FOOD, ENERGY, AND SOCIETY

(3rd edition) by David Pimentel and Marcia H. Pimentel, compiled by Andrew Ferguson

The opening instalments of this synopsis — up to and including Chapter 11.

One of the many things about which David Willey and I agreed was that, between them, Clive Ponting's *Green History of the World* and David and Marcia Pimentel's *Food, Energy, and Society*[1] cover almost everything that needs to be said about the fundamental proposition that OPT has always advocated, namely that the European population, the UK population and world population need to be very much smaller.

The first edition of *Food, Energy, and Society* came out in 1979. In 2008, the 3rd edition was published. It is certainly not going to be possible to convey all the subjects that are covered in its 380 pages, but I feel sure that a few gems from it will be appreciated. After making just one introductory note, namely that 1 kcal = 4186 joules, let me start right off with one of those gems, taken from the Preface. No quotation marks are used, as from now on I will let the authors speak for themselves, except for a few square bracket interjections.

xvii Large number of humans throughout the world are facing hunger and malnutrition because of political struggles and the overwhelming increase in population. The World Health Organization reports there are 3.7 billion who are malnourished. This is the largest number ever in history, and signals a serious food problem now and certainly for the future. Since 1984, food production, especially cereal grain production, has been declining per capita because of growing numbers of people, shortages of energy in agricultural crop production (e.g. fertilizers), and shortages of fresh water. …

At a time when more cropland is needed, valued fertile soil is being lost because of erosion that is 10–30 times faster than sustainability. With this environmental impact, crop yields decline, or more fertilizers and pesticides (fossil energy dependent) are used. Obviously on a per capita basis, cropland resources are declining and now are less than one-half of what is needed for a diverse diet for the world population.

Energy and Power

12.6 The survival of humans in their ecosystem depends upon the efficiency of green plants as energy converters. Plants convert sunlight into food energy for themselves and other organisms. The total foundation of life rests on plants' unique capacity to change radiated solar energy into stored chemical energy that is biologically useful for humans and other animals. …

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1 Pimentel, D, Pimentel, M. 2008. *Food, Energy, and Society*. Third edition. Boca Raton, Fl; London; New York: CRC Press. ISBN 978-1-4200-4667-0. CRC Press website http://www.crcpress.com

In agricultural eco-systems, an estimated 15 million kcal of solar energy (net production) is fixed per ha per crop season. Even so, this amounts to only about 0.1% of the total solar energy reaching each hectare during the year and equals about 3500 kg/ha of dry biomass...

Under optimal conditions, during sunny days in midsummer and when crops are nearing maturity, crops such as corn and sugarcane capture as much as 5% of the sunlight energy reaching them. However, the harvested plant material is only about 0.1% because over much of the year, including winter, there is no plant growth.

Manipulating Ecosystems for Agriculture

38.9 Neither humans, their crops, nor their livestock can exist independently from species in the natural ecosystem. A relatively small number of species — about 15 major crops and 8 major livestock types — are agriculturally produced in the world. By comparison, an estimated 750,000 species of wild plants, animals and microbes exist in the United States alone. A majority of these wild species are necessary for maintenance of the wild life system. At present, no one knows how many of the 750,000 species in the U.S. ecosystem can be reduced or eliminated before human life is jeopardized. Therefore, the existing biological diversity should be preserved and treasured. Environmental degradation caused by chemical pollutants, construction, deforestation, and other factors should be prevented.

43.8 The relationship of energy expenditure and standard of living also can be clarified by comparing production of corn by labor-intensive and energy-intensive systems. In Mexico, for instance, about 1140 h of human labor are required to produce 1 ha of corn by hand. In the United States, under an energy-intensive system, only 10 h of labor are expended per hectare. In the midwestern United States, one farmer can manage up to 200 ha of corn with the help of large fossil fuel inputs and mechanized equipment. The same farmer producing corn by hand could manage 1.5 ha at most.

Hunter-Gatherers and Early Agriculture

45.2 Before the development of agriculture and formal crop culture, wild plants and animals in the natural ecosystem were the only food for humans. How much wild plant and animal biomass is available for food, and how much land do hunter-gatherers need to meet their food needs? …

Based on the preceding calculations, a family of five would require an estimated 200 ha of habitat from which to gather animal and plant food. This estimate is based on an ideal ecosystem, one containing those wild plants and animals that are most suitable for human consumption. Researchers report that, in fact, modern-day hunter-gatherers need much more than 40 ha per person. For instance, Clark and Haswell (1970) estimate that at least 150 ha of favorable habitat per person is needed to secure an adequate food supply. In a moderately favorable habitat, these scientists estimate that 250 ha per person would be required. These estimates are four to six times greater than in the model presented earlier.

In marginal environments, such as the cold northwestern Canadian region, each person needs about 14,000 ha to harvest 912,500 kcal of food energy per year [i.e. 2500 kcal/day].

50.9 If hunters and gatherers have to work an average of 2.2 days/week to obtain food, that leaves approximately 4.8 days for other activities. These include gathering firewood, moving, constructing shelters and clothing, caring for children, and enjoying leisure time. Observations indicate that Bushmen value their leisure and enjoy dancing, visiting other camps, and engaging in other social activities.

52.4 Early plots were planted and harvested for about 2 years, then abandoned because production declined as nutrients in the soil became depleted and other problems (such as pests outbreaks) developed. Interestingly, this "cut/burn," or "swidden," type of agriculture is still practiced today in many parts of the world. Swidden agriculture demands that farmed land lie fallow for 10 to 20 years before it can be cleared again and farmed. During the long fallow period, the soil gradually accumulates the nutrients needed for successful crop production.

52.8 When the New Guinea community was studied, the village numbered 204 inhabitants and occupied about 830 ha. Only about 364 ha of this land was suitable for cultivation. The village annually planted about 19 ha of crops, but because some crops required 2 years before they could be harvested, about 37 ha were cultivated at any one time. As a result, nearly 90% of the village croplands lay fallow each year. The villagers' food was almost entirely (99%) of plant origin. …

The adult person's diet averaged about 2400 kcal/day and contained about 35 g of protein, mostly of plant origin. This protein intake is low by current Food and Agriculture Organization (FAO) standards, which recommend a daily intake of about 40 g of protein per day for an adult living under these conditions. …

From the 11.4 million kcal/ha harvested, as noted, 45% (5.1 million kcal/ha) was fed to the pigs. If 65 kcal were required to produce 1 kcal of pork, the yield would be only 78,461 kcal/ha. This 78,461 kcal, added to the 6.3 million consumed directly by humans, provides a total yield of food energy of 6.4 million kcal/ha [i.e. enough to support 7 people per hectare at 2400 kcal/day; but note that if it is necessary that 90% of the cropland should lie fallow, then 1 hectare of the area suitable for cropland supports less than one person; as is also obvious from the fact that in order to allow sufficient fallow periods, 204 people need 364 ha of land suitable for cultivation.] Rappaport (1968, 1971) mentions one advantage to pork production: Keeping pigs was a practical way to store some of the excess food during productive years. When crop harvests were poor, the villagers slaughtered some of the pigs to provide the needed food.

59.1 The Dodo tribe illustrate the important role that livestock can play in providing food for humans. First, the livestock effectively convert forage growing in the marginal habitat into food suitable for humans. Second, the herd serve as stored food resources. Third, the cattle can be traded for sorghum grain during years of inadequate rainfall and poor crop yields.

61.1 …the total energy input to till 1 ha by human labor alone is about 200,000 kcal.

Oxen, small hand tractors, and 50-HP tractors all require a greater total energy expenditure to till the same hectare of land. However, it should be noted that all these other power systems can complete the tilling task in far less time than the human can. For example, two oxen take only 65 h but expend almost 50% more energy than a human does. The oxen must be fed and need a person to guide them as they work. Likewise 6-HP and 50-HP tractors take much less time — 25 and 4 h, respectively — to till 1 ha than humans. But they use far more energy than either humans or oxen because of the large input of petroleum needed to run the engines. [The table shows that humans take 400 hours, and that the two tractors use total energy that amounts to 441,000 and 553,000 kcal respectively.]

62.8 Many nations have replaced draft animals with tractors and other machinery. For example, when the United States was first settled in 1620, human muscle power was the prime power source for work, but by 1776 an estimated 70% of the power was supplied by

animals and only 20% by humans. By 1850 animal power had declined to 53% and man power to 13%. By 1950, about 100 years later, animal and human power had declined to only about 1%, and fossil-fuel-powered engines provided 95% of the power. Thus, a dramatic change with far-reaching consequences has taken place, as humans continue to consume ever-increasing quantities of non-renewable fossil fuels.

Animal Food-consumption Patterns

63.5 Throughout history animals, either hunted or husbanded, have been valued by humans for food. Even so, the majority of humankind has had to depend primarily on plant materials for energy and other nutrients. Even today most of the world's people live on about 2500 kcal/day and obtain most of their food energy and protein from grains and legumes.

63.8 A study of 12 rural villages in southern India showed that individuals consumed, on average, between 210 and 330 g of rice and wheat, 140 ml of milk and 40 g of pulses and beans per day. This diet provided about 1500 kcal and 48 g of protein per day, with a major share of both calories and protein coming from plants. …

In central America, laborers commonly consume about 50 g of corn per day. Along with the corn they eat about 100 g of black beans per day, and together these staples provide about 2118 kcal and 68 g of protein daily. The corn and beans complement each other in providing the essential amino acids that humans need. Additional food energy is obtained from other plant and animal products. …

A sharp contrast to all these examples is found in the United States, where the daily protein intake is 112 g, of which 75 g is animal protein. U.S. per capita animal and animal protein consumption is among the highest in the world, although similar consumption patterns appear in many highly industrialized nations in Europe. In 2006, annual U.S. per capita meat consumption was 92 kg.

Nutritional Quality of Protein Foods

65.3 One of the important considerations in evaluating the relative value of plant and animal protein sources is their nutritional content. A broad comparison shows, for instance, that one cup of cooked dried beans (190 g) is quite similar to an 85 g serving of cooked ground beef in the amounts of protein, iron, and important B vitamins. Further, the beans contain no fat, no cholesterol, and no vitamin B_{12}.

Although these foods contain similar amounts of protein, the nutritional quality of the protein differs in terms of both the kind and amounts of "nutritionally essential" amino acids. Animal proteins contain eight essential amino acids in optimum amounts and in forms utilisable by humans for protein synthesis. For this reason, animal proteins are considered high-quality proteins. … In addition, some plant proteins are deficient in one or more essential amino acids. … Fortunately, it is possible to combine plant proteins to complement the amino acid deficiencies. Thus, when cereal and legume proteins are eaten together, the combined amino acid supply is of better quality than provided by either food eaten alone.

More attention and thought must be given to planning a diet that is either limited in or entirely devoid of animal protein. Variety is of prime importance in achieving a nutritionally balanced diet under such constraints. Further, because B_{12}, an essential vitamin, is not found in plant foods, this must be taken as a supplement.

Chapter 8. Livestock Production and Energy Use

67.3 The World Health Organization recently reported that more than 3 billion people are malnourished in the world. This is the largest number and proportion of malnourished people ever recorded in history. In large measure, the food shortage and malnourishment problem are primarily related to rapid population growth in the world in addition to declining per capita availability of land, water, and energy resources required for food production.

Animal products consumed in the U.S. diet

67.8 In the United States, more than 8 billion livestock are maintained to supply the animal protein consumed annually. In addition to the large amount of cultivated forage, the livestock population consumes about seven times as much grain as is consumed directly by the entire American population.

68.7 For every kilogram of high quality animal protein, livestock are fed nearly 6 kg of plant protein. In the conversion of plant protein into animal protein, there are two principle "costs": (1) the direct costs of production of the harvested animal including the grain and forage and (2) the indirect costs for maintaining the breeding animals (mother and father).

70.5 The average fossil energy input for all animal protein production systems studied is about 25 kcal of fossil energy input per kilocalorie of animal protein produced. This energy input is more than 10 times greater than the average input to output ratio for grain protein production, which was about 2.5 kcal per kilocalorie of protein produced as food for humans, however, animal protein has about 1.4 times the biological value as food compared to grain protein.

Land resources

70.6 Livestock production requires a large number of hectares to supply the grains, forages, and pastures for animal feeds. In fact, nearly 300 million hectares of land are devoted to producing the feed for the U.S. livestock population. Of this, 262 million ha are pasture and about 30 million ha are for cultivated grains.

70.9 Each year about 90% of U.S. cropland is losing soil at an average rate 13 times above the sustainable rate of 1 t/ha/yr.

71.4 The costs of soil erosion are well illustrated by the loss of rich U.S. soils. Iowa, which has some of the best soils in the world, has lost more than one-half of its topsoil after only 150 years of farming. Iowa continues to lose topsoil at an alarming rate of about 30 t/ha/yr, which is about 30 times faster than the rate of soil formation. The rich Pelouse soils of the Northwest United States have similarly lost about 40% of their topsoil in the past century.

71.8 Erosion often goes unnoticed by some farmers because soil loss is difficult to measure visually. For instance, one night's wind or rain storm could erode 15 t of soil per hectare as a sheet, which would be only 1 mm of soil; the next morning the farmer might not even notice this loss. This soil loss continues slowly, quietly, year after year, until the land is no longer productive.

Water resources

71.9 Agricultural production, including livestock production, consumes more fresh water than any other human activity. Western U.S. agriculture accounts for about 81% of the fresh water consumed after being withdrawn.

72.6 A hectare of U.S. corn producing about 8000 kg per year transpires about 5 million L of water during the growing season. Approximately 1000 mm (10 million L per hectare) of rainfall or other sources of water are needed during the growing season for corn production. Even with 800-1000 mm of annual rainfall in the Corn-Belt region, corn usually suffers from some lack of water during the summer growing season.

73.1 Water shortages are already severe in the western and southern United States. The situation grows worse as the U.S. population and its requirements for water, including for agriculture, rapidly increase.

World food needs

73.6 If all the 323 million tons of grain currently being fed to livestock [in the U.S.] were consumed directly by people, the number of people who could be fed would be approximately 1 billion. … Exporting all U.S. grain that is now fed to livestock assumes that livestock production would change to a grass-fed livestock production system. Animal protein in the diet would then decrease from the current level of 75 g to 36 g per day, or about one-half. Again, the diet for the average American would be more than adequate in terms of protein consumption, provided that there was no change in the current level of plant protein consumed. In fact, consuming less meat, milk, and eggs and eating more grains and vegetables would improve the diet of the average American.

Conclusions

74.5 As human food needs escalate along with population numbers, serious consideration must be given to the conservation of fossil energy, land, and water resources. The careful stewardship of these resources is vital if livestock production, and indeed agriculture, will be sustainable for future generations. In the end, population growth must be reduced, in the United States and in the world, if we are to achieve a quality life for ourselves and our grandchildren.

Chapter 9. Energy Use in Fish and Aquacultural Production

77.2 Worldwide, approximately 95 million metric tons of seafood, including fish, crustaceans, and mollusks, are harvested annually. …. About 28 millions tons of fish are fed to livestock, and humans consume an estimated 67 million tons. Nonetheless, fish protein represents less than 5% of the total food protein (387 million tons) consumed annually by the world's human population and less than 1% of the overall caloric intake.

77.9 Water covers more than 70% of the earth, but only about 0.03% of the sunlight reaching an aquatic ecosystem is fixed by aquatic plants, primarily phytoplankton. This equates to about 4 million kcal/ha/year or about one-third the energy fixed in terrestrial habitats.

The phytoplankton that collect light energy in oceans and freshwater are eaten by zooplankton. The light energy passes through four to six links in the food chain before humans harvest it as fish.

79.2 Energy expenditures for fishing vary, depending on the distance traveled to harvest and the type of fishing gear used. … Wiviott and Mathews reported that the Washington trawl fleet produced 61.5 kg of fish per liter of fuel, compared with the Japanese production of only 11.4 kg of fish per liter of fuel. They attribute the difference to the fact that the Japanese frequently have to travel long distances for fishing.

80.8 Small fishing units are nearly four times more efficient than the larger vessels that travel great distances. The inshore fishery's greater efficiency also is due in part to the more productive fish population of the inshore regions. … [and referring to the U.S. Northeast fishery] The inshore fishery expends about 2.2 kcal of fossil energy per kcal of fish protein produced, whereas the offshore fishery requires 9.6 kcal of energy per kcal of fish protein output. … For the U.S. fishery industry as a whole, Hirst reported, about 27 kcal of fossil energy input are required to harvest 1 kcal of fish protein. Leach reported about 20 kcal of fossil energy input per kcal of fish protein output in the United Kingdom. … the wooden vessels used for inshore fishing require only 2.1 kcal fossil energy input per kcal of fish protein output.

82.8 Of the 49 fishery stocks monitored in the Northeast, 27 have been identified as overexploited. Large harvests continue because the fishing system in this region is overcapitalized and requires a high level of exploitation to remain profitable.

83.8 The most efficiently harvested fish is herring, with only 2 kcal of fossil energy expended to produce 1 kcal of herring protein. A common fish such as haddock requires an input of 23 kcal of fossil energy per protein kcal produced.

Aquaculture

87.5 Aquaculture is the farming of fish, shellfish, and other aquatic animals for food. In many regions of the United States, commercial catfish aquaculture is practiced. Catfish is an excellent eating fish and its popularity has spread throughout the United States. … The input/output ratio is about 34 kcal of fossil energy input per kcal of catfish protein produced.

89.9 In addition to the catfish system described in detail above, five other aquaculture systems have been analysed. The first is Malaysian prawn production in Oahu, Hawaii. The fossil energy input per kcal of protein output for this system was about 67 to 1.

Conclusion

94.2 Small-scale fishing systems are generally more energy efficient than large-scale systems. … Large-scale vessels are inefficient, usually requiring government subsidies for their operation. In addition, the high costs of large vessels contribute to over-capitalization and overfishing of fishery resources. … In the near future, overfishing is more likely to cause fish scarcity than fossil fuel shortages and high energy prices.

94.8 Even if fish production is improved, the rapid growth of the human population will tend to negate the contribution of increased yields. In all probability, the world's fishery industry will not be able to supply more than 1% of the world's food energy in the future. It should be emphasized that fish provide high-quality protein, and thus this 1% is extremely valuable to society.

Chapter 10. Energy use in Grain and Legume Production Energy inputs in grain production

99.2 Although some plant foods eaten by livestock, such as grasses and forages, are not suitable for human foods, grains and legumes most certainly are. In the United States, about 816 kg of grains and legumes produced per person and suitable for human consumption are diverted to livestock. Almost 90% of the plant calories/protein consumed by humans come from 15 major crops: rice, wheat, corn, sorghum, millet, rye, barley, cassava, sweet potato, potato, coconut, banana, common bean, soybean, and peanut.

99.7 By eating combinations of cereals and legumes, humans can obtain sufficient quantities of the essential amino acids. In fact, grains and legumes have long been staple foods for people in many areas of the world.

102.6 Although the yields of corn produced by hand are significantly lower than yields of corn produced by mechanization in the United States, the reason is not related to the type of power used. The lower yields for hand-produced corn can be attributed to the reduced use of fertilizers, lack of hybrid (high-yielding) varieties, poor soil, and prevailing environmental conditions. With the use of suitable fertilizers and more productive varieties of corn, it should be possible to increase crop yields employing only human power.

105.9 The fossil energy inputs into U.S. corn production are primarily from petroleum and natural gas. Nitrogen fertilizer, which requires natural gas for production, represents the largest single input, about 30% of the total fossil energy inputs.

Machinery and fuel together total about 25% of the total fossil energy input. About 25% of the energy inputs in U.S. corn production are used to produce human and animal labor inputs, the remaining 75% to increase corn productivity.

106.6 Wheat farmers in the Uttar Pradesh region of India use human/bullock power. A total energy input of about 2.8 million kcal [per ha] is required to obtain a wheat yield of 2.7 million kcal [821 kg] of food energy, for an output/input ratio of 0.96:1. Thus, the wheat energy produced is less than the energy expended, and the system appears to create no net gain. However, this output/input ratio may be somewhat misleading, because one of the largest inputs in this production system is for the two bullocks. Because the bullocks consume primarily grasses and little or no grain, they are in fact a type of food conversion system. The bullocks convert the grass energy into wheat energy through their labor in the wheat fields. If the bullock input is removed from the analysis, then the output/input ratio increases to 5:1, which is a more favorable and realistic representation of this mode of production.

108.9 Rice is the staple food for an estimated 3 billion people, mostly those living in developing countries. … As in corn production, yields decline as human labor input increases, except in Japan and China. In those countries, high yields of rice can be grown employing human power because appropriate high-yielding varieties, fertilizers, and other technologies are used.

In the Philippines, both human and animal power are used in rice production. Total energy inputs of 1.8 million kcal/ha produce 1650 kg/ha of rice, which has the equivalent of

6.0 million kcal of food energy. The resulting output/input ratio is 3:1, about half that of the Iban [a tribe in Borneo that cultivates rice by hand] rice production system. However, like the bullocks used for wheat production in India, the Philippine carabao used in rice production convert grass energy into rice energy. If the energy input for the carabao is removed from the accounting, the output/input ratio rises to 10:1.

As with other grains, the United States uses large inputs of energy, particularly fossil fuel energy, to produce rice. Based on data on rice production in the United States, the average yield is 7367 kg/ha (26.5 million kcal), significantly greater than yields from the other systems discussed. However, the high energy input of 11.8 million kcal/ha results in a low 2.2:1 output/input ratio. Although most of the energy input is for machinery and fuel, fertilizers account for about 50% of the total fossil fuel input. The other inputs are for irrigation, seeds, and drying. The human labor input is only 24 h/ha, still a relatively high figure for U.S. grain production.

By comparison, rice production in Japan is still relatively labor intensive, requiring about 640 h/ha of human labor. Fossil energy inputs are lower in Japan than in the United States, but rice yields in the two countries are about the same. As a result, Japanese production methods achieve an output/input ratio of 2.8:1, reflecting more efficient use of energy than the U.S. system.

Energy inputs in legume production

114.1 Peas, beans, and lentils, all members of the Leguminosae family, are extremely important plant foods, especially in those areas of the world where animal foods are scarce and expensive or where religious or cultural reasons dictate the avoidance of animal flesh as food. Most legumes have a high carbohydrate content of 55%–60% and a high protein content of 20%–30%. The 30% protein content of soybeans is exceptionally high for plants. Legumes are excellent plant sources of iron and thiamine in addition to protein.

115.2 Legumes need less nitrogen than most other crops. For example, soybeans require only one-tenth the nitrogen input needed for corn. Soybeans and other legumes obtain nitrogen from the atmosphere through their symbiotic relationship with microbes in the soil. … Overall it is more economical for plants to provide their own nitrogen than for humans to make and apply nitrogen fertilizer. The 100 kg of soybean yield that is lost to nitrogen fixation is worth about $9.25, much less than the $58 cost of the 100 kg/ha of nitrogen produced by the plants.

PEANUTS

116.7 Data on production of peanuts employing a large input of labor (936 h) for northeast Thailand have been reported by Doering (1977). Total inputs, including a large labor input, total 1.9 million kcal/ha, and the peanut yield is 5.6 million kcal/ha. Thus the output/input ratio for this peanut production system is 2.6:1.

Peanut production in the United States (Georgia) yields 15.3 million kcal/ha, or about three times that in Thailand. However, with the large energy expenditure required, the system achieves an output/input ratio of only 1.4:1.

Chapter 11. Energy use in Fruit, Vegetable, and Forage Production

121.5 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. The next largest input is for pesticides, which represent nearly 17% of the total energy input in apple production. … The total labor input is calculated to be about 17.1 million kcal, 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.

POTATOES

123.5 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. … The total energy input for potato production is 17.5 million kcal/ha. 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.

SPINACH

123.9 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.

The largest energy input in U.S. spinach production is for nitrogen fertilizer, amounting to nearly 50% of the total energy input. 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 0.21:1. This negative ratio means that about 5 kcal of fossil energy is required to produce each kcal of spinach.

TOMATOES

126.7 Based on U.S. data, one-third of the energy inputs in tomato production are for fuel and machinery that reduce labor inputs. 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 [41,778 kg/ha], the protein yield of 496 kg/ha is excellent, even though tomatoes average only 1% protein and have a high water content.

CASSAVA

128.8 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. 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. 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 the quality and quantity of the protein is so inadequate.

133.6 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. Non-vegetarian 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, so we assumed a constant intake of 3500 kcal/day for all three types of diet. The protein intake is over 100 g per day in the non-vegetarian 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 non-vegetarian diet as in the vegetarian diet. 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.

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 foods 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.

Note: The text above comprises parts 1 to 4 of Andrew Ferguson's synopsis which is appearing in instalments in the OPT Journal. Further instalments may be found in the contents lists of the April 2011 and subsequent issues as they appear.