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Productivity and energy storage

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PRODUCTIVITY AND ENERGY STORAGE

Working as cooperators in the International Biological Program, we have examined the primary production of Wisconsin landscapes (Stearns, et. al. 1971). Net annual production of plant communities is traditionally determined by measuring or estimating dry matter accumulation at the end of the growing season. Published records list crop or forest yields, i.e. the bales of hay, tons of silage, bushels of grain or cords of wood harvested. The yield represents only a portion of the organic matter produced. Each year a tree forms leaves, twigs and bark which are not harvested, and each year an entire new corn plant–roots, stalks and leaves–must develop to produce the bushels of grain. Primary production is the entire amount of growth for the year. For many purposes, the accumulation of organic matter (on a dry weight basis) is an adequate measure of production; however, total dry matter production may be misleading as a measure of the energy actually stored. For example, oat fields in northern and southern Wisconsin may show similar dry matter accumulation each year and thus appear equally productive. If however, these oats were fed to cattle, the animals would not necessarily derive equal amounts of energy from the two sources. We found that oats in a northern Wisconsin field (Forest County) concentrated energy at 4488 calories per gram dry weight while the southern (Ozaukee County) oats had 99 fewer (4389) calories per gram. A typical oat field may produce 6 metric tons of organic matter per hectare each year; the northern oat field stored perhaps 600 million more calories per hectare (2.1 acres) than did the southern field. This difference is approximately 3% of the total energy annually stored by a field of oats, i.e., 25,000 million calories per hectare.

To compare energy storage of agricultural crops and marsh plants, it was necessary to determine their caloric content. Major plant parts: seeds, cobs, leaves, stems, and roots, were analyzed separately. (Previously published values for agricultural plants include only economically important structures, the seeds and fruits). Corn, oats, peas, and alfalfa hay were harvested in Ozaukee and Calumet Counties and oats and hay in Forest County. Marsh plants were sampled in the Theresa Marsh by Jeffrey Klopatek. Energy content was determined using a Parr oxygen bomb calorimeter (Parr, 1968).

In areas with similar soils and climate, we found that energy storage in each gram of dry matter was constant from field to field. In general a single caloric value will suffice for energy estimates on entire plants. (Table I). As described above, there are differences in caloric content between northern and southern locations. In cooler climates, oats assimilate less mineral material (northern 5.8% ash, southern 7.3% ash) with the result that each gram of dry matter has a higher energy content.

Annual crop plants store energy chiefly in the seeds and fruits. In contrast the (perennial)marsh species contained proportionately more energy in roots and rhizomes, not an unexpected result (Jordan, 1971) (Table 2). The range of values

Table 1. Average caloric values,[1] percentage ash and ash-free caloric values for entire crop plants.

Crop	Location sample date	cal/gram dry wt.	Percentage ash	cal/gr ash-free
Oats				
Avena sativa	Forest County 8/12/71	4488	5.8	4762
	Calumet County 8/5/71	4458	5.3	4705
	Ozaukee County 7/30-8/2/71	4388	7.3	4727
Peas				
Psium sativum	Ozaukee County 6/25/71	4351	9.9	4836
Corn				
Zea mays	Calumet County 9/6/71	4417	4.1	4609
	Ozaukee County 9/15/71	4410	4.3	4614
Alfalfa				
Medicago sativa	Calumet County 9/6/71	4405	8.0	4791
	Ozaukee County 9/15/71	4412	8.6	4778

1. Caloric values are expressed in gram calories "c", the kilogram calorie "C" usually used to calculate human diets contains 1000 times as much energy.

illustrates the dry weight and energy distribution in various crops and native forbs that grow in Ozaukee County.

Knowing the caloric value of the net annual production, one may calculate the efficiency with which the plant stores solar energy. Likewise, one can compare the energy stored with that in the fossil fuels used for plowing and in food needed to "fuel" the farmer. Potatoes proved to be the most efficient Ozaukee County crop and sweet corn the least. All of the crops utilize only a small amount of the available solar energy. When solar energy is discounted (taken as free), the energy stored by the plant proves to be considerably greater (2 to 28 times) than the direct energy input in fossil fuel and food (Table 3). This comparison does not include the energy utilized in manufacture of the tractor, manufacture and transportation of fertilizer, housing and maintaining the farmer, and in the multitude of other activities involved in agriculture. If energy requirements of those activities were included, it is probable that the fossil energy invested in modern mechanized farming would exceed the yield in energy stored by crops

(Perelman, 1972). Total energy expenditures for crop production are large and not often considered.

Our estimate of productivity of Wisconsin crops was based on yields reported in state agricultural statistics (Wis. Stat. Rept. Serv. 1970). This requires expansion from yield figures to total primary production and entails several conversions. As a result, our productivity estimates are open to considerable refinement. Nonetheless, the work to date provides a useful tool with which to estimate the impact on agriculture of land use changes such as urbanization or highway construction.

Table 2. Caloric values, percentage dry weight and percentage ash for representative crop and marsh species illustrating differences between plant parts.

Plant	cal/gr dry wt.	% dry wt.	% Ash	cal/gr ash-free wt.
Cattail				
Typha latifolia [1]				
Spikes	4628	54	6.2	4934
Stems and leaves	4355	26	9.1	4791
Roots and rhizomes	4155	20	7.7	4718
Entire plant	4463	100	7.3	4854
River Rush [1]				
Scirpus fluviatalis				
Tops	4380	64	9.9	4861
Roots and rhizomes	4502	36	5.4	4759
Entire plant	4419	100	8.3	4820
Corn [2]				
Zea mays				
Tassels	4529	1	6.6	4850
Grain	4525	39	1.9	4612
Cobs	4439	11	1.5	4508
Husks	4453	7	3.0	4591
Stems	4374	24	5.8	4643
Leaves	4232	12	11.0	4755
Roots	4247	6	9.0	4666
Entire plant	4410	100	4.3	4614
Oats [3]				
Avena sativa				
Fruits (grain)	4570	44	4.0	4757
Leaves and stems	4386	35	8.9	4812
Roots	3996	21	10.4	4471
Entire plant	4389	100	7.1	4718

1 Samples obtained at Theresa Marsh, Washington County, July 16, 1972

2 Samples harvested in Cedarburg, Ozaukee County, September 15, 1971

3 Samples harvested in Cedarburg, July 30, 1971

Table 3. Efficiency of energy storage by selected crops relative to solar energy received during the growing season and to fossil fuel and food consumed in crop production. Values for Ozaukee County.

Crop	Yield	Percentage efficiency of energy use[1]	Ratio of calories of yield to caloric input of fuel and food
Sweet corn	3.9 tons/A	0.10	1.9:1
Corn for grain	44 bu/A	0.55	11:1
Corn for silage	10 tons/A	0.80	15:1
Soy beans	19 bu/A	0.17	7:1
Oats for grain	67 bu/A	0.30	9:1
Alfalfa hay	3 tons/A	0.80	25:1
Potatoes	220 HDW	0.70	28:1

1 This value represents the efficiency with which the crop uses solar radiation received during the growing season in Ozaukee county. For example the caloric content of 44 bu of corn is equivalent to 0.55% of the sunlight received. Approximately 3,285,000 x 10^6 cal reached each hectare of surface. The fossil fuel input and food used by the farmer was never more than 3,300 x 10^6 hectare.

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