3 Solar Energy in Natural and Managed Ecosystems

Natural ecosystems, of which humans are a part, are fundamentally a network of solar energy and mineral flows. Green plants capture solar energy and convert it into chemical energy for use by themselves and the remainder of the biological system using the elements of carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, and others. The food supplied by plants in the ecosystem is basic to the survival of all animals, including humans. It is the foundation of the entire life system. Some of the solar energy plants convert into stored chemical energy is passed on to herbivores and parasitic microbes. The success of agriculture and forestry is measured by the amount of solar energy captured as biomass in crops and forests. The biomass yield depends on the manipulation of these plants—which need fertile soil, water, and a favorable climate—using human, animal, and fossil fuel power for tilling, planting, weed control, harvesting, and various other activities.

In this chapter, we focus on solar energy as a fundamental resource for the functioning of both natural and managed ecosystems. Also considered are the limitations of solar energy and the land area of the terrestrial ecosystems in the United States.

NATURAL ECOSYSTEMS

The solar energy reaching a hectare of land in temperate North America averages about 14 billion kcal per year (Reifsnyder and Lull, 1965). This is the equivalent of the energy contained in about 1.4 million liters (370,000 gal) of oil, or the energy used by 133 Americans for 1 year. However, most plants in the temperate zone of the United States do not grow during the winter months, achieving most of their growth during a relatively short 4-month summer. During this period, nearly 7 billion kcal—about half of the year's sunlight energy—reach each hectare of land.

Consider now how the solar energy is converted into biomass by vegetation. The total area in the United States, including lakes and rivers, is 1049 million ha. The total biomass produced annually is 2793 million tons, or nearly 3 tons/ha (Table 3.1). If we assume 4200 kcal per kg of biomass, then the total energy captured is 11.7 million kcal/ha per year, or slightly less than 0.1% of the total sunlight energy reaching each hectare.

Although in the tropics there are no winters, there are dry periods during which little plant biomass is produced. Thus, biomass productivity in the tropics, on average, is quite similar to that of temperate regions. In the tropics, the prime limiting factor is moisture, whereas in the temperate United States temperature is the prime limiting factor.

TABLE 3.1
Total Annual Plant Biomass Production in the United States

Location	Area (million ha)	Biomass (dry tons/ha)	Total Biomass (dry Mt)[a]
Terrestrial farmland			
Cropland	135	6	810
Cropland idle	21	4	84
Cropland in pasture	36	4	144
Grassland in pasture	183	2	366
Forest and woodland	45	3	135
Farmsteads, roads	11	0.1	1
Other			
Grazing land	117	2	234
Forest land	202	3	606
Other land, urban, marshes, desert	167	0.1	17
Subtotal	917	—	2397
Aquatic			
Lakes and rivers	132	3	396
Total	1049	—	2793

[a] Mt = million metric tons.

In natural ecosystems, the approximately 3 tons/ha/year of biomass available limits the number of consumers and the number of links in the food chain. Usually only about 10% of the energy is passed on from one consumer level to the next. Therefore, rarely do links in the food chain number more than 4 or 5. This explains why some large predators, such as tigers, must range over hundreds of hectares to find adequate amounts of food. Thus, energy, along with moisture and nutrients (nitrogen, phosphorus, potassium, etc.), is a major limiting factor for natural ecosystems.

Plants in the United States fix about 13.5×10^{15} kcal of solar energy per year (Figure 3.1), which is significantly less than the current annual fossil energy consumption of about 20×10^{15} kcal. Indeed, Americans burn about 40% more fossil energy than the total solar energy captured by all the plant biomass in the United States each year (Figure 3.1). These figures illustrate that humans' use of fossil energy is far out of balance with the energy naturally available and renewable in their ecosystem. In addition, fossil energy has made drastic changes in the U.S. ecosystem, including the removal of forests and natural prairies.

About 70% of the total energy fixed in the terrestrial United States is produced on agricultural lands, the remainder from plants growing on nonagricultural lands (Table 3.1). Any analysis of the effectiveness of biological solar energy conversion in nature and managed ecosystems must consider agricultural and forestry production. About 70% of the U.S. land area is used for food and forest production (Table 3.1). Each year the total amount of solar energy harvested annually in the form of agricultural crops and forestry products is about 6.9×10^{15} kcal (5.8×10^{15} kcal net

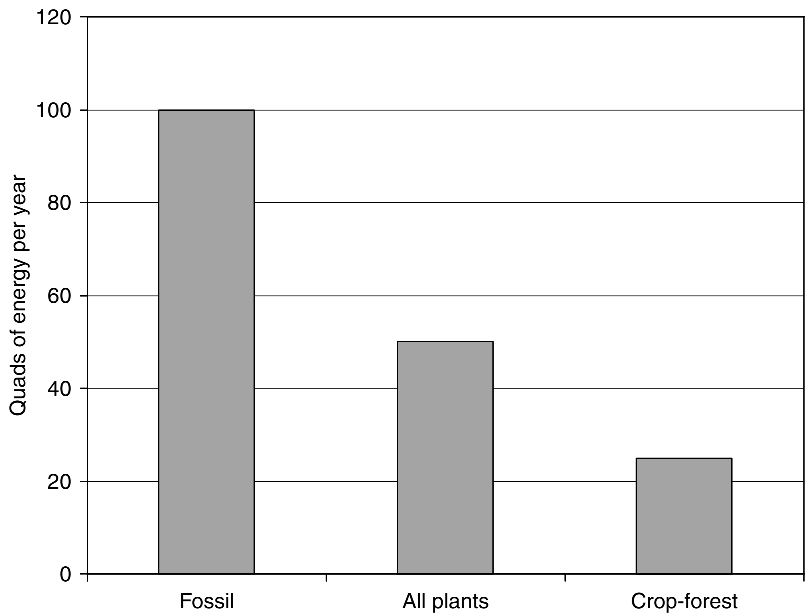

FIGURE 3.1 The solar energy captured annually in the United States compared with fossil energy consumption and the amount of solar energy harvested as crop and forest products.

energy). This represents about 30% of the fossil energy consumption in the United States. Pasture and other forage crops account for about 66% of the harvested energy, whereas food crops total 16% and forest products 18%.

The 6.9×10^{15} kcal of biological energy harvested in the form of agricultural and forestry products has several significant implications. First, about half of all the solar energy fixed by plants in the United States is harvested and used by humans and livestock, whereas the other half is used within the natural ecosystem. Thus, the energy produced in both agriculture/forestry and the natural ecosystem is vital to the functioning of the human economy and sustains the health of the natural environment. This conclusion suggests that Americans are making maximal use of the land to produce biomass for food and forest products and that their natural ecosystem also requires a large amount of biomass to maintain it. Furthermore, the use of biomass as fuel must be limited, because food and forest biomass support the diverse needs and activities of human society.

FOREST ECOSYSTEMS

Net primary production in U.S. forests is about 3 tons/ha/year (Table 3.1). This yield is slightly more than the average net primary production for all the ecosystems in the nation. It includes leaves and small twigs, so the net harvest of biomass wood is, optimistically, about 2 tons/ha, which provides about 8.4 million kcal of energy when burned to produce heat energy. Each American consumes the equivalent of 81 million kcal in fossil fuel annually, or the energy produced from about 10 ha of forest.

AGRICULTURAL ECOSYSTEMS

Annual net primary production in U.S. agricultural ecosystems is about 5 tons/ha (Table 3.1). This figure is higher than the overall average yield of biomass per hectare because crops are grown under favorable conditions regarding moisture, soil nutrients, and soil quality. For example, corn grown under favorable conditions will produce 9 tons/ha of corn grain, plus an additional 9 tons/ha of stover. Converted into heat energy, this totals about 66×10^6 kcal per ha. This represents about 0.5% of the solar energy reaching 1 ha during the year, a relatively high rate of conversion for crops and natural vegetation. Most crops have about a 0.1% level of conversion.

In summary, the terrestrial ecosystem is extremely important to the survival of humans because more than 99% of their food and 100% of their forest products comes from terrestrial plants that capture solar energy. In addition, the terrestrial ecosystem, in capturing solar energy, helps maintain the natural ecosystem and a quality environment.

REFERENCE

Reifsnyder, W.E. and H.W. Lull. 1965. Radiant energy in relation to forests. Technical Bulletin No. 1344. Washington, D.C.: U.S. Department of Agriculture, Forest Service.