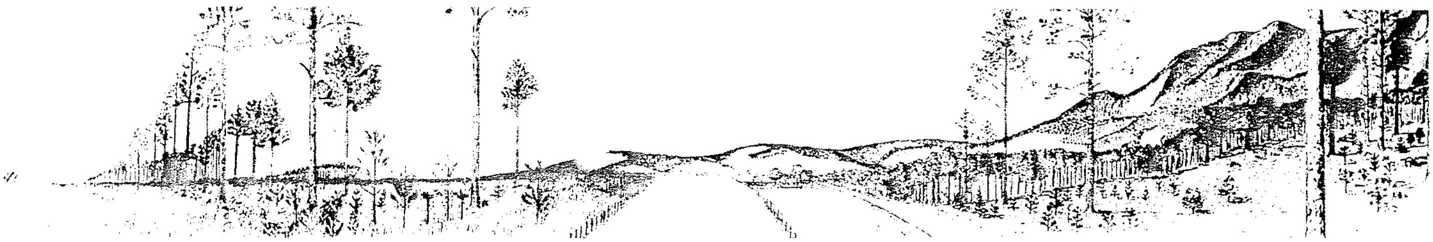

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# Caloric Value of Some Forest Fuels of the Southern United States

**Abstract.** -The caloric value of a variety of southern forest fuels was determined in an oxygen bomb calorimeter. High heat values ranged between about 3,600 and 5,200 cal./g. for fuels as sampled and between 4,500 and 5,600 cal./g. for fuels on an ash-free basis. Additional tests of forest fuels from the Southern, Eastern, and North Central United States showed a wider range of heat values: from 3,400 to 7,800 cal./g. for fuels as sampled.

## INTRODUCTION

The energy which maintains the chain reaction of combustion is the heat of combustion. This heat value can be measured for any particular fuel by testing samples in an oxygen bomb calorimeter. Because complete combustion occurs in the test apparatus, calorimeter values are an indication of the maximum amount of energy liberated when a material reacts with oxygen. Even though complete combustion never takes place in forest fires, measurements of heat values of fuels are a basic factor in predicting the potential heat release from such fires. These values may also be useful to plant ecologists in calculating energy transfer and efficiency of energy utilization in woodland communities.

## METHODS

Samples of various forest and range fuels common to the Southern United States, each consisting of several hundred grams of material, were collected in the field and sent to the Southern Forest Fire Laboratory for testing. All samples were ground in a Wiley Mill to pass a 20-mesh screen, compressed into small pellets, and ovendried at 85” C. The pellets were then placed in a bomb calorimeter and ignited under 20 atmospheres of pure oxygen.

The author wishes to thank Dr. J. D. Dodd of Texas A&M University for supplying the samples of Texas fuels and B. H. Underwood of the Southern Forest Fire Laboratory for making the bomb calorimeter runs.

Standardized benzoic acid was used to determine the thermal coefficient of the calorimeter system. Corrections were made for the combustion of the ignition wire but not for the energy remaining in the free acids formed by combustion of the fuel. This latter factor has been shown to be small compared with differences in heat values that occur between replicate tests (Gorbatova 1964).

The mineral ash content of each fuel was measured after the samples had been subjected to a temperature of 650° C. in a muffle furnace.

The gross or high heat value in mean calories was computed for each sample tested in the calorimeter. These values were based on the ovendry weight of fuel which contained inorganic material as sampled in the field. Ash-free heat values were also computed for ovendry material by correcting for the inorganic residue. Analyses of variance were made, separately and in combination, for the heat values of the vegetative fuels and of the fuels in contact with the ground. Multiple range tests (Duncan 1955) were made when significant differences were found.

After completion of the original study of southern fuels, additional data were collected for other fuels from the Southern, Eastern, and North Central United States. The methods used were the same as above, with heat values being determined on duplicate samples. In addition to total ash

*Southeastern Forest Experiment Station - Asheville, North Carolina*
*U. S. Department of Agriculture - Forest Service*

content, silica-free ash values were obtained for some fuels. Statistical analyses of heat values for these additional fuel samples were not made.

## RESULTS

The high heat values were computed for the samples of the various southern forest and range fuels tested (table 1). Analyses of variance of combined data showed that the differences between the heat values of the fuels, either as sampled or ash-free, were highly significant. The greatest difference between the heat values of the various fuels as sampled was 1,624 cal./g. After corrections were made for ash content, the difference between the highest and lowest values amounted to 1,063 cal./g.

Ground fuel data from litter layers and organic soil were analyzed. Multiple range tests of ground fuels as sampled showed highly significant differences between the heat values of the lower (decomposed) and the upper (fresh) litter layers. For the hardwood and the pine species, fresh litter had the higher heat value. Pine litter layers were collected in three strata — upper (fresh), middle (weathered), and lower (decomposed). The middle layers had lower heat values than did the fresh layers but higher values than did the decomposed layers. The heat values of the organic soil did not differ significantly from the heat values of the hardwood upper litter.

Multiple range tests indicated that there was no significant difference between the ash-free heat values of the three litter layers collected from stands of slash pine or loblolly pine. Although there was no significant difference between the values of the upper and lower hardwood litter, there was a highly significant difference between the values of the upper and lower litter of scrub oak. The decomposed layer of scrub oak had the higher ash-free heat values. In general, pine needle litter, either ash-free or as sampled, had a higher heat value than did hardwood leaf litter.

Analyses of variance of data on the vegetative fuels (which included material from both dead and live standing plants) were made. The more important differences found included the following: the heat value of slash pine needles was greater than that of loblolly pine needles; the heat values of leaves of scrub oak species were greater than those of leaves of other hardwood species ; and the heat values of needles of pine species were greater than those of leaves of hardwood and grass species. Among the species sampled at several locations (gallberry and Spanish moss), the heat values of the samples differed according to the location. Significant differences were also found between the heat values of live and dead material of the same species (wiregrass and herbaceous plants) : living material had higher heat values than did dead material. Similar results have been reported for live and dead standing broomsedge (Golley 1961).

Some rearrangement of average heat values occurred when vegetative fuels were analyzed on an ash-free basis, but the general trends described above remained the same.

On the basis of the gross caloric values determined for the fuels as sampled, the fuels can be grouped in arbitrary classes as follows :

I. < 4,000 cal./g. — Mixed scrub litter (Texas type), dead herbaceous plants, post oak litter, and yaupon litter.

II. 4,000 to 4,500 cal./g. -Live herbaceous plants, lower litter of upland hardwoods, lower litter of scrub oak (from Georgia), dead wiregrass (*Aristida stricta* Michx.), lower litter of loblolly pine, and leaves of upland hardwoods.

III. 4,500 to 5,000 cal./g. -Elm leaves (*Ulmus alata* Michx.), Spanish moss (*Tillandsia usneoides* L.), lower litter of slash pine, upper litter of upland hardwoods, live wiregrass, upper litter of scrub oak (from Georgia), leaves of live oak (*Quercus virginiana* Mill.), organic soil, saw-palmetto fronds (*Serenoa repens* (Bartr.) Small), post oak leaves (*Quercus stellata* Wangenh.), turkey oak leaves (*Quercus laevis* Walt.), loblolly pine needles (*Pinus taeda* L.), fetterbush leaves (*Lyonia lucida* (Lam.) K. Koch), and middle litter of loblolly pine.

IV. > 5,000 cal./g. — Middle litter of slash pine, laurel greenbrier leaves (*Smilax laurifolia* L.), redbay leaves (*Persea borbonia* (L.) Spreng.), evergreen yaupon leaves (*Ilex vomitoria* Ait.), upper litter of loblolly pine, gallberry leaves (*Ilex glabra* (L.) Gray), deciduous yaupon leaves (*Ilex decidua* Walt.), upper litter of slash pine, and slash pine needles (*Pinus elliottii* Engelm.).

**Table 1. — Caloric value of ovendry forest and range fuels common to the Southern United States**

| Samples by species-type | Location | Date collected | No. of tests | Caloric value[1] Mean | Caloric value[1] Range | Coefficient of variation | Ash content | Mean ash-free caloric value[1] |
|---|---|---|---|---|---|---|---|---|
| | | | | Cal./g. | | - - Percent - - | | Cal./g. |
| Slash pine type | | | | | | | | |
| Palmetto fronds | Georgia | 8/31/65 | 6 | 4,800 | 4,772-4,822 | 0.2 | 3.4 | 4,968 |
| Gallberry leaves | Georgia | 8/31/65 | 7 | 5,213 | 5,191-5,244 | 0.2 | 2.1 | 5,326 |
| Spanish moss | Georgia | 8/31/65 | 6 | 4,541 | 4,525-4,564 | 0.1 | 2.9 | 4,678 |
| Spanish moss | Florida | 8/25/65 | 6 | 4,627 | 4,611-4,649 | 0.1 | 3.4 | 4,792 |
| Slash pine needles | Georgia | 8/31/65 | 6 | 5,206 | 5,181-5,237 | 0.2 | 1.2 | 5,268 |
| Slash pine upper litter | Georgia | 11/5/65 | 7 | 5,163 | 5,128-5,197 | 0.2 | 2.1 | 5,272 |
| Slash pine middle litter | Georgia | 11/5/65 | 6 | 5,021 | 4,999-5,060 | 0.2 | 2.8 | 5,167 |
| Slash pine lower litter | Georgia | 11/5/65 | 8 | 4,622 | 4,536-4,758 | 0.6 | 11.4 | 5,216 |
| Loblolly pine type | | | | | | | | |
| Loblolly pine needles | Georgia | 9/27/65 | 7 | 4,945 | 4,861-5,051 | 0.6 | 2.3 | 5,060 |
| Loblolly upper litter | Georgia | 9/27/65 | 6 | 5,076 | 5,063-5,114 | 0.2 | 2.7 | 5,216 |
| Loblolly middle litter | Georgia | 9/27/65 | 6 | 4,955 | 4,936-5,047 | 0.3 | 3.7 | 5,187 |
| Loblolly lower litter | Georgia | 9/27/65 | 6 | 4,432 | 4,386-4,477 | 0.4 | 15.5 | 5,244 |
| Scrub oak type | | | | | | | | |
| Wiregrass-live | Georgia | 9/1/65 | 6 | 4,661 | 4,631-4,693 | 0.2 | 2.8 | 4,798 |
| Wiregrass-dead | Georgia | 4/12/65 | 6 | 4,393 | 4,370-4,430 | 0.3 | 5.4 | 4,643 |
| Turkey oak leaves | Georgia | 9/1/65 | 6 | 4,893 | 4,833-4,965 | 0.4 | 2.8 | 5,032 |
| Scrub oak upper litter | Georgia | 9/1/65 | 7 | 4,672 | 4,609-4,750 | 0.5 | 6.0 | 4,971 |
| Scrub oak lower litter | Georgia | 9/1/65 | 7 | 4,324 | 4,035-4,518 | 1.6 | 21.9 | 5,537 |
| Upland hardwood type | | | | | | | | |
| Hardwood leaves | Georgia | 9/23/65 | 7 | 4,456 | 4,384-4,543 | 0.6 | 7.2 | 4,800 |
| Hardwood upper litter | Georgia | 9/23/65 | 6 | 4,654 | 4,576-4,756 | 0.7 | 6.7 | 4,988 |
| Hardwood lower litter | Georgia | 9/23/65 | 7 | 4,249 | 4,016-4,480 | 1.6 | 11.9 | 4,824 |
| Organic soil type | | | | | | | | |
| Greenbrier leaves | N.C. | 3/28/66 | 7 | 5,027 | 4,979-5,069 | 0.3 | 2.9 | 5,176 |
| Redbay leaves | N.C. | 3/28/66 | 7 | 5,048 | 4,989-5,091 | 0.3 | 3.1 | 5,210 |
| Gallberry leaves | N.C. | 3/28/66 | 6 | 5,086 | 5,041-5,120 | 0.3 | 1.9 | 5,183 |
| Fetterbush leaves | N.C. | 3/28/66 | 7 | 4,970 | 4,920-5,010 | 0.2 | 2.6 | 5,102 |
| Organic soil | N.C. | 11/1/64 | 6 | 4,788 | 4,744-4,875 | 0.4 | 14.1 | 5,575 |
| Texas scrub type | | | | | | | | |
| Herbaceous spp. - live | Texas | 5/24/66 | 6 | 4,223 | 4,194-4,245 | 0.2 | 9.3 | 4,656 |
| Herbaceous spp. - dead | Texas | 5/24/66 | 7 | 3,653 | 3,533-3,831 | 1.2 | 19.0 | 4,512 |
| Winged elm leaves | Texas | 5/24/66 | 6 | 4,506 | 4,465-4,542 | 0.3 | 8.5 | 4,924 |
| Live oak leaves | Texas | 5/24/66 | 6 | 4,708 | 4,640-4,771 | 0.5 | 4.3 | 4,919 |
| Scrub litter | Texas | 5/24/66 | 7 | 3,589 | 3,501-3,680 | 0.7 | 26.5 | 4,882 |
| Post oak leaves | Texas | 5/24/66 | 6 | 4,882 | 4,809-4,920 | 0.4 | 2.4 | 5,000 |
| Post oak litter | Texas | 5/24/66 | 7 | 3,854 | 3,668-4,000 | 1.2 | 19.9 | 4,814 |
| Evergreen yaupon leaves | Texas | 5/24/66 | 6 | 5,061 | 5,033-5,106 | 0.2 | 5.2 | 5,338 |
| Deciduous yaupon leaves | Texas | 5/24/66 | 6 | 5,092 | 5,057-5,132 | 0.3 | 4.1 | 5,311 |
| Yaupon litter | Texas | 5/24/66 | 7 | 3,982 | 3,873-4,085 | 0.7 | 27.6 | 5,501 |

[1] These are high heat values; subtract 300 cal./g. for low heat value.

High heat values of the additional fuels collected after the original study (table 2) showed even greater ranges in values than those reported above. The values for ovendry material as sampled in the field differed by 2,015 cal./g. for the southern fuels and by 3,767 cal./g. for the eastern and central fuels. If the arbitrary heat-value classes established above are followed, these additional fuels can be grouped thus:

I. Organic soil, inner bark of sweetgum (*Liquidambar styraciflua* L.), and European larch litter (*Larix decidua* Mill.).

II. Reindeer moss (*Cladonia rangiferina* L.), dead bracken fern (*Pteridium latiusculum* (Desv.) Underw.), and hazel leaves (*Corylus cornuta* Marsh).

III. Hazel twigs, eastern larch needles (*Larix laricina* (Du Roi) K. Koch), European larch needles, white spruce needles (*Picea glauca* (Moench) Voss), jack pine duff (*Pinus banksiana* Lamb.), outer bark of sweetgum, mixed aspen-oak litter, aspen twigs (*Populus tremuloides* Michx.), new needles of sand pine (*Pinus clausa* (Chapm.) Vasey), black spruce needles (*Picea mariana* (Mill.) B. S. P.).

IV. Needles and twigs of balsam fir (*Abies balsamea* (L.) Mill.), twigs of white and black spruce, aspen leaves, needles and twigs and litter of jack pine, sand pine twigs, sand pine needles, and bark of white birch (*Betula papyrifera* Marsh.).

## DISCUSSION

The data given in this report are high heat values because the water vapor produced by combustion is condensed to liquid in the calorimeter. In a forest fire, moisture resulting from combustion is not condensed and therefore retains its heat of vaporization. In such a case, the quantity of heat produced is expressed as a low heat value.

The proportion of carbon, hydrogen, and oxygen in a specific fuel influences the quantity of water vapor released when it burns. Among the fuels tested, exact proportions of these elements were not known. At present, the best estimate of heat stored in the water of reaction is that used for wood (Byram 1959) — about 300 cal./g. When approximations of low heat values are desirable, as in estimating the heat yield from combustion of forest fuels in a

Table 2. -Caloric value of ovendry forest fuels from the Eastern United States

| Samples by species-type | Location | Date collected | Caloric value[1] | Total ash content | $SiO_2$-free ash content | Ash-free caloric value[1] |
|---|---|---|---|---|---|---|
| | | | *Cal./g.* | . . *Percent* . . | | *Cal./g.* |
| Sweetgum outer bark | Macon, Ga. | 1/20/69 | 4,709 | 6.4 | | 5,010 |
| Sweetgum inner bark | Macon, Ga | 1/20/69 | 3,810 | 7.4 | — | 4,092 |
| Organic soil | Lakeland, Fla. | 11/7/68 | 3,428 | 40.00 | | 4,199 |
| Sand pine new needles | Ocala, Fla. | 3/18/69 | 5,379 | 2.0 | 1.2 | 5,487 |
| Sand pine new needles | Ocala, Fla. | 5/14/69 | 4.865 | | — | — |
| Sand pine old needles | Ocala, Fla. | 3/18/69 | 5,443 | 2.1 | 1.9 | 5,557 |
| Sand pine old needles | Ocala, Fla. | 5/14/69 | 5,242 | — | | |
| Sand pine twigs | Ocala, Fla. | 3/18/69 | 5,293 | 1.5 | 0.8 | 5,372 |
| Sand pine twigs | Ocala, Fla. | 5/14/69 | 5,112 | — | | |
| Eastern larch needles | Mexico, Pa. | 10/11/67 | 4,637 | 7.39 | 4.34 | 4,980 |
| European larch needles | State College, Pa. | 10/11/67 | 4.608 | 8.47 | — | 4,998 |
| European larch litter | State College, Pa. | 10/11/67 | 3.996 | 20.33 | — | 4,808 |
| Dead bracken fern | Mille Lacs, Minn. | 5/5/69 | 4,414 | 7.79 | 2.61 | 4,758 |
| Mixed aspen-oak litter | Mille Lacs, Minn. | 5/5/69 | 4,753 | 7.71 | 5.20 | 5,119 |
| Aspen leaves | Ely, Minn. | 6/26/69 | 5,053 | 4.60 | 4.55 | 5,285 |
| Aspen twigs | Ely, Minn. | 6/26/69 | 4,864 | 3.16 | 3.12 | 5,018 |
| Hazel leaves | Ely, Minn. | 6/25/69 | 4,424 | 4.98 | 4.75 | 4,644 |
| Hazel twigs | Ely, Minn. | 6/25/69 | 4,556 | 3.74 | 3.60 | 4,726 |
| Jack pine needler | Ely, Minn. | 6/25/69 | 5,102 | 1.94 | 1.41 | 5,201 |
| Jack pine twigs | Ely, Minn. | 6/25/69 | 5,156 | 1.66 | 1.44 | 5,262 |
| Jack pine litter | Ely, Minn. | 6/26/69 | 5,148 | 2.62 | 1.41 | 5,283 |
| Jack pine duff | Ely, Minn. | 6/26/69 | 4,700 | 9.80 | 1.74 | 5,161 |
| Balsam fir needles | Ely, Minn. | 6/25/69 | 5,060 | 2.90 | 2.66 | 5,207 |
| Balsam fir twigs | Ely, Minn. | 6/25/69 | 5.040 | 2.73 | 2.56 | 5,178 |
| White spruce needles | Ely, Minn. | 6/26/69 | 4,700 | 4.91 | 3.34 | 4,931 |
| White spruce twigs | Ely, Minn. | 6/26/69 | 5,050 | 3.50 | 2.32 | 5,247 |
| Black spruce needles | Ely, Minn. | 6/25/69 | 4,926 | 2.38 | 1.98 | 5,043 |
| Black spruce twigs | Ely, Minn. | 6/25/69 | 5,125 | 3.08 | 1.84 | 5,283 |
| White birch bark | Ely, Minn. | 6/25/69 | 7,165 | 1.30 | 0.68 | 7,864 |
| Reindeer moss | Ely, Minn. | 6/25/69 | 4,360 | 1.86 | 0.72 | 4,441 |

[1] These are high heat values; subtract 300 cal./g. for low heat value.

natural atmosphere, 300 cal./g. should be deducted from the appropriate high heat values.

The chemical composition of a fuel influences its caloric value as well as the amount of water produced in combustion. For example, the heat values of several plant constituents vary as follows: 9,300 cal./g. for fats, 6,300 cal./g. for lignin, 5,700 cal./g. for proteins, 5,100 cal./g. for carbohydrates, and 3,700 cal./g. for glucose (Kramer and Kozlowski 1960). This variation explains, in a general way, why resinous conifers and waxy evergreen shrub species have higher caloric values than do most hardwood or grass species.

Two exceptions to the generalization that conifers have higher caloric values than do hardwoods have been noted among the fuels from Minnesota. Bark from white birch had the highest caloric value of any forest fuel tested at this laboratory (7,763 cal./g.). This value would indicate a very high content of fat or essential oil. Such oils are, in fact, extracted on a commercial scale from birch bark (Kramer and Kozlowski 1960). Quaking aspen showed the highest heat value among the hardwood leaves tested. This value was as high as those of some pine species and probably indicates a relatively high fat content.

Part of the variation in caloric value between fuels may be the result of collecting samples at different times of the year. Richards (1940) has noted that a number of species in the Northern Rocky Mountains exhibit seasonal variation in heat value. He found that the heat value of one species increased 600 cal./g. during the fire season. Short et al. (1966) noted that some browse species in Colorado exhibit seasonal changes in heat value of about 400 cal./g. Such seasonal variation may account for the difference found between the heat value of gallberry leaves collected in Georgia during August and in North Carolina during March. The effect of season was obvious for sand pine samples collected from the same trees in March and May (table 2).

Caloric values for fresh litter and decomposed litter under a pine plantation have been reported by Ovington and Heitkamp (1960) ; in almost all cases, the fresh litter contained more energy than did the decomposed litter. This same relationship between fresh and decomposed litter was evident in the present study.

Differences in caloric value between litter fuels resulted, in part, from the dilution of the combustible material with inorganic ash. When corrections were made for ash, however, the lower layers were as high in heat value as were the upper layers, or higher. Similar results have been reported by Bocock (1964) for several hardwood species. This higher heat value which results when the decomposed litter is corrected for ash content indicates that the low-energy components (carbohydrates and cellulose) decomposed more rapidly than did the high-energy components (lignin). Dilution of lower litter layers with inorganic matter cannot be ignored, however, because fuels are not ash-free in the field.

The wide range in heat values reported here (from 3,428 to 7,763 cal./g.) is not unexpected. The caloric values of different vegetative and litter materials in England were found to vary from 3,317 to 5,187 cal./g. (Ovington and Heitkamp 1960), and in Russia a similar variation from 3,770 to 5,250 cal./g. was noted (Gorbatova 1964). However, the full influence of a difference of 100 cal./g. or even 4,000 cal./g. on the behavior of a forest fire is unknown. For this reason, the statistical differences reported here may not be significant to fire behavior. Only through further study of the effect of heat value on fire behavior can this point be resolved.

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Walter A. Hough, Plant Physiologist
Southern Forest Fire Laboratory
Macon, Georgia