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## SOME PRELIMINARY ESTIMATES OF ENERGY UTILIZATION IN EVEN-AGED NORTHERN HARDWOODS

*Abstract.*—Estimates of energy utilization from various sources indicate that even-aged northern hardwood stands utilize less than 1/2 percent of net solar radiation for wood, leaf, and seed production, and only about 1/10 percent for production of merchantable wood. Forest managers should seek to understand and manipulate the remaining 99+ percent of solar energy, for improving the efficiency of merchantable wood production.

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Both timber managers and ecologists are highly interested in the productivity of timber stands, but often from widely divergent points of view.

Timber managers are concerned with the ability of stands to produce useful primary products—veneer logs, sawlogs, bolts, and pulpwood. Production of non-merchantable material usually is of incidental interest.

Forest ecologists, on the other hand, are particularly interested in the total production of dry matter and the total energy flow within an entire forest ecosystem.

Each group has something valuable to learn from the other. Particularly in view of current trends in multiple forest land use and rapid advances in wood utilization, the timber manager needs a better appreciation of how the energy in a forest ecosystem is utilized—and wasted—in producing merchantable and potentially useful material, as well as in underwriting various other types of biological activity. Similarly, the forest ecologist should appreciate the need to direct part of his efforts toward developing a better understanding of how available energy can be harnessed in the production of useful products.

Recently developed estimates of growth and yield, coupled with available ecological information, enabled us to develop some preliminary estimates of energy utilization in even-aged northern hardwood stands of New England. Although approximate, these estimates provide some gross comparisons of energy utilization in the production of merchantable timber, leaves, and seeds. Implications of these findings for the management of northern hardwoods are discussed briefly.

## Production Data

The available productivity information for even-aged northern hardwoods is shown in table 1. Cubic-foot volumes per acre were developed from yield tables for unmanaged even-aged stands (site index 60) published in *A Silvicultural Guide for Northern Hardwoods in New England (Leak et al 1969)*. Volumes, which are taken to a minimum 4-inch d.i.b.

**Table 1.—*Wood, seed, and leaf production per acre for even-aged northern hardwood stands in New England.***

| Stand age (years) | Cumulative[1] merchantable wood | | Annual[2] seed production | | Annual[3] leaf production |
|---|---|---|---|---|---|
| | Green | Oven-dry | Green | Oven-dry | Oven-dry |
| | *Cu. ft.* | *Kg.* | *No.* | *Kg.* | *Kg.* |
| 0 | — | — | — | — | — |
| 10 | — | — | — | — | — |
| 20 | — | — | — | — | — |
| 25 | — | — | 2,838,660 | 15.809 — 41.352 | — |
| 30 | — | — | — | — | — |
| 40 | — | — | — | — | — |
| 50 | 1,900 | 28,514 | — | — | 1279.13 |
| 60 | 2,100 | 31,519 | — | — | — |
| 70 | 2,250 | 33,766 | — | — | — |
| 80 | 2,400 | 36,019 | 8,172,687 | 23.452 — 70.034 | — |
| 90 | 2,550 | 38,271 | — | — | — |
| 100 | 2,700 | 40,524 | — | — | — |
| 110 | 2,850 | 42,771 | — | — | — |
| 120 | 3,000 | 45,024 | — | — | — |
| 130 | 3,100 | 46,523 | — | — | — |
| 140 | 3,250 | 48,776 | — | — | — |
| 150 | 3,400 | 51,028 | — | — | — |
| 160 | 3,550 | 53,281 | — | — | — |
| 170 | 3,700 | 55,528 | — | — | — |
| 180 | 3,800 | 57,028 | 10,915,930 | 16.696 — 52.448 | — |

[1] Leak et al *(1969)*.
[2] Leak et al *(1961)*.
[3] Hart et al *(1962)*.

Table 2.—*Some conversion factors and estimates used to determine energy flow in northern hardwood stands.*

**Radiation:**

1. Incoming solar radiation, Portland Maine = 439-550 langleys per day, averaging 506.2[1] during May-August.
2. Albedo of hardwood canopy, May-August = 0.17.[2]

**Wood:**

1. Average northern hardwood specific gravity = 0.53.[3]
2. Energy value = 4,267 to 4,679 gram calories per gram, averaging 4,473.[4]

**Seeds:**

1. Average moisture content 10 to 30 percent.[5]
2. Average energy value = 5,065 gram calories per gram.[6]
3. Number of seeds per pound:[5] beech 1,300 to 2,300; yellow birch 278,000 to 907,000; sugar maple 3,200 to 9,100; red maple 12,700 to 38,200; paper birch 610,000 to 4,120,000; white ash 5,500 to 18,200; pin cherry 11,900 to 21,800.

**Leaves:**

1. Energy value = 4,229 to 5,092 gram calories per gram, averaging 4,660.[4]

**Physical conversions:**

1. 1 kilogram calorie = 1,000 gram calories.
2. 1 pound = 0.453592 kilograms.
3. 1 langley = 1 gram calorie/square centimeter.
4. 1 joule = 0.0002388 kilogram calories.
5. 1 newton meter = 1 joule.
6. 1 kilogram (weight) = 9.8 newtons.
7. 1 acre = 40,468,564.224 square centimeters.

[1] U.S. Dep. Commerce *(1960, 1963, 1964, 1965, 1967).*
[2] Federer *(1968).*
[3] USDA Forest Service *(1955).*
[4] Golley *(1961)* and Ovington et al *(1967),* respectively.
[5] USDA Forest Service *(1948).*
[6] Golley *(1961).*

top, represent total estimated cubic-foot yield in sawtimber and pulpwood. Estimated oven-dry weights are based on the conversions in table 2.

Annual numbers of seeds produced were taken from unpublished data for the Bartlett Experimental Forest *(Leak et al 1961).* Data from an old-growth uneven-aged stand were used for the 180-year class in table 1. Because of great variability in both seed production and the seed conversion factors in table 2, oven-dry seed production is expressed as a range of values.

The leaf production data were adapted directly from the oven-dry weights published by Hart et al *(1962).* These data, taken in a stand of hardwoods about 50 to 60 years old, also containing some old holdovers and saplings, probably hold true for a wide range in stand age *(Moller 1947)*.

## Energy Flow Estimates

The first step in developing energy-flow estimates was to fill in a complete range of data for seed and leaf production to accompany the basic data in table 1. Assuming that leaf and seed production are 0.0 at stand age zero, and that leaf production remains constant after age 50, annual values for each 10-year class were filled in by straight-line interpolation.

Next, cumulative estimates of leaf and seed production were developed. Since leaf production rises rapidly as a young stand develops, we assumed that the annual leaf production estimate for each 10-year age class applied to each of the 10 *previous* years. Since seed production in hardwood stands develops more slowly, we assumed that each annual seed production estimate applied to each of the 10 *subsequent* years. By summing annual leaf and seed production rates, cumulative estimates were developed corresponding to the cumulative cubic-foot volumes of wood shown in table 1.

The gram-calories of chemical energy represented by given weights of woods, leaves, and seeds are fairly well documented in the literature (table 2). These energy conversions have not been worked out for northern hardwoods specifically. However, the range in conversions for other tree and plant species is not great. Thus we feel reasonably confident in applying these factors to produce the cumulative estimates of energy tied up in wood, leaf, and seed production shown in table 3.

Notice, first, that mean annual energy utilization at stand maturity (120 to 160 years) is about 6.7 to 7.0 million kilogram calories. Based on an average daily solar radiation of 506 langleys (table 2) over a 100-day growing season, with an albedo (reflection) of 0.17 *(Federer 1968)*, the net incoming solar radiation is estimated at 1,700 million kilogram calories per acre over the growing season. Thus energy utilization for wood, leaf, and seed production is a little less than ½ percent of the net solar radiation. Mean annual energy utilization for merchantable wood production alone is only about 1/10 percent. The remaining 99+ percent energy is accounted for by heat or radiation loss to the atmosphere, evapotranspiration, respiration, and the production of other organic materials within the forest ecosystem.

At stand maturity, the ratio of energy utilization for wood, leaf, and

Table 3.—*Cumulative and mean annual energy estimates for merchantable volume, leaves, and seeds by stand age, in millions of kilogram calories per acre.*

| Stand age (years) | Merchantable wood | | Leaves | | Seeds | | All | |
|---|---|---|---|---|---|---|---|---|
| | Total | Mean annual | Total | Mean annual | Total | Mean annual | Total | Mean annual |
| 0 | — | — | — | — | — | — | — | — |
| 10 | — | — | 11.9 | — | — | — | — | — |
| 20 | — | — | 35.8 | — | 0.3-.8 | — | — | — |
| 30 | — | — | 71.5 | — | 1.0-2.5 | — | — | — |
| 40 | — | — | 119.2 | — | 1.8-4.7 | — | — | — |
| 50 | 127.5 | 2.5 | 178.8 | 3.6 | 2.7-7.2 | 0.1 | 309.0-313.5 | 6.2 |
| 60 | 141.0 | 2.3 | 238.4 | 4.0 | 3.7-10.0 | .1-.2 | 383.1-389.4 | 6.4-6.5 |
| 70 | 151.0 | 2.2 | 298.0 | 4.2 | 4.7-13.0 | .1-.2 | 453.7-462.0 | 6.5-6.6 |
| 80 | 161.0 | 2.0 | 357.6 | 4.5 | 5.8-16.3 | .1-.2 | 524.5-535.0 | 6.6-6.7 |
| 90 | 171.2 | 1.9 | 417.2 | 4.6 | 7.0-19.8 | .1-.2 | 595.4-608.2 | 6.6-6.7 |
| 100 | 181.3 | 1.8 | 476.2 | 4.8 | 8.2-23.3 | .1-.2 | 666.3-681.4 | 6.7-6.8 |
| 110 | 191.3 | 1.7 | 536.4 | 4.9 | 9.3-26.7 | .1-.3 | 737.0-754.4 | 6.7-6.9 |
| 120 | 201.4 | 1.7 | 596.0 | 4.9 | 10.4-29.9 | .1-.3 | 807.8-827.3 | 6.7-6.9 |
| 130 | 208.1 | 1.6 | 655.6 | 5.0 | 11.4-33.1 | .1-.3 | 875.1-896.8 | 6.7-6.9 |
| 140 | 218.2 | 1.6 | 715.2 | 5.1 | 12.4-36.2 | .1-.3 | 945.8-969.6 | 6.7-6.9 |
| 150 | 228.2 | 1.5 | 774.8 | 5.2 | 13.4-39.2 | .1-.3 | 1016.4-1042.2 | 6.7-6.9 |
| 160 | 238.3 | 1.5 | 834.4 | 5.2 | 14.4-42.2 | .1-.3 | 1087.1-1114.9 | 6.8-7.0 |
| 170 | 248.4 | 1.5 | 894.0 | 5.2 | 15.3-45.0 | .1-.3 | 1157.7-1187.4 | 6.8-7.0 |
| 180 | 255.1 | 1.4 | 953.6 | 5.3 | 16.2-47.8 | .1-.3 | 1224.9-1256.5 | 6.8-7.0 |

seed production is in the neighborhood of 10:30:1. Under repeated thinnings, merchantable wood production might be doubled *(Leak and Filip 1969)*, which would (1) raise the energy utilization for wood production to perhaps two-thirds of that for leaf production, and (2) raise the percent utilization of net solar radiation for wood production to perhaps 1/5 percent. This latter percent utilization is, quite logically, considerably lower than the values calculated by Hellmers and Bonner *(1959)* of 1.4 to 2.5 percent for *total current annual dry matter production* in even-aged stands of European beech. Furthermore, these authors based their percentage on *visible* solar radiation, which comprises roughly half or a little less of the net solar radiation.

Another usage of energy considered in this analysis of energy flow was the potential mechanical energy represented by the standing trees—the energy released when a tree falls to the ground. Assuming that the center of gravity of the typical northern hardwood tree (the merchantable portion) is at 9 meters above ground, cumulative potential mechanical energy was estimated at only 200 to 400 kilogram calories per acre—negligible compared to the chemical energies.

## Discussion

Although approximate, these figures emphasize that timber-growing accounts for a very minute proportion—1/10 to 1/5 percent—of the net solar energy that enters into a northern hardwood stand.[1] Furthermore, merchantable timber growth comprises only a small proportion of the energy utilized in the total production of dry matter. Apparently, more energy is tied up in leaf production than timber production.

No manufacturing system is perfectly efficient. However, northern hardwood timber production ranks very low in efficiency when compared, for example, with gasoline or diesel engines, which commonly attain efficiencies of 10 to 25 percent. In the laboratory, photosynthesis may attain efficiencies of up to about 35 percent *(Daniels 1956)* under optimum conditions.

These findings hold two important implications for timber-oriented foresters.

First, because of the relatively high efficiency of the photosynthetic process under optimum conditions, the possibilities for increasing the efficiency of northern hardwood timber production appear great; and ways must be sought to accomplish this end. In fact, I find it difficult to see how timber production can remain competitive with other forest land uses unless more efficient production ratios are obtained. Some of the known possibilities for increased production are fertilization, genetic improvement, optimum thinning programs, conversion to faster-growing species or species mixtures that more fully utilize the site, and improved wood utilization.

Second, forest managers in the past have been almost exclusively concerned with less than 1 percent of the solar energy entering the forest properties under their control. As land managers in the broadest sense, we should seek to understand and manipulate for human benefit the remaining 99+ percent.

[1] Note that these proportions would be roughly doubled if based on *visible* solar radiation instead of net solar radiation.

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