act on inorganic minerals both physically and chemically. They tend strongly to increase the nitrogen supply in soil.

Bacteria may be divided into groups accirding to the work they do.
1) Break down cellulose, chiefly by fermentation.
2) Decompose protein bodies. This action occurs in all soils, and reduces organic matter of all kinds.
3) Nitrifying bacteria: a very common form. They need lots of air to carry on their work well, and require a temperature of over 50° F. The soil must be either neutral or alkaline. These bacteria prefer soil with plenty of lime and organic food. They use the free nitrogen of the air.
4) Tubercle bacteria: take free nitrogen and bind it; they do this only in symbiotic relations. They are not mycorhiza, as some people have mistakenly thought. They are found chiefly on the Leguminosae, and also on alder. The tubercles swell up for a time; they then cease, become inactive, and are absorbed.

Denitrifying bacteria take nitrogen from the soil, and are very harmful. They do not do very much danger, as they are not plentiful, and then only under certain conditions.
Other groups are sulphur bacteria, iron bacteria, etc. There are very many groups of bacteria in the soil; they occur by tons, ever active, ever ready to do a variety of things with organic things. They accomplish a tremendous amount of work.

b. Filamentous fungi.
These fungi are more common in forest or untilled soil than in the farmer's tilled land. Tillage helps to climate them. Their chief value lies in the disorganization of organic matter; the formation of humus is largely due to fungi. They penetrate theu the soil and distribute their filaments ~~fairly~~ evenly thru the soil, helping to feed other fungi and mellowing the soil.

There are more fungi in the mulch of hardwoods than with conifers. The life and growth of fungi are similar to that of bacteria, but are more limited. They need organic, and are helpless with inorganic matter. They are larger and more resistent to heat and drouth than are bacteria. They take up organic material (and cement it) only thru a distinct process, leaving the job for another fungus to work over in the next step of decomposition.

Fungi live part of their life in the soil, and part as parasites.

The bulk of bacterial action takes place in the upper 12" of grass or agricultural lands; in forests it goes a little deeper. Bacte always abound in large numbers, when present; the greatest number per centimeter in rich clay was 600 million bacteria; the upper inch usual contains most. The abundance of bacteria varies widely, even in adjace localities, and yields from soils vary in about the same proportion.

Reproduction of bacteria is very rapid; cell division may be co pleted in 30 minutes, which rate would produce 50 generations in 24 ho if carried on continuously. One of the chief values of stable manure is the fact that it supports and retains bacterial life in the soil (Hilg

Bacteria produce two principal effects:

1) Change of organic material in soil, both animal and plant.

2) Secretions act on inorganic minerals both physically and chemically. They tend strongly to increase the nitrogen supply in soil

Bacteria may be divided into groups according to the work they

1) Break down cellulose, chiefly by fermentation.

2) Decompose protein bodies. This action occurs in all soils and reduces organic matter of all kinds.

3) Nitrifying bacteria: a very common form. They need lots o air to carry on their work well, and require a temperature of over 50° The soil must be either neutral or alkaline. These bacteria prefer so with plenty of lime and organic food. They use the free nitrogen of th air.

4) Nodule bacteria: take free nitrogen and bind it; they c this only in symbiotic relations. They are not saprophytes, as some peop have mistakenly thought. They are found chiefly on the legumes, and also on alder. The bacteria build up for a time; they then cease, be- come inactive, and are absorbed.

5) Denitrifying bacteria take nitrogen from the soil, and are very harmful. They do not do very much damage, as they are not plentiful, a then only under certain conditions.

Other groups are sulphur bacteria, iron bacteria, etc. There a very many groups of bacteria in the soil; they occur by turn, ever so ever ready to do a variety of things with organic matter. They accom- plish a tremendous amount of work.

b. Filamentous fungi.

These fungi are more common in forest or untilled soil than in the farmer's tilled land. Tillage helps to eliminate them. Their chi value lies in the disorganization of organic matter; the formation of humus is largely due to fungi. They penetrate thru the soil and distri bute their filaments evenly thru the soil, helping to feed oth fungi and mellowing the soil.

There are more fungi in the mulch of hardwoods than with conif

The life and growth of fungi are similar to that of bacteria, are more limited. They need organic, and are helpless with inorganic tter. They are larger and more resistant to heat and drouth than are bacteria. They take up organic material (and cement it) only thru a dis- tinct process, leaving the job for another fungus to work over in the next step of decomposition.

Fungi live part of their life in the soil, and part as parasit on plants, as with the rusts and smuts. They go thru regular life cycles, with alternate generations.

Algae in the soil are more important in cold or humid countries but are able to live in the tropics. Symbiotic relations mark the first beginnings of soil accumulation.

c. Plants. This topic was passed over.

d. Animals.

The lower animals may be considered in groups:

1) Living in soil all their life, as the mole, earthworms, and perhaps the shoat.

2) Living in the soil part of their life, as the Junebug, and beetles(in larval condition).

3) Making their home in the ground but feeding above the ground: burrowing animals; insects as ants, wasps, etc.; bumble bees.

4) Digging in the ground for food: from the beetle to the hog; lizard, snake, birds, etc.

These Animals are useful to the soil:

1) They chew up the organic material of the soil and transform it to a desirable physical and chemical form.

2) They dig and till the soil. Worms, ground squirrel.

3) They make passages thru which water and roots pass for a considerable depth, affecting water movement. Worms, wolves, etc.

4) They add manure from excrement, and also be decomposition of dead bodies.

For an interesting experiment take 1 square yard of earth and see how many lower animals you can find.

Lower animals develop rapidly, are big eaters, and short lived, as moth larvae. The worms have been most studied of these forms of life. The earthworm accompanies the bacteria everywhere; they are most common in the farmer's tilled land. Tropical earthworms are larger; lengths longer than 12" are quite common there. Worms have been much studied in Central Europe: 25 worms can eat and chew up 1# of dry leaves in 1 year. 1 acre of hardwoods should give 2 tons of leaves (beech); 1½ tons of hay grow on 1 acre; assume 5000 sq.yds.per acre; this gives 0.8# per sq. yd. Therefore it would take only 20 earthworms to work this material over in one year, and they would be able to more than take care of all that was furnished them. Such figures as these bring the actual conditions more vividly to our minds.

Worms make passages in the ground. They are more common in loam.

Altitude seems to have some effect on worms, as these figures will indicate:

In Switzerland: at 4000':

meadow: 6400 animals, including 400 worms.
forest: 4500 animals, including 300 worms.

at 6000':

meadow: 1300 animals, including 61 worms.
forest: 400 animals, including 100 worms.

Insects and their larvae, as the Junebug, make passages in the ground to a certain extent; these pockets frequently fill up. Ants and wasps may also be mentioned.

Tilling discourages insects, also the removal of crops, and other on plants, as with the roots of the moulds. They go thru regular life cycl with alternate generations.

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conditions favoring or discouraging insects or animals in the fiеld as against the forest. The hog was formerly used very extensively by the forester.

Higher animals.

Badgers, moles, etc. break the ground, and break up the mulch. Cattle eat reproduction and trample things down into the ground. In soft soil they tramp down hard; they make trails, stir up mulch and work it down, which retards decay. Sheep and goats are more injurious to the forest than are cattle.

Man:

Tillage is very influential in soil. It changes both its physics and its chemistry. Tillage mellows and improves plowed soil, but neglects the soil right below it. Plowing may produce so great a change in soil that former plants may refuse to return. Continued tillage modifies the soil, tho not always favorably.

A "tired" soil is one that is exhausted for crops requiring certain elements, as spruce, or something similar. A mixed forest has often been advocated. Such crops excrete toxins.

L) Forest and Soil.

The forest affects the formation of soil from rock, the transportation of soil material, soil biology, soil physics, and soil chemistry.

1. Forest and Soil Formation.

a. The forest ~~aaaa~~ protects rock against rapid changes in temperature, against frost, mechanical action of water, ice and wind. By so doing it retards the physical and mechanical disintegration of rock.

b. The forest keeps the soil moist and the CO_2 applied to the rock, thereby assuring continual action in dissolving rock material.

c. Roots of trees enter cleavage lines or cracks in rocks, and by growth and expansion assist in the breaking of ground.

d. The forest adds large masses of organic matter and thereby adds bodily to the soil. This effect varies with the climate and condition of the rock, as does the total effect of the forest. New England has granite, Pennsylvania has shale, Kentucky has limestone.

2. The forest retards or prevents entirely the transportation of ~~aaaaa~~ soil by water, ice and wind. Water transportation becomes very slow, gullying is excluded. All the Bad Lands formations, as in Wyoming, the Black Hills, Texas and New Mexico, are carved in sharp hills and ravines; such conformations never exist in forest land.

Cutting the forest at oncechanges it. Forest countries have normally a rounded topography and all changes are slow. Ex: Mississippi R.

In regions like the Alps where rocks readily disintegrate, a tough forest cover often holds the soil so long that landslides occur owing to the deep disintegration and decomposition.

Summary: 1) Forest accumulates and builds up the soil.

2) Forest ~~aaaaaa aaaaaaa aa aaaaa~~ makes for permanent soil conditions,.

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Summary: 1) Forest accumulates and builds up the soil.
2) Forest affords protection as those makes for permanent soil conditions.

3. Forest and Soil Physics.

a. General.

1) The forest as a tall shelter protects the soil against sun, wind and rain; against rapid changes in temperature, and frost.

2) The forest affects the entrance of water into the soil, water contents, and percolation, and therefore it affects leaching, solution of salts and the movement of those salts.

3) The forest protects the air in the forest. It shades it, and modofies its temperature, movement, and humidity, and this reacts upon the soil.

4) The forest evaporates and transpires large amounts of water and thereby reduces soil moisture; but it also cools the air and makes the forest air more humid.

5) The forest gives organic matter which may be worked over into mulch and cover to soil, and thereby aids in its protection against evaporation and in maintaining its mellowness and permeability.

6) The forest furnishes material for humus, which affects the water-holding capacity of the soil, both in regard to hygroscopic water and capillary water.

7) Forest roots permeate the soil at various depths; generally theytill the soil deeper than is the case in agriculture.

b. Detail.

1) The forest as a tall shelter: the forest air is shaded and all within, materially affecting plant and animal life within the forest.

2) The action of the wind is materially modified. A wind with a velocity of less than 20 miles an hour is scarcely felt in the interior of a large forest. Therefore there is no exchange of air between the forest interior and the great body of air moving outside. This materially retards water evaporation from the soil itself and also transpiration from plants, including the trees themselves.

3) Summer rains do not strike the ground, but the trees instead, therefore the greater portion of the precipitation comes in th form of spray of as drippings from the foliage. Heavy rains tend to har den the soil; part of the water then evaporates at once. As much as 10-75% may evaporate; this seeming loss adds to the humidity of the forest air, keeps the trees damp, and lessens the transpiration, and this in turn reacts on the soil.

4) The frost is less deep in the forest. This affects animal and plant life, and especially the entrance and movements of wat in the soil. It is important in regard to spring thaws. Open lands have floods, and frozen ground.

The temperature of the soil is more uniform, and generally lower in summer, in the forest, than without the forest. Therefore all proces ses depending on higher temperatures are retarded or prevented. This includes chemical changes and decomposition of organic matter. Bacteria life is more plentiful in open fields than in the forest. In cold and

wet situations mulch can readily get too deep, especially in northern climates.

5) The effect of the forest is in proportion to the density of the forest, and the kind of timber. It is more conspicuous in a more extreme climate. This may be illustrated by conditions in exposures on the sides of hills.

c. Entrance of water to soil, water contents, and water movement.

1) The surface in the woods is normally uneven, humps and depressions being found in hardwoods. These tend to hold water in rains. The situation varies with the character of soil and topography. Mountain slopes eliminate mild effects.

2) Debris in woods is normally abundant. This debris takes up water (like a broom) ; after a rain it dries down to about 20% or thereabouts. This debris prevents the entrance of water to the soil and also its exit. Its drying helps to keep the air in the woods moist and cool, reacting on the soil. Debris retards the flow of water on the surface; this is very important in regard to rainfall. A weeded ditch may hinder the waterflow by half. Compare the paved street with a grass lawn.

3) The mulch, as a normal part of the forest, acts just like debris. The surface is irregular; mulch materials absorb easily and hold large quantities of water. There is a great difference between sod and a smooth pavement. A fall of 1" in 2 hours is exceptional; more than this would be a flood. Look up the proportion held by the foliage, sod, and a smooth pavement.

Prairie sod is influential in holding water. In the western country of bunch grass, the condition of no sod and little rainfall effect is at once seen.

Gullies increase the actual gradient of water flow; water reaches a greater depth in gullies; most of the water falls on the steeper slope of a gully. Compare the different effects of cloudbursts on prairies and other parts of the country.

Mulch absorbs and holds much water, obstructs mechanically the entrance of water, prevents lots of water from reaching the fround, and holds water better than most soils. The effect of mulch varies in wide limits. There is scant mulch in spruce forests compared with hardwoods. Both debris and mulch are permanent conditions in the forest, and are working all the time, day and night. They are different from the farner's land; tilling is here merely a temporary condition.

4) Roots of forest trees till the soil. The mellowness and tillage of the forest soil is due to forest tree roots. Mulch keeps it mellow. Decaying roots afford channels for water to enter and run in.

5) Organic matter is converted to humus and therefore aids the water-holding capacity of the soil, retards water-flow, and the salts taken up by the water are re-distributed, preventing leaching.

6) Trees take water from the soil for their own use. Agricultural people assume that for every pound of dry organic substance is required 300# of water pumped from the soil. Forest trees get along with less.

On #1 beech land a 60 year old beech stand produces about 5000# wood per acre per year, and over 5000# of leaves and small twigs, or about 10,000# of organic matter all told. On the basis of 300# water per pound dry matter, this would require 16" rain.

On #1 pine land half as much material is produced, but even that would require 8" of rain.

Water taken up by the roots leave the soil driest in the localit of the most roots. Shallow rooters dry out the top layers, deep rooters the lower layers. In forest the top layers contain more water than the low layers. Soil in the forest is drier than soil in bare land, as indicated by experiments. There has been much discussion on this point, and much misinterpretation of facts and experiments.

Table

Average for the year, in % water in the soil.

	Spruce		
Depth	25 year	120 year	Bare land
6"	19.2%	19.3%	20.6%
12	19.1	18.3	20.5
18	18.4	20.2	20.2
36	18.0	21.1	20.5

This difference is greater in the summer, and almost disappears in the winter. Look up the previous table of amounts of water in the soi and the amounts evaporated by trees. (pp.112,117,119,etc).

Species differ in the amount of water taken from the soil. The ash will not grow on jack pine land, as the latter cannot furnish as much water as the ash needs, which majes the ash a sensitive tree. The ash can bring up more organic material, but needs more water to do it with. If it has less water it may not die, but it will not grow as much or as good wood (thinner rings, etc.).

Amount of soil water, or free ground water.

A general claim is made that the forest lessens the amount o free ground water. This is generally conceded today, but Mr. Roth thinks this notion is absolutely wrong. It contradicts actual experience, Michigan for example, in the past and the present, and also in Wisconsin and the Great Lakes country. Swamps, etc. actually do not have as much wate as formerly; the removal of forest dried out the land, and this fact contradicts the generally accepted claim that forest lessens the amount of free ground water.

This same claim is contrary to the conditions found by the U.S. Geological Survey in prairie regions. Prairie rivers are not regula they are either a flood or a drouth.

Hydraulic engineers are coming to believe strongly in the influ ence of the forest in steadying stream flow.

Forest regulates water movement, and makes it more steady. The conditions of water movement here continue undisturbed for many years In this respect they differ radically from agricultural lands, where the conditions of water movement are disturbed constantly.

The importance of water regulation is far greater in poor land than in good land.

The forest regulates the aeration of lands. There is more CO_2 in the air of forest soils than in the air of open or bare lands. The following table gives the number of cubic feet of carbon dioxide in 1000 cubic feet of air in soil in the first 30" of soil for spruce woods of 25, 60, and 120 years of age respectively, and in bare land:

Bare land	7.0 cu.ft.CO_2
25 yr. spruce	6.5
60 " "	12.5
120 " "	10.2

Hardwoods compared with conifers:
60 yr. beech: 7 cu.ft.CO_2 per 1000 cu.ft. air.
60 yr. spruce: 17 cu.ft.CO_2 per 1000 cu.ft. air.

The amount of CO_2 which is in the soil air is in a certain proportion to the oxygen. More CO_2 gives less O. Ramam and others have called attention to the fact that hardwoods have more fertile land ~~better~~ because of the better aeration there; this aeration is better under hardwoods than under spruce on the same kinds of land. Probably much of this contention is true. The amount of soil life depends closely on the amount of oxygen present.

e. Structure of soil in tilth.
Forest mulch prevents soil from puddling and from pounding by rain; it makes and maintains tilth. The action of the mulch is not to ~~pro~~ produce, but to maintain condition. In a clean-cut forest where the water hits the ground the effect is worse on clay than on sand. Prairie vegetation cannot maintain tilth like the forest.

4. Forest and Soil Chemistry.
a. The production of organic material by the forest is usually taken as a measure of the amounts of salts which the forest must take from the soil.

Site I Species	Wood produced per acre per yr.
Beech	5500# wood
Spruce	6500
Pine	4500

Spruce outgrew pine and beech.

It has often been suggested that site be classified by the amount produced.

Of all organic matter produced by the forest:
Conifers:
Leaves & fine twigs produce 25-30% or ½-1/3 of total.
Wood " 75%

Hardwoods:
Leaves and twigs " over 50% more than half.
Wood " less than 50%.

(to next page)

Mineral salts are mostly in the leaves.

From Buesgen we obtain the following figures: In 100# of dry leaves:

Conifers: ashes form 2-3%
Hardwoods: ashes form 4-7%.

In some species, as ash and black locust, the ashes run as high as ~~89~~ 8-9%, or 8-9# per 100#.

The young bark is mostly ash.

Ash in bark of conifers forms	1-2%
" " " " hardwoods "	2-4%.

The smallest amount of ashes is in the limbs:

Pine	0.2-0.25%
Hardwoods	0.3-0.4 %.

b.~~&~~. The mineral matter taken from the soil per year by forest tre is largely spent in building up leaves and small twigs; only a small amount is used in building up wood.

In 100# of dry substance:

1) Hardwoods:

Leaves and twigs: 50#, of which 6% or 3# are ashes.
Wood (timber) : 50#, of which 0.4% or 0.2# are ash
Total ash is 3.2# per 100#

Therefore from 32# of salt: 30# goes to leaves and twigs, and 2# to timber; therefore only 1/16 of all mineral matter goes to timber, th other 15/16 to the leaves and twigs, the bulk of which is dropped every year.

2) Conifers: (kept 4 years)

Leaves and twigs: 25#, of which 3% or 0.75# is ash.
Wood : 75#, of which 0.2% or 0.15# is ash
Total ash is 0.8# per 100#

There are here only ¾# of ashes as against 3# ashes in hardwoods therefore conifers can do better on sand than hardwoods.

N. forms 16% of dry protoplasm and therefore is absolutely essential. No N and no growth. Gather green leaves:

Young leaves contain 4% N.
Old leaves are poorer: 2-2.5% N. (Heavier in minerals).

It is an old story that one acre needs a minimum of 40-50# of N per year. Conifers need less than hardwoods, supposedly 35-40# per year

The amount of K and P_2O_5 <u>increases</u> in each leaf from budding to dropping of leaf. They are carried to it by solution and are left by evaporation, as are also other minerals, tho most of them decrease.

In 1000# beech leaves: May 0.51 gm. K
Oct. 0.80 gm. and more, K.

This increased the amount almost double. The same was true of phosphoric acid.

In 100# leaf ash : Ca and Mg are richest in fall;
K and P_2O_5 are richest in spring.

	K:	P_2O_5:
May	31#	21#
July	7	5
fall		3

About 90% of the ash goes back to the ground, or 15/16 of the salts in the leaves and twigs. This is a large proportion. In this respect hardwoods are very good for the land. Conifers return about 75%.

The salts are given back to the ground regularly every year, with the leaf fall. This is no feast and famine affair.

Much matter from fruits go to the ground, also, as with nuts, etc. They frequently are rich in nitrogen and phosphoric acid, and so give the soil high grade material. Crops of fruits are repeated again and again. Begin, say, at 40 years. Then to 100 years of age there may be 12 crops of fruit (5 year seed periods). This means that loss of litter in the forest is robbing the land. This is an important extravagance.

The forest protects the soil; it allows uniform chemical decomposition of rocks and retards the leaching of salts.

c. The forest adds organic material, aids soil life, aids the water-holding capacity of the soil, aids the production of compounds, and aids chemical decomposition.

The forest may add too much to the soil, as with Ca and clay. When the soil lacks lime, or when the climate is cold, as in the north-west, trees may fail entirely to reproduce.

5. Forest and Soil Biology.

The most important factors are temperature and moisture.

a. Soil temperature changes less in the forest than outside. Forests have cool but even climates. This reduces the number of species and the number of individuals, but keeps more uniform conditions than on agricultural or bare land.

b. Moist and cool forest air favors plant and animal life in the upper layer of the soil. It obviates the alternate frosts and hot sun, etc. which are met with on bare land. They are fewer but more regular.

c. In humid districts the soil is more moist in the forest; in less humid districts the layer is less moist, perhaps because the trees draw heavily on it for water supply. The forest also helps on poorly drained lands, as on the verge of a swamp; it keeps them from getting soggy and enables the soil to produce growth.

d. The forest has a large body of fauna and flora above and below the ground. It is inhabited by thousands of insects and fungi, etc. It thus bears more or less relation to the surrounding fauna and flora. Log tops are breeding grounds for many species. The cleaner a forest is kept the more this condition disappears.

M) Kind and Condition of Forest in relation to Soil.

1. Individual tree of scattered stand.

a. The seedling is of little consequence to the soil. Kinds differ in importance. One seedling is not very essential in its effect. A 2-year oak seedling has more effect on the soil than a 2-year spruce. An oak seedling has already a big root system, and produces a tilling effect, besides the leaves it drops for mulch.

b. Young tree 5-20 feet high; There is considerable tillage by the roots. Little mulch is supplied. The crown is being shaped during

this period. Species differ materially. A 5' Scotch pine makes a cover, tills the ground and makes mulch. The ground gets a little shade.

c. Larger and older trees continue the same action. The individual tree does not influence the ground outside of its own reach.

2. Stand of Trees.

a. Stand of seedlings: varies with the density of the seedlings. When seedlings are planted 4' apart they do not take up much room, probably not over 0.1% of the total area. Seedlings do not help the soil except in a dense stand. In dense stocking, the stand shades the soil, the leaves make mulch, the roots till the soil, and there is some slight protection from snow. A dozen seedlings per square foot can produce these effects; then they begin to help the soil.

b. Stand of young trees 3-10 feet tall: have a large amount of growth; much organic stuff is produced each year. Consider the proportion of leaves and twigs to the total growth in the young and the old tree: does the young stand do more for the land than the old stand?

The young stand forms a densr cover close to the ground, and shelters it from rain, wind, sun, snow, and reduces the waste of water.

The care of the soil by the young stand is good. In this respect compare scotch pine and spruce, and these with locust, ash and elm (not so good protection, big sod grows). At this age there is no sod under the Scotch pine, as may be witnessed at the Saginaw Forestry Farm west of Ann Arbor.

There is an immense difference between a stand of conifers and of hardwoods. A leaf cover keeps the ground warmer, the snow melts faster, and flows faster in the spring; it warms the soil quicker; it freezes in winter. Grasses are encouraged by the warming and moisture before the hardwoods leaf out. This affects soil life. Conifers have a comparatively clean soil.

The intolerance of the pine is not so marked at this early age as it is later. The same is true of oak, which may have thickets as thick as beech, up to this age. Lodgepole and Jack pine also, and tamarack, may have as many as a dozen trees per square yard.

c. Stand of trees 10-30' high: Growth in volume and other growth is greater than in stand 3-10' high. The stand is now approaching its maximum growth. On account of cleaning this stand puts the largest amount of litter on the ground. Decay ordinarily is rapid. Along with organic matter comes an increase in insects and fungi. Suppressed trees are attacked by organic life. (Forest Sanitation: getting rid of these organisms). Since the crown cover is complete we have good protection against sun, wind, etc., but not as good as in the younger stage. At this stage we get the most intensive tillage of the soil. At this stage we get the first danger of duff, organic matter which falls on the ground but does not rot, as the needles of the conifers, etc.

d. Pole stage, 30-50' high: At the end of this stage the crowns begin to open up. In intolerant species the stand itself opens up. The crown is even higher than in the preceding stage. The maximum growth per acre of the stand has been reached and passed in this stage. Litter and leaves are not so abundant. Roots are larger and interfere.

Results of this stage:
1) Less perfect use of soil.
2) Greater air movement, therefore more drying out of soil.
3) More rain driving thru cover, which tends to harden soil.
4) Diffused light mostly at ground.
5) Temperature effect is more pronounced; i.e., lower and more uniform than outside.

Maximum growth, mulch and cleaning, root development and fertilit drain on land and loss of water, and redistribution of salts.

e. Tree stage proper, 60-100 years and over.
The intolerant stand opens up decidedly. 30-50% of the la is opened up to the rain, sun and wind. The crown opens up more decidedl The trees are taller; the canopy is higher, and gets the effects that go along with it. Growth in height and volume per acre has fallen off. Weeds are apt to come in, etc.

Effect on soil is:
1) Hardened.
2) Dried out.
3) Less mulch
4) Less life (bacteria, fungi)
5) Less tilth by roots
6) Only partial use of soil, less demand on soil
7) On account of decrease in growth, less demand for salts and water.

These effects are more pronounced in open stands. Old stands are less able to take care of the lands than younger ones.

3. Special Cases of Forests.
When forest trees are unable to compete with and suppress fore growth, weeds, grass, bushes, etc., come in. The soil is affected more by the undergrowth than by the trees themselves.

a. Grass and weed cover on good soil, especially in cases of reforestation of farm lands, yellow pine areas, in parks of the Rocky Mountains. The effect of the grass is to form a sod which consists of a dense mass of roots limited to the upper 6 inches. This hardens and drie out the upper layers.

On good land grass does not exhaust plant foods, but it does draw upon the water. In dry and cold situations this effect may become very great. The chief harm is that it checks reproduction.

b. Moss cover. There are two groups:
1) Ordinary moss.
2) Sphagnum moss.

Ordinary moss is not injurious; it prevents hardening of the soil from rain impact and keeps the soil cool. In a cold climate, however, keeping the soil cool may check the bacteria, thus leading to a duff for mation.

Sphagnum mosses take up moisture easily but <u>they hold it</u>. They do not need mineral ~~salts~~ soil and dislike potash and lime. They <u>do</u> need light, however; since they do not need K and Ca they are found on poor lands. In cold and humid climates they go into the woods and turn the forest into marshes and moss-bogs. Thousands upon thousands of square miles of such areas may be found, conspicuous among which are the muskeg of Canada, in the spruce.

<u>c</u>. Small bushy, woody plants, etc.

Such are huckleberry, heather, bramble, etc. Huckleberrie dislike rich soil; they tend to form dense mats on the soil, and form sour humus. Their effect is to:

1) Harden sand

2) Destroy flocculation, thus reducing the pore space, and therefore the aeration.

Heather is worse than huckleberry.

The total effect, however, is not injurious to the soil, as consideration must be given to the protection given against rain, holding snow, and forming some litter.

<u>d</u>. Chaparral.

In California, Washington, etc. See Forest Service Bulletin 85.

This condition of chaparral occurs on good soils in arid regions. It consists of a variety of species of trees. In San Gabriel county they are permanent. They resist frost. In the Mt. Shasta region they come in on old burns.

The form of chaparral is much like a forest cover. The growth is like that of forest trees growing near the timber line. Such a cover keeps the soil in good condition. It is a better preventative of erosion than the forest. This cover resists forest growth more in arid regions. They are intolerant and cannot stand shade.

<u>4</u>. Cases of very Typical Forest in regard Soil.

This will be a comparison of different forms of forest, to some extent.

1) Pine forest on sandy land in both north and south.

<u>a</u>. Case of young growth 3' high: Growth rapid, stand dense, good production of mulch, roots get down; effect good, soil well tilled.

<u>b</u>. Sapling stand: Maximum growth. The stand opens up a little; the crown rises. The soil is still helped, but not as much as in the former stage, so far as regards cleaning and mulch.

<u>c</u>. Pole stage: About the same as given before (under 2d, page 135).

<u>d</u>. Tree stage: Same as before (2e, page 135).

<u>e</u>. On poor sites; poor, cold, etc.

On such lands we have to get such stands as lodgepole pine, Jack pine, etc. These sites may stagnate. The trees are stunted. Such a stand may be old and yet very small. The crowns are poor, deformed; the mulch on the soil is almost lacking; there is poor soil life, much leaching, mosses and lichens, etc., and no growth. Often the climate is cold, preventing small and brush growth. The soil hardens and

leaches. Often there is no ground cover except lichens and scrub huckleberry. The forest and the soil cannot help each other until burned over or until it dies. Then Jack pine comes and rejuvenates it.
(quite common in reforestation)

f. From the above conditions, the roots often get diseased and die out, killing the forest. Trees die and thin out; the root disease does not show much above the ground. Pine and spruce in Switzerland are good examples. There they improved spruce temporarily by manual tilth, with hoes and mattocks. The condition was probably due to insufficient aeration from agricultural lands.

g. Cared-for stand-s of pine. These are pure and thrifty, tho fewer in number; the total growth is the same as in the dense wild stand, but abundant thinnings are made, so there is less mulch from leaves, twigs, bark, etc. Is the forest soil here as well benefited as the uncared for stand with more mulch? Consider this point; Mayr said not: that wild woods without thinning by man is better in soil; when man thins it out the soil decreases and no longer improves and holds the land. Duff may come. This is an interesting question.

h. Lack of assistance to soil in these pineries has led to the practice of underplanting pine with beech. This adds a new young stand with more and better mulch and better tillage and helps the soil.

i. The clear-cutting and planting method is now common. The soil is opened up and exposed to sun, wind and rain. The humus burns out. The soil heats, dries, freezes, settles, hardens and leaches. Soil life is decreased to a small % of the normal, therefore fertility is seriously reduced. The soil being a poor sand (light), the changes are all the more disastrous. The wind is the most important factor. It is better to cut small areas at a time. Mulch blows in too. A larger area has worse conditions of soil than a small area when cut clean.

j. Clear-cutting: the young plantation takes 5 years to make a cover, and several years mor to bring the soil back to normal. This is a loss of growth to trees themselves. This loss of fertility is felt for years afterwards. The loss from badly ~~leaking~~ leaching sands is never regained.

2) Spruce Forest.

a. Young stand 3' and over: is dense; the cover is perfect. The shallow roots till the soil near the surface, the growth is rapid, there is moderate mulch. The mulch of the leaves is inferior, packs closely, and resists decay.

b. Sapling and pole stand: there is a very large growth per acre per year. The debris and mulch are abundant, the root system continues shallow, and uses the top soil; it even works in duff or mulch itself. There is good cover, the mulch is fairly abundant, but of inferiot quality; the shallow tillage dries and exhausts the top soil. There is poor aeration and poor soil life; therefore the soil settles, tends to leach, and becomes deficient in salts, especially nitrogen.

c. Pole or tree stage: spruce continues without material change; it keeps a very dense cover, preventing all kinds of herbaceous growth and reproduction (grass, etc.).

d. Generally spruce requires special climatic sites, does not help the soil, and tends to convert the land to a form supporting only spruce (toxins). On large acres of beech land, the introduction of spruc drove the beech out. This was probably due to a change in the physical condition of the soil. Lands sometimes get "tired" of spruce, and then it is difficult to grow other species there. Ramam applies this to all species, but this is a doubtful policy, for beech and certain species will put the soil in a condition good for anything. But large areas are abused by certain species; spruce, heather in Europe, and mosses, which deaden the soil, hardens it and kills bacteria. So Ramam is partially correct. Get the hardwoods back on the land; they will help the soil even if the venture is not financially profitable for direct crops. Hard wood foresters believe in rotation; this can be done but is difficult. Spruce in southern Germany grows $10.00 per acre, which is $6.00 net ove all expenses; few foresters will give up such an income for beech on a long-time rotation, for beech does not pay as well as that.

3) Beech Forest. Mixed hardwoods.

a. Young growth: The roots are dense, deep and intensive; there is much growth per acre, ~~that~~ a large proportion of the growth is of the best mulch; the stand is deciduous, and the sun gets to the groun in the fall and spring; consequently there is always some spring herbacious vegetation. The winds affect the ground part of the year. There is better ventilation of the woods, better mulch and better aeration of soi

The soil is benefited by excellent tillage, there is much mulch o high quality, good aeration, abundant soil life making for fine soil, an great moisture capacity.

b. The same conditions continue to mature timber. The time of maximum growth in beech comes late. Mulch material always forms more tha half than half the growth. The tillage os good, there is good soil life. A large proportion of the mold and top-soil is made of the excrements of animals.

c. On poor land, especially sand with little lime and much mulch, beech sometimes grows well and yet is unable to prevent turf form ing and growing under the stand. This is rare even in Europe. A longer season and higher temperature obviates this difficulty.

4) Oak.

Oak isSimilar in its behaviour to beech.

a. Young stand: dense growth, planty of mulch, deep roots, starts late in the spring.

b. Pole stand: the stand and the crown open up, so vegetation comes in; the soil dries and hardens for lack of protection.

c. From now on the oak is unable to care for the soil. Therefore underplanting is used. Nature normally does the same thing herself.

d. On poor sands in moderate climates oak can do more for the soil than other hardwoods, because of its deep rooting.

5) Mixed forest and all-aged forest in regard to soil.

a. A mixed forest of several species makes various demands on the soil, soil quality and soil moisture; it differs in the size of the

trees, in density, and therefore in tillage and in the mulch prodüced. It stinulates soil life, owing to the variety of mulch. Where the mixtyre is part deciduous there is the advantage of greater soil formation, aeration, and soil moisture, and herbaceous plants come in and assist in working up the humus, therefore the action is beneficial. This is valuable in spruce woods, as it affords a means of cleaning out the debris.

b. In an all-aged stand, even if pure, there is a variety of tree sizes, from brush to timber; therefore there is a variety of cover, shape, protection from wind and rain, a difference in tillage and use of soil, and a difference in mulch production. Unfourtunately, lean sands are driven to pine; others will not come. Pines do not do well as uneven-aged stands. An extreme case of this is the Jack pine in the north. It will not grow in uneven-aged stands; it will come in on burns, but not under an old stand. It gives the least amount of help to the forester. This is also true of hard pines. It is largely a matter of tolerance.

N) Physiography of Soil.

1. Depth of soil depends on its origin and manner of building up.

a. Water and wind transportation give large areas of uniform deep soils, sands, and silts.

b. Water transportation gave and gives smaller areas of such uniform soils in valleys, etc.

d. Glacial drift gave large areas of unusually deep soil accumulations, very variable in kind and structure of material.

d. Soils in place usually vary in wide limits, even on small areas, in keeping with the variation of the rock material itself.

e. Shallow soils are more variable than deep soils; this variation is felt more by plants. This is also true of hardpan.

2. Topography affects soils.

a. Steep grounds tend to wash off bodily. Agriculture ceases at 30% slopes, cultivated forest at 60%. Beyond this point woods are "protected forests", rocks holding the sand, etc.

b. All slopes wash (this is axiomatic), and the best soil tends to go down to the bottom.

c. Soil on slopes is normally over-drained; water moves faster and soils leach more than on the level.

d. Slope affects soil temperature. Cold and warm sites on east and west slopes. Following is the order of the different exposures in regard to warmth and coldness, beginning with the warmest and ending with the coldest: SW, S, SE, W, E, NE, NW, N.

The effect of the direct sun in latitude 48° N. is practically nil in January, when the angle of slope is 55° or more, for north slopes. The soil warms up in summer:

June : Jan. :: 8 : 7
Sept. : Jan. :: 3 : 1 on the level.

e. Slope, by affecting temperature, affects soil evaporation,

and transpiration from plants, and therefore affects the moisture contents and condition of soil. A warmer slope dries more and therefore grows warmer. This may often reach an aggravated condition.

f. Topography affects transportation of soil. It is the great influence.

g. Topography determines drainage and water distributiona dnd levels, the abundance of moisture, and therefore the moisture contents. Topography locates swamps, and it may fill them up bodily with soil material, also lakes, and peat bogs.

3. Climate (temperature, moisture, wind) affects soil.

a. Arid soils are rich in salts regardless of temperature.

b. Humid soils are constantly leached and must rebuild. In deep sands rebuilding is a precarious process: there is little to build from, and the soil must stay poor, often too poor for any vegetation.

c. Low temperature and low (great?) soil moisture aggravate the case and give cold sour dead soils.

d. Wind affects soils in arid countries and with very poor soils it transports and drifts the soil. In mountains with~~ááá~~ SW exposures the wind aids drying, especially in the upper soil layers and therefore it affects most the reproduction of growth. Heating aggravate wind circulation.

e. Snow affects soil temperature in winter and spring, prevents frost and affects percolation and saturation of the soil, and there fore affects the underground runoff.

f. Stony material left by water ~~ááá~~ protects the soil from erosion, and evaporation, and tends to raise the soil temperature. In Pennsylvania and the Appalachians it tends to warm the soils.

O) Biotic Factors of Site.

Here will be discussed the effects of plants and animals.

1. Plants and animals may help, hinder, and sometimes prevent forest growth.

a. Plants and animals bearing some relation to the fertility of the soil have been discussed before, and so here we will discuss only those which are not connected with the soil but which affect trees and their development directly.

b. Every forest tree 100 years old has probably been attacked somewhere by insects and fungi for more than 75 years.

c. Every forest tree 100 years old has shed leaves, bark, roo and has been mutilated by the wind, and therefore portions have been broken away and destroyed.

d. Every kind of forest tree is subject to attacks of many fungi and insects, and most trees are eaten in parts by animals.

e. More than 500 species of insects attacks the oaks in the United States. They destroyed completely the tamarack, and the pine in

parts of the west over large areas. The beetle hinders the black locust all thru the eastern United States. The gypsy moth is now endangering all the spruce all over the United States. The bark disease of the chestnut threatens to annihilate it. The fungus Pisisa stopped the extension of European larch in Germany and France. The bamboo exterminates whole forests in parts of the tropics. The Sphagnum moss has and is now destroying millions of acres of forest.

f. This matter is more serious on poor soil and in cold climates, because here we have little choice of species. Those same conditions are found in hot countries: moss in the north, chaparral in California, bamboo and canes in the tropics.

g. In general the forest is not driven out permanently by other biotic factors. The forest is itself a tremendous biotic factor. But it may be temporarily driven out, except in the cases of Sphagnum and chaparral, which are more or less permanent. The extent of the effect is therefore not estimatable, in general. Buffalo and other game animals furnished food, multiplied and became potent biotic factors, together with grazing animals, as they probably checked forest growth and encouraged grasses. The fringe forest was restricted.

Usually the effect is the loss of one or two species and a temporary change in composition.

Biotic factors are universally and always on hand; they everywhere tend to interfere with growth, with development in size and form, and with reproduction. They are as important to the woods as soil.

2. Fungi and larger plants (herbaceous).
Few fungi and bacteria actually help trees; most of them injure trees. All wood-destroying fungi are a necessary scavenger feature in the economy of the forest. It is necessary for Nature to employ such agents.

3. Insects and larvae are generally injurious, and next to man are the great enemy of the forest. They are, however, useful as side factors in regard to cross-fertilization, and they are an especially tremendous factor in fighting each other. They may be adapted, therefore, as biotic factors in combating injurious insects.

4. Rodents and browsing animals are generally injurious, but often are useful biotic factors. Beechnuts and other seeds are frequently planted by these animals, ~~Larger~~ including squirrels. Larger animals act as a check on insect ravages.

5. Man is an important regulator and the worst destroyer of the forest. He has removed the forest over enormous areas, he has destroyed it by fire, he has used its wood, and introduced new species.

P. Classify, Judge, and Use the Site.
A good reference is Hilgard, page 487 and following. Copy the table from page 497 in that book.

1. Usually we classify sites in five classes. Ordinarily three classes are sufficient.
a. The classification of site by volume of useful material is scientific and probably will be the final form everywhere. It is difficult to apply in the wild-woods because stands growing under reasonably

average conditions are ~~(not)~~ uncommon. Conditions are better in Europe. Different nations have different methods, but they all agree on site classification.

b. The classification of site by size of the individual tree (stem analysis) is easier to apply and simpler for the wild-woods conditions.

c. The study of composition, stand, and herbacious flora ~~&&~~ and shrubs is helpful. If a species will or will nor quit, it indicates sour soil, or some such clew. Local studies are necessary, but may not be satisfactory or convincing, especially if carried on too large a scale, or not exact or definite enough. Such are studies of topography, site, etc., which are carried on by some farmers. The presence of Jack pine shows poor land.

d. The study of the site factors themselves is laborious, and should include an analysis of soils, etc. Of the site classifications in Europe, not 1 in 1000 was determined by the study of the site itself. This is scientific study, and is often good for preliminary work.

e. The study, classification and mapping of sites is always one of the important tasks of the forester in the field. Sites, especially in regard to soil, topography and exposure, vary in wide limits on both small and large areas. Mistakes in European work occur because they generally do not take these variations into consideration.

In the United States we do not plant ~~as~~ big areas with one species as has been done in Europe, but we have tended to other mistakes of our own.

2. Variations in site. The forester and the site.

a. These variations, as mentioned above, results in different growth and different kinds of timber, volume, quality, size, and rate of growth, which affects the money question. Here was an important case in hand: Europe raised oak on different classes of lands; it was good on sites I and II, but it was not profitable even on II at 3%. Sites III, IV and V were not profitable.

b. These variations demand different species and proper choice of species.

c. These variations demand different treatment for different kinds of stands, as selection, etc.

3. Site and the Forester.

We make site: we irrigate, till, manure, give it organic and inorganic matter, and even change the topography.

The forester affects site only thru the forest cover itself. His means are:

1) A choice of species. Avoid poor trees of poor cover; exposed or poor lands, etc.

2) Keep the cover in the best shpe possible to keep the soil alive and active, and do not waste the soil moisture.

3) Avoid even temporary breaks in soil protection unless the climate and soil are amply able to stand it.

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SILVICULTURE

Chapter IV.

THE STAND.

A. THE SILVICS OF THE STAND.

1. The Tree.

The tree starts as a ssedling and passes thru several stages, sapling, pole, standard, veteran. There is no special stimulus for heigh hrowth; there is good diameter growth, the stem is thick at the butt, the tree is windfirm; the final form is typical of the species.

With plenty of food the volume growth is fast and is kept up to old age, with no maximum for ordinary ages. The fruits are ample and the reproduction is vigorous.

The tree in the open depends on itself, as it gets no help from the outside in the beginning or in its development.

2. The Stand of Trees.

General development:

a. At first there is a dense stand of natural reproduction, with several trees per square yard.

b. A struggle for soil moisture begins early, followed by a struggle for light and crown space.

c. At a height of 5 feet there are about 10 trees per square yard, and all trees suffer from the crowding. No tree has the space, the soil or the light which it wants and can make use of.

d. Strong trees outgrow the weaker trees, while both suffer and are retarded in growth and development. They cannot spread their roots or their tops according to their nature, because they are so crowded.

e. The results in the sapling age are: a thin weak stand, a contracted sparse crown, less food and therefore less root growth; a weaker tree, less windfirm and resistant to snow, less vigorous in its own anatomy and less resistant to fungi and even to insects.

For this stage of the tree Sanitation of the forest is especially beneficial.

f. The feeding is small and insufficient for growth, therefore there is less and slower growth per tree. When the limit for the twig is reached it dies. When the limit for the tree is reached it dies, from starvation.

g. Thus a separation takes place in the stand, some trees dropping out and dying: the strong portion of the stand continues, faste at first and gradually getting slower in its growth with age until it ceases to grow any more at about 100 years; in 10, 15, or 20 years more they begin to die out again.

This results in the production of a Principal and a Secondary stand: the principal stand is composed of healthy and actively growing

trees; the secondary stand is formed of trees which began to lose in the race, were dropping behind in growth and general progress, and were to be culled out.

h. The number of trees per acre in the stand necessarily decreases as the stand grows older. The rate varies with species and with site. The following table gives the number of trees per acre of spruce on the first four sites, and of pine, beech and oak, on site I, at different ages, assuming that 5000 trees per acre were planted of each species:

Age	Spruce Site I	Spruce Site II	Spruce Site III	Spruce Site IV	Pine Site I	Beech Site I	Oak Site I
1	5000	5000	5000	5000	5000	5000	5000
20	2500	3000	4000	4500	1800	2400	3000
40	900	1600	3000	4000	620	900	680
60	450	700	1000	1400	290	400	240
80	300	380	500	600	170	260	130
100	220	260	310	360	136	190	88
200							45

Notice the elimination on Site I. An average of 2500 trees dropped out in 20 years. More elimination had taken place on Site I at 20 years than on Site IV at 40-60 years and above. Conservative thinning shows its effect.

Poor sites have less growth, even with more room. These are all European figures.

It will be noticed that the pines dropped out rapidly, because of their intolerance. Site I pine land is nevertheless poor land.

The oak site is good land and there is less decimation.

The beech follows the spruce; it is fully as tolerant, but has a larger crown and demands more room, etc.

A 100 year oak is only half grown. It requires a 2-century rotation, so the above figures for oak are not quite in the same class as the others. Oak at 20 years still has enormous numbers of trees per acre, and the big drop comes at 20-40 years.

i. A similar decrease in numbers takes place in wild-woods, tho here it is more erratic, slower or faster in different cases. If it is too slow for the good of the stand, the stand is stagnated, usually on poor sites. But lodgepole on a good site may do the same thing. Jack pine, Norway pine, and spruce also show this effect.

j. The forester is interested in the amount of growing space necessary for the tree at different periods of its life on properly stocked land. One acre contains about 4900 square yards (70 x 70); call it 5000 sq.yds. Then

$$\frac{5000}{\text{no. of trees per A}} = \text{no. of sq.yds. growing space per tree.}$$

In the wild-woods the trees are placed more irregularly than in a cared-for stand, and they grow more irregularly. The freeing and riddance of suppressed trees takes place by fits and jerks. Groups of trees are separated out. They lack balance or adjustment; there is a greater number of trees in a young stand, and they clean more thoroly than in the old stand, where there is a smaller number.

Growing space is important. How much room should the different species have at different ages? A few figures are given for reference:

1) Pine)		at 20 yrs.	2 yds.sq.	or	6 ft. sq.
Beech)	Site I:	40	3	"	9
Maple)		60	4	"	12
		80	5	"	15
		100	6	"	18
		120	7	"	21
		160	8	"	24
		200	9	"	27

2) Spruce)
Balsam) 25% less than above.

3) Oak: 25% more than above, especially after 60 years.

These figures should be helpful to give some idea. They are easy to remember in sequence, if the run of the figures be noticed.

k. The stand forms a cover on the land. Is it fully or partially stocked and what is its expression? A crown cover is shading. It may be one-storied, two or more storied, or it may form an irregular canopy. This differs for pine and spruce. The spruce has a better and more perfect crown cover than pine.
The crown cover must be estimated; it can not be measured. A convenient standard of estimate should be used.

1. Best way: In order to arrive at definite measurements we commonly employ the sum of the area of the cross-sections of trees. Caliper the trees and get their areas (in cross-section). Assume such a figure as 200 ft.; perhaps a good fully stocked stand should have 220 ffet. This gives us a means of comparison: Europeans divide this by the area of an acre, 43000 feet, say. Then:

$$\frac{200}{43000} = \frac{1}{225} = 2.15\%,\ \text{ratio of sum of areas and land.}$$

This ratio ordinarily ought to vary between 0.15% and 0.50%, as trees grow larger in area as they grow older.

Another European method is the use of the distance factor. This is a different point of view. As before, calipering gives the average diameters:

185 trees per A at 20" ave. diam. gives 1.6 ft.

$\frac{5000}{185}$ = no. of sq.yds. per tree, gives distance between them; about 25 sq. yds. or 5 yds.sq. Call this "e" = 15 ft.

Then $\frac{e}{\text{diam.}} = \frac{15}{1.6}$ = 0.9ft. or over, which is the distance factor.

The following table shows how this works:

Beech (an actual case):				
Age in yrs.	60	80	100	120
Ave.cross-sec.	100	120	140	160 sq.ft.
Distance factor	17.5	16	14.5	14-+-declines.

If a stand at 80 years had a distance factor of 23, it was under stocked, as may readily be perceived from this table. Thus the distance factor gives a clue as to the condition of the stand.

m. The behaviour of the tree in the stand is partly good and partly bad. Trees help each other:

1) They protect the site for each other.
2) They protect each other from the wind, snow and frost.
3) Trees force each other to take on better form, a cleaner bole, and higher quality. The tree itself cares nothing about the last point; the first two only are important to the tree itself. Here the forest is a great factor of site: they help each other, and afford mutual protection.

Trees hurt each other:

1) Competition for soil, moisture and light.
2) Retard each other's growth, fruiting or reproduction, and in very dense stands they diminish each other's vigor and safety.
3) Smaller individual growth--a longer time elapses before they are valuable to man.

n. The edge of the stand presents important peculiarities, yet they have never been dealt with extensively. Mayr was the first to treat of this point. It has been studied by practioners but not much by writers. It forms a line of contact of dissimilar elements.

Two trees close together force the development of one-sided crowns. This is of universal occurrence.
The same if true of the spreading tree in the forest. It affects others unpleasantly and injuriously.

The edge of an opening in the woods: develops poorly cleaned timber; it is a border where the trees differ from those within, with all species. They are limby all the way down, are one-sided, and therefore there are no straight boles. But the border is valuable and necessary to the stand. Young trees on the edge have to grow outward to get a fighting chance, as for instance, the fight between oak and Scotch pine, or between birch and spruce or white pine. They are whipped, crowded, and disfigured.

Such edges are more injurious with mixed stands on opposite sides less injurious with pure stands on opposite sides. Hardwoods are more aggressive than conifers, especially beech. The condition along the edge are aggravated with respect to the north and south sides. They are worse on the north or shady side than on the sunny or south side; the fight is easier on the south side.

In general the edge of a group, line or point of contact of larger or dissimilar elements or stiff results in a difference in development, injures growth, form, and quality, just as with small groups. There is less growth per acre, more deformed and less perfectly cleaned timber. This is important, and is well appreciated by European practitioners. They often cut young balsam clear off of an area to avoid such trouble.

Fire lines and compartment lines also present the above difficulties, as does the strip system forest. Choose the least of several evils according to whether you want the timber or the reproduction, etc.

The edge in the forest is one of the important silvicultural phases with which the forester must deal.

o. Growth in the ~~un~~Cared-for Stand. Schwappach's figures will be used in the tables given here. He worked them up for spruce, pine, beech and for oak, in separate books. A few have been selected by Mr. Roth for this topic.

Volume growth of stand. This table gives the average volume of cordwood on Site I, on a fully stocked acre; the figures are based on actual measurements taken every 5 years by under the direction of the German Experimental Stations.

Spruce. Vol.growth cdwd. Site I.

		Ave.tree in stand:				Sum of	Current growth		
	# trees:	Ht.:	Diam.:	Vol.	Vol.of	thinnings			Ave.
Age:	per A.	ft.:	DBH.:	cu.ft.:	main stand:	cu.ft	cu.ft.:	%	growth:
20:	2600	22	3.0	0.25	650	0	200	14.0	22
40:	900	55	6.0	6.3	5700	500	310	4.6	155
60:	450	83	9.5	21.0	9600	2000	220	1.9	193
80:	320	100	12.8	37.0	12000	3600	180	1.2	195
100:	220	112	15.6	46.0	14000	5000	150	0.8	190
120:	180	122	17.3	89.0	16000	6100	125	0.6	184
					per acre.				

The "main stand" is the Principal stand; the secondary stand is the thinnings.

Notice the current growth: at 120 years it grew 1/3 as much as at 40 years. At 60 years it grows less than 2% in volume; this is a small interest on the capital after 60 years.

The average growth is $\frac{\text{total growth}}{\text{age}}$. It is greatest at 80 years, which is later than the current growth.

The next table is for spruce on Sites I,II,III,IV,V, trees above 3 inches in diameter: main stand plus thinnings: in hundred cu.ft.:

Total Growth per acre.

Age	Site I	Site II	Site III	Site IV	Site V
20	6.5	0.8	0.	0.	0
40	62.0	33.	16	6.5	1.8
60	116.0	80.	52	29	14
80	156.0	120.	86	56	34
100	190.0	150.	113	83	53
120	215.0	173.	140	93	no more

Site I: at 60 years there were nearly 2 cords per acre. This is about the maximum.

Site II should have ¾ the timber on Site I.)
Site III should have ¾ the timber on Site II.) Stock figures.

(To next page)

Current Growth, Site I. (in cu.ft.)
Pine, beech, oak.

Age	Pine	Beech	Oak
20	0	60	0
40	160	170	200
60	120	180	180
80	100	165	150
100	84	145	116
120	75	125	95
140	55	100	85

The current growth comes to a maximum very early in the life of the stand; at 40 years with pine and spruce; 60 years with beech; at 120 is 1/3 of best. (and oak)

Total Growth in hundred cu.ft.

Age	Pine	Beech	Oak
20	16	---	---
40	90	19	27
60	67	55	59
80	91	91	88
100	109	121	112
120	125	146	132
140	136	168	147

Above a certain age the maximum drops off and the timber gets old.
Beech starts slowly but passes pine between 80-100 years. The same is true of oak at 120-140 years, when it reaches its maximum.

Quality Growth Value per cu.ft. in cents.
German prices for Site I.

Age	Pine	Spruce	Beech	Oak
20	--	6¢	--	--
40	6¢	9	5.0¢	9.8¢
60	7	10	5.0	12
80	9	12	5.0	13
100	10	13 mx:	5.2	16
120	12	13	5.2	19
140	13	no more	5.3	21
	max.			

Pine adds heartwood as it gets older; it is different from spruce. This is not regarded in the United States.

Beech is used for firewood in northern Germany. In this respect they are behind Michigan today in the proper Utilization of beech timber. The figures show it, too.

Oak varies in different parts of Germany. It is often rejected in favor of beech, which we would be glad to use. It is raised for big timber (200 years for 25¢ ave.) in the Rhine country and France. Its chief use is veneer.

When a man pays $10 per M feet he pays 6.5¢ per cu.ft. of logs, counting 10 logs per M. This gives us a basis of comparison between these European figures and our figures.

Current Growth, Site I. (in cu.ft.)
Pine, beech, oak.

Age	Pine	Beech	Oak
20	0	60	0
40	150	170	200
60	120	180	150
80	100	165	190
100	84	145	125
120	75	125	95
140	58	100	85

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Total Growth In hundred cu.ft.

Age	Pine	Beech	Oak
20	16	---	---
40	30	19	27
60	60	52	59
80	81	91	80
100	103	121	112
120	125	140	133
140	136	165	147

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Quality Growth Value per cu.ft. in cents. German prices for Site I.

Age	Pine	Spruce	Beech	Oak
20	--	6¢	--	--
40	5¢	9	5.4¢	9.5¢
60	7	10	5.0	12
80	9	12	5.0	13
100	10	13 max	5.2	16
120	12	13	5.2	19
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When a man pays $10 per M feet he pays 0.5¢ per cu.ft. of log[illegible] counting 10 logs per M. This gives us a basis of comparison between European figures and our figures.

p. Growth in Uncared-for Land: The trees all proceed similarly at the start; they must fight, success is variable, in spots and clumps where the stronger trees go ahead. At a certain age the acre is stocked as fully as it can be stocked. A portion of the stand is being annihilated during growth, to be thinned out. If the stand is not cared for, will this annihilation go on side by side with growth? At what time would you have the maximum amount of timber on the acre, with spruce, Scotch pine, etc.? Annihilation finally takes the whole stand at the end.

We have reached the most interesting part of Forestry, the development of stands of timber or The Study of the Life of the Forest. Notice the salient features of this development and study them more in detail.

As said above, there comes a time when the maximum stand is reached, and it will deteriorate afterwards. At what age is this?

With Scotch pine in Mich. this age is reached at 60 years, if uncared for. Thinning helps, but not indefinitely; the limit is again reached at 80 years. You must either thin the stand or have it die on your hands. The limit comes later on in tolerant trees.

So there are two factors with which the forester must deal:
In early life: competition. kills trees.
In maturity: trees die naturally.

An even-aged stand: the trees come up together. They generally are not all one size, but develop size classes. The difference is greater in wild-woods. Even in cared-for woods in Germany, in a 100 year stand of spruce on Site I:
Height varied from 100' down to 70';
Volume " " 100 cu.ft. down to 30 cu.ft.
This shows a rather astonishing variation between a small and a large tree in the same stand.

In 100 year pine height varied from 90 to 60 ft.
In 90-60 year beech height varied from 80-60 ft.
Generally the difference is greater in tolerant trees than in intolerant trees. The height difference here was less than in spruce.

q. The development of a stand of timber is never uniform on a large area; it varies from acre to acre, according to site, accident, etc. Disturbance may be by single trees, by clumps, or by tracts. A large stand rarely has the same requirements in different parts. Wind, frost, ice, etc., are normal conditions; insects, hail, etc., all affects the tree.

One hundred acres of 60 year spruce densely planted is sensitive, and as soon as it is broken anywhere trouble comes. The European forester uses small compartments, and develops strong borders with good crowns. It is good Silvicultural practice to have as small patches as possible. The German forester today is going down, not up, in the size of his patches, often even to 20 acre lots in big forests. Small lots are easier to handle. If it is injured, it is easy to cut it clean and reforest, easier than if it was on a large lot. This method gives a lot of independent pieces, which may be separated by a lane wide enough to separate the crowns, say about a chain (66 feet).
(Insert : Dorr Skeels and Lodgepole pine).
Shelterwood 5-plat forests near the Black Forest.
Nature does the same thing, but is wasteful.

g. Growth in Uncared-for Land: The trees all proceed simila at the start; they must fight, success is variable, in spots and clum where the stronger trees go ahead. At a certain age the acre is stock as fully as it can be stocked. A portion of the stand is being annihi ted during growth, to be thinned out. If the stand is not cared for, this annihilation go on side by side with growth? At what time would you have the maximum amount of timber on the acre, with spruce, Scotc pine, etc.? Annihilation finally takes the whole stand at the end.

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(Insert: Dark Thesis and Lodgepole pine)

Shelterwood 3-plot reaches near the Black Forest.
Results from the same thing, but is greater.

(Different Forms of Forests and their Development)
3. All-aged or Many-aged Stands.
We will consider the pure forest.

a. For this discussion we will assume reproduction by seed primarily; we will not include sprouts, tho they occur sometimes. There are three conditions which arise: Seedlings:

1) Reproduction under the mother tree. The young stuff here lacks light, suffers from severe root competition, is deprived of rain that is shed from the tree, may be stunted for years, may barely live when finally free, and may go on as a runt or may recover and grow to be a tree. Eastern spruce and southern pine are good examples. Austin Cary sent Mr. Roth a stem which was 50 years old and less than 3 inches in diameter; what would such a tree do if released from binding conditions? Would it yet form a fair tree? There is always a severe struggle for the young trees; their growth is slow and more or less deformed; it rarely ever forms good timber unless freed before it is 25 years old even with tolerant species.

2) Reproduction in gaps between larger trees. The seed from the crown drops into the "trough". The young trees has a hard struggle, with especially grave root competition. It receives some light and rain thru the gap; it pushes toward the light, fights the edge conditions offered by the mother conditions, and in general is obliged to bend, and becomes distorted or one-sided.

3) The young stuff comes up in larger gaps between the trees It commonly forms a dense thicket, is of small form; they fight among themselves and the big stuff at the edge. In this group a few go ahead and they make fine trees; those at the edge always suffer from competition with old trees and young stuff.

4) Occasionally only a few trees start thus, grow up as in the open and develop into large spreaders, big-crwon stuff. They are under almost ideal conditions of space and protection. Nature keeps up her influence and out of many trials a few succeed.

It is the business of the forester to help the trees. If he has more trees than is desirable he has the axe. But is it easy for him likewise to affect reproduction in the many-aged stand in a large forest? The selection system leads to this condition. In general it is not easy to materially influence reproduction in the many-aged stands.

b. When these trees become saplings they are all right if in groups where they get normal competition. Whenever they border an opening they tend to spread one-sidedly; they normally clean one-sidedly, ten to produce a bent stand, and even a crooked stand in many species, even with good trees. Often the sapling remains stunted, defective, and hopeless. Under good conditions for growth, the growth is of the best, bevause the site conditions are maintained.

c. The pole and tree stage. The timber is good; the runts are dead or have been culled out. The few trees which did start right grow well because of good protection against wind, etc. and protection of site Usually the timber in all-aged stands is especially sound, it has great vigor and is able to live to a great age, but always a goodly per cent are spreaded, limby and while hardy is deformed timber. Good illustrations of these conditions are to be found in the wild-woods.

d. The statements in the previous paragraph (c) apply to tolerant and mixed hardwood species. In pine and oak of the similar tolerancy a number of trees usually give up, the ground does not fill with reproduction, many weeds and brush come in, and the soil becomes hardened.

Stands start in the open and come up in even-aged thickets, and go down together, giving rise to fungi.

4. Mixed Stands.

a. Mixed even-aged stands.

Different kinds start and grow differently even in the same acre. There is a differende in the rate and persistence of growth in the crown. One species may gain in height, top development and spread, and modifies in cleaning. This tends to an unequal and therefore unsymmetrical development: it produces poor, crooked, bent timber, often a result of suppression. Under suitable conditions the best of timber results, because the site is maintained by the mixed stand: this produces rapid growth, health and longevity, at the best. Help is not easily given to a stand of this kind, because each species has its own needs, differing from the other species.

b. Mixed many-aged stands.

Here may be applied all the statements under (a), emphasized Everywhere the edge conditions develop: cleaning, reproduction and growth of seedling, sapling and pole are as described before but subject to a more severe struggle because to unequal size is added unequal kind. They must also fight grass and weeds.

In a mixed stand the seed years come often, with the different species, therefore there are many starts and trials; some succeed. A large proportion of the stuff becomes mutilated and disfigured by the tremendous struggle between the different ages and kinds. The volume of good merchantable materials suffers materially.

5. Wild-woods Stands. Salient features.

a. There has been much misconception in regard to wild-woods from the silvicultural standpoint. It has been usually assumed:

1) That they are all-aged.
2) That they are mixed.
3) That they are mixed singly or in small groups.
4) That reproduction is under other trees.
5) That this form of forest is rigidly adhered to.

Most of this is only partly true.

b. Reproduction is mainly from seed, and yet there is much sprouting. Many species sprout: basswood, redwood, poplar, willow, etc.

Layering is important in some places. Aspen and pure white birch in the Thumb of Michigan propagate by layering. There are almost no trees but many young stands. White cedar also layered to a surprising extent. Many of the young growths there could be traced to an origin by layering. In the Cascades the spruce, balsam and hemlock often produce dense clumps by layering, especially in Alpine woods.

Reproduction in the form of sprout woods takes place over a large area, especially on wind-fall areas. They often follow a seed forest.

c. Wild-woods forests are well defined in older and younger timber. It is rare that uniform age and composition occur. They are

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c. Wild-woods forests are well defined in older and younger
timber. It is rare that uniform age and composition occur. They are

poorly defined along the edge. Often they give an impression of greater uniformity than really exists, tho clumps may be uniform.

Perfect single tree mixture in regard to age or kind is exceptio ~~ahla~~ al, as are also mixtures of pure groups.

d. Large areas of hardwoods are many aged in the proper sense of the word; even so it is common for stands to separate into older and younger timber. Even-aged stands occupy a very large portion of the are in the west, especially short-lived species, as the aspen, tamarack and allies; also on special sites: as lodgepole and Jack pines, on mountain sides and sands.

There also occur in the wild-woods quite commonly, stands which called "All old stands" or all-old timber. They are not even-aged stand but are composed entirely of old stuff. Such occur in western yellow pi sugar pine, redwood, red fir, the southern pinery, Norway and white pin eastern spruce, hemlock, and some hardwoods.

The all old stand is the end of any stand under ordinary conditions, if no injury of calamity happens to the forest. To the young man they may appear even-aged, but they may vary from 150 to 350 years in age. Finally decay sets in, and they break up rapidly when they do break. Most of the lumberman's logging timber is this all-old timber.

The "reserve tree" form also occurs in the west. Here the bulk of the stand has been dropped, leaving a few old ones standing. Then seed blows in, as elm, aspen, etc., and soon produces a secondary stand, with one or two old pines towering over it. This is common in Michigan.

The two-story forest is also a natural form of wild-woods. This form is often found in pine and hardwoods in the Great Lakes states, an with pine and hemlock in New York. This form may be produced in two way

1) All-old, simply differing in height: white pine and hardwo
2) Natural under-planting, as with beech under oak.

e. Pure and Mixed Wild-woods.

1) Hardwoods are generally mixed; they are pure only on special sites, often as temporary stands. Aspen and white birch form such temporary stands. Scrub oak is permanent. In southern swamps 10-20 acres of pure black gum are often found as a permanent form.

2) Coniferous forest are largely pure. Usually they are composed of better than 75% of one species. Over 50% of our coniferous forests are pure, possibly 80%. This shows indisputably that in the United States wild-woods are not mixed.

f. The reproduction of wild-woods is largely from seed. A lar amount of reproduction takes place from the sides, blown in on bare lan Such is the case with lodgepole and Jack pines. Reproduction may also occur from artificial seeding, from birds, and from some sprouting.

g. Wild-woods keep the land pretty well covered and over larg areas. They are continuous in area and continuous in time. Large areas bare land are due to failures of forests; they are more common in coniferous forests and especially on bad sites. Such may be illustrated by Ontario and its white pine, which has been burned over repeatedly. The Rocky Mountains have such situations also, and the Fringe Forest is another example.

Growth in the wild-woods is continuous and large. If the soil is

good, the trees are healthy, there is good active chlorophyll producing food, and then later the decay is tremendous. Hardwoods in southern Mic make wood at the rate of 1 cord per year, and then later decay sets && at the same rate. How much must the Forester leave on the land to keep the conditions for fertility? Should he leave just the leaves and branches, or more?

Even-aged and all-aged stands in wild-woods go out rapidly when decline sets in. Lumbermen have furnished valuable information in this spect. In wild-woods of a certain rotation it sometimes happens that t ordinary life of the species is longer than that usually set by men, an it goes farther than the net volume of the stand reached by growth. Thi may often be double or even thrice as much.

h. Wild-woods vary from place to place and from time to time. There is often great variety to be met with, sometimes so bewildering t we lose sight of certain forms which, after all, make up the body of th forest. The natural forest makes a dense cover, introduces insects and other agencies to break it up, and then patches of reproduction come in Thus Nature varies her program almost indefinitely, with both conifers and hardwoods.

B. SYSTEMS OF TREATMENT AND RESULTING FORMS OF FOREST.

This subject may also be called "Silvicultural Systems", which i nicer and better; it may also be called "Silvicultural methods" or "Met s of Treatment" They have sometimes been called "Systems" or "Methods Management", which is not accurate.

1. In Silviculture we take over from the forests of Nature certa forms, and we modify these forms. In Agriculture, in a similar way, the took over plants of Nature, rearranged, and spoiled them.

Lodgepole pine is a good example of a form of forest: it is pure and even-aged; this is very apparent here, and also with tamarack. In t wild-woods it is not so striking; many forms are here present.

Form of forest: forest which during a certain definite part of i lifetime has a definite form; example: lodgepole pine.

a. Forms recognized in wild-woods and adopted in Silviculture:

These may be considered under three heads:

1) Composition: pure or mixed

2) Origin: seed or sprout

3) Age: development: even-aged, two-aged or storied, many-aged, etc.

In detail:

a. 1) Pure and mixed forms are always distinguished sharply from beginning to end.

2) Seed and sprout forests tend to resemble each other. A 20-year old coppice does not differ from seed forest at 20 yards away; in early life there is a sharp distinction at close range, which is not so evident in later ages.

3) Even-aged stand, or form at 40 years, either of conifers or hardwoods, has just the same appearance, character and development

regardless of origin, whether from seed blown in, planted, or shelterwood. The resemblance follows from the 20-30 year on, there being then no points of difference, either advantageous or disadvantageous.

4) Two-storied form starts as even-aged forest, later being underplanted, either naturally or artificially. When its real character develops, this form is very distinct, not at all like the even-aged stan The reserve tree form is merely an extreme form of the two-storied fores in which the upper story is thinned to the point where there is merely a lot of scattering seed trees. They are often left for seed trees and are harvested with the next generation.

5) All-age or many-aged form is always distinct; it is the only form that is continuous in its physiography and development.

The all-old form is conspicuous in wild-woods, and forms a large per cent of the merchantable timber. It has not been adopted in Silviculture, because it requires too long a rotation.

<u>b.</u> In later years Silvicultural authors classified forms. Gayer is a notable example.

Of the older authors, Lorey did not classify <u>forms</u>; he classified simply the <u>methods</u> used to <u>get</u> these forms of forests.

1) Gayer's Classification:
A) Timber Forest (the Seed Forest of the Forest Service)
I. Fundamental Forms
a) Even-aged forms
<u>1</u>. Clear cut
<u>2</u>. Shelter-wood
<u>3</u>. Strip system

b) Uneven-aged forms
<u>4</u>. Selection form
<u>5</u>. Irregular forms (Gayer was indefinite: on a 100 acre lot there may be many small stands differing radically from the main stand; a "higgledy-piggledy" affair). See Graves, later.
<u>6</u>. Selection-shelterwood combination, as balsam-spruce combination. The shelterwood is extended over many seed years, an leads to a peculiar form of forest in its physiography. It looks like a selection forest on a short rotation, at an early age. At a late age it looks even-aged, with an immense difference in the age of the timber and size classes. Gayer bases his classification of <u>age</u>.

II. Auxiliary Forms.
<u>7</u>. Reserve tree forms
<u>8</u>. Two-story forms

B) <u>9</u>. Coppice form
C) <u>10</u>. Standard coppice.

Judging from the above classification, Gayer might have made thre heads under age: even, uneven, and many-aged.

~~2) Graves's Classification (Principles of Handling Woodlands page 31) This a modification of Gayer.~~
~~A) High Forest Form (Seed or Timber forest)~~
~~<u>1</u>. Selection form~~
~~<u>2</u>. Regular or even-aged form~~
~~<u>3</u>. Irregular form~~

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A) High Forest Form (Seed or Timber forest)
1. Selection form
2. Regular or even-aged form
3. Irregular form
4. Two-story form
5. Reserve form

Graves leaves out the distinction between fundamental and auxiliar form.

B) Coppice Forms
1. Regular coppice (even-aged)
2. Irregular coppice (uneven-aged)
3. Standard coppice

All these forms differ from each other; you cannot have similar forms of forest from absolutely different origins. Even Gayer confused system and form. A system (or method) leads to a form.

c. These forms of forests, as taken from Nature, have been modified in practice to suit site, species, and the notions of practione
These modifications may be:

1) In composition. As from pure to mixed forests and betwee

2) In area arrangement. Any form of forest can occupy a lar area or a small area, or it may take a whole compartment, strip, or irregular patch. This area modification led to much modification in writings and teachings in regard to the different systems, and in literature are to be found many different systems and combinations with pure and mixed forests.

3) The form of forest may be frequently modified in regard to its adherence to a definite form. It may start one way and may deviat from the form adopted. An even-aged stand may be later underplanted and becomes a two-storied form. A shelterwood form gives an even-aged stand in about 15 years; it may be extended intentionally, with light cutting, and become a combination of selection and shelterwood forest. All gradations are possible between these.

In Germany they combine the selection and shelterwood forms on th edge of a forest. In France there is a variety in coppice practice; much is clear-cut and even-aged; in some parts of France they cut only part, which produces a two-storied form, or even a selection form.

Mayr classified 72 different Silvicultural systems, each with a name, which had been introduced and practiced for some reason or other; all were successful, and had good standing in literature. But all of the forms of forest produced may be classed under one or other of the few groups above mentioned; they are merely variations or modifications of the few primary forms.

2. Systems of Methods.

a. Nature produces the principal forms of forest by dinstinct ways of reproduction rather than by influence or care after the stand is started. 1)

1) By sprout or seed.
2) Restocks burns or clear areas by seed from near-by trees
3) Starts young growth in the open parts of the stand long

before the old stand disappears, as in the shelterwood form. The old stand may remain till the two-storied form comes. With a small part of the old stand the reserve form appears.

4)By the same form of seeding in irregular areas and at various times, thus producing irregular forms, while in other placeś for certain periods it continues to give an even distribution. This produces characteristics of anall-aged or many-aged form.

b. Man has only modified these methods; he has systematized the work, extended and perfected artificial as against natural reproduction, tho he has not added any radical improvement. Like Nature he depends primarily on the method of reproduction which gives the particular form of forest desired. The methods of reproduction are therefore so intimately wrapped up with the forms of forest desired that the classifications of forms has not separated itself from the methods. Thus the methods of reproduction took on the dignity and importance of Silvicultural Systems; so in speaking of Systems we mean primarily Reproduction and not Care.

These methods may be modified:

a) In regard to composition.

b) In regard to origin or manner of starting, as seed or sprout. Seed may be classed under three heads:

1) Seeding or planting in the open; reproduction after the stand goes.

2) Seeding under trees befores the stand goes.

3) Seeding under trees continuously without the removal of the stands.

c) In regard to the time employed. Clear cutting may thus be modified for some cases. Some stands seed from the side, others seed gradually, 10-15 years, accwrding to the seed years. The shelterwood system, with one seed fall, may take k0-k5 years. This may be modified by artificial reproduction. A shelterwood on slope land may have seed years every 5 or 6 years, and continue for 40 years in all. A selection system seeding year by year has continuous reproduction. Thus these methods may be modified a great deal, in:

Area,
Size,
and the Shape and position
which is taken in hand at any one time.

Some examples will be given as found in practice:

1) A simple case: clear cut form with natural or artificial reproduction on a good sized tract. A whole 40 acre plot is cut over at one time. On a small piece may use artificial reproduction, except that many foresters are afraid of small strips; they like large pieces. On small plots there is not enough work to keep gangs of men busy, there is a small amount of stock and transportation for each plot; they are claim to be expensive and "puttering".

The regulation way now is to take it by strips in successive periods of years.

In intensive tracts as in Michigan, odd blocks of 5 to 10 acres could be treated thus.

Compartments may be formed on a large property, and each compart-

ment may be taken in strips.

They may appear even-aged, but in cross-section they will look somewhat like the following Sketch:

This is actually done in Europe.

Another modification is small patches of defective timber. Clear-cutting system is actually used when the forester gets rid of this defective timber on those plots, and he practically restocks.

If in 4 or 5 years he finds the same disease spreading he may cut along the dotted lines. This cutting will really take the form of a strip. So he has here changed from the patch to the strip method, but he has not changed to a new method; he has merel modofied the general method in regard to the shape and area and position of the timber cut.

A few definitions may be of convenience here: (U.S.F.S.)

1) Group method: a method of conservative lumbering in which groups of young trees which have sprung up in openings caused by logging, insect damage, windfall, snowbreak, or other agency, are taken as starting points for the future forest; or if these are insufficient, small openings are purposely made. Reproduction by self-sown seed from the mature stand at the edges of these groups is secured by careful cuttings which extend the groups until they join.

2) Patch method: The clean cutting of small patches to invite reproduction by self-sown seed from the surrounding forest.

3) Strip method: That method of conservative lumbering in which reproduction is secured on clean-cut strips by self-sown seed from the adjoining forest.

4) Stand method: That method of conservative lumbering in which reproduction is secured from self-sown seed by means of successive cuttings made thruout the mature stand, thus leading to the production of a new stand approximately even-aged. These successive cuttings encourage seed production, create conditions favorable to the growth of seedlings, and gradually remove the remaining trees of the mature stand as the young growth develops.

In the West other modifications are used. Sometimes a whole eighty acres may be cut but in an irregular form.

Scattered seed trees method (Graves): Patches may be left with seed trees, say 2 per acre. Would there be too many seed trees to be a clear cutting? Not with lodgepole pine. With yellow pine 40-50 seed trees are too many for clear cutting: it becomes the shelter-wood system. Supervisor W.N.White, on the Bitterrot National Forest, uses this scattered seed tree method.

Reserve stand method: leave trees which you are sure will stay for a long time. Select unusually good and hardy trees. This is a different choice from that which obtained in the scattered seed tree method. Here the quality of the trees modifies the system, but does not alter it.

Groups of seed trees may be left when the clear cutting system with natural reproduction (which is the fundamental system) is employed. This is simply another modification of the fundamental system

Seed trees left in blocks is another modification of the clear cutting system with natural reproduction. The difference between a group and a block is the difference in their sizes. A block "is the unit of management treated in a working plan", and contains at least two compartments. There are, therefore, more trees in a block than in a group, and the size of the plot is larger. So here the size of the plots modifies the fundamental system.

Thus we see that there are many modifications of the fundamental Clear Cutting System with either natural or artificial reproduction. It is the same system in all cases, but is applied differently in details. These modifications are based on:

1) Distribution of seed trees
2) Quality of seed trees
3) Number of seed trees
4) Distance of seed away
5) Area
   a. Shape
   b. Size
   c. Position

2) Shelter-wood ~~form~~ system is just the same in practice as the clear cutting system. For instance, on this 40 acre plot, the forester might cut for light in 1910
cut for seed in 1915
cut clear in 1920

Another and a very common modification, is to cut as above in a moderately sized compartment. The same can be done with a big set of compartments. It may also be tried with patches of defective timber, often with natural reproduction already started in beech or balsam.

A common modification of this is: to be sure that you systematically cover your compartment, use strips.

Some people modify modify this in still another way, as in the sketch at the left.

In this modification the idea is to get less of a sweep of wind, especially when the winds are hot and dry.

The silvicultural system used here is the same in all cases. The difference is the area arrangement: the way in which you attack your land. This depends on the size, shape and position of your area.

With a strong border it is well never to disturb tb disturb the border at first, but to begin inside and cut a strip clean, then begin a sort of selection system on the border, but not as long as its protestion is needed.

3) Selection System: the same modifications apply here as before. The forester may cut it over all in one winter and then let it go for 15 years.

Or he may use compartments, cut one at a time, and come back in 15 years. The bulk of the reproduction comes right after the cutting. If cut again in 1925, he may expect the bulk of the reproduction in 1926-1930; in other words, the reproduction after the ~~fir~~ first two cuttings comes in 1911-1915, and 1926-1930, so that in reality we do not have an even-aged stand, but a several-aged stand on the same plot. There would be about 6 distinct types.

Selection cuttings: the stand tends to group itself more and more.

Various other modifications of the Selection System are made as with the other two systems.

Often French and German terms are used. "Coulissenschla

Much of the confusion current in books in regard to Silvicultural systems is based on this area relation.

4) ?

5) Methods naturally <u>vary</u> but often <u>grade</u> into each other.

(a) The clear-cut with seed trees system readily merges into the shelterwood system.

(b) Likewise, after a long time, the shelterwood system tends to merge into the selection system.

It will be interesting to note the ground we have covered thus far We first considered the salient features of the stand, then the Wild-wood and its various forms, then we told which of these forms had been adopted and then the methods used to get these forms, and then the way in which these methods have been modified according to conditions.

6) These modifications are interesting to the United States: we are just developing our literature and our methods, and so we must understand clearly:

(a) Mayr enumerated 70 methods, falling under the fundamental methods, which are modifications of the fundamental methods according to area and time (speed).

(b) The fundamental forms or systems group as follows:

(1) Clear cut with reproduction <u>after</u> the crop is removed, leading to an even-aged form of forest.

(2) Shelterwood ~~syste~~ with reproduction before the entire crop is removed also leads to an even-aged form of forest.

(3) Selection system with reproduction continues all the time; where the stand is never removed entirely it leads to a many-aged form of forest.

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(2) Shelterwood method with reproduction before the entir[e] crop is removed also leads to an even-aged form of forest.
(3) Selection system with reproduction continues all the time; where the stand is never removed entirely it leads to a many-age[d] form of forest.

(4) Coppice where cut clear, represented by sprouts, leads to an even-aged stand.

(5) Standard coppice may be a combination of 2 distinct systems on the same area:

i. Ordinary coppice leads to an even-aged stand.

ii. A modification of the slection system leads to a severàl-aged stand on the same area.

7) We learn much from classifications. The following are classifications from Lorey and from Graves, and show how these men looked at the subject from different angles.

a) Lorey in an older edition of his famous Handbuch classified Silvicultural Systems in 1888: "Betriebsarten" (a system of Management). This was the older idea. This terminology is not in favor now; we should use Silvicultural systems, not Management systems. Yet Lorey is a good author, in spite of the fact that he did not have the right pointt of view.

A. High Forest or Seed Forest.

The tree originates from seed and the tree is used but once. A sprout stump will last thru many plantings.

1. Reproduction goes on thru the entire rotation.

1) The selection system produces an all-aged or many-aged stand.

2. Reproduction occupies only part of the period of rotation and leads to an even-aged or nearly even-aged form of stand.

1) Clear cut system with artificial reprodution.

2)

3) Shelterwood system.

4) Selection-shelterwood system. This is the shelterwood system prolonged over 40-50 years.

B. Coppice System.

C. Standard Coppice System.

Lorey felt that he ought to separate the Selection-Shelterwood system from the others.

b) Gayer: nearly follows the classification of Forms as given before (page 154).

c) Mayr in his classification again speaks, not of a Silvicultural system, but of a system of Management and Reproduction, following Lorey.

1. Clear cut system, with 5 modifications.

2. Shelterwood system, including the selection system as a form or method of shelterwood on smallest areas and for long time periods which is quite curious. The selection system should be kept separate from the shelterwood as 2 distinct systems: they give different Forms of Forest, and, also, Mayr makes his classification more complex than necessary. It all depends on the point of view.

3. Coppice

4. Standard Coppice.

d) Graves (in Principles of Handling Woodlands)

I. Systems depending on Reproduction by Seed.

A. Selection system

B. Clear cutting systems

1. Clear cut with artificial reproduction
   (a) Whole stand
   (b) Strip
   (c) Patch

2. Clear cut with natural reproduction
   (a) Whole stand at once
   (b) Reserving blocks of seed trees
   (c) " scattered seed trees
   (d) " groups of seed trees
   (e) " thrifty standards
   (f) Clear cut in strips
   (g) Clear cut in patches

   Modifications.

C. Shelterwood system

1. Cutting whole stand uniformly
2. Cutting in groups
3. Cutting in strips

II. Systems depending on Reproduction by Sprouts (Wholly or in part on sprouts (How much is "part"?)).

A. Coppice

B. Coppice with standards

C. Pole wood coppice: sprouts and seed to 40-80 years ~~old~~ (long rotation coppice).

The salient point here is distinguishing between Sustems depending on seed and on sprout. The seed systems are arranged according as the reproduction follows the cut at once, precedes the cut for some time, or goes on all the time.

8) On every large prop~~/~~erty a combination of these different systems of treatments is employed. This is axiomatic, because conditions vary so much that different treatments are required. This is found even to extremes even on National Forests: for poor timber, use the selection system; for good timber use some other system. The choice of system depends on the site and on the species. Species favor or are easier to hand with ~~[illegible]~~ certain systems. The choice also depends to some extent on the market and the object of raising the timber: for protection, for lumber, for secondary uses, for aesthetic purposes on private property or in public parks, etc.

9) We have seen that Silvicultural systems are based on the Reproduction of the forest, therefore reproduction is important, but is easily exaggerated and over-rated. In late years we have begun to realize that not only Reproduction is important, but Care of the forest is even more important. Care takes more time and therefore costs more than a "little" planting job; thinnings, etc., must be looked after. Care takes judgement and brain work. Planting is simple and well known. Thinning and caring for accidents require knowledge, experience, and judgement. It would be well not to exaggerate or over-rate Reproduction.

10) Most of these Silvicultural systems are intimately related to and bound up with the Care of the Forest. In the shelterwood and selection systems the success of the work is bound up with Forest Utilization. It is hard to log on the selection system, somtimes, and this operation is not

always successful. This applies also to the shelterwood system.

But when we call them Systems of Conservative Lumbering, as in some books (See U.S.F.S.Bulletin 61, Terms used in Forestry and Logging, pages 7,13,18,19,21,22,23,24; and other books) we are going too far. By using such nomenclature, some men, including men in high positions, become misinformed thru the magazines, and think it is merely a matter of lumbering. Lumbering is today primarily Forest Destruction . Our business of the Growing of the Forest.

With the clear cut system lumbering has no relation to us.

c. 1. Description of the Silvicultural Systems; their Operation; the Resulting Forests, and their advantages and disadvantages.

1) Compare different systems in regard to the systems themselves and their results; we must first have certain criteria:

a. Applicability of system to various species and sites.

b. Assurance of success of the system, especially in reproduction.

c. Results of the system in the quality of the stand as regards growth in volume and value.

d. Ability of the system and the resulting form of forest to maintain the site.

e. Value of the resulting forest from the business standpoint.

f. Value of the forest from the political economic standpoint, especially market, industry, labor, protection of watersheds, capital, utilization of poor lands, and finally the stability which the system assures. Some systems degenerate.

g. Special cases of secondary benefits as affected by these systems: grazing, turpentine, bark, and also the matter of beauty and park uses.

"From various authors."

2) Seed Forest compared with Sprout Woods. Their advantages and disadvantages: Advantage of seed forest:

a. The seed forest is applicable to nearly all species and all sites. It naturally occupies large areas and involves large forest areas fit only for seed forest.

b. Nature maintained seed forests for ages; man-cared forest are largely seed forest: therefore there is great assurance of success and permanence, tho ordinarily coppice is the easier of the two to reproduce.

c. The seed forest produces the largest volumes and the best qualities possible.

d. The seed forest maintains the site, soil, and leaves the forest undisturbed for long periods; it furnishes dense cover, much mulch, good tillage. Coppice requires good land and exhausts the land.

e. In business, the seed forest requires a large capital, and therefore gives opportunity for larger investment, and requires large areas for real business. The intervals between harvest are theoretically normally long (this is easily overstated; be cautious in such statements, especially in arguments: investors are easily scared) but are not so in practice: after the age of 25-30 years you can get something from your forest every ten years. With large properties yearly crops can be

obtained from different portions.

As said before, the seed forest takes more capital. In coppice you can get down to the half-acre. Seed forest gives a larger net income per acre per year, by giving us better timber.

Disadvantages: It is claimed that the seed forest makes a smaller interest on the investment. As soon as the property pays a net income, up goes the land value. Pine is usually land on a net income--the higher the net income the higher the cost. The human element enters independently.

The seed forest produces more readily salable material than coppice, and a much smaller amount of cheap unmerchantable goods. It requires more skill and knowledge to handle successfully. Mistakes which the forester makes in the seed forest are apt to live longer than those made in coppice; there is greater danger from storm, insects, etc. The crop is raised larger and in larger bodies.

f. As a whole, the seed forest is more important and valuable than the coppice can be; it supplies the market better; it can supply materials which coppice cannot; it affords more labor and gives a chance for more investment of capital; it builds up a big property per acre. The State forests of Baden and Saxony could not be bought at $1.50 per acre. If they had to tried to put in coppice, a large portion would have become valueless. The seed forest builds up a property worth 6 times as much as coppice.

The seed forest is generally more stable as a forest propoerty--it receives more care even from private individuals; it is more important as waterwhed protection; today it utilizes large areas of non-agricultural land where coppice would be of much less value.

g. Special cases of usefulness are not comparable. Grazing hurts coppice more but coppice will stand more abuse, than seed forest. Turpentine applies only to species which grow in seed forest. Tanbark today is obtained from seed forest. When prices go up we may raise tanbark coppice. For parks and pleasure grounds coppice drops out: it is not an attractive form. Some people regard the Adirondacks as more important as a playground than as a watershed and for timber. Americans could buy up forests and use them as mixtures between water protection and playground. Seed forest would be the more satisfactory for such a purpose.

h. The seed forest is doing more for the name of Forestry than is coppice.

3) Clear Cutting.

a. The forest starts from seeds, or from plants started artificially. If planted, seeds are spared, you save several years without a cover, and the crowns form an even cover; strata form, trees begin to crowd, there is great height growth, and there are no edge conditions except at the edge; the canopy pushes up, the development of individual crowns is hindered, and the height growth continues. The trees are slender, and are rapidly cleaning. In the sapling and pole stage light is effective only in the upper strata of the canopy. There is equal reduction in numbers, the largest growth in quality, the stand becomes largely cleaned, the canopy rises high above the ground; soil protection diminishes; the depth and density of the crown become variable, depending on species and site.

The secondary stand becomes supptessed and is removed; the stands begin to open; the greatest thrift is past, and the rate of volume growth rapidly dedline.

In the tree stage the maximum volume per acre is reached and passed. The stand opens up, the crowns are relatively small, and do not readily fill gaps. Any openings which occur now must remain as gaps. Growth becomes slower and slower; only put on a smaller number of the best trees which form the final crop. Now injury and stagnation require underplanting, because the stand is no longer able to help itself.

b. This system is applicable to any species which thrives as a plant in the open on that particular site. Almost all of our forest trees can be started in this way on fair or good sites.

If reproduction is natural from the side or from seed trees, this method is applicable only to high-seeded brush and to those species which seed abundantly. It is also restricted to suitable sites-- elm, ash, etc. Larch (?) is especially good; it is not too limby, and occurs on burns.

c. The clear cut with artificial reproduction system has proven successful wherever tried, and has almost completely replaced other systems over large areas in Europe. Generally young plantations suffer when the soil becomes hot and dry. In northern countries they also suffer from frost and from the freezing of the ground, and the sapling and ~~pole stage~~ small pole stage suffer from snow. Small tender ones grow close together. They also suffer from storm, but more so in the small tree stage. Plantations also suffer from fungi and insects. In very dense stands lack of a ? means an opening for insects and fungi. Pure forest aggravates the biotic factors and makes less use of variation in the soil.

d. Growth in volume and quality is in the clear cut system the greatest of any system for species, site and time. Even the secondary stand, which is out-topped, yields thinning material of well cleaned stuff and good form. The clear cut system does not always produce great timber, but nearly every tree after its 40^{th} year is a valuable stick of timber. Edge conditions present cracked and limby stuff.

The stand normally consists of a large number of trees of moderate size and well cleaned, but often has too much defective material if kept too dense.

e. The ability to maintain the soil is great, especially in the bush and sapling stages; it decreases with tree age and is zero in the period between cutting and the closing up of the next youn stand. This feature is charged as one of the greatest disadvantages of the clear cut system. The ability to preserve the soil varies with the species, as tolerant and intolerant, and this difference is greater here than in other systems. For long rotations, as 200 years and over, where reproduction is at long intervals, this difference is over-rated.

The difficulty of maintaining the soil increases with the difficulty in reproduction. The bigger the area that you cut clean the less perfect the resulting reproduction and the more the land differs.

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f. Good business prefers the clean cut and planting system and has caused it to replace other systems. The main points which business considers are:

(1) Simplicity of control, perfect control, simple bookkeeping.

(2) Cheap and simple logging--easy removal, easy measurement, etc.

(3) Easy and cheap reproduction (?). Some question this claim.

(4) Better organization, better chance in planting stuff independently of seed years; easier to make fight against fungi and insects. Largest yields of salable material.

(5) Less call on abolity and industry of foresters. One man can handle a larger area and more intensively than in the shelterwood and selection systems.

(6) Both gross and net incomes have vastly increased with the spread of this system.

(7) The greatest losses from insects and from snow and storm have come since the spread of the clear cut system. But stress should not be laid upon the loss by insects.

g. From the standpoint of the State this system and the resulting forest are ideal forests and do the same as under seed forest (pages 162-163), except that the permanency of the forest is questioned on account of insects and also from deterioration of land. In the supply of the modern market demands this system and its resulting forest excell all others. We use hardwoods more extensively and effeciently than they do in Europe but we want 3 feet of Softwoods to 1 foot of ~~xxxxxxx~~ hardwoods. Softwood is King and we can raise it in the the clear cut system.

h. The clear cut with natural reproduction system:

(1) Has proven a failure in Central Europe; it has succeeded fairly well in Scandinavia and parts of Russia. It may be that people there are willing to wait, because the soil is poor and rocky, and they cannot use it otherwise anyway. Growth is slow; they have to wait 50 years to get railroad ties, so people are willing to wait. In France and Germany, where land is costly, they cannot afford to wait, or could not 130 years ago, in Central Europe.

(2) The land becomes dead, brushy; the seed years are not numerous, and when they come are dependent on the weather. This system has largely been abandoned in Central Europe.

Suppose forest land is worth $2.50 average rental. Then:

	Natural	Plant
Reproduction	$0.00	$10.00
Rent	25.00	25.00
Total for 10 yrs	$25.00	$35.00
Results:	Stand variable	Stand well stocked
Age:	10 yrs.	12 yrs.
Spots:	(Dense (Thin (Park	
Actual value:		$100.00 in New England
Could not have the species you want; stand very irregular.		

It is hard to plant fail places in natural reproduction. (Fail spot: a place where natural or artificial reproduction has failed).

(3) If successful in reproduction the stand is too dense, at least in spots,, competition is too great for successful growth, and may easily lead to a break-down, and therefore to the introduction of fungi, insects, and in some cases to stagnation (in lodgepole). To avoid these we should use early attention, which is expensive.

(4) If the stand recovers fully the development goes on as in the planted stand.

(5) This method may be much modified, varying from one seed tree per acre to solid bunches on one side--a shelterwood standing over the area.

(6) This method has been so much praised and condemnėd that we need caution against extreme views. Loblolly, Jack pine, lodgepole, tamarack, and to a lesser extent spruce, are suited to this method. Western yellow pine is perhaps not so well suited to seeding from the side. Heavier seed gives less distance to which it will seed. Wilfred N. White believes in using open shelterwood for yellow pine. In Arizona they feel the same way, but there shelter against heat is the main thing.

4) Shelterwood System or Stand Method (U.S.F.S.)

Gayer calls this a natural form of an even-aged timber forest. It is qualified in the United States, where they seed in from the side; lodgepole with natural undergrowth is an example, or often artificial reproduction.

a. Shelterwood with natural reproduction developed largely in beech and balsam. It has been largely abandoned for spruce, and entirely for pine. Usually the stand is thinned to stimulate trees to special growth. It is again heavily thinned when the seed year comes. The remaining stand removed after serving as a shelter, when the young stand is thoroly established. When the thinning is done properly this system reproduces the stand in 3 cuts.

Cut for light: 1/3 of the timber is taken out 5-10 years before the second cut.

Cut for seed: another 1/3 is taken out when the seed year is expected, and the seed is already on the trees or on the ground.

Lastly, removal at the final cut when the young stand is 1-3 feet tall.

In ordinary practice more than 3 cuts are required, and especially the first cut is replaced by several cuts at various intervals. After one cutting, after beech has responded to stimulus another cut is made for light, and then finally the third cut is made. If beech were to be thinned too much at one thinning havoc would be created. The less care the stand gets in the sapling the more sensitive it is.

Normally young growth from seed comes up in dense patches; even oak does it; this is more so with heavy seeded trees than with light seeded trees because the seeds don't go so far away. Invariably (?) there are some patches without reproduction coming around stumps of the biggest timber, and also on poor or limby spots; such spots need artificial work. The young growth is sheltered; the amount of shelter depends on the notion of the forester; he is guided by the amount the species will endure. Shelter is provided against wind; beech forest, and with it the soil is protected.

The growth of the seedling is slow due to competition. In less tolerant species like pine there is great danger of injury to young growth from too much shade, even to the point of loss of reproduction. If the shelter is removed the stand starts as clear cut,--but starts too densely in spots and wants early help. In patches of more or less spindly growth: they suffer from snow and storms. When 20 years old it ought to resemble an artificial stand; the rest follows the system of clear cutting.

b. This system is applicable as follows: theoretically it is good for all species; practically it is applied to but few. It is possible with all species and on all sites, if you have to use it. Hartig prescribed this system for all the State forests of Prussia; they worked in pine, which is least adapted to this system.

To succeed:

(1) The tree must be tolerant si it will grow under the shade of another tree.

(2) The tree must have sufficient seed years and be a good seeder.

(3) The seedling must rest for a long time--and still recover from suppression.

(4) The tree must still be windfirm enough so you can take out cover and expose the tree. This can not be done with spruce.

c. This system was generally advocated and officially ordered as late as 1800. It was the system which had the most universal application of the time. It has been largely abandoned for most species in Central Europe because:

(1) The seed years there are far apart; some of the best species, like the beech, are poor seeders. Then, the stand opens; much blows down; the soil deteriorates and becomes limby, and closes up; there is much loss of actual income and rent altho the last third of the stand keeps growing.

(2) The reproduction is dense, and requires artificial help.

(3) Edge conditions obtain in fail spots, and they are not always of a kind that can be remidied. Above the height of 20 feet this cannot be helped; the land is practically wasted.

(4) The system did not work well in important species: pine either either refuses to seed or the reproduction dies, from shading or competition.

d. Growth, development and reproduction of the stand.

Fail ~~past~~ places are incurable, and normally cause considerable loss. If the reproduction is good and the stand variable, it varies from overdense to normal, needing early attention, expense and care for dense stands. The remaining development and results are as before because the stand is even-aged. This system has produced some magnificent stands of timber.

e. This system protects the soil better than the clear cut. The slow process is better. It needs tolerant timber; where the process fails and artificial help is not given the soil may suffer as much as in the clear cut system.

f. Intensive good business rejects the Shelterwood system.

(1) The reproduction is too uncertain, too slow, uneven, and dependent on seed years.

(2) The young stand requires too much care in the bush

and sapling age.

(3) The loss of growth suffered by the reproduction is not always made up by the growth of the old stand as shelterwood.

(4) It increases the cost of logging piecemeal, and causes an extra cost to prevent injury to old and young trees. This difficulty grows, the slower the forest develops.

(5) Because of the injury to the old stand as shelterwood, especially thru blowdowns, sunscald and the dying of the soil. Beech suffers much from sunscald, oak from watersprouts, pine from spiketopps; hemlock is good but dies if there is no reproduction and shelter.

(6) This system requires increased attention and unusual knowledge and experience to assure success. Business tolerates and uses the system:

a) The reproduction is cheap where seed is expensive or impossible to get.

b) The reproduction and the soil are sheltered, which is especially valuable in dry hot, also dry cold situations, and with certain species as balsam and spruce.

c) With the right conditions of site, a large light accretion or growth of opened-up stand, this system may prove profitable.

d) With certain species, as beech, balsam, hemlock, the clear cut system does not work well and the forester is obliged to have some shelterwood.

The shelterwood system cannot and does not produce the net income that the clear cut system does, except in beech and balsam. This has been disputed tho demonstrated by experience. The clear cut and planting system makes bigger money for the European forester than the shelterwood system. But this is impossible from the business point of view!

g. From the standpoint of the State the shelterwood system ranks closely with the clear cut system. It has the advantage of a little more stability; it hangs on till replaced. Disadvantage: the shelterwood system has not been able to maintain good forest on poor sites as well as the clear cut system has done. Such sites are sand, muck, etc.

h. The shelterwood system is old practice, especially in beech and balsam, and is still used in the Black Forest of Baden. They use several seed years and thus leisurely take out the ~~stand~~ old stand in 30-50 years time in a variable number of cuts. Here the success of this system is great. The soil is perfectly protected but the stand is normally uneven, to a considerable age has edge conditions and poorly cleaned timber. This form, or variety of system, is called by the Germans Femelschlag and is classed by Gayer as uneven-aged, and by Lorey as even-aged (also by Roth: he thinks it depends on the time of the cuts).

i. The shelterwood with artificial reproduction system is extensively used especially in Denmark, to a less extent in North Germany, Holland, Belgium, and North France. ~~It~~ It tills the soil thoroly. Often artificial ~~fertilization~~ fertilizers are used by the Danes; the seed is put in, harrowed in thick, and the success is great and certain. The stands are dense, uniform, and the growth and development is like the clear cut except that the young stand needs more care in the bush and sapling stage. This method is primarily suited to beech, also can be used for maple, sah and elm. The system is always costly, pays only on a reasonably good site and in a good locality, and works in the direction of a clear cut stand. Since the Danes use a two cut performance they thin out and this leaves only a shelterwood.

j. The shelterwood system applies to large and to small areas in the strip, patch, group or any combination, but it always remains the same system in the characteristic method and result.

5) Selection System or Single Tree Method.

This is Gayer's Mature Form; it is Nature's form of forest.

a. Theoretically all ages, from the seedling to the mature tree, exist on any one acre; mixed, single, etc.

Practically this is rarely if ever the case. The timber is usually in a many-aged form; either the young, middle-aged or the old stuff prevails and forms the bulk of the stand. This is equalized on larger area, of a thousand or more acres, so that all the age ~~calsse~~ classes appear in fairly perfect representation. This representation is not numerical, but is an <u>area</u> representation, as there must always be a larger proportion of young than of old trees; nor is this representation indicated by what is in the even-aged stand, for here the stand always starts with larger numbers than needed, but this can vary. If you plant 3x3 or 10x10, you will need a different extra proportion for the two cases.

Normally natural reproduction gives much young stuff wherever it is started.

The single tree mixture picks up in spite of the forester's effort. It tends to an even-aged stand. A period of over 70 years may pass, during which there is no reproduction till the stand is over; when this is once done reproduction sets in all over the stand and agains drifts in the direction of an even-aged shelterwood, as soon as the stand is opened up from any cause.

Thus the selection and shelterwood systems grade into and replace each other in this system. Here is a typical case: young trees start in or near small openings. Usually groups of thrifty seedlings grow near the edge and fight their way out, to the light. Such a small area is hidden from view, and receives no attention usually till the end of the next cycle; it may therefore perish entirely, it may be stunted beyond recovery, or a group composed of a few specimens may grow up limby. This struggle along the group edge always exists and leads to regular edge conditions (page 146). If the opening is small and the trees about the opening are young enough, as in hardwoods sometimes, they push toward the light into the opening and may entirely close up the gap or close so much of it as to suppress the young trees.

If the forester foresees the situation he helps, by thinning about the opening sufficiently to protect the reproduction. In this manner the cutting becomes complex: he harvests, thins, and works for reproduction at every cut.

Normally in the selection system the young growth starts and grows slowly and only the better survive, and much of this is stunted. They are crowded and shaded. The young trees push up but their neighbors are tall and shade them and compete with them. On the other hand, the neighbors protect the young stuff from the wind and frost, and protect the site. But they do not afford protection against snow in openings; snow fills up instead.

As the young tree grows, the crowns push up against and into the crowns of the old timber, and therefore edge conditions follow. Those along the group edge are weaker and succumb. In the center they push out, clean well, and make large, healthy timber.

Various variations of the Selection system occur. The nearer to the strict selection system the stand is, the more single tree cases ther are; there is more fight, more edges, large crowns, poor cleaning; but on the other hand there is more eneven ~~&&&&&&~~ canopy, more windfirmness, and more protection.

Before the stand becomes even-aged it resembles a shelterwood: ~~the~~ there is less fight, and cleaner timber.

b. In ordinary practice every large tract and prop~~p~~erty on the selection system is divided up into a number of pieces; the forester comes to each piece at the end of a number of years (cutting return or cutting cycle). At each cut he harvests. The reproduction theoretically and practically goes on all the time.

The character of the selection forest depends on the cutting cycle to a large extent. If you return to the same acre every 10 years, the forest takes the shape desired by the foresters. If you return every 50 years and cut conservatively, the forest takes on the character of the Wild-woods. If on the other hand you cut heavy every 50 years the forest takes on that devastated form which has disgraced the selection system as a system of Silviculture. Like the clear cut and the shelterwood systems, so may the selection system be applied to large and to small areas, patches, etc., which may modify the appearance of the forest. It is applicable to all kinds of forest because it is a modification of Nature. Financially it is not applicable as a producer of forest. It must be used for high mountain countries, because it is cheap; the seasons are short and planting is very expensive.

In hard pine and other species the selection fails because of insufficient reproduction, unless we drift toward the clear cut system and seed in at the side.

The selection system is admirable for beech, maple, and tolerant hardwoods, and also for a mixture of hardwoods and tolerant conifers, as balsam. Nature is the model in the Wild-woods.

c. The selection system, if used judiciously, is very safe, therefore the forest stays, regardless of reproduction. In active practice, however, the selection system drifts toward devastation. The forester is asked to cut and produce a crop. He keeps on cutting, while the reproduction fails to make good the loss. This was the great trouble with the selection system. The forester trusted to Providence to make good but she was not in as much of a hurry as he; she is sure, but slow. In the third generation the forest is gone.

d. Growth in Volume theoretically is great; there is much light; the crown surface is exposed to light. Excellent site protection obtains, and also there is constantly on the land a large amount of growing stock. These are the three essentials. In practice it has never been proven that the selection system makes more forest than the other systems It generally drops behind, especially even-aged stands. European statistics show that they do drop behind.

Growth in quality always is behind; this is admitted even by the advocates of this system, because:

There is much fight between the large and small materials. Ther is much edge business, always some spreading and deformed stuff; we retard the young stuff, the ground cover is less perfect and less readily controlled, the trees are less easily helped and help is more needed. These are the ugly points of this system.

e. The system protects the site as does no other system; it produces much mulch, and a good cover reaching right down to the ground.

f. Good business rejected the Shelterwood system and gave it up in all large enterprises, especially State enterprises, because:

(1) There is no satisfactory control of affairs.
(2) No uniformity
No two acres alike
No sufficient inspection possible. This affects the Service all thru.
(2) Instructions unsatisfactory.
(3) Utilization always costly, difficult and injurious.

In this system every large tree ought to be separately inspected and marked at the time of Utilization.

(4) There is more danger from fire in the selection system, because there is always a large amount of bush stuff on the ground to carry the fire from the ground to the tops.
(5) Growth is less in Volume and Quailty.
(6) This system requires much care, and much knowledge on the part of the forester for success.

The system is recommended for business: because:
(1) A small owner can have big timber.
(2) He raises and has on hand a variety of stuff on a small area.
(3) There is never any great outlay at any time for planting, reproduction, etc. This appeals to most people, but is not a reliabl argument.
(4) "The selection forest is simple and easy to care of"; this is a stock claim everywhere. Take warning! If practiced with care and success this is the most intensive of all systems. But it is possibl to have a forest and carry on forestry at least expense and least care, so the claim is both true and false. Michigan hardwoods must be cared fo No care is necessary for lodgepole and other species in the Rockies: the land is of little value, the rent is small, and the system is practiced extensively. You can't clear cut and plant extensively; such a system must be intensive: the work must be well done and is expensive.

To the State, the selection system is important: it presents the great method for our Protection forests and is the most acceptable metho for game and preserve forests.

6) Secondary Systems in the Seed Forest.

These systems are distinct in their final product and in the manner of reproduction.

a. Reserve tree system (U.S.F.S. Reserve seed tree method)

(1) In the clear cut, shelterwood and selection systems we maintain trees or groups of trees standing to grow to a special size. This gives the forest, for a time, a ~~pecual~~ peculiar appearance; it modifies the systems and affects the work of reproduction.

(2) If only the clear cut system is used, and only a few trees are left, they are rarely able to go thru the entire rotation. The are apt to blow down, and are normally cut 10-20 years after the main stand, and before the removal does too much damage to the young stand.

(3) In the shelterwood system we merely leave the best trees for the last, instead of the poorest for shelter. We may keep them 20-30-40 years, according to circumstances. Where oak and beech are used in misture, it is common to leave the oak thru the second rotation of the beech.

(4) In the selection system no particular or special tree is necessary. Simply leave as many of the best as you choose.

(5) The method of reproduction is not modified. It may be planting, seeding, shelterwood or selection.

(6) To be successful, the system requires that the reserve trees be vigorous, that they do not suffer by the exposure of their crowns, that they be windfirm, and that they be trees worth while. The soil must be kept in good shape right along. This system may not be good for hardwoods; woodlots frequently dried up and became sodded. Therefore the reserve tree system is not as good in connection with the clear cut and plant system; it is better with the shelterwood; it is best with the selection forest.

(7) Advantages of the reserve tree system:

a) It raises only specially heavy sizes. The timber os often great and means money. In Europe it may change the value of timber from 12¢ to 15¢ per cubic foot, a change of 3¢ per cu. ft. of 25%, which is good business.

Disadvantages of the reserve tree system:

a) The reserve treesshade the young stuff, and prevent them from growing around the foot of the reserve trees.

b) The logging of the reserve stuff means breaking down the young stuff.

c) The timber often blows down all the time, making logging out constantly necessary all the time.

(8) In seeding from the side, the rewerve tree method has an additional advantage in so far as the reserve tree performs two distinct functions:

a) It seeds the land.

b) Extra growth of timber of reserve trees is obtained.

b. Two-storied Forest.

(1) In south German oak forests they start a dense oak forest by artificial seeding in rows or drills; they thin early and often according to the species and at 50 years of age they underplant with beech. Thus the beech grows up under and into the oak and is handled on the shelterwood plan. It reproduces at 80-120 years and a second generation of beech comes up under the oak. All this time the oak is protected against the beech, and is treated as the preferred stand or final crop. Thus the oak normally goes thru two or three generations of beech, and finally the beech and oak are completely harvested and a new stand of oak is started.

(2) Ordinary form: Seebach's Form of Two-story Forest: this consists of a stand of beech or other hardwoods, which is opened up at the age of 20 to 60 years and is underplanted with beech or some other tolerant species. After the underplanting there are two forms of treatment possible:

a) The lower story is left to shift for itself. It receives no care. The upper story grows rapidly, closes up the openings, and practically kills the lower story out by the end of the rotation.

b) Advantage: rapid growth in the upper story is obtained and therefore a shorter rotation is possible; there is good protection of the site by the upper story and a large amount of firewood is obtainable from the upper story. This form of forest is especially good for pine for improving the site.

b) The upper story may be thinned out to make room for the under story trees. Both stories are thus cared for together.

In either case there is always a definite end of the rotation. When the upper story matures, both stories are cleared off.

c. Method of Light Accretion or Accretion Cutting.

The Forest Service definition of an accretion cutting (or accretion thinning) is: a thinning made specifically to increase the rate of growth in diameter of the trees which are left standing.

(1) The accretion cut is an accessory enterprise in the clear cut and shelterwood systems when it is used at all. It occurs to a less extent in the selection system. It means a specially severe thinning, and is often classed as a thinning method rather than as a Silvicultural system, as is indicated in the above definition. That is the better term. The stand is opened beyond the point of further closing. The accretion cut gives openings which are beyond the maximum closing by the stand.

(2) As in the reserve tree system, the site must be cared for by underplanting. In case the remaining stand, after an accretion cut, consists of but few tree per acre, the method practically becomes the reserve tree method.

(3) The accretion cut means greater growth, fewer trees, and therefore a larger size of timber obtained, and a shorter rotation is possible.

Note: These extra methods: two-story, accretion cutting, etc., are not common; they are not much used except in pine. They are promising for valuable forests of large sized timber.

The Germans give the Accretion Cut two names:
1) Lichtungszuwachs: opening for growth.
2) Lichtungsbetrieb: opening the way of management.
These are different meanings for the same system.

These secondary systems are not so much systems of reproduction as they are systems of caring for the forest. They apply more to older stands which are nearing maturity.

7) Coppice System.

a. The coppice system has a great variety of forms according to the timber raised and the object in view.
Timber: short rotations.
Eucalyptus: firewood system.
Others for shelter-belts and wind-breaks.
Others for tanbark; willows for baskets, etc.

Ordinarily the stand is cut clear: the sprouts come principally from the stump, always a number of them for each stump. Some get ahead and suppress the rest. There is rapid growth, 6 to 8 feet in one season, even 12 feet. Therefore in the first year there is a stand of bushy appearance. Thus the soil is not exposed. The stand goes up in the air rapidly, the trees growing in clumps of 3 to 5; therefore the crowns are unsymmetrical and one-sided, and, also, the trunks are bent toward the light. Cleaning is always variabble. There is more cleaning in tolerant species. Rapid growth end early, the old stump decays away, and the sprouts may or may not suffer.

The sprout stand is distinctly even-aged. The rotation is short, the thinnings are restricted, and severe. Where a long rotation is used, the tops become long, some seed is produced, and seedlings start up. This frequently happens in chestnut.

A modification of the coppice is used in France and southern Europe: two cuts are made; the first cut is for the best timber, leaving the rest to grow, and new sprouts also come in. Object: the soil is protected from dying out.

c.~~a~~. The coppice is the safest of all the systems we have. We know its effect on site. It occurs under thriving conditions. The fact of its safety shows itself in that the reproduction is safe; there is no risk of cutting clear and having no reproduction for a time.

b. The coppice is applicable to but few of the conifers; the redwood is the only good conifer in the United States. Shortleaf pine is not a sprouter. The Japanese Cryptomaria is a good sprouter. It must have a mild climate, good for grapes, and good soil. We can often use overflow bottoms, wet lands, and gully, rocky, and shallow soils, according to the species. Coppice is good for a soil binder.

d. The volume growth is very great from the start, therefore the growth of the ten years after reproduction may be ten times as great as that of seedlings produced.

The quality growth also is rapid; the trees are slimmer; most coppice does not make saw timber. The heartwood has a variety of uses. It is very useful stuff: poles, handles, posts, ties, firewood, etc.

e. Coppice is restricted to good soils. A short rotation takes off more young stuff and exhausts the soil. The stand opens because of intolerant species and is not sufficiently cared for, therefore the soil is apt to dry out, tho this is a necessary part of the system. There is good reproduction and it ought to have good protection of the site.

f. Ordinary business rejects coppice systems in large enterprises, as State, etc., because:

(1) Coppice needs good land. (Agricultural)

(2) It raises poor cheap stuff which is not acceptable to the general market.

(3) It yields a small gross income per acre per year.

(4) The stand easily depreciates; there is a tendency to overcut the stand.

(5) The coppice system is unable to serve most of the important forest species and sites. The most important forest species are the conifers, which are not served by this system.

On the other hand, the coppice system is recommended, because:

(1) A small capital only is needed, the returns are frequent, and therefore it leads to a big industry.

(2) There are few dangers in a stand of this kind.

(3) It affords simple, cheap handling.

(4) It allows simple harvesting, by clear cutting, etc.

(5) It may be used as a method for raising particular kinds of stuff.

g. The State always will be more or less interested in the coppice system:

(1) It is good for the ~~small~~ small man.

(2) It provides local people with small timber, which is nevertheless necessary for the locality.

(3) It takes possession of sites and protects them against erosion.

(4) It is adapted to grazing uses, particularly sheep on grass lands. It can be alternated with agriculture.

8) Coppice Standards or Standard Coppice.

This has also been called Composite Coppice.

a. Standard Coppice may be illustrated by a concrete case: Assume a standard of different species. Suppose we have 100 acres of beech or maple; make an annual cut of 5 acres, or a 20-year rotation. After each cut plant in on that area 20 pine seedlings (or locust, etc.). Say the first cut is in 1912; this is a 5-acre cut; plant in twenty 3-year old pine seedlings or transplants. Then the same 5 acres will be cut again in 1932, and now we will have a stand of 20-year pines plus 20 new seedlings. Thus we will have in:

1952: 20 of the 40-year pines
20 of the 20-year pines
20 new seedlings

and therefore in 2 coppice rotations we will have 60 pines on that 5-acre area. Thru another rotation:

1972: 20 of the 60-year old pines
20 of the 40-year old pines
20 of the 20-year old pines
20 new seedling

This gives us a stand of 60 trees varying from 20 to 60 years of age. These then are the standards. If the pine were cut on a 60 year rotation we would plant first in 1912 and cut in 1972, and plant new pines right along addition to the coppice till it is exhausted.
(in)

To show how much area standards take up we may refer to the following figures:

20	20-year pines need	80	sq.yds. each
20	40-year pines need	180	sq.yds. each
20	60-year pines need	320	sq.yds. each
60	pines need	580	sq.yds. on 5 acres. or 1/8 A.

Therefore in this illustration 1/8 acres is actually covered by the standards, out of an area of 5 acres. Thus practically 4 7/8 acres are left for coppice and others. The standards grow open and above the coppice and therefore develop larger crowns than in normal woods. There are here 60 standards in three age classes.

b. Variations of this method are possible according to the individual ideas. There are gradations between straight coppice and timber.

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Some of the common forms of standard coppice follow: the standards may be a part of the coppice; the standards may be of a more tolerant species; the standards may be intolerant and the coppice tolerant, in which case we can use more standards without hurting the coppice. This is better than having to use more coppice, which may hurt the standards.

The French and Germans make a specialty of standard coppice, and frequently cut in 20-40 year rotations. They often produce two distinct stands on the ground. The standards may be of one or several age classes.

Disadvantage of standard coppice: The upper story of the standards is too open, the trees get limby; the lower story is held back by the standards. In spite of this limbiness the standards are long-lived, and healthy because they get much light.

The standards in high forest are different. They are exceptionally good trees which have been left. They grew in a closed stand; on opening up the stand we may have trouble. In standard coppice the trees grow up in constant conditions: there is no sudden change, and therefore there is better health.

c. The standard coppice is as safe as the ordinary coppice but in practice it needs more care and knowledge. It is apt to go back to straight coppice. There is a tendency to abuse it just because it is safe.

d. The volume and quality growth is large; it is even claimed to beat that of the even-aged stand. A high quality of timber and a large amount of smaller stuff is obtained, but this never compares with spruce, balsam and pine in the amount of medium sized shapely building and saw timber. In practice it is sure to get limby.

e. The standard coppice system may change the site well; then there is nothing better if well handled.

f. Business reasons for rejecting this system:

(1) All the same reasons as with ordinary coppice (page 174), tho better crop and money is obtained if it is good.

(2) It requires greater care because every standard needs watching.

(3) It is liable to injury from exposure in open stand conditions.

(4) There is danger of many water-sprouts in oak, etc.

(5) There is danger of sun-scald in beech, because of its thin bark, dry tops, etc.

Business reasons in favor of standard coppice:

(1) All the good points of the ordinary coppice (p.175).

(2) It produces a certain amount of large timber in good condition.

(3) It gives a larger yield per acre per year for the money.

(4) It allows a production of conifers and hardwoods on the same land.

3. Choice of Systems.

a. Matter of species dealt with.
b. Site conditions.
c. Safety and dangers, including characters under species and site, biotic factors, etc.
d. Reproduction or hard, etc.
e. Objects of the business, Public Forests, etc.
f. Intensity of the enterprise.
Amount of capital
Labor necessary or available
g. Secondary uses of the forest.

a. Matter of the species dealt with.

1) Certain species, as most conifers, exclude the use of coppice or standard coppice in the woods on account of the nature of the species. Certain other species practically demand the coppice: willow, alder, chestnut, catalpa, black locust and eucalyptus. This is probably the best and easiest method to use here.

2) Hard pines, tamarack, cypress, oak, walnut, hickory, and most of the intolerant species do not make a satisfactory selection forest, and so the choice here is limited to a few species. These species tend to open up and the stand opens up. A selection stand requires a tolerant species mixed with an intolerant species. The above named species usually need different systems.

3) Hemlock, balsam, and beech have a dislike for the clear cut system, and so we cannot use this system fot these species unless they are very small. They are good for the selection and shelterwood systems.

4) Hard pines, tamarack and intolerant species are not able to hold out as seedlings under the mother trees and so are naturally not satisfactory in shelterwood. ~~They may be used in either of two systems,~~ They are shut out from the two systems of selection and shelterwood, but can be used under the clear cut system.

5) All seeded trees, as hardwoods, are of no use in natural reproduction by seeding in from the side.

6) In general: the species is the first consideration in determining the method of treatment.

b. Site conditions.

Site conditions limit the species in their possibilities. They affect the distribution of species, etc., and thus affect the system which may be used.

1) On poor lands we usually use only pine and therefore only the systems suited to pine, or the clear cut with natural or artificial reproduction. This is very useful on poor sites, as sandy lands.

2) Swamp lands have peculiar species: tamarack and cedar in northern swamps and cypress in the south. Some black spruce and ash occurs on the edges. The intolerant tamarack and cedar are not for the selection and shelterwood systems, but include the use of seeding from the side methods: strip, seed tree, or clear cut methods.

3) In Northern countries (N. Canada, N. New England), and high altitudes we are limited to spruce and therefore to the system suit-

able to spruce and similar species. The selection and shelterwood systems are especially good for high mountains. It is impossible to seed in from the side.

4) Many of the higher ridges in the Rockies exclude the Yellow pine and take the lodgepole pine, which is very intolerant.

5) Good moist soil and mild climate take any system. On poor land, even in a mild climate, use a system that will keep up the site. Compare timber and seed trees versus coppice. The selection is best.

6) Sand in the Southern pinery excludes the hardwoods and white pine because of the soil and site together. Hard pines and their systems are used here.

7) Dry situations, as yellow pine in the west, need to keep moisture in the soil, therefore the clear cut system would not be used here. The shelterwood system is particularly applicable, and is much used by the Forest Service.

8) On steep slopes and soils which wash easily and gully, the clear cut system is risky. The selection system is best.

9) In general: follow Nature wherever the site is difficult, whether in climate or in soil, topography or even bad biotic factors and competition of animals (insects). Insects stopped the use of the tamarack, because of the tamarack saw-fly. The black locust borer made it almost impossible to have any success in planting black locust. These are treated as distinct dangers, not as part of the site.

c. Choice affected by safety and dangers.

1) Safety from theft is not considered in this connection, but even here there is some difference in the systems. The selection is easy to steal from.

2) Safety from fire. In the hardwood district there are many possibilities; there is less danger than in conifers, and you can use almost any system you desire. It is claimed that the coppice system is least dangerous. It is simply a part of the larger hardwood feature.

An even-aged stand should be in small bodies, then the fire will not spread. The young stuff is in danger; it is drier, the crown is close to the ground and the fire spreads to a top fore. The stand is more jammed.

In a coniferous district there is only one choice between an even-aged and a many-aged stand: the even-aged stand in small bodies is safer than the many-aged stand. Yellow pine in the southwest or in the southern pinery at 40 years of age is safe. A ground fire does not hurt these trees In Colorado fire can be used safely at any time.

3) Safety from storms, snow, etc. Coppice is the best, then the selection system, then the even-aged stand. The shelterwood is worse than the clearcut, as the trees which have been closed up are exposed and tend to be wind-blown. It is good for timber to be in small bodies or in compartments. Avoid lines making the mature cutting stuff face the wind. This is bad, especially in spruce, particularly in the prevailing winds.

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4) Safety from snow damage. All dense stands, and tall and slender saplings, suffer regardless of the system used, so that protection from this danger is chiefly a matter of spacing to make the trees resistant and become stiff.

5) Frost hurts mostly in reproduction. The shelterwood is best for the protection of young stands; the selection system also is good. The clear cut system is not good. Even coppice is bad with some species.

6) Insects attack all kinds of timber regardless of system. They are worse in conifers than in hardwoods, and in the pure forest than in mixed forest because each insect has its pet species, and takes the whole stand. This is not so bad in a mixed stand.

The site tells whether to use a pure forest. Most of these stands are pure and so tun right into danger. We have the choice of the clear cut, shelterwood and selection systems. Large areas of young trees and large bodies of old trees are more attacked. To avoid these conditions use the selection or clear cut systems with the timber in small bodies. The greatest damage is done to reproduction and to over-mature stands.