Sustainability of meat-based and plant-based diets and the environment[1–3]

David Pimentel and Marcia Pimentel

ABSTRACT Worldwide, an estimated 2 billion people live primarily on a meat-based diet, while an estimated 4 billion live primarily on a plant-based diet. The US food production system uses about 50% of the total US land area, 80% of the fresh water, and 17% of the fossil energy used in the country. The heavy dependence on fossil energy suggests that the US food system, whether meat-based or plant-based, is not sustainable. The use of land and energy resources devoted to an average meat-based diet compared with a lactoovovegetarian (plant-based) diet is analyzed in this report. In both diets, the daily quantity of calories consumed are kept constant at about 3533 kcal per person. The meat-based food system requires more energy, land, and water resources than the lactoovovegetarian diet. In this limited sense, the lactoovovegetarian diet is more sustainable than the average American meat-based diet. *Am J Clin Nutr* 2003;78(suppl):660S–3S.

KEY WORDS Meat-based diet, plant-based diet, environment, natural resources, fossil, energy, fuel

INTRODUCTION

Worldwide, an estimated 2 billion people live primarily on a meat-based diet, while an estimated 4 billion live primarily on a plant-based diet. The shortages of cropland, fresh water, and energy resources require most of the 4 billion people to live on a plant-based diet. The World Health Organization recently reported that more than 3 billion people are malnourished (1, 2). This is the largest number and proportion of malnourished people ever recorded in history. In large measure, the food shortage and malnourishment problem is primarily related to rapid population growth in the world plus the declining per capita availability of land, water, and energy resources (3).

Like the world population, the US population continues to grow rapidly. The US population doubled in the past 60 y and is projected to double again in the next 70 y (4) (**Figure 1**). The US food production system uses about 50% of the total US land area, approximately 80% of the fresh water, and 17% of the fossil energy used in the country (3). The heavy dependence on fossil energy suggests that the US food system, whether meat-based or plant-based, is not sustainable. The use of land and energy resources devoted to an average meat-based diet compared with a lactoovovegetarian (plant-based) diet is analyzed in this report. In both diets, the daily quantity of calories consumed was kept constant at about 3533 kcal per person.

LACTOOVOVEGETARIAN DIET

The lactoovovegetarian diet was selected for this analysis because most vegetarians are on this or some modified version of this diet. In addition, the American Heart Association reported that the lactoovovegetarian diet enables individuals to meet basic nutrient needs (5).

A comparison of the calorie and food consumption of a lactoovovegetarian diet and a meat-based diet is provided in **Table 1**. In the lactoovovegetarian diet, the meat and fish calories were replaced by proportionately increasing most other foods consumed in Table 1 in the vegetarian diet except sugar and sweeteners, fats, and vegetable oils. The total weight of food consumed was slightly higher (1002 kg per year) in the lactoovovegetarian diet than in the meat-based diet (995 kg per year). The most food calories consumed in both diets were associated with food grains, and the second largest amount of calories consumed was from sugar and sweeteners.

The amount of feed grains used to produce the animal products (milk and eggs) consumed in the lactoovovegetarian diet was about half (450 kg) the amount of feed grains fed to the livestock (816 kg) to produce the animal products consumed in the meat-based diet (Table 1). This is expected because of the relatively large amount of animal products consumed in the meat-based diet (7). Less than 0.4 ha of cropland was used to produce the food for the vegetarian-based diet, whereas about 0.5 ha of cropland was used in the meat-based diet (8). This reflects the larger amount of land needed to produce the meat-based diet (Table 1).

The major fossil energy inputs for grain, vegetable, and forage production include fertilizers, agricultural machinery, fuel, irrigation, and pesticides (8, 9). The energy inputs vary according to the crops being grown (10). When these inputs are balanced against their energy and protein content, grains and some legumes, such as soybeans, are produced more efficiently in terms of energy inputs than vegetables, fruits, and animal products (8). In the United States, the average protein yield from a grain crop such as corn is 720 kg/ha (10). To produce 1 kcal of plant protein requires an input of about 2.2 kcal of fossil energy (10).

MEAT-BASED DIET

The meat-based diet differs from the vegetarian diet in that 124 kg of meat and 20.3 kg of fish are consumed per year (Table 1). Note that the number of calories is the same for both diets because the vegetarian foods consumed were proportionately

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[3] Address reprint requests to D Pimentel, Department of Ecology and Evolutionary Biology, Cornell University, 5126 Comstock Hall, Ithaca, NY 14853. E-mail: dp18@cornell.edu.

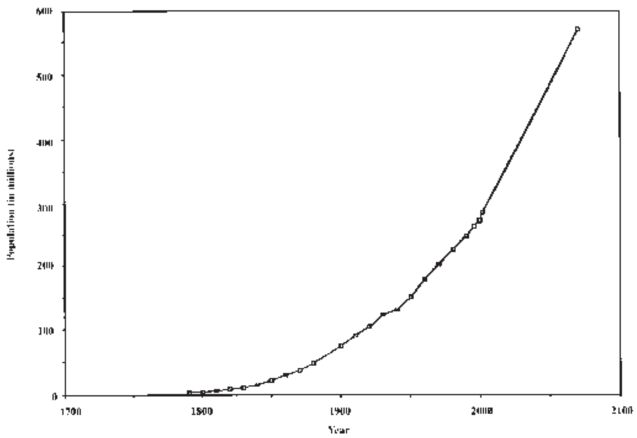

FIGURE 1. Projection of US population growth in the next 70 y (4).

increased to make sure that both diets contained the same number of calories. The total calories in the meat and fish consumed per day was 480 kcal. The foods in the meat-based diet providing the most calories were food grains and sugar and sweeteners—similar to the lactoovovegetarian diet.

In the United States, more than 9 billion livestock are maintained to supply the animal protein consumed each year (11). This livestock population on average outweighs the US human population by about 5 times. Some livestock, such as poultry and hogs, consume only grains, whereas dairy cattle, beef cattle, and lambs consume both grains and forage. At present, the US livestock population consumes more than 7 times as much grain as is consumed directly by the entire American population (11). The amount of grains fed to US livestock is sufficient to feed about 840 million people who follow a plant-based diet (7). From the US livestock population, a total of about 8 million tons (metric) of animal protein is produced annually. With an average distribution assumed, this protein is sufficient to supply about 77 g of animal protein daily per American. With the addition of about 35 g of available plant protein consumed per person, a total of 112 g of protein is available per capita in the United States per day (11). Note that the recommended daily allowance (RDA) for adults per day is 56 g of protein from a mixed diet. Therefore, based on these data, each American consumes about twice the RDA for protein. Americans on average are eating too much and are consuming about 1000 kcal in excess per day per capita (12, 13). The protein consumed per day on the lactoovovegetarian diet is 89 g per day. This is significantly lower than the 112 g for the meat-based diet but still much higher than the RDA of 56 g per day.

About 124 kg of meat is eaten per American per year (6). Of the meat eaten, beef amounts to 44 kg, pork 31 kg, poultry 48 kg, and other meats 1 kg. Additional animal protein is obtained from the consumption of milk, eggs, and fish. For every 1 kg of high-quality animal protein produced, livestock are fed about 6 kg of plant protein. In the conversion of plant protein to animal protein, there are 2 principal inputs or costs: 1) the direct costs of production of the harvest animal, including its feed; and 2) the indirect costs for maintaining the breeding herds.

Fossil energy is expended in livestock production systems (**Table 2**). For example, broiler chicken production is the most efficient, with an input of 4 kcal of fossil energy for each 1 kcal of broiler protein produced. The broiler system is primarily dependent on grain. Turkey, also a grain-fed system, is next in efficiency, with a ratio of 10:1. Milk production, based on a mixture of two-thirds grain and one-third forage, is relatively efficient, with a ratio of 14:1. Both pork and egg production also depend on grain. Pork production has a ratio of 14:1, whereas egg production has a 39:1 ratio.

The 2 livestock systems depending most heavily on forage but also using significant amounts of grain are the beef and lamb production systems (**Table 3**). The beef system has a ratio of 40:1, while the lamb has the highest, with a ratio of 57:1 (Table 2). If these animals were fed on only good-quality pasture, the energy inputs could be reduced by about half.

The average fossil energy input for all the animal protein production systems studied is 25 kcal fossil energy input per 1 kcal of protein produced (Table 2). This energy input is more than 11 times

TABLE 1
Per capita food consumption, energy, and protein of foods of a meat-based compared with a lactoovovegetarian diet in the United States

Food	Meat-based diet[1]	Energy	Protein	Lactoovovegetarian diet[2]	Energy	Protein
	kg	*kcal*	*g*	*kg*	*kcal*	*g*
Food grain	114	849	24.9	152	1132	33.2
Pulses (legumes)	4.3	40	2.0	7.5	70	4.5
Vegetables	239	147	6.6	286	155	8.8
Oil crops	6	71	3.0	8	95	4.0
Fruit	109	122	1.4	112	122	1.9
Meat	124	452	41.1	0	0	0
Fish	20.3	28	4.7	0	0	0
Dairy products	256	385	22.5	307.1	473	30.0
Eggs	14.5	55	4.2	19.2	73	5.6
Vegetable oils	24	548	0.2	25	570	0.2
Animal fats	6.7	127	0.1	6.7	127	0.1
Sugar and sweeteners	74	686	0.2	74	686	0.2
Nuts	3.1	23	0.6	4.0	30	0.8
Total	994.9	3533	111.5	1001.5	3533	89.3
Feed grains[3]	816.0	—	—	450.0	—	—

[1] Data from FAOSTAT (6).
[2] Estimated.
[3] Feed grains are cereal grains fed to livestock.

TABLE 2
Animal production in the United States and the fossil energy required to produce 1 kcal of animal protein

Livestock and animal products	Production volume[1]	Ratio of energy input to protein output[2]
	$\times 10^6$	*kcal*
Lamb	7	57:1
Beef cattle	74	40:1
Eggs	77 000	39:1
Swine	60	14:1
Dairy (milk)	13	14:1
Turkeys	273	10:1
Broilers	8000	4:1

[1] Data from US Department of Agriculture (11).
[2] Data from Pimentel (9).

greater than that for grain protein production, which is about 2.2 kcal of fossil energy input per 1 kcal of plant protein produced (**Table 4**). This is for corn and assumes 9% protein in the corn. Animal protein is a complete protein based on its amino acid profile and has about 1.4 times the biological value of grain protein (8).

LAND RESOURCES

More than 99.2% of US food is produced on land, while < 0.8% comes from oceans and other aquatic ecosystems. The continued use and productivity of the land is a growing concern because of the rapid rate of soil erosion and degradation throughout the United States and the world. Each year about 90% of US cropland loses soil at a rate 13 times above the sustainable rate of 1 ton/ha/y (28). Also, US pastures and rangelands are losing soil at an average of 6 tons/ha/y. About 60% of United States pastureland is being overgrazed and is subject to accelerated erosion.

The concern about high rates of soil erosion in the United States and the world is evident when it is understood that it takes approximately 500 y to replace 25 mm (1 in) of lost soil (28). Clearly, a farmer cannot wait for the replacement of 25 mm of soil. Commercial fertilizers can replace some nutrient loss resulting from soil erosion, but this requires large inputs of fossil energy.

WATER RESOURCES

Agricultural production, including livestock production, consumes more fresh water than any other activity in the United States. Western agricultural irrigation accounts for 85% of the fresh water consumed (29). The water required to produce various foods and forage crops ranges from 500 to 2000 L of water per kilogram of crop produced. For instance, a hectare of US corn transpires more than 5 million L of water during the 3-mo growing season. If irrigation is required, more than 10 million L of water must be applied. Even with 800–1000 mm of annual rainfall in the US Corn Belt, corn usually suffers from lack of water in late July, when the corn is growing the most.

TABLE 3
Grain and forage inputs per kilogram of animal product produced

Livestock	Grain[1]	Forage[2]
	kg	*kg*
Lamb	21	30
Beef cattle	13	30
Eggs	11	—
Swine	5.9	—
Turkeys	3.8	—
Broilers	2.3	—
Dairy (milk)	0.7	1

[1] Data from US Department of Agriculture (11).
[2] Data from Morrison (14) and Heitschmidt et al (15).

TABLE 4
Energy inputs and costs of corn production per hectare in the United States

Inputs	Quantity	Energy	Cost
		kcal × 1000	*$*
Labor (h)[1]	11.4 (16)[2]	462	114.00[3]
Machinery (kg)	55 (8)	1018 (17)	103.21 (18)
Diesel (L)	42.2 (19, 20)	481 (17)	8.87 (21)
Gasoline (L)	32.4 (19, 20)	328 (17)	9.40 (21)
Nitrogen (kg)	144.6 (22)	2688 (23)	89.65 (21)
Phosphorus (kg)	62.8 (22)	260 (23)	34.54 (21)
Potassium (kg)	54.9 (22)	179 (23)	17.02 (21)
Lime (kg)	699 (22)	220 (17)	139.80 (16)
Seeds (kg)	21 (8)	520 (17)	74.81 (24)
Irrigation (cm)	33.7 (25)	320 (17)	123.00
Herbicides (kg)	3.2 (22)	320 (17)	64.00[4]
Insecticides (kg)	0.92 (22)	92 (17)	18.40[4]
Electricity (kWh)	13.2 (19, 20)	34 (17)	2.38[5]
Transportation (kg)[6]	151	125 (17)	45.30[7]
Total (kg yield)	7965 (27)	7047[8]	844.38

[1] It is assumed that a person works 2000 h/y and uses an average of 8100 L oil equivalents/y.
[2] Reference.
[3] It is assumed that farm labor is paid $10/h.
[4] It is assumed that herbicide and insecticide prices are $20/kg.
[5] The price of electricity is $0.07/kWh (26).
[6] Goods transported include machinery, fuels, and seeds that were shipped an estimated 1000 km.
[7] Transport was estimated to cost $0.30/kg.
[8] Ratio of kcal input to output = 1:4.07.

Producing 1 kg of animal protein requires about 100 times more water than producing 1 kg of grain protein (8). Livestock directly uses only 1.3% of the total water used in agriculture. However, when the water required for forage and grain production is included, the water requirements for livestock production dramatically increase. For example, producing 1 kg of fresh beef may require about 13 kg of grain and 30 kg of hay (17). This much forage and grain requires about 100 000 L of water to produce the 100 kg of hay, and 5400 L for the 4 kg of grain. On rangeland for forage production, more than 200 000 L of water are needed to produce 1 kg of beef (30). Animals vary in the amounts of water required for their production. In contrast to beef, 1 kg of broiler can be produced with about 2.3 kg of grain requiring approximately 3500 L of water.

CONCLUSION

Both the meat-based average American diet and the lactoovovegetarian diet require significant quantities of nonrenewable fossil energy to produce. Thus, both food systems are not sustainable in the long term based on heavy fossil energy requirements. However, the meat-based diet requires more energy, land, and water resources than the lactoovovegetarian diet. In this

limited sense, the lactoovovegetarian diet is more sustainable than the average American meat-based diet.

The major threat to future survival and to US natural resources is rapid population growth. The US population of 285 million is projected to double to 570 million in the next 70 y, which will place greater stress on the already-limited supply of energy, land, and water resources. These vital resources will have to be divided among ever greater numbers of people.

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