11 Energy Use in Fruit, Vegetable, and Forage Production

FRUITS

Fruits, the edible material adhering to the seeds of a plant, are eaten raw, cooked, or dried. Fruits have a high water content, ranging from about 75% to 90%. Carbohydrates, usually in the form of sugar, are the second-largest constituent, ranging from about 6% to 22%. Fruits contain only small amounts of protein and negligible amounts of fats. Citrus fruits, cantaloupes, and strawberries are excellent sources of vitamin C, whereas yellow-orange fruits are considered outstanding sources of beta-carotene, the precursor of vitamin A.

In this section, apple and orange production in the United States are analyzed to illustrate energy expenditure and food energy yield in fruit production.

APPLES

Apples are an economically valuable crop in many parts of the world. In the United States, petroleum products are used to operate machinery employed in apple orchards, and the inputs for this machinery account for a large percentage of the total energy input (Table 11.1). The next largest input is for pesticides, which represent nearly 17% of the total energy input in apple production.

The labor input of 385 h/ha expended in apple production is high compared with those of most other food crops grown in the United States. Most of the labor input occurs during harvesting. The total labor input is calculated to be about 17.1 million kcal/ha, which represents only 34% of the total energy input for apple production. The yield in fruit is about 30.7 million kcal/ha, making the output/input ratio only 0.61:1.

ORANGES

Oranges are another valuable fruit in U.S. agriculture. Although oranges and other citrus fruits have more than double the vitamin C content of potatoes, they supply only about half as much vitamin C in the U.S. diet as potatoes.

The production of oranges requires less energy than apples (Tables 11.1 and 11.2). Specifically, orange production uses less petroleum products and pesticides than apple production. The return in food energy in the form of oranges is 23.5 million kcal/ha, for an output/input ratio of only 1:1. Apples, then, are more energy intensive to produce

TABLE 11.1
Energy Inputs in Apple Production in the Eastern United States

	Quantity/ha	kcal/ha
Inputs		
Labor	385 h	17,150,000
Machinery	88 kg	1,408,000
Diesel	483 L	5,506,000
Gasoline	1346 L	13,406,000
Nitrogen	45 kg	837,000
Phosphorus	114 kg	472,000
Potassium	114 kg	372,000
Insecticides	47 kg	4,700,000
Herbicides	6 kg	600,000
Fungicides	49 kg	4,900,000
Electricity	66 kWh	57,000
Transportation	2974 kg	787,000
Total		50,195,000
Outputs		
Apple yield	55,000 kg	30,660,000
Protein yield	109 kg	
kcal output/kcal input		0.61:1

Source: Pimentel, D., An Organic Center State of Science Review, August 2006, http://www.organic-center.org/science.pest.php?action=view&report_id=59.

TABLE 11.2
Energy Inputs in Orange Production in Florida

	Quantity/ha	kcal/ha
Inputs		
Labor	210 h	9,354,000
Machinery	30 kg	480,000
Diesel	90 L	1,096,000
Gasoline	96 L	960,000
Nitrogen	228 kg	4,239,000
Phosphorus	54 kg	224,000
Potassium	228 kg	783,000
Insecticides	9 kg	900,000
Herbicides	11 kg	1,000,000
Nematicides	37 kg	3,700,000
Electricity	66 kWh	57,000
Transportation	500 kg	128,000
Total		22,921,000
Outputs		
Orange yield	46,000 kg	23,519,000
Protein yield	404 kg	
kcal output/kcal input		1.02:1

Source: Pimentel, D., An Organic Center State of Science Review, August 2006, http://www.organic-center.org/science.pest.php?action=view&report_id=59.

than oranges. From the standpoint of vitamin C content, oranges, with about 50 mg per 100 g, are more valuable than apples, which contain only 3 mg per 100 g.

VEGETABLES

Vegetables are the various parts of herbaceous plants consumed by humans. For example, cabbage and spinach are plant leaves, carrots and turnips are roots, squash and tomatoes are fruits, peas and corn are seeds, onions are bulbs, and potatoes are tubers.

Vegetables are similar to fruits in that they have high water content (80%–95%) and low fat and, except for beans and peas, low protein content. The carbohydrate content, mainly starch, varies considerably from a high of about 22% for lima beans to a low of 2% for lettuce. Vegetables generally have a higher mineral and vitamin content than fruits. In particular, dark green leafy vegetables such as spinach are high in vitamin C, beta-carotene, and iron. Also, except for spinach and chard (goosefoot family), these vegetables are excellent sources of calcium. Oxalic acid in spinach may chemically bind some of the calcium, making it insoluble, hence less available to humans. Many vegetables, especially seeds, are reliable sources of thiamine.

This energy analysis covers a broad cross-section of vegetables, including potatoes, spinach, brussels sprouts, tomatoes, sugar beets, and cassava.

POTATOES

The white potato is one of the 15 most heavily consumed plant foods in the world today. Even in the United States, where a wide variety of vegetables are available, the potato is the most frequently eaten vegetable. There, about 60 kg of potato is consumed per person per year (USDA, 2003).

Based on data from the United States, the greatest energy input in U.S. potato production is fertilizers, which represent about one-quarter of the total inputs (Table 11.3). Another one-quarter of the energy is expended for petroleum and machinery inputs that reduce the human labor input, which averages 35 h/ha. The total energy input for potato production is 17.5 million kcal/ha. The potato yield equals 23.3 million kcal/ha, resulting in an output/input ratio of 1.3:1, slightly lower than the 1.6:1 reported by Leach (1976) for the United Kingdom (Table 11.4). The differences in inputs between U.S. and U.K. production are considered insignificant.

Although potatoes are only 2% protein, the total yield of protein per hectare is substantial, amounting to 814 kg/ha. This is a relatively high yield, especially for a food so high in water content.

SPINACH

Spinach, a green leafy vegetable, is eaten raw or cooked. Although it is not a major vegetable throughout the world, it is nutritionally valuable. Like other dark green leafy vegetables, spinach contributes iron, riboflavin, and vitamins A and C to the diet.

TABLE 11.3
Energy Inputs in Potato Production in the United States

	Quantity/ha	kcal/ha
Inputs		
Labor	35 h	1,964,000
Machinery	31 kg	574,000
Diesel	152 L	1,735,000
Gasoline	272 L	2,750,000
Nitrogen	231 kg	4,294,000
Phosphorus	220 kg	911,000
Potassium	111 kg	362,000
Seeds	2408 kg	1,478,000
Sulfuric acid	64.8 kg	0[a]
Insecticides	3.6 kg	360,000
Herbicides	1.5 kg	150,000
Fungicides	4.5 kg	450,000
Electricity	47 kWh	135,000
Transportation	2779 kg	2,307,000
Total		17,470,000
Outputs		
Potato yield	40,656 kg	23,296,000
Protein yield	722 kg	
kcal output/kcal input		1.33:1

[a] Sulfuric acid production is an exothermic process.

Source: Pimentel, D., An Organic Center State of Science Review, August 2006, http://www.organic-center.org/science.pest.php?action=view&report_id=59.

TABLE 11.4
Energy Inputs in Potato Production in the United Kingdom

	Quantity/ha	GJ/ha[a]
Inputs		
Field work		
Fuel for tractors (to harvest)	2.85 GJ	2.85
Fuel for harvester, transport	3.38 GJ	3.38
Tractor depreciation and repairs	1.14 GJ	1.14
Harvester depreciation and repairs	6.70 GJ	6.70
Nitrogen	175 kg	14.0
Phosphorus	175 kg	2.45
Potassium	250 kg	2.25
Sprays	13 kg	1.24
Seed shed fuels (620 MJ/t seed)	1.57 GJ	1.57
Storage (1.65 kWh/net t)	0.57 GJ	0.57
Total		36.15

TABLE 11.4 (continued)
Energy Inputs in Potato Production in the United Kingdom

	Quantity/ha	GJ/ha[a]
Outputs		
Potato yield	26,300 kg	56.9
Protein yield	376 kg	
Energy output/energy input		1.57:1

[a] 4186 Joule = 1 kcal.

Source: After Leach, G., *Energy and Food Production*, IPC Science and Technology Press Ltd., Guildford, Surrey, UK, 1976.

TABLE 11.5
Energy Inputs in Spinach Production in the United States

	Quantity/ha	kcal/ha
Inputs		
Labor	56 h[a]	26,040[b]
Machinery	30 kg[c]	480,000
Fuel	297 L[a]	2,970,000[a]
Nitrogen	470 kg[a]	6,909,000
Phosphorus	354 kg[a]	1,062,000
Potassium	136 kg[a]	217,600
Limestone	454 kg[a]	143,010
Seeds	33.6 kg[a]	135,300[a]
Irrigation	69,500 kcal[a]	69,500[a]
Insecticides	2 kg[a]	173,820
Herbicides	2 kg[a]	199,820
Electricity	300,000 kcal[a]	300,000[a]
Transportation	287 kg	73,759[d]
Total		12,759,849
Outputs		
Spinach yield	11,200 kg[a]	2,912,000
Protein yield	358 kg	
kcal output/kcal input		0.23:1

[a] Terhune, E., in *Energy Use Management*, Pergamon, New York, 1977, 769–778.
[b] 56 h × 465 kcal/h.
[c] Estimated.
[d] 287 kg × 257 kcal/kg.

The largest energy input in U.S. spinach production is for nitrogen fertilizer, amounting to nearly 50% of the total energy input (Table 11.5). The next largest inputs are for fuel and machinery. The overall energy cost is 12.8 million kcal/ha, and the spinach yield is 2.9 million kcal/ha. The output/input ratio is 0.2:1. This negative ratio means that about 5 kcal of fossil energy is required to produce each kcal of spinach.

TABLE 11.6
Energy Inputs in Tomato Production in the United States

	Quantity/ha	kcal/ha
Inputs		
Labor	363 h	14,580,000
Machinery	100 kg	1,600,000
Diesel	246 L	2,808,000
Gasoline	628 L	6,348,000
Nitrogen	200 kg	3,000,000
Phosphorus	100 kg	300,000
Potassium	150 kg	225,000
Limestone	50 kg	16,000
Seedlings	13,600	100,000
Irrigation	125 cm	1,010,000
Insecticides	1.5 kg	150,000
Herbicides	1.5 kg	150,000
Fungicides	16 kg	1,600,000
Electricity	77.5 kWh	200,000
Transportation	1024 kg	272,000
Total		32,389,000
Outputs		
Tomato yield	41,778 kg	8,358,000
Protein yield	496 kg	
kcal output/kcal input		0.26:1

Source: Pimentel, D., An Organic Center State of Science Review, August 2006, http://www.organic-center.org/science.pest.php?action=view&report_id=59.

Tomatoes

Botanically speaking, tomatoes are fruits, but they are included in this section because they are usually consumed as a vegetable. They are eaten in a variety of ways, including raw, cooked, canned, and as juice. They are valued nutritionally for vitamin C (23 mg per 100 g of raw tomato), vitamin A, and iron.

Based on U.S. data, one-third of the energy inputs in tomato production are for fuel and machinery that reduce labor inputs (Table 11.6). The second largest input is for fertilizers. The total energy input is 32.4 million kcal/ha, and the average tomato yield is 8.4 million kcal/ha. These figures result in an output/input ratio of about 0.26:1, or about 4 kcal of energy expended for every kcal of tomato produced. Because the yield of tomatoes per hectare is so high, the protein yield of 496 kg/ha is excellent, even though tomatoes average only 1% protein and have a high water content.

Brussels Sprouts

Brussels sprouts are a favorite vegetable in the United Kingdom but are less popular in the United States. Like spinach, they are an excellent source of vitamin A, vitamin C, and iron.

TABLE 11.7
Energy Inputs in Brussels Sprouts Production in the United States

	Quantity/ha	kcal/ha
Inputs		
Labor	60 h[a]	27,900[b]
Machinery	30 kg[c]	480,000
Fuel	285 L[a]	2,881,065
Nitrogen	180 kg[a]	2,646,000
Phosphorus	45 kg[a]	135,000
Potassium	40 kg[a]	64,000
Limestone	40 kg[a]	12,600
Seeds	4 kg[a]	16,120[a]
Insecticides	5 kg[a]	434,550
Herbicides	10 kg[a]	999,100
Electricity	300,000 kcal[c]	300,000[c]
Transportation	249 kg	63,993[d]
Total		8,060,328
Outputs		
Brussels sprouts yield	12,320 kg[a]	5,544,000
Protein yield	604 kg	
kcal output/kcal input		0.69:1

[a] From Pimentel, D., in *Enciclopedia della Scienza e della Tecnica*, Mondadori, Milan, 1976, 251–266.
[b] 60 h × 465 kcal/h.
[c] Estimated.
[d] 249 kg × 257 kcal/kg.

As with most vegetable production, the major energy inputs for Brussels sprout production in the United States are for fuel and machinery, amounting to more than one-third of the total input (Table 11.7). The next major input is for fertilizers. The total energy input for Brussels sprouts production is 8.1 million kcal/ha, and the yield equals about 5.5 million kcal of food energy. Hence, the output/input ratio is 0.7:1. Although Brussels sprouts do not yield as much food energy or protein per hectare as potatoes, they do yield a significant 604 kg/ha of protein. Of the vegetables analyzed here, Brussels sprouts place second to potatoes in calories and protein yield per hectare.

Sugar Beets

The sugar beet is another plant that is not generally classed as a vegetable but is included in this section because it is a valuable food commodity in many parts of the world. Both sugar beets and sugarcane contain large quantities of sucrose. Although the sweetener is valued for its energy, it contains no vitamins, minerals, or protein. Sugar beets can be grown in temperate regions, whereas sugarcane can only be produced in tropical or subtropical regions.

TABLE 11.8
Energy Inputs in Sugar Beet Production in the United Kingdom

	Quantity/ha	GJ/ha
Inputs		
Field work		
Tractor fuels (to harvest)	2.50 GJ	2.50
Harvester, transport fuels	2.54 GJ	2.54
Tractor depreciation and repairs	2.00 GJ	2.00
Harvester depreciation and repairs	2.80 GJ	2.80
Nitrogen	160 kg	12.80
Phosphorus	50 kg	0.70
Potassium	150 kg	1.35
Salt	70 kg	0.10
Kainit (17% K_2O)	280 kg	0.43
Sprays	10.9 kg	1.09
Seed (144 MJ/£)	7.5 £	1.08
Total		27.39
Outputs		
Sugar beet yield	35,500 kg	99.1
Energy output/energy input		3.62:1

Note: 4186 Joule = 1 kcal.
Source: After Leach, G., *Energy and Food Production*, IPC Science and Technology Press Ltd., Guildford, Surrey, UK, 1976.

Based on data from Leach (1976), about 50% of the energy input for sugar beet production in the United Kingdom is for nitrogen fertilizer (Table 11.8). Machinery and fuel constitute the second largest input. The beet yield averages 35,500 kg/ha and contains about 16.5% sugar for processing. For sugar alone, the output/input ratio is about 3.6:1, making sugar beets one of the more efficient crops analyzed in this section.

Cassava

Cassava is an important crop worldwide, especially in Africa and South America. It is one of the highest producing crops in terms of carbohydrate per hectare but one of the lowest in terms of protein. The low protein content is one of the reasons the crop can grow in soil that is low in nutrients, especially nitrogen.

The data for cassava production are from the Tanga region of Africa. Cassava grown in that region has the efficient output/input ratio of 23:1 (Table 11.9). The root of the cassava shrub is harvested 9–12 months after the planting of stem cuttings. Production of this crop requires about 1300 h of hand labor per hectare. Total energy input is calculated at about 838,300 kcal/ha, and the yield is about 19.2 million kcal/ha. This high energy yield comes mainly from the starch content of cassava.

TABLE 11.9
Energy Inputs in the Tanga Region of Africa for Cassava Production

	Quantity/ha	kcal/ha
Inputs		
Labor	1284 h[a]	821,760[b]
Hoe	16,500 kcal[c]	16,500[c]
Stem cuttings	None	
Total		838,260
Outputs		
Cassava yield	5824 kg	19,219,200
Protein yield	58 kg	
kcal output/kcal input		22.93:1

[a] From Ruthenberg, H., *Smallholder Farming Development in Tanzania*, Munich, Germany, Weltforum Verlag, 1968.
[b] On a per day basis, the human power energy input is 8 h of work at 350 kcal/h; 6 h of other activities at 145 kcal/h; and 10 h of rest at 45 kcal/h. This totals 4120 kcal input per person.
[c] Estimated.

The protein yield, as mentioned, is low, only 58 kg/ha. Furthermore, the quality of cassava protein is considered the lowest of all plant proteins. Given the efficiency of cassava production and the breadth of its consumption in the tropics, it is unfortunate that the quality and quantity of protein is so inadequate.

FORAGE PRODUCTION

Forage production is an essential part of most livestock production systems, especially for ruminant animals. Like all crops, forage requires energy inputs. In general, these crops are not intensively managed because they bring a low monetary return.

Alfalfa, tame hay, and corn silage production are analyzed to estimate typical energy output/input ratios for forage production.

ALFALFA

Alfalfa is not only one of the most productive forages but also one of the most nutritious for livestock. Because it is fairly typical in the United States, data from Ohio were analyzed. The data indicate that the major inputs in U.S. alfalfa production are for fuel and machinery (Table 11.10). Together, these total about 70% of total inputs. In contrast to most other crops, alfalfa needs little or no nitrogen fertilizer; like legumes, it is associated with nitrogen-fixing bacteria. Because nitrogen fertilizer is an energy-costly input, this savings helps keep alfalfa production relatively energy efficient.

The total energy input for alfalfa production is calculated to be 2.5 million kcal/ha. With a yield of about 15.4 million kcal/ha, the output/input ratio is about 6:1.

TABLE 11.10
Energy Inputs in Ohio Alfalfa Production

	Quantity/ha	kcal/ha
Inputs		
Labor	13 h[a]	6,045[b]
Machinery	20 kg[c]	360,000
Gasoline	129 L[a]	1,304,061
Nitrogen	7 kg[a]	103,900
Phosphorus	45 kg[a]	135,000
Potassium	59 kg[a]	94,400
Limestone	179 kg[a]	56,385
Seeds	4.5 kg[a]	279,000[d]
Insecticides	0.4 kg[a]	34,764
Herbicides	0.2 kg[a]	19,982
Electricity	26 kWh[a]	74,438
Transportation	132 kg	33,924[e]
Total		2,501,899
Outputs		
Alfalfa yield	6,832 kg[a]	15,440,320
Protein yield	1,127 kg	
kcal output/kcal input		6.17:1

[a] From U.S. Department of Agriculture (USDA), *Firm Enterprise Data System*. Stillwater, OK, USDA, ERS, and Oklahoma State University Department of Agricultural Economics, 1977.
[b] 13 h × 465 kcal/h.
[c] Estimated.
[d] From Heichel, G.H., in *Handbook of Energy Utilization in Agriculture*, CRC Press, Boca Raton, FL, 1980, 27–33.
[e] 132 kg × 257 kcal/kg.

In addition to a high energy yield, alfalfa provides a high protein yield of about 1100 kg/ha. Alfalfa supplies a major share of the plant protein fed to animals in the United States.

Tame Hay

The major forage feed for cattle, sheep, and other ruminants in the world is tame hay consisting of numerous grass species. Animals are allowed to graze the hay as it grows in the pasture and do the harvesting themselves. Humans mechanically harvest some of the hay, and this production system is analyzed here.

As with alfalfa, two major energy inputs for tame hay production in the United States are for fuel and machinery (Table 11.11). Together these account for about 42% of the total energy expended for production. The average yield is estimated to be about 8.6 million kcal/ha in forage feed energy. Balanced against the total energy input of about 1.7 million kcal/ha, the energy output/input ratio is 5:1 for U.S. tame hay production.

Note that the 5:1 ratio for the United States is far better than the 2:1 ratio reported in the United Kingdom (Table 11.12), even though yield in the United Kingdom are more than double those in the United States. The reason is that the nitrogen input

TABLE 11.11
Energy Inputs in Tame Hay Production in the United States

	Quantity/ha	kcal/ha
Inputs		
Labor	16 h[a]	7,440[b]
Machinery	20 kg[c]	360,000
Fuel	36 L[d]	363,924
Nitrogen	7 kg[d]	102,900
Phosphorus	8 kg[d]	24,000
Potassium	16 kg[d]	25,600
Limestone	15 kg[c]	4,725
Seeds	30 kg[a]	630,000[e]
Herbicides	1 kg[d]	99,910
Electricity	75,000 kcal[c]	75,000[c]
Transportation	88 kg	22,616[f]
Total		1,716,115
Outputs		
Tame hay yield	5,000 kg[a]	8,578,680
Protein yield	200 kg	
kcal output/kcal input		5.0:1

[a] From Pimentel, D., in *Enciclopedia della Scienza e della Tecnica*, Milan, Mondadori, 1976, 251–266.
[b] 16 h × 465 kcal/h.
[c] Estimated.
[d] Federal Energy Administration (FEA), Energy and U.S. Agriculture: 1974 Data Base, Washington, D.C., U.S. Government Printing Office, 1976.
[e] From Heichel, G.H., in *Handbook of Energy Utilization in Agriculture*, CRC Press, Boca Raton, FL, 1980, 27–33.
[f] 88 kg × 257 kcal/kg.

TABLE 11.12
Energy Inputs for Tame Hay Production for a Typical U.K. Production System

	Quantity/ha	GJ/ha[a]
Inputs		
Field work, fuels	2.57 GJ	2.57
Field work, machinery	3.53 GJ	3.53
Nitrogen	250 kg	21.62
Total		27.7
Outputs		
Hay yield	10,300 kg	65.5
Energy output/energy input		2.36:1

[a] 4186 Joule = 1 kcal.
Source: After Leach, G., *Energy and Food Production*, Guildford, Surrey, UK, IPC Science and Technology Press Ltd., 1976.

used in the United Kingdom is more than 30 times that required in the United States. Another, less intensive hay production system in the United Kingdom yielded a more favorable ratio of 6:1 (Table 11.13).

Corn Silage

Corn silage consists of mature corn plants that are cut, chopped, and stored in a silo. During storage the chopped corn ferments, and this process helps preserve it. In U.S. production, the total energy input for silage production averages 6.3 million kcal/ha (Table 11.14). Even with 70% water content, corn silage produces high yields,

TABLE 11.13
Energy Inputs in Tame Hay Production in an Efficient U.K. Production System

	Quantity/ha	GJ/ha[a]
Inputs		
Field work, machinery	2.0 GJ	2.0
Nitrogen	80 kg	7.48
Total		9.48
Outputs		
Hay yield	5600 kg	53.0
Energy output/energy input		5.6:1

[a] 4186 Joule = 1 kcal

Source: After Leach, G., *Energy and Food Production*, Guildford, Surrey, UK, IPC Science and Technology Press Ltd., 1976.

TABLE 11.14
Energy Inputs in New York Corn Silage Production

	Quantity/ha	kcal/ha
Inputs		
Labor	15 h[a]	6,975[b]
Machinery	40 kg[c]	720,000
Diesel	110 L[d]	1,255,540
Gasoline	105 L[d]	1,071,554
Nitrogen	116 kg[a]	1,705,200
Phosphorus	66 kg[a]	198,000
Potassium	75 kg[a]	120,000
Limestone	560 kg[a]	176,400
Seeds	19 kg[a]	475,000[e]
Insecticides	2.5 kg[a]	217,275
Herbicides	2.5 kg[a]	249,775
Electricity	12 kWh[d]	34,356
Transportation	211 kg	54,227[f]
Total		6,284,302

TABLE 11.14 (continued)
Energy Inputs in New York Corn Silage Production

	Quantity/ha	kcal/ha
Outputs		
Corn silage yield	31,020 kg[a]	25,284,402
Protein yield	393 kg	
kcal output/kcal input		4.02:1

[a] From Snyder, D.P., *Agricultural Economic Research Report* 25, Cornell University Agricultural Experiment Station, Ithaca, NY, 1976.
[b] 15 h × 465 kcal/h.
[c] Estimated.
[d] Federal Energy Administration (FEA), Energy and U.S. Agriculture: 1974 Data Base, U.S. Government Printing Office, Washington, D.C., 1976.
[e] From Heichel, G.H., in *Handbook of Energy Utilization in Agriculture*, CRC Press, Boca Raton, FL, 1980, 27–33.
[f] 211 kg × 257 kcal/kg.

averaging 25.3 million kcal/ha. Thus, the output/input ratio for corn silage is 4:1, significantly greater than the 2.5:1 output/input ratio for corn grain.

VEGETARIANISM AND NONVEGETARIANISM AND ENERGY INPUTS

In Chapters 8 through 11, energy inputs for the production of various animal and plant foods have been analyzed. The question then arises as to what the fossil fuel requirements would be for human diets made up of various combinations of animal and plant foods. Do some diets use more fossil energy than others? Humans seldom eat just one or two foods; rather, they make dietary choices from a variety of available foods. Basically, however, eating patterns can be classified as to the type of protein eaten. Nonvegetarian diets include both animal and plant proteins, often, as in the United States, with a predomination of animal protein. In the lacto-ovo diet, eggs, milk, and milk products represent the only animal protein eaten, whereas in the complete vegetarian diet no animal protein is eaten.

The following analysis illustrates some of the differences in the fossil fuel requirements of these three dietary regimes. The calculations are based on data for various foods produced in the United States. The average daily food intake in the United States is 3500 kcal (Pimentel and Pimentel, 2003), so we assumed a constant intake of 3500 kcal/day for all three types of diets. The protein intake is over 100 g per day in the nonvegetarian diet and declines to about 80 g in the all-vegetarian diet. Both protein intakes significantly exceed the recommended daily allowance of 56 g/day.

Nearly twice as much fossil energy is expended for the food in a nonvegetarian diet as in the vegetarian diet (Figure 11.1). As expected, the lacto-ovo diet is more energy intensive than the all-vegetarian diet. Based on these sample calculations, the pure vegetarian diet is more economical in terms of fossil energy than either of the other two types of diets.

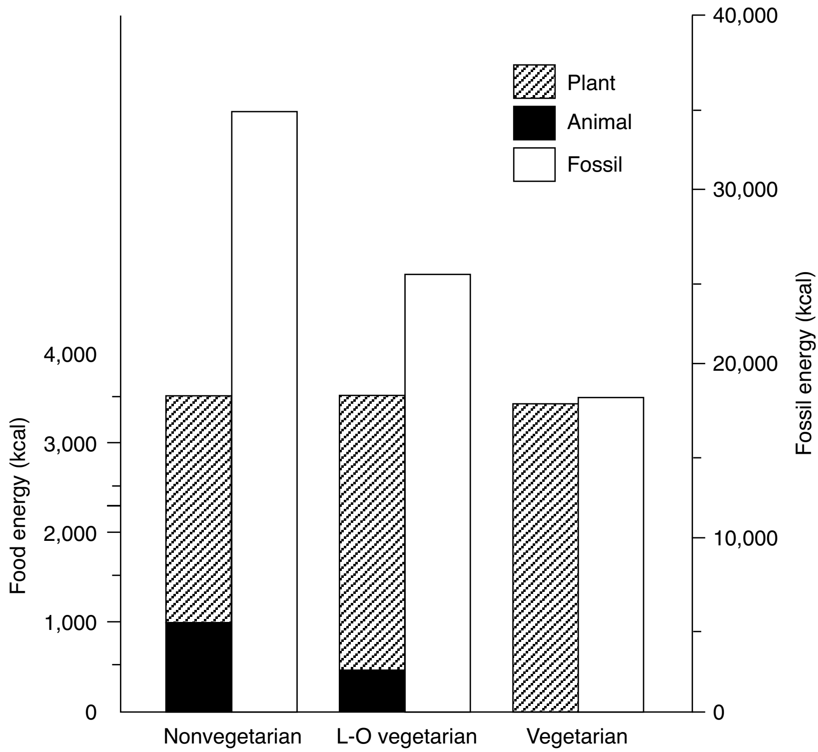

FIGURE 11.1 Daily food energy intake of pure vegetarians, lacto-ovo (L-O) vegetarians, and nonvegetarians and the calculated fossil energy inputs to produce these diets under U.S. conditions.

Energy expenditure is not the only factor to be evaluated when dietary choices are made. Decisions are often based on individual preferences and tastes. In addition, there are significant nutritional differences between the pure vegetarian diet and those that include animal products. Pure vegetarian diets lack vitamin B_{12}, an essential nutrient, so this must be taken as a dietary supplement. Further, the quality of protein depends on the combination of foods consumed. When the essential amino acids from a variety of plant food are combined, then the protein quality of a vegetarian diet will be satisfactory. A pure vegetarian diet usually consists of greater volume and bulk than a mixed diet, making it difficult for young children to consume the quantities necessary to meet all nutritional needs. In addition, nutritionally vulnerable people such as infants, rapidly growing adolescents, and pregnant and lactating women may need nutritional supplements of vitamins A and D, calcium, and iron while on a pure vegetarian diet.

When faced with future food options, both in agricultural policy and in personal diet, we must consider the fact that plant food is significantly more energy efficient to produce than a combination of animal and plant food.

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